Study to assess barriers and opportunities to improving energy efficiency in cooling appliances/systems

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Executive Summary

The amount of electricity used in Europe to cool buildings is substantial at 150 TWh per year, equivalent to around 5% of total electricity use. Demand for cooling continues to increase and on a “business as usual” basis would increase by over 50% by 2020, although recent economic events may result in a somewhat smaller increase.

There is no shortage of ways to reduce consumption. This study uses a purpose-built model and reanalysis of existing research to assess “realisable savings” over the EU-27 and in each EU Member State. It estimates that if current air conditioning equipment were replaced by the best available technology and operational practice, the electricity savings could be in excess of 80%.

The gap between current practice and the minimum energy consumption that is theoretically possible could be reduced by action in three areas:

•reduced cooling loads from improved building design, and through the use of more efficient lighting systems and appliances

•improved technical efficiency of air conditioning systems

•reducing wasteful operation of air conditioning systems

Realistic objectives for energy saving must take account of a range of practical constraints. This report considers “realisable savings” that would accrue over a ten year period. It takes into account the replacement rate of air conditioning systems and appliances, refurbishment rates of buildings and rates of market growth. Levels of “realisable savings” are estimated for different levels of ambition for performance regulations placed on air conditioning equipment and systems.

Having estimated the current and theoretically possible consumption levels, the study assesses the impact of a range of possible policy options. From these, the seven with the largest realisable savings were selected for closer examination in terms of actions that would be needed to implement them. The estimated cumulative 10-year savings for each of these ranges between 40 TWh and 180 TWh. The options are not mutually exclusive, but interactions between measures mean that the savings are not simply additive.

The existence of unrealised energy saving opportunities implies that barriers and constraints exist.

A set of specific recommendations for policy actions has been produced to address these. They include measures to improve the technical efficiency of the installed stock of systems, to reduce loads and to encourage more effective operation and management. This wide range of factors that influence air conditioning energy use is reflected by the number of national and EU policy instruments that are relevant: notably the EcoDesign Directives, the Energy Performance of Buildings Directive, and Member States national energy standards. A coordinated approach is needed and the recommendations are mapped against these instruments to assist this process.

The first part of the report explains and illustrates the processes that lead to the recommendations. It also reports the potential impact of policy options beyond the seven that are highlighted. A second part contains more detailed information, including country by country impacts, details of the modelling process and data inputs, and background information on the European air conditioning market and on relevant existing regulations in Europe and overseas.

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Glossary of terms

- "system level MEPS", Minimum Energy Performance Requirements applied at the level of a complete system (rather than to a specific product such as a chiller)
- "building level MEPS". Minimum Energy Performance Requirements applied at the level of a complete building and its building technical systems (usually heating, cooling, ventilation, lighting and hot water services). This is the level at which the EPBD requires building energy performance requirements to be set.
- Technical Potential Savings: savings that can in principle be achieved using proven (but not necessarily cost-effective) technology
- Economic Potential Savings: the subset of Technical Potential Savings that are cost-effective (see below for different definitions of cost-effective)
- Realisable Potential Savings: Technical or Economic Savings theoretically achievable over a given period, taking into account constraints such as product replacement rates
- EER. Energy Efficiency Ratio: the ratio of cooling produced by a product to the consumption of electricity under defined operating conditions
- SEER. Seasonal Energy Efficiency Ratio. the ratio of cooling produced by a product or system to the consumption of electricity over the whole year. Often approximated by combining EER values under a range of test conditions (see, for example ESEER below).
- $SEER_{on}$ A special case of SEER that ignores energy used when the product or system is not actually cooling, such as in thermostat off mode, standby mode, off mode and crankcase heater consumption.
- ESEER: A European voluntary standard method of estimating SEER from a set of EER measurements
- Societal cost effectiveness: A measure is cost effective from this perspective when the values of the benefits exceed that of the costs, in both cases from the perspective of society as a whole. (That is net of tax and subsidies, including shadow prices for externalities, use of a social discount rate). This is the fundamental perspective for policy assessment.
- End user cost effectiveness: A measure is cost effective from this perspective when the financial benefits exceed the financial costs, in both cases from the perspective of the end user. (In other words, including taxation, subsidy, actual cost of capital or opportunity cost). This is important to assess the impact of policy on different groups of end users.
- Cost optimal: A measure is cost optimal when the difference between the value of the benefits and the cost is a maximum. At this point incremental change (for example of MEPS level) in either direction reduces this difference.
- FTELH (EFLH): Equivalent Full Load Hours: This is the ratio between the annual energy requirement (in this case cooling demand) and its peak value. It is a measure of load factor
- GWP global warming properties (of refrigerants)
- SFP Specific fan power in Watts/Litre/second
- SBEM Simplified Building Energy Model. This software is used as a compliance tool for EPBD integrated energy calculations and ratings in several European countries

Summary

1. The Energy Gap For Air Conditioning

The amount of electricity used by air conditioning equipment to cool buildings in Europe is substantial at 150 TWh per year, around 5% of total electricity use. Demand for cooling continues to increase and, on a « business as usual » basis would increase by over 50% by 2020 [1] - although recent economic events may result in a somewhat smaller increase. It is estimated that annual product sales (measured by kW cooling) will be about 35% higher in ten years' time.

There is no shortage of technically established options to reduce consumption. If current air conditioning equipment were replaced by the best available technology and operational practice it is estimated that the electricity savings could be in excess of 80%.

The difference between the minimum energy consumption that is technically possible and actual consumption is often termed the "energy gap". It is more accurate to categorise it as a series of gaps, each with different causes and correspondingly different possible measures to address them.

In particular there is significant scope to reduce the gap in three broad areas:

- reducing cooling loads through improved building design and construction, and through the use of more efficient lighting systems and appliances
- improving the technical efficiency of air conditioning systems
- reducing wasteful operation of air conditioning systems

2. Key Measures To Reduce The Energy Gap

This study uses a purpose-built model and reanalysis of existing research to assess "realisable savings" over the EU-27 and in each EU Member State. The modelling takes account of constraints imposed on the rate of implementation by product and systems replacement rates and by building refurbishment rates. Substantial realisable savings over a ten year period have been identified and are summarised in Figure S1 and Table S1 below.

[1] This is based on projections in Ecodesign Preparatory Studies (Lots 10 and 6) referenced at the end of this report

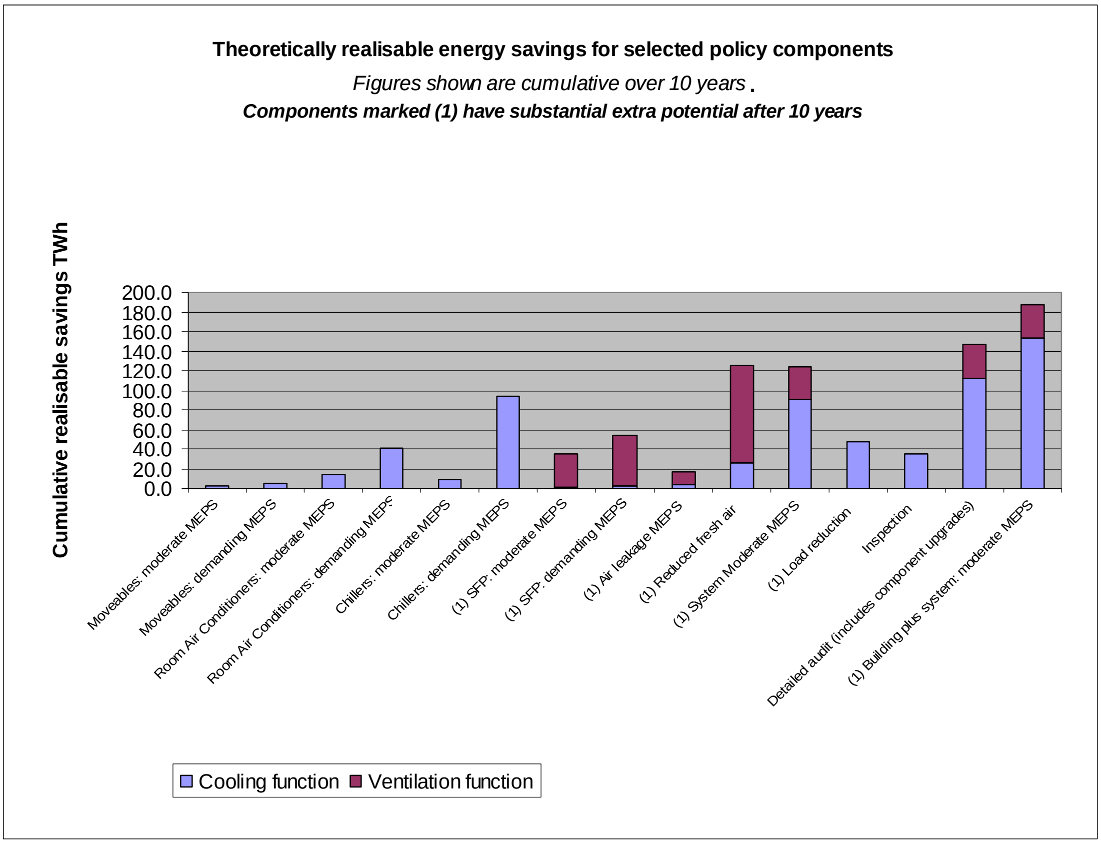

Figure S1: Estimated realisable potential savings over a ten year period

The largest savings were found to result from (in order of savings[2]):

A. minimum performance standards applied at the building level but taking into account air conditioning system performance

B. detailed energy audits of cooling systems

C. minimum performance standards for air conditioning systems

D. reduction of fresh air supply in buildings where smoking is no longer permitted

E. minimum performance standards for air conditioning chillers

F. minimum performance standards for air handling systems

G. minimum performance standards for room air conditioners and other self-contained systems

[2] The total saving is not simply the sum of those for single measures: the introduction of some measures reduces the potential for others. For example, reducing cooling loads reduces the potential savings from higher system efficiency and vice-versa.

Key	Measure	Impacts on		
		Cooling load	System efficiency	Operation
A	Minimum performance standards applied at the building level	XXX	XXX	
B	Detailed energy audits of cooling systems	XX	XX	XXX
C	Minimum performance standards for air conditioning systems		XXX	
D	Reduction of fresh air supply in buildings where smoking is no longer permitted	XXX	XX	
E	Minimum performance standards for air conditioning chillers		XXX	
F	Minimum performance standards for air handling systems	X	XXX	
G	Minimum performance standards for room air conditioners and other self-contained systems		XXX	

Table S1 Major measures by type of impact

These potential realisable figures are for relatively ambitious levels of performance which are within the range of products and procedures that are available today, but are not widely used. The report also presents estimates of the lower levels of realisable savings that would result from the implementation of less demanding performance levels. These performance levels are typically less costly to implement and less disruptive of supply chains. They offer stepping stones towards implementation of the "demanding" performance levels.

A rational choice of appropriate performance level depends on the expected cost-effectiveness of measures with different performance levels. From a policy perspective cost effectiveness can be viewed from the perspective of the direct costs faced by building owners and operators, or from the costs and benefits to society as a whole. Regulatory intervention may be justified for measures that are cost effective for society but not from the end-user perspective. Broadly speaking, the "demanding" performance levels referred to above reflect measures that are currently only likely to be seen as cost effective by a few building owners and operators in a limited number of building types and climates. The issues surrounding the definition and estimation of cost-effectiveness are discussed in section A3 of the report.

Part A of this report is intended for policy makers and provides a summary of the results of the study and its recommendations, with a brief explanation of how they were formulated. Part B provides the details behind the methodology, presents the analysis and discusses the findings. It is intended to be of use to people who have a higher degree of interest in the detail of the study.

3. Implementation Issues, Barriers and Recommendations

Implementation frameworks already exist in Europe for some of the measures listed above, although they do not constitute a coordinated or comprehensive suite of policy instruments. Nevertheless, each of the measures faces a number of constraints that affect deployment in addition to questions of cost-effectiveness. Some of these are functional barriers to implementation, others relate to the degree to which cost and benefits are distributed between different groups within society – to questions of social equity.

The recommendations of this report are directed to removing or reducing the hurdles to effective implementation. Issues of social equity are discussed in the report but not addressed by the recommendations.

Section 3.1 below addresses barriers and recommendations that relate to the major opportunities listed above. The following section, 3.2 considers more generic constraints that apply to more than one opportunity, and recommendations for reducing their impact. Section 3.3 covers recommendations for new studies. These address areas where the assumptions underlying the modelling are particularly uncertain and may lead to overly pessimistic estimates of potential savings. Finally, Section 3.4 maps the recommendations onto both the major measures described in section 2 and onto the policy instruments to which each recommendation applies.

3.1. Major Opportunities: Barriers, Missed Opportunities And Recommendations

The energy gap is a series of opportunities that are constrained in some way. The constraints identified by this report are denoted below as « barriers to improved efficiency ».

Each of the following subsections relates to one of the key measures listed above.

3.1.1. Minimum performance standards applied at the building level but taking into account air conditioning system performance

The Energy Performance of Buildings Directive (EPBD) already requires Member States to have whole-building energy performance requirements that include the effects of system and product efficiency and load reduction. This allows designers to develop the most cost-effective combinations of measures for each specific building.

The principle of subsidiarity applies to this Directive, which allows Member States to set requirements in the form and at the level best suited to their needs. A consequence of this is that the processes differ between Member States. In particular, few Member States have detailed calculation methods for the efficiency of air conditioning systems. In a survey by the EPBD Concerted Action[i], only 6 of the 15 respondents claimed to have such a calculation method. The survey did not look into what the methods were.

Barrier to improved efficiency: *Implementation of calculation requirements for air-conditioning energy use is patchy.*

Recommendation 3: *Member States that do not have such procedures should be required to implement them.*

Where calculation procedures exist Member States have developed them in isolation. There is no recognised standard. Ideally such a standard should be consistent with the procedures that are already in place in several Member States. The development of an agreed procedure is likely to require resources for testing candidate procedures and, probably, further development of them.

***Barrier to improved efficiency**: There is no recognized standard for the calculation procedure.*

***Recommendation 2**: A consensus should be developed for a generally acceptable procedure.*

An acceptable calculation procedure is will require the calculation of the seasonal efficiency of air conditioning systems and products. Standardised seasonal cooling efficiency is required to be reported as part of the European ling requirements but the results of the individual part-load tests are not. The provision of this information would allow system efficiency calculations to be more realistic by taking account of the interactions between climate, building design and product-specific information.

***Barrier to improved efficiency:** EPBD calculations require the knowledge of the individual part-load performance figures but these are not reported on the labelling.*

***Recommendation 3**: Product Information sheets for air conditioning products should contain the key part-load performance data used in the ratings.*

3.1.2.Detailed energy audits of cooling systems

The EPBD requires the regular inspection of air conditioning systems of more than 12kW cooling capacity. Mandatory inspection requirements are generally not seen as being cost effective to end-users in their present form[ii], although they undoubtedly identify cost-effective energy saving measures in many systems. Research [iii] has shown that inspections do identify ways of reducing energy consumption, and that these are predominantly low-cost operational changes.

"Inspection" is a non-invasive process that avoids interference with equipment, or detailed monitoring or technical performance assessment. The measure described here as a "detailed energy audit" is a more detailed investigation that includes an element of consumption monitoring and associated diagnosis. It also includes the possibility of more detailed physical inspection and testing of systems than is possible by "inspection". Research [iv] has demonstrated that there are significant energy-saving opportunities in existing air conditioning systems that are missed by inspections. The most effective combination of measurement, analysis and physical inspection is being investigated [v] but is still uncertain.

***Barrier to improved efficiency:** Existing inspection requirements only identify a small proportion of the potential energy savings in existing air conditioning systems*

***Recommendation 4**: The potential use of electronic monitoring of air conditioning systems to improve the cost-effectiveness of inspection should be investigated*

Implementation of the existing inspection requirements is also still uneven. The EPBD CA report [vi] reports that a survey of Member States found that that 4 of 20 respondents have no inspection regulations. It also found that "most MS are convinced that there is room for improvement in their inspections scheme".

("Inspection" here applies to air conditioning inspections and also to boiler inspections in Member States where these are required).

Barrier to improved efficiency: *Uneven implementation of the requirement for regular inspection*

Recommendation 5*: Encourage Member States to strengthen implementation where necessary.*

3.1.3.Minimum performance standards for air conditioning systems

The EPBD Recast specifically calls for the introduction of minimum performance standards for technical building systems. Some Member States have minimum acceptable performance levels for systems within their building energy codes, although this is not common.

Taken in isolation this measure offers substantial potential savings. However, many of the savings would also be captured by the measures described in 3.1.1 for whole-building energy performance requirements. The whole-building requirement has the additional advantage that it allows designers to trade off the costs and benefits of system and envelope measures.

System-level energy performance requirements could have an influence on new installations in existing buildings which do not always fall within the scope of national building energy requirements. However many of the benefits would be obtained by minimum performance requirements for air conditioning products as described in 3.1.5 and 3.1.7.

To a large extent therefore, system-level energy performance requirements are an alternative to a combination of building- and product energy performance requirements that requires a new supporting infrastructure. System-level energy performance requirements would require either the training of installer/designers in the calculation of system performance or that they employ an expert to do this for them, and a process by which they could be checked.

This suggests that higher priority should be placed on improving existing actions. The high potential suggests that the issue should not be forgotten, however.

Barrier to improved efficiency: *System-level performance requirements for new installations in existing buildings are in place in only a few Member States*

Recommendation 6: *Air conditioning system-level performance requirements should not be treated as priority issue, but the case for them should be reviewed from time to time.*

3.1.4.Reduction of fresh air supply in buildings where smoking is no longer permitted

The energy used to supply ventilation air depends on the quantity of outdoor air that is required. The outdoor air also contributes to cooling demand when the outdoor air is warmer than the room temperature. Many existing air conditioning systems were designed in the anticipation that occupants would be permitted to smoke. In many buildings smoking is no longer permitted. There is scope for new systems to have lower ventilation energy requirements than older ones, and also for many existing systems to be modified to have lower outdoor air supply rates.

The minimum outdoor air rates are typically an element of building codes or design guidance and are commonly based on the relevant European standards.

Barrier to improved efficiency: *Reduction of fresh air supply in buildings where smoking is no longer permitted is a generally unrecognised opportunity for energy saving.*

Recommendation 7: *Fresh air design rates and regulatory requirements should be reviewed in the light of smoking legislation and amended where appropriate. Air conditioning inspectors should also be reminded of the potential.*

3.1.5.Minimum performance standards for air conditioning chillers

In Europe there are currently no mandatory minimum performance requirements or energy labelling schemes for air conditioning chillers, although a voluntary labelling system covers many but not all chillers. Such measures do exist in a number of non-European countries. A Preparatory Study for the Ecodesign Directive is under way which may recommend such measures.

Barrier to improved efficiency: *The absence of MEPS and mandatory energy labels for chillers obstructs the acheivement of energy savings*

Recommendation 8: *Introduce mandatory energy labelling and MEPS for chillers. .*

3.1.6.Minimum performance standards for air handling systems

Minimum performance standards for air handling systems exist only in the national building codes of a few, mainly Scandinavian, countries. The largest savings come from minimum performance requirements for specific fan power, but those from reduced leakage from ductwork and air handling units are not negligible. Specific fan power is determined by ductwork design, air handling unit design, (including cooling coil design and filter specification) and fan and fan motor efficiency. Minimum performance requirements therefore give the system designer the ability to choose the most cost-effective combination of these components to meet the specified performance level. A Preparatory Study for the Ecodesign Directive which is under way might recommend energy labelling or minimum pressure drop or specific fan measures for air handling units, but this is uncertain. .

Barrier to improved efficiency: *In many Member States there is no restriction on the use of air handling systems which have low energy efficiency.*

Recommendation 9: *Minimum energy performance requirements for specific fan power should be introduced in those Member States that do not already have such requirements.*

Recommendation 10: *Minimum energy performance requirements for ductwork and air handling unit leakage should be introduced in those Member States that do not already have such requirements.*

Recommendation 11: *To assist Member States to introduce these requirements, model clauses and guidelines should be developed, based on the experience of those that already have them.*

3.1.7. Minimum performance standards for room air conditioners and other self-contained systems

Energy performance labelling for is currently required for fixed room units of up to 12kW cooling power. Changes in labelling procedure and the introduction of minimum performance standards have been agreed and will be introduced in 2013 and made more demanding in 2014. .

The requirements are based on the results of a Preparatory Study which reported in 2009 based on analysis carried out during the previous three years. Since then, sales of A-rated (and better) products have increased markedly in some important countries such as Italy, and the impact of the proposed requirements will be less than initially expected. It is likely that more demanding requirements could now be justified.

Barrier to improved efficiency: *Because of changes in the market since the development of the MEPS criteria, the levels to be introduced from 2013 now look weak.*

Recommendation 12: *Evaluate the case for progressively making the minimum performance requirements more demanding.*

3.2. Generic Barriers, Missed Opportunities And Recommendations

In addition to the obstacles that restrict the take-up of specific energy-saving opportunities, there are others that apply to classes of potential measures or to interactions between existing and possible future policy measures. They are discussed in this section. These concerns do not arise directly from the modelling analysis but become apparent when considering either interactions between policy instruments or uncertainties in some modelling assumptions. In the latter case the existing modelling assumptions might (or might not) be pessimistic: the recommendations are for further work to reduce the uncertainty. More robust assumptions would allow more confident assessment of the some policy options.

3.2.1.Consistency of evaluation criteria between policies

Opportunities to reduce air conditioning energy consumption occur in building design, equipment efficiency and building and system operation. Each of these areas is addressed by different sets of policy instruments, which sometimes overlap. Some, such as building energy codes are set nationally (under the framework of the Energy Performance of Buildings Directive). Others, such as minimum energy performance requirements for equipment, are set at an EU level. The policy instruments are evaluated using different criteria which can result in undue emphasis being given to some measures or insufficient to others. This is most evident when contrasting the procedures for setting minimum performance levels for buildings and for equipment. Minimum performance levels for equipment are assessed using an “end-user” perspective[3]. In some Member States building minimum performance levels are also set on this basis, but in others more demanding requirements are justified by the application of a societal perspective. [4]

From an economic point of view, the societal perspective is fundamental for policy making. The end user perspective is practically important in order to assess whether

[3] Actually from that of an idealised “typical” user, without considering variations between end users.

[4] Policies relating to renewable energy are also justified by a societal approach. Current proposals under the EPBD Recast for building minimum performance levels to be “cost-optimal” take an end-user perspective, but allow Member States to optionally use a societal perspective.

some sections of society are disadvantaged, possibly calling for supplementary policies. Application of the societal perspective could justify more demanding performance requirements for equipment and, in some countries, buildings.

Barrier to improved efficiency: *Societal cost-effectiveness is not applied to all relevant policies resulting in sub-optimal levels of performance requirements*

Recommendation 13*: All assessments of policy instruments should be based on a common approach which reflects the costs and benefits to society.*

3.2.2. Implementation of Minimum Performance Requirements at Member State level

Economically justifiable minimum performance standards vary between applications: air conditioning systems with long hours of use can justify higher performance levels (provided that their life is not impaired). Because the hours of use vary with climate and with the use of the air conditioned space, any specific performance requirement cannot be cost-optimal for all applications. On the other hand, there are practical advantages for the supply chain (and legal requirements) in having EU-wide requirements for traded products. This creates a difficult conflict between the objectives of energy saving and social equity. For building-level requirements this is partially handled by the Subsidiarity principle, which allows Member States to set building and (air conditioning) system requirements at a national (or sub-national) level. [5]

One way of addressing this conflict for air conditioning products would be to set EU minimum performance requirements at levels such that products are cost-effective for the majority of users. This would not preclude the use of high-performance products where this can be justified, though take-up would be subject to the market barriers that minimum performance requirements are introduced to overcome. This could be addressed by allowing Member States to implement more demanding minimum performance requirements where these are justifiable.

An alternative approach would be to apply different levels of minimum performance requirement according to climate. This would reflect the climate-dependent definitions of seasonal efficiency in the latest version of EN14825 [vii] but would be more complex to police.

Barrier to improved efficiency: : *If MEPS are set at demanding levels uniformly across Europe, some countries will be obliged to use products that are more efficient than is cost-effective for them*

Recommendation 14: *Before introducing Europe-wide demanding levels of product minimum performance requirements, consideration should be given to implementing them via national building codes, accompanied by an over-riding but less demanding European minimum performance requirement.*

3.2.3. Existing buildings: measured energy consumption

Energy performance certification of buildings which is based on measured consumption is one of the few existing regulatory procedures which address the

[5] For air conditioners operating in a heating mode, energy labels are required to show seasonale heating effieincy for each of three climatic zomes. Equivalent information is not required for the cooling function.

quality of management as well as the efficiency of the building and its systems. The process of generating a rating is relatively straight-forwards as it does not require a building inspection. The rating itself identifies buildings that have higher than normal consumption and are therefore likely to have opportunities for energy saving. When the information is displayed publicly, it acts as an incentive to efficient management.

The energy used for air conditioning is not normally reported separately, and is often not metered separately. If this were to be the case the information could be used to focus attention (and the more frequent inspection permitted by the EPBD Recast) on air conditioning systems with high consumptions. It could also be a stepping stone towards the more sophisticated analysis methods referred to in section 3.1.2

Barrier to improved efficiency: *Lack of visibility of actual air conditioning energy consumption impedes the identification of systems with the biggest potential for savings.*

Recommendation 15*: Require the electricity consumption of major items of air conditioning equipment to be sub-metered and reported when Energy Performance Certification of buildings is based on measured consumption.*

The use of measured consumption is mainly confined to public buildings at present: wider application would expand its potential impact.

Barrier to improved efficiency: *The absence of energy consumption reporting for many buildings prevents the identification of high-consumption systems which may have large opportunities for savings.*

Recommendation 16: *Encourage Member States to expand the use of measured energy ratings to a wider range of buildings.*

Existing buildings: calculated system efficiency

In principle, the calculation process for an EPC requires the calculation of air conditioning energy use and therefore of system efficiency although, as noted earlier this does not appear to be universally implemented at present. When an air conditioning efficiency calculation is carried out, neither the system efficiency nor the air conditioning consumption are reported separately from the overall energy consumption. This information would help the assessor who is producing the EPC (and the building operator) to judge whether specific air conditioning recommendations are worth further investigation.

Barrier to improved efficiency: *The calculated air conditioning system energy performance carried out as part of building energy performance certification is not reported.*

Recommendation 17*: Where air conditioning energy consumption is calculated, this – and the system efficiency - should be reported in a form that assists the assessor in formulating recommendations, preferably on the Energy Performance Certificate, so that the building owner can also see it .*

3.2.4. Take up rates for measures

A generic problem (and the binding constraint) for energy efficiency policy instruments that provide information is the need to persuade recipients to take action. For air-conditioning, this applies specifically to recommendations arising from air conditioning inspections and from energy performance certificate assessments.

Barrier to improved efficiency: *Poor take-up of recommendations*

Recommendation 18: *introduce measures to incentivize the implementation of recommendations.*

Such measures could include training for assessors in communicating the results to building owners, support measures from Energy Agencies to facilitate implementation of recommendations, or financial incentives such as low cost loans.

3.3. Recommendations for further work

This section focuses on areas where there is limited directly relevant empirical evidence for the assumptions used in the modelling. The resulting uncertainty may result in be pessimistic estimates of potential savings. "Barriers" here are really uncertainties that relate to policy evaluation.

3.3.1.The effectiveness of energy efficiency information-provision mechanisms in business-to-business supply chains

The literature relating to the impact of information provision measures such as energy performance labelling deals almost exclusively with household goods. The market for most air conditioning products and systems is characterized by (sometimes lengthy) business-to-business supply chains. Energy labelling (for example) can play a role here but it is likely to be by different routes [6] and have different impacts from those for consumer goods.

Barrier to improved efficiency: *Significant uncertainty about the impact and cost-effectiveness of energy labelling and similar instruments for business-to-business supply chains.*

8: *Investigate the effectiveness of energy efficiency information-provision mechanisms in business-to-business supply chains. (This would also be pertinent to whole-building performance information and other products.)*

3.3.2.The relationship between minimum performance requirements and product cost.

Cost effectiveness calculations depend on many assumptions, including that for changes in the initial cost of products. Engineering assessments show that the immediate impact of higher efficiency is an increase in product cost. For air conditioning products this seems to be of the order of 0.5% to 2% increase in cost for each 1% increase in efficiency. At the same time, the real cost of many air conditioning products has decreased over time, which can give the impression that costs are not related to performance.. "Learning by doing" theory suggests that, over time, the incremental costs of innovative products (over and above a general decline in prices) may decrease through, for example, improved design or manufacturing processes or economies of scale in production and distribution. But evidence for this is lacking.

[6] For example, through inclusion in formal procurement specifications

Barrier to improved efficiency: *The medium and long-term impact of minimum performance requirements on product cost is uncertain.*

Recommendation 22: *Investigate the relationship between product price trends, energy performance and the introduction of minimum performance requirements for air conditioning products and systems.*

3.4. Overview of Recommendations

The recommendations result from the identification of potential energy saving measures and the constraints which impede their realisation. They focus on possible regulatory measures or work to support such measures and would need to be implemented through policy instruments – and preferably existing policy instruments. Table S2 below provides a mapping of the recommendations (expressed in shortened form) against both the relevant Policy Instruments and the energy-saving measures. There is often an interaction between the EPBD and National Building Energy Codes, so some recommendations straddle both columns.

Measure		**Recommendations and relevant Policy Instruments**		
Ref		**EPBD**	**National Building Energy Codes** *(may be implemented via EPBD)*	**EcoDesign Directives**
A	Minimum performance standards applied at the building level	1 and 2. Develop agreed air conditioning system efficiency calculation procedure		3. Provision of part-load information
B	Detailed energy audits of cooling systems	5. Stronger implementation of current requirements	4. Use of automatic performance monitoring	
	Supporting actions for B	17. Report calculated system efficiency on EPC 15. Report measured air conditioning energy consumption 16. Expand use of measured energy ratings		
C	Minimum performance standards for air conditioning systems	6. Introduction of system MEPS		
D	Reduction of fresh air supply in buildings where smoking is no longer permitted		7. Review of outdoor air requirements	
E	Minimum performance standards for air conditioning chillers			8. Introduction of MEPS
F	Minimum performance standards for air handling systems		9, 10 and 11. Wider introduction of requirements	
G	Minimum performance standards for room air conditioners and other self-contained systems			12. Review MEPS
Generic Recommendation			14. Consider combination of EU and national MEPS	
Recommendations for further work		18. Investigate effectiveness of information provision measures in business to business supply chains		

	19. Investigate relationship between product price trends, energy performance and MEPS

Table S2 Mapping of recommendations against Policy Instruments and energy-saving measures

SECTION A

Overview, analysis and recommendations

A1. INTRODUCTION

A1.1 Background and Scope

Although parts of Europe have a seasonally hot climate, the European air-conditioning market is rather small when compared with those of Asia and North America, although it has been growing steadily for a number of decades. It has been estimated [viii] [ix] that the cooling[7] element of air conditioning currently accounts for about 10% of tertiary electricity consumption in EU Member countries, rising to 30% to 40% in southern European countries.

In terms of energy efficiency policy, air conditioning has received less attention than other aspects of energy use in buildings. Although the EcoDesign Directive (Directive 2009/125/EC)[1], the Energy Labelling Directive (Directive 2010/30/EU) [x] and the Energy-Performance of Buildings Directive [xi] each addresses some aspect of the market, they cannot be said to comprise a comprehensive, coordinated suite of policy instruments. Compared to other parts of the world such as Japan, which have larger air conditioning markets and have therefore addressed the issues with m more urgency, European energy efficiency requirements for air conditioning are rather weak.

This study aims to provide a positive contribution to the EU policy making debate as it relates to energy consumption by air-conditioning in buildings, by identifying and quantifying the potential impact of possible policy measures. Many of these relate to the performance of products and equipment, but there is also considerable potential in the areas of load reduction and more effective operation and management of systems.

In particular, it addresses

- the maximum potential for savings from improved cooling system and appliance performance,
- a breakdown of the potential savings by country,
- the barriers to achieving the total potential savings,
- policy options to address these barriers
- “realisable” savings associated with these policy options.

The analysis and associated recommendations[8] are of particular pertinence to several current European policy activities and relate to the following policy areas:

- Consistency of approach between policy instruments: recommendation 13
- Coordinated implementation: recommendations 14
- The Ecodesign Directive
    - o the current review of the Directive: recommendations 6, 13,
    - o the work in progress on central air conditioning systems (Lot 6) : recommendation 8
    - o room air conditioners: recommendation 12 goes beyond the requirements recently agreed for MEPS
- The implementation of the EPBD Recast
    - o by Member States: recommendations 1, 3, 5, 11,15, 16, 17
    - o guidance from the EC, notably on the requirement for a check on the cost-optimality of minimum performance regulations: recommendation 13,
- National regulations (within the framework of the EPBD) : recommendations 7, 9, 10
- Revision of European standards: recommendation 2, and

further studies for the longer term: recommendations 4, 18, 19 The principal existing policy frameworks that impact on air conditioning energy consumption are the:

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[7] As against heating, humidification etc.

[8] These numbered recommendations are described in detail in Section A3 of this report

- Ecodesign and Energy labelling Directives are internal market Directives, applied across the whole of the EU and the European Economic Area (EEA). Most products considered to date are standardised, mass-produced, consumer goods (including room air conditioners) and components such as electric motors. Larger air conditioning systems are not standardised products but consist of relatively bespoke “products” comprising of a mixture of series produced, and purpose-made components that is specific to the particular application. A Preparatory Study into the possible application of these Directives to this type of system (or, more likely, to some their series-produced components) is under way.

- Energy Performance of Buildings Directive, which applies to whole buildings including their energy-using fixed building services, such as air conditioning systems. It includes requirements for minimum energy performance requirements, for Energy Performance Certification and for the regular inspection of air conditioning systems. Implementation of the Directive is subject to the principle of subsidiarity and each member state has its own implementation process and sets its own levels of requirements

- National or regional building energy legislation (variously called, regulations or codes) provides the route by which the EPBD is implemented at Member State level. In most Member States there is an existing tradition of such legislation which has an influence on their implementation procedures and levels of requirement. National design guidance reflects these legislative requirements

This study is aimed at both policy makers and other readers who are interested in gaining a deeper understanding the technical potential that exists for reducing energy consumption and corresponding carbon emissions from the use of cooling systems across Europe. The report consists of two main elements:

Part A of this report is intended for policy makers and provides a summary of the results of this study and its recommendations, with a brief explanation of how they were formulated.

Part B provides the details behind the methodology, presents the analysis and discusses the findings. It is intended to be of use to people who have a higher degree of interest in the detail of the study. The chapters in this part are referred to in Part A to enable ease of reference between the two parts where additional detail may be required.

A1.2 Overview of Approach

The objectives mentioned above require quantified estimates of current and future air conditioning energy consumption at national and European level for a range of different sets of policy assumptions. Even for existing consumption, data at national and supranational level are extremely sparse. This study therefore uses a purpose-built model, which takes into account *inter alia* climate, system type, system and product efficiency, product and system replacement rates, building type, and differences of cooling demand between existing and new buildings. The results of a number of existing studies have also been reanalysed to develop some of the modelling data and to refine some of the modelling results

In particular, the analysis takes account of

- available sales data for air conditioners by category (movable, room and central)
- energy efficiency level and distribution of models by efficiency level of equipment and systems
    - in the current market,

- o after the possible introduction of policy instruments,
- o of the best available technology

- currently estimated annual growth rate of the air conditioner market over the next 10 years
- operating characteristics of each category of cooling equipment

The model was used to estimate the potential annual energy savings that would hypothetically result by implementing the measures described for every sale of a new product in each of the *Cases,* compared to the current 'no change' situation (by suddenly replacing the current stock of equipment by only those pieces of equipment that would be included in the particular *Case* being studied). The model estimates the savings in terms of annual energy consumption in the EU, broken down by Member State for each specific *Case*, and projects the energy savings over the next 10 years.

The potential savings are tabulated by Member State and by Case and the results are analysed.

The study then goes on to identify:

- barriers to the uptake of more efficient technologies and
- potential cost-effective solutions by country and region to addressing these barriers are identified

Finally policy recommendations are provided for application at either individual country level or for the EU/EEA as a whole.

The estimates were produced by a model that integrated a large number of influences including: market data, equipment properties and characteristics, knowledge about how each type of equipment is operated, influence of climate on operating hours, and cost of operation, equipment limitations. As there are significant national variations, the model was constructed to provide a European perspective by combining figures for individual countries. Where relevant – notably for room air conditioners - this study draws heavily on the work already carried out by BRE in support of the Ecodesign Preparatory Study for Room Air Conditioners (Lot 10 study[xii]). Central plant systems are the subject of a separate and ongoing Ecodesign Preparatory Study (Lot 6)[xiii]. In particular, the estimation of past and future stock and sales of air conditioning systems leans heavily on this prior work. Only those aspects of this work that is in the public domain have been used in the present study. BRE is not an active participant in the later stages of the Preparatory Study but had expected to be able to use additional publicly available information, including some model structures and system efficiency comparisons. In the event, work on the Preparatory Study was not sufficiently advanced to be able to do this so it was necessary to develop a new model structure that is appropriate to the present work.[9] The recently published HARMONAC study[xiv] and the KeepCool and KeepCool II studies [xv] are used to inform the modelling and the resultant policy recommendations presented in this report.

The first task of the study was to use the models to provide an estimate of the current situation in terms of energy consumption and CO_2 emissions associated with air conditioning across the EU. The next stage was to identify the potential for savings.

The technical potential for savings, based on the application of the best available technologies (BAT), was estimated by comparing the energy consumption of a hypothetical

[9] The results of the present study are expected to inform discussion of the Preparatory Study

situation where all the opportunities in current buildings to switch cooling equipment to the BAT were implemented, and then compared against the energy consumption of cooling equipment currently in use in the same buildings (base case). This estimate provides a ceiling for each type of equipment. A series of (realistic) examples of energy saving measures were also applied to the model such as the introduction of more stringent MEPS requirements, reductions of cooling load by improvements in the building shell, more effective use and control of existing systems and others. This allowed the study to compare the magnitude of the potential savings with a variety of options ranging from improved system design and operation to higher product performance levels (technology-based savings potential) and thus provide a more detailed understanding of the subject area and how product policies might potentially interact with other initiatives aimed at reducing the energy consumption of cooling systems across the EU and thus reducing carbon emissions.

The model was used to estimate the ***market potential*** savings for each of the cases developed to represent the various initiatives. For product (and system component) level cases, e.g., equipment MEPS, the market potential savings are calculated using the sales figures for new and replacement air conditioning products, and the difference in average consumption between equipment currently in the market and the new mix of equipment that would exist after the initiative described in the case study is fully implemented, calculated based on the cumulative savings for the next 10 years. For system and building level cases the potential savings that could be achieved in the existing stock of air conditioning products are also assessed.

In situations where the consumer is involved in the decision making for a more efficient (and likely more expensive product) the actual savings that might be achievable via the application of each option can be estimated by calculating the ***economic potential*** of each specific initiative; this exercise requires undertaking a market and economic study in the country of interest to determine the number of cases that would be sufficiently attractive economically for consumers to implement. Such detailed analysis is beyond the scope of this study, but an indication of how cost effective each particular case is likely to be at the EU level is provided.

This study then goes on to provide an overview of barriers to reducing the energy consumption of cooling appliances and systems, and the potential for energy savings from better design of cooling systems, different technical and other changes to the products/devices and their use. Both across EU and EEA countries as a whole and individual countries were included in the analysis.

The possible policy instruments (and packages of instruments) considered were those that address and seek to remove the identified barriers and maximise the attainment of cost-effective energy efficiency and CO_2 savings potentials. They include those that can arise from EU Minimum Energy Performance Standards as set out in the Ecodesign Implementing Measures, and through the adoption of Best Available Technology (BAT). This study also considers the impact of whole-building energy requirements arising from the Energy Performance of Building Directive (EPBD). The potential impact of mandatory inspections as required in the EPBD and related processes is also addressed, using the findings of the European Harmonac project. The current study's outputs include an overview of the current situation including efficiency levels, energy consumption and CO_2 emissions followed by an assessment of energy and CO_2 savings and cost-effective solutions by type of appliance and typical size and system (Sections A3and B5). A review of the barriers to achieving more energy and CO_2 savings is also provided (Sections A2), taking into account BAT and best combined systems, both at European, and national/regional level, as well as existing and planned thermal building regulations and energy requirements for new and existing residential and commercial buildings. Finally a set of policy recommendations are developed which are aimed at addressing the gaps identified in existing policy (Section A4).

A2. MARKET OVERVIEW AND SCOPE OF SYSTEMS AND PRODUCTS ADDRESSED

A2.1 Market Overview

Three broad categories of cooling systems were considered separately for this study:

1. **Moveable units.** These are appliances bought over the counter or through internet suppliers and do not generally require any installation expertise. These appliances are mostly used in dwellings and small commercial buildings.

2. **Room air conditioners/Packaged systems.** These are series-produced self-contained units or systems comprising a unit that conditions a single room. They should generally be installed professionally[1]. These systems are used in both commercial buildings and dwellings.

3. **Central systems.** These are larger systems that serve more than one room (often large numbers of rooms or an entire building). They are generally bespoke systems designed for specific buildings, but are largely composed of standardised component products. In Europe they are predominantly used in non-residential buildings.

None of these three types of systems is exclusively used in residential or commercial properties; it is therefore not practical to associate, for example, room air conditioning units only with residential buildings because these units are also used in offices, stores, etc. Some central systems may also be used in large houses or multifamily buildings. This fact presents some barriers to the association of programmes related to specific products with specific target markets. More detailed information relating to the types of equipment covered by each category is provided in Section B1.

Air conditioning systems are installed in all EU and EEA countries, but six countries stand out as having the largest amount of installed cooling and also the largest markets (in terms of cooling power). These are (in order of decreasing size) Italy, Spain, France, UNITED KINGDOM, Germany and Greece. We observe that countries with hot climates have large markets for room air conditioners, while those with large floor areas of non-domestic buildings have large markets for central systems. More detailed information on national markets is provided in Section B5

Country	Large market for central systems and large floor area of non-domestic buildings	Large market for room air conditioners and hot climate
Italy	X	X
Spain	(X)	X
France	X	(X) (part of country has hot climate)
Germany	X	
United Kingdom	X	
Greece		X

Table A2.1 Countries which dominate the market for cooling systems

The relative importance of different types of product differs considerably: moveable units account for only about 4% of annual sales across the EU/EEA (expressed as cooling capacity rather than by number of products). Fixed room conditioners account for just under 50% of the cooling capacity sold, and central systems account for the remaining 47%. It should be noted that there is a potential overlap between room air conditioners and central systems in terms of both their application and the potential policy interventions. In particular, split systems may serve one space (single-splits) or several (multisplits and VRF systems). For the purpose of this study single split systems <12kW were considered to be room air conditioners, whilst larger single split systems (>12kW) and multisplit systems and VRF systems were included in the central system category. This division coincides with the boundary adopted for energy labelling and the minimum performance requirements for domestic air conditioners that will be introduced in 2013.

Section B1 provides more detailed background information on cooling systems, including the applicability of systems for different buildings types, the efficiency of different systems, prices and cost effectiveness, market trends and air conditioning controls,

A2.2 Summary of Approach Taken

The central purpose of this report is to identify and rank effective policy instruments that can significantly reduce energy consumption by air conditioning of buildings, and the carbon dioxide emissions that result from mechanical comfort cooling.

Policy instruments can be used to encourage or to enforce the implementation of energy efficiency initiatives to the air conditioning market. Practical programs such as providing information on air conditioning products and use for users and suppliers, energy efficiency comparative labels, the imposition of MEPS, making MEPS more restrictive, etc. can be used in order to encourage or force the move towards the sale of more efficient equipment and the disappearance from the market of the inferior performance products.

A series of realistic measures or initiatives called "Cases" was developed for each type of equipment that could be the subject of policy instruments for implementation. The purpose of this exercise was to determine the maximum potential impact in the market in terms of calculated energy savings by comparing the expected energy consumption of the number of products currently being sold (in each country) against the higher efficiency models that would result from the implementation of the specific initiative. This is equivalent to a technical potential for the specific measure. In actuality, the energy savings achieved will depend on the level of success of the programmein terms of the number of actual sales of the more energy efficient products.

This study first modelled the energy consumption of the estimated current European stock of air conditioning systems. The next step was to model the estimated energy consumption if it was subjected to a range of different constraints or incentives of the type imposed by policy instruments for example, the enforcement of MEPS that restrict the availability of products to the more efficient models across the EU, the labelling of components of central air conditioning systems, the introduction of incentives towards the selection of higher efficiency products and combinations of these ("cases"). These Modelled Cases are not explicitly policy instruments, but are idealisations used to identify the relative magnitude of Europe-wide and national energy-savings potential of each type and of different levels of requirement. To provide a reference point against which to view the modelling results, cases were constructed to indicate the maximum potential savings, assuming the universal application of "best available technology (BAT)".

Having identified which approaches might deliver the maximum potential savings (BAT), the constraints and barriers which prevent – or delay – the realisation of such savings were examined.

From the maximum potential savings and identification of barriers, recommendations for policy instruments and – equally importantly – packages of instruments that seem to have the biggest realistic potential were made. The extent to which the potential savings identified by the modelling are likely to be cost effective was considered. For air conditioning systems and products cost-effectiveness is sensitive to climate, building type and local prices. It also depends on whether cost-effectiveness is judged from the perspective of the end-user or of society as a whole. These issues are discussed further in section A3 and Appendix B1. These constraints meant that it was not possible to carry out detailed assessments.

All the cases, including BAT, are for products that are on or close to the market and, by implication, are expected to be attractive and presumably cost-effective for some users in some circumstances. Furthermore, for products like cooling systems (where this is a growing market with significant technical potential for performance improvement) the cost of improved energy performance may fall significantly over a relatively short timeframe. Market transformation policies such as product MEPS can speed up this process and additionally impact on pricing strategies, for example leading to lower prices for more efficient products due to economies of scale for production.

The policy options identified in this study are minimum performance requirements for products, energy labels and requirements placed on building design to reduce cooling loads.

Ideally, all policy instruments relating to air conditioning energy would be coordinated with each other and with those relating to building energy consumption as a whole. This would require more detailed analysis and programme design and is beyond the scope of this report. However, the report does consider appropriate implementation routes e.g., European product regulation, national regulation by building energy codes, or improved management of existing buildings, etc.

Section B4 on the Modelling Process provides more details on modelling the energy use from moveables, room air conditioners (RACs) and central systems. It also provides information on current/base case system efficiencies, modelling the potential savings from system switching for central systems, using the model to determine potential energy and carbon savings, input data and other modelling assumptions.

For modelling purposes it is necessary to estimate the aggregate seasonal efficiency of the installed stock. The following section explains the main points and more detail is available in Section B.

The energy performance of a particular cooling system is determined primarily by the efficiency of the product (for self contained units) or system (for centralised systems) and the cooling demand that the system is required to meet. Air conditioners have traditionally been tested at a single outdoor temperature and humidity level to obtain the Energy Efficiency Ratio, (EER), defined as the cooling output divided by the electrical input power under steady operating conditions. In fact, the efficiency depends on the climate and on its use. The efficiency of air-cooled air conditioners declines as the outdoor temperature increases. At high humidity water-cooled heat rejection also becomes less efficient.[10]

In order to take into account the typical range of outdoor temperatures and humidity levels during an entire cooling season it is necessary to estimate the Seasonal Energy Efficiency Ratio (SEER) defined as the number of kWh of cooling delivered during the season divided by the electrical consumption in kWh. This is determined by repeating the test for several outdoor conditions and weighting the results according to an average number of hours of operation at each condition. This process combines the performance at different parts of the cooling season to produce the Seasonal Energy Efficiency Ratio. [11] Recent revisions to European Standard EN14825 [xvi] now provide a formal standard for doing this (with optional different weightings for different climate zones for heating). [12] This revision was not in place during the work described in this study, though a number of products have been subject to voluntary energy labelling using the very similar "ESEER" procedure. In other instances, SEER was estimated by methods described in Section B4.

Aggregate efficiency of the installed stock (or annual sales) of a particular type of product was determined [13] from estimates of the distribution of products of different performance installed (or sold). Where possible, distributions from survey data were used. In other cases, proxy distributions (typically based on distributions of models rather than sales) were used. Table 1 below is an example of aggregate SEERs: in this case for new (rather than already installed) products for the "base case". More details are contained in Section B4

System Category	System Types	Average System SEER
Moveable units	Single Duct	1.25
	Double Duct	1.25
RAC units	Window/Wall	1.61
	Split systems <12 kW	2.35
Central and Larger Systems	Split systems >12 kW	2.15
	VRF	2.42
	Roof top	1.75
	All air constant volume	1.58
	All air VAV	1.18
	Water based fan coil	1.77
	Water based induction	1.92
	Heat pump loop	1.92
	Active chilled beam	1.88
	Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation	2.37

Table 8 A2.2: Comparing the average system performance (SEER for projected new installations across the EU from 2010-2019

[10] In principle this means that the same air conditioner operated in two different climatic zones will have a different consumption and efficiency level (therefore different operating costs) . We have not modelled this refinement

[11] Strictly, this defines a parameter called SEERon, which ignores atandby and other consumption during periods when the unit is not operating, SEER (as quoted in table 1 includes these elements of consumption)

[12] The new energy labelling and MEPS for fixed room air conditioners use the same methodology

[13] Actually as the weighted harmonic mean efficiency

The figures in Table A2.1 relate to seasonal system efficiency, including energy attributable to the cooling function that is consumed by system components at times when cooling is not required but the system is operating, or when the system is in an “off-mode”. In some cases, they are therefore lower than the more familiar values quoted for products under standard test conditions as described above. They are calculated within the model described in section B4, but not explicitly output.

This example table shows that across all EU/EEA applications, certain types of systems (split systems and chilled ceilings and passive chilled beams with displacement ventilation) tend to be more efficient than others, with variable refrigerant flow systems (VRF) - a type of split system – being the most efficient of all. Moveable units and centralised all-air constant volume systems tend to be the least efficient. However, it should be remembered that the SEER for a particular system is dependent on the specific application. A more detailed analysis of how system performance varies with application is provided in Section B5 as part of the analysis of potential savings from “system switching”.

The actual performance of a cooling system in a particular application will also depend on how well the system operation is matched to the cooling load. It was not possible to explicitly model the potential savings that could be achieved though better size matching and improved controls (waste avoidance). Instead these potential savings are identified from other studies, in particular, the Keep Cool Project[1] and the HARMONAC study[1]. In the Modelled Cases it is assumed that the system is well controlled. **A2.5 Data availability and assumptions used in modelling energy savings**

This study is primarily based on existing data sources as large scale data collection is beyond the remit of this study. Therefore a number of assumptions have been made in calculating the potential energy and carbon savings associated with the modelled Cases that are described in Section B3. The primary modelling inputs are the existing and projected stock of cooling systems across buildings in Europe (expressed in terms of kW cooling installed), from the Lot 10 and Lot 6 Ecodesign preparatory studies[1]. The cooling demands for these systems for different building types (expressed as cooling Full Time Equivalent Load Hours, FTELH) are also taken from these studies. These FTELH take into account the typical cooling demand for six main building applications and include the effects of climate and are based on typical national constructions, including prevalent national building codes. This proportion of cooling installations in each of these six building types in each country is then used to represent the range of building applications in each country.

As this study covers more countries than the Lot 10 and Lot 6 studies, the installed stock of systems was extrapolated from that of a country judged to have the most similar climate from population on a pro rata basis.

At the outset of this study it had been anticipated that the Lot 6 system modelling would have generated results that could be drawn on directly. However, this project has experienced delays and this work is still in progress, therefore it was necessary to use an alternative approach for this study. Instead, the algorithm which is used to calculate the HVAC system performance within SBEM, which form part of the UK’s National Calculation Methodology[1] was used. It is simple enough to be adapted for the large number of calculations needed for this study while also being capable of modelling the energy performance of a range of different system types and taking account of the efficiency of various system components and different cooling demands.

The data sources and additional assumptions made in the course of the modelling are described in Section B4.

A3. MODELLING THE OPPORTUNITY: THE POTENTIAL IMPACT OF POLICY MEASURES

A3.1 Introduction

Section A3 presents an overview of the modelling process and results carried out for this study, which calculates the technical potential savings of a variety of measures to save energy used for cooling in EU and EEA countries. The results presented in Section A3 focus on the measures that are identified as having the greatest potential savings. More detail is provided in Section B5.

The following section, A4, addresses the barriers and obstacles that currently prevent these being realised, and provides recommendations for addressing these obstacles.

The modelling differentiates between the current installed stock of cooling systems and projected new installations. For new installations it also separately considers sales to supply:

1. real growth of the market (Installation in new buildings and first-time installation in existing buildings)

2. replacement of equipment (or systems) that have reached the end of life (including the case of components of central systems)

The *technical potential savings* associated with energy efficiency improvements are calculated from the difference in annual energy use between the currently installed mixture of products and systems (the Base Case), and a variety of Cases that represent the universal application of energy-efficient alternatives across the whole existing stock of systems. In these Cases *potential savings* are estimated for the application of load reduction measures to the building envelope and improvements in system management. The former has been explicitly modelled for this study, whilst the expected saving from the later have been drawn from existing studies.

However, it is not possible to suddenly replace all existing products with more energy efficient models or to instantly introduce load reductions. The modelling constrains the scope of potential savings by taking into account the replacement rate of existing systems and components, and the construction and refurbishment rates of buildings to produce "theoretically realisable savings" over the next ten years. These provide more realistic limits for potential savings corresponding to each modelled Case.In reality, the rate at which the composition of a market changes depends on many factors, including regulations, policies, information or incentive programs, etc. aimed at energy saving measures. The modelled "theoretically realisable savings" define the scale of the potential savings available from the measures considered in each Case.

The model deals with the markets for all types of equipment and systems that are used to provide mechanical "comfort cooling" in buildings in the EU/EEA and also reductions from measures applied to building envelopes. Enhanced ventilation is included and is considered as a load reduction measure rather than a cooling system per se.

In particular it includes all three product types:

- Moveable air conditioners
- Fixed room air conditioning units < 12 kW
- Central cooling systems (and their component parts)

This section, A3, summarizes the total technical potential savings associated with applying various types of measures to each market segment. Each measure could potentially be one element within a more comprehensive policy package (for example, the application of different energy saving measures to different market segments)

The modelled results define the relative size of technically possible potential savings under hypothetical idealised conditions. The results provide one important dimension (theoretically realisable savings) to assist in the selection of measures of policy packages. But the technical potential and the theoretically realisable savings are just a starting point: practicable policy packages have to reflect constraints and technical and non-technical factors including economic and social aspects, which are not part of the modelling process.

Table A3.2 below maps the Modelled Cases onto possible policy intervention points. The modelling process is described in B4, the definition of the Modelled Cases in B3 and the modelling results and their interpretation in Section B5. The range and role of possible policy instruments is discussed in Appendix B1.

A3.1.1 Potential Savings

For “Best Available Technology” (BAT) the modelling reports “potential savings” in the existing stock as the hypothetical savings that would arise if a measure was universally and instantly applied to the existing stock of systems. They are derived by comparing consumption for BAT systems with that of existing systems. These theoretically available maximum savings are used to give a reference point for the less extreme measures and to focus attention on policy initiatives to those areas with greatest long-term technical potential in the current stock. [14]

The energy consumption in the Base Case includes that from installations of new air conditioning systems during the ten year period considered. There are therefore also potential savings associated with air conditioning systems installed to meet the growth in the market. These arise from the difference between the performance of BAT systems and the current mixture of products and systems. In the Base Case current systems are, on aggregate, taken to be more efficient than for the existing stock, reflecting past trends in efficiency, so the potential savings per system for mew systems are relatively smaller than for the replacement of older ones.

The modelling estimates the savings that could be achieved in both new and replacement systems over the course of the next decade. These figures take account of the rates of product and system replacement as they reach the end of their life and of new installations representing market growth (whether in new or existing buildings). The discussion of the implications of the modelling results on policy measures focuses on the aggregate savings over ten years, referring to other figures when necessary.

Other time constraints such as implementation rates for building envelope load reduction measures or lead-in times for policies are not modelled but form part of the more general discussion of practical considerations.

There are 11 BAT Modelled Cases, each relating to a different product (including “systems” and “buildings”) or combination of products. (They are M7, M9, RAC11, RAC13, Cp, C14,

[14] BAT cases are for products which are on or close to the market and, by implication, are expected to be attractive and presumably cost-effective for some users in some circumstances. They do not include products which are technically possible but have not been placed on the market, or have failed to make a significant market impact. This may be for reasons of cost, or because they have unattractive features such as size, safety etc. For example, a number of solar-driven absorption air conditioning systems have been built and demonstrated, but most of them have fallen out of use because switching to conventional technology has proved more attractive than continued maintenance and repair.

C20, C17, C22, C26, C28). The assumptions and the basis for their selection are described in Section B3.

A3.1.2 Current Energy Consumption for the Base Case

The Base Case represents the current situation and includes energy savings measures that are already in effect. It includes existing policies such as mandatory energy labelling of units smaller than 12 kW, voluntary labelling of chillers and air handling units and national regulations on duct leakage (where these are known to be in place). The Base Case also takes account of typical building construction and prevalent building codes via the typical annual cooling demand (FTELH cooling as kW/m^2) for six representative building types in each country in each country (See Section B4 for further details). The modelled Base Cases are M0, RAC0, C0, for moveables units, fixed room air conditioners < 12kW and central systems (and packaged system > 12 kW) respectively. These are described in Section B3.

The modelled total energy consumption for cooling of air conditioning systems is 92.3 TWh pa with an additional 63.6 TWh pa consumed by air conditioning systems to support the ventilation function. (The majority of fan energy consumption is assumed to support the provision of fresh air: the component that is used to support the cooling function is accounted under the cooling heading.) By comparison, the EECCAC study [xvii] in 2003 estimated likely consumption for cooling (comparable to the 92.3 TWh for this study) in 2010 to be about 94.7 TWh pa while the Harmonac study estimated the total consumption for cooling and ventilation functions of air conditioning systems to be about 198 TWh pa. This compares to this study's estimate of 155.9 TWh pa. The estimated consumption for the cooling function alone represents about 11% of electricity consumption by the tertiary sector.[xviii] When the ventilation function is added, the percentage increases to 18%

These are appreciably higher than the figures reported by JRC[xix]. The only reference given in the JRC report is to the Ecodesign Preparatory Study for air conditioners of less than 12kW cooling capacity and it seems likely that it therefore omits central systems, and only includes fixed and moveable room units. The estimated energy consumption of such products in the present study is similar to the JRC figure. The modelled figures in the present study may be under-estimates as they assume reasonably well-controlled systems, but research[xx] shows that many systems operate for unnecessarily long hours.

Name of Study	**Total estimated Annual cooling consumption in EEA andEU countries** **TWh pa**	**Comments**
This study	76.91 (moveables+ Room ACs + central systems) plus 63.6 for ventilation-related energy consumption (140.5 cooling and ventilation)	Model results from the present study
EcoDesign Preparatory Studies	Cooling: 38.6 (Lot 10 but for earlier	

xxi	year) + 74 (Lot 6) = 112.6 Ventilation (not only associated with air conditioning) 100 TWh [15]	
EECCAC study [xxii] in 2003	94.7	
Harmonac study	198	
Electricity Consumption and Efficiency Trends in European Union - Status Report 2009, European Commission Joint Research Centre Institute for Energy [xxiii]	38.6	Likely omits energy consumed by central systems

Table 9 A3.1 Comparison of air conditioning annual consumption estimates for EU by various studies

To put the relative magnitude of energy use by product type, the following pie chart illustrates that the large systems account for nearly two thirds of the total energy consumption of AC systems.

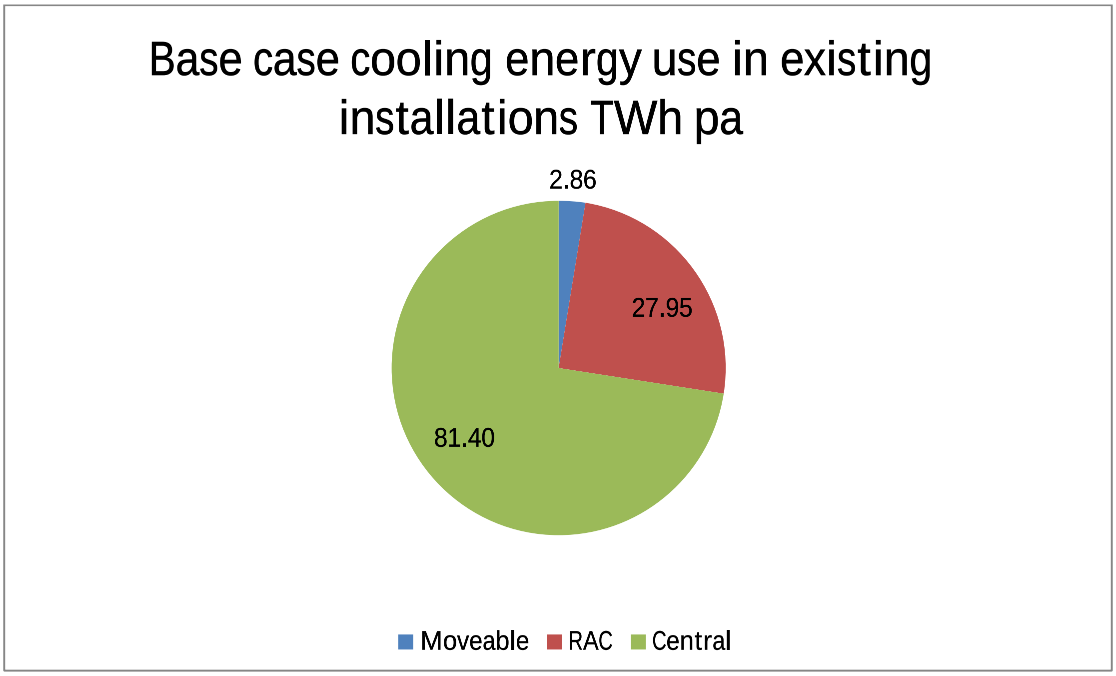

Figure 1 A3.1 Base Case Energy Consumption for Cooling by System Type (excludes system energy use for providing ventilation function)

Figure A3.1 shows that fixed and moveable room units of less than 12 kW cooling capacity account for less than a third of cooling-related consumption. Moveable units only account for 8%. In addition, essentially all ventilation energy associated with air conditioning systems is for central systems. (Energy used by mechanical ventilation systems without mechanical cooling has not been considered in the modelling studies). When energy consumption for

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[15] This figure is not explicitly stated in the report but has been inferred from data in the report)

both cooling and ventilation is considered, central systems account for more than three-quarters of consumption.

Table A3.2 shows the modelled *annual* consumption for current air conditioning units in operation. The size of existing cooling energy consumption varies considerably among the EU and EEA Member States. There are differences in population size, climatic conditions, type of construction, differences in building codes, shading practices and differences in simple things such as the installation of (secure) openable windows to allow natural ventilation. Many new office buildings, for example, are not provided with windows that can easily be opened, and all ventilation air and cooling must be provided mechanically.

Estimated Energy Use by Existing Installations (2010)						
Energy Consumption TWh pa	**Cooling**				**Ventilation**	**All Cooling and Ventilation**
	Moveable	**RAC**	**Central**	**All Systems**	**Central**	**All systems**
Austria	0.03	0.35	1.59	**1.97**	0.79	**2.76**
Belgium	0.02	0.27	1.90	**2.20**	1.64	**3.84**
Bulgaria	0.11	0.60	0.72	**1.43**	0.41	**1.84**
Cyprus	0.00	0.23	0.31	**0.54**	0.12	**0.66**
Czech Republic	0.15	1.69	1.22	**3.06**	0.89	**3.95**
Denmark	0.01	0.13	0.40	**0.55**	0.48	**1.03**
Estonia	0.00	0.04	0.10	**0.14**	0.10	**0.25**
Finland	0.03	0.16	0.86	**1.05**	0.59	**1.63**
France	0.20	2.17	5.91	**8.28**	3.88	**12.16**
Germany	0.22	0.27	5.82	**6.31**	3.86	**10.17**
Greece	0.00	2.57	2.46	**5.03**	0.96	**5.99**
Hungary	0.01	0.43	1.90	**2.34**	0.80	**3.14**
Iceland	0.00	0.01	0.06	**0.07**	0.05	**0.12**
Ireland	0.01	0.04	0.85	**0.90**	0.85	**1.76**
Italy	1.21	6.12	18.35	**25.68**	8.50	**34.18**
Latvia	0.01	0.07	0.13	**0.20**	0.12	**0.32**
Liechtenstein	0.00	0.00	0.00	**0.00**	0.00	**0.01**
Lithuania	0.00	0.01	0.16	**0.16**	0.15	**0.32**
Luxembourg	0.00	0.01	0.03	**0.05**	0.03	**0.08**
Malta	0.02	0.09	0.08	**0.18**	0.04	**0.22**
Netherlands	0.04	0.39	2.09	**2.52**	1.36	**3.88**
Norway	0.02	0.13	0.91	**1.07**	0.62	**1.69**
Poland	0.22	2.45	1.05	**3.72**	0.87	**4.59**
Portugal	0.00	0.30	1.16	**1.46**	0.68	**2.14**
Romania	0.28	1.45	1.76	**3.48**	0.87	**4.35**
Slovakia	0.04	0.24	0.67	**0.95**	0.36	**1.31**
Slovenia	0.02	0.09	0.28	**0.39**	0.25	**0.64**
Spain	0.00	6.35	16.25	**22.60**	8.34	**30.95**
Sweden	0.04	0.25	1.77	**2.06**	1.24	**3.31**
United Kingdom	0.17	1.05	12.59	**13.80**	10.64	**24.45**
All Countries	**2.86**	**27.95**	**81.40**	**112.21**	**49.51**	**161.72**

Table 10 A3.2 The estimated annual energy consumption of existing cooling installations plus the additional energy used by these systems to provide a ventilation function.

Many potential energy-saving measures would target the technical energy efficiency of systems and would only have an impact on existing systems when they are replaced. Since air conditioning systems have relatively long lives, decisions taken today will affect consumption for decades to come. Measures targeting technical efficiency would also have an impact on new first-time installations (in new or existing buildings) in the expanding European air conditioning market.

For such measures, a more useful metric is the energy consumption of new and replacement systems. Table A3.3 shows estimates of the cumulative energy use for all new and replacement installations for a 10-year “business as usual” case. Roughly two-thirds of this consumption is market growth; the remaining one-third is replacement sales, though the proportion of replacements is increasing.

Estimated Cumulative Cooling Energy Consumption for all new installations between 2010 and 2019 (including replacements)						
Energy Consumption TWh pa	**Cooling**				**Ventilation**	**All Cooling and Ventilation**
	Moveable	**RAC**	**Central**	**All Systems**	**Central**	**All systems**
Austria	0.16	2.81	7.29	**10.26**	3.77	**14.04**
Belgium	0.17	2.65	5.92	**8.74**	5.99	**14.73**
Bulgaria	1.43	3.36	1.97	**6.76**	1.53	**8.29**
Cyprus	0.00	1.25	1.04	**2.28**	0.57	**2.86**
Czech Republic	0.90	17.29	2.73	**20.92**	2.44	**23.36**
Denmark	0.08	1.30	1.35	**2.74**	1.80	**4.54**
Estonia	0.04	0.53	0.50	**1.07**	0.53	**1.60**
Finland	0.29	1.30	3.97	**5.55**	2.84	**8.39**
France	1.31	19.41	27.43	**48.14**	20.12	**68.26**
Germany	1.36	2.04	17.59	**20.99**	14.36	**35.35**
Greece	0.00	16.98	12.55	**29.53**	5.07	**34.60**
Hungary	0.03	3.33	3.69	**7.06**	1.74	**8.80**
Iceland	0.01	0.07	0.27	**0.35**	0.19	**0.53**
Ireland	0.10	0.45	1.72	**2.27**	1.99	**4.26**
Italy	15.00	33.73	61.13	**109.86**	30.18	**140.04**
Latvia	0.07	0.86	0.67	**1.60**	0.60	**2.20**
Liechtenstein	0.00	0.01	0.01	**0.03**	0.01	**0.04**
Lithuania	0.02	0.08	0.80	**0.90**	0.71	**1.61**
Luxembourg	0.01	0.14	0.13	**0.27**	0.13	**0.41**
Malta	0.18	0.46	0.32	**0.96**	0.21	**1.17**
Netherlands	0.26	3.78	7.12	**11.17**	4.97	**16.14**
Norway	0.24	1.13	3.72	**5.09**	2.35	**7.44**
Poland	1.90	22.30	3.90	**28.10**	3.48	**31.58**
Portugal	0.00	2.24	4.73	**6.97**	3.10	**10.07**
Romania	3.19	8.67	4.10	**15.96**	2.52	**18.48**
Slovakia	0.57	1.42	1.61	**3.60**	1.06	**4.66**
Slovenia	0.20	0.56	1.45	**2.20**	1.35	**3.55**
Spain	0.02	46.63	65.68	**112.33**	33.23	**145.57**

Sweden	0.47	2.17	7.19	**9.84**	4.70	**14.53**
United Kingdom	1.98	9.10	25.16	**36.25**	26.00	**62.25**
All Countries	**30.02**	**206.05**	**275.74**	**511.81**	**177.52**	**689.33**

Table 11: A3.2: the estimated cumulative energy consumption attributed to cooling plus the additional energy used by these systems to provide a ventilation function for all new installations 2010- 2019

As can be seen from Tables A3.1 and A3.2, there is a wide variation in air conditioner types from one country to the next, and also a wide variation in energy consumption from one country to the next. These variations are attributed to the diverse country populations, climates and mix of building types.

The large differences in absolute consumption and market structure suggests that in order to capture a large fraction of the potential savings, policy instruments will have to be practical and economic for both high and lower air conditioning-using countries and will have to try and cover all air conditioner types (i.e. lower programmeinitial costs), bearing in mind that all countries are already obliged by the EPBD to have whole-building integrated minimum energy performance requirements.

A3.1.3 Modelled Cases

The modelled cases assess the realisable annual savings over a ten year period from a series of possible measures of policy, such as different levels of MEPS. These savings are the difference between projected consumption in the base case and that of the modelled case. They capture both the savings resulting from the replacement of existing systems and products by more efficient ones (and, for load reduction, the upgrading of existing buildings) and also the reduction in the growth in consumption from the use of more efficient products and systems (or reduced loads). The Modelled Cases consider the effect of a range of different performance standards from BAT level downwards that are applied at either the product/component, system or building level.

System Type	Policy Intervention Point		Base Case	Labelling and information	Labelling information and financial incentives	MEPs and labelling		MEPs, labelling and financial incentives		BAT
						Light	Moderate	Light	Moderate	
Moveables	***Product/System***		MO			M1/M2	M3	M4/M5	M6	M7
	Building						M8			M9
RAC	***Product/System***		RAC0			RAC1/RAC2/RAC3	RAC4/RAC5	RAC6/RAC7/RAC8	RAC9/RAC10	RAC11
	Building						RAC12			RAC13
Central and Larger Systems	***Product***	Chiller	C0	C1	C2	C3/C4	C5	C6/C7	C8	C9
		AHU (incorporating fans)		C10	C11		C12		C13	C14
		Pumps					C18		C19	C20
		Terminal efficiency					C15		C16	C17
	System	Ductwork air leakage					C21			C22
		Overall performance					C25/C24/C23			C26
	Building						C27			C28

Table 12 A3.4Summary of Modelled Cases (details of the cases can be found in Section B3: detailed results in B5)

Table A3.4 presents an overall picture of the cases that were modelled. The first column indicates the system types covered by each Case. The second column refines this to separate interventions targeted at systems, system components and buildings. The remaining columns show levels of ambition associated with each case. starting with the base case (no new intervention) and progressing through different levels of MEPS, labels and financial incentives, and ending with the Best Available Technology case. The letters and numbers in the boxes represent the various case numbers that were run through the modelling process, where the products are identified as follows:

- M0 to M9 represent mobile AC cases,
- RAC1 to RAC13 represent mobile air conditioning cases, and
- C1 to C28 represent central AC systems and components cases.

These Modelled Cases are described in more detail in Section B3.

A3.1.4 Cost-effectiveness

Demonstration of cost-effectiveness is, in principle, a necessary condition for policy measures that address energy efficiency: lack of cost-effectiveness is a fundamental barrier. However, the calculation of cost-effectiveness depends on many assumptions, some of which are more robust than others. Not least problematic are the assumptions about future energy and product prices. Historically, the real price of air conditioning products has fallen and the cost of energy has risen, so that measures which are not cost-effective at current prices may become so in the future. Even if the data were all reliable, the results would differ between applications: from country to country and building to building. This section discusses these issues and illustrates how the results vary between countries and applications.

A3.1.4.1 Cost-effectiveness Perspectives

A fundamental issue (and, in practice, an inconsistency) in the assessment of cost-effectiveness is that it is assessed from several different perspectives in different parts of policy assessment: notably from;

- that of society as a whole, which includes shadow prices for externalities, exclude taxes and subsidies, uses a (low) social discount rate and does not take account of different levels of impact on different parts of society
- that of end-users (typically a hypothetical “average” end-user). This includes taxes and subsidies, excludes non-priced impacts and uses commercial interest rates. Typically this only justifies lower performance levels than the societal perspective

In principle, from an economic perspective, all energy policy packages and measures should be designed to be cost-effective to society as a whole. However, policy measures that are societally justifiable may not seem so from the end-user perspective. In the present context, practice differs between different policy instruments.

In practice, the cost effectiveness of product MEPS is generally assessed from that of an idealised end-user (who typically is assumed to take a perspective that reflects the whole life of the measure and applies a social discount rate). For building energy standards and regulations, practices vary between Member States. Roughly equal numbers of countries use a societal perspective and an end-user perspective, with a significant number considering both perspectives. Renewable energy policy generally takes a societal perspective. By including the cost of externalities, application of the societal perspective would usually justify more demanding performance levels for products (and, for those countries which do not currently base building energy requirements on the societal perspective, also for buildings)

For consistency of policy making it would be desirable to have an agreed set of conventions. The proposed EPBD methodology for cost-optimal building energy standards could be, in principle, a suitable basis for this. Proposals have been put forwards but not yet agreed. They require cost-optimality from a user perspective, while permitting additional assessment from the societal perspective. This proposal would be consistent with the existing perspective of the Ecodesign Directive but, as noted above, out of line with practice in some related fields. The Ecodesign Directive is currently under review, but the perspective for calculating cost-effectiveness does not appear to be under consideration.

The extent to which the potential savings identified by the modelling are likely to be cost effective (to the individual user or to society) was considered in the modelling. For air conditioning systems and products whether a measure is cost effective or not depends on climate, building type and local prices – and therefore differs between countries and market sectors. According to industry sources, for air conditioning products such as chillers, split and multisplit systems, the additional capital cost per 1% improvement in efficiency is typically between 1% and 1.5%.

Cost effectiveness is also dependent on climate and building use. What is cost-effective or cost-optimal in one situation may not be in another and, since Europe-wide MEPS do not reflect this, they are inevitably sub-optimal in some applications and – depending on the levels of requirement demanded – probably not cost-effective in some countries or building types. Balancing these imperfections against the overall benefits is an essentially political judgement, not simply a matter of economic appraisal. These issues are discussed further in Appendix B1. Because of the fact that the cost effectiveness of more efficient equipment is so dependent on the local climate (and use) and the costs of power and of equipment, detailed quantification of the cost-effectiveness or cost-optimality of the savings identified was not carried out within this study. However, existing assessments of cost-effectiveness have been used to make a qualitative assessment of the probable cost effectiveness of the technical potential identified by different Cases. For example, the values of MEPS levels used in the Modelled Cases are explicitly compared with the results of the cost-optimality studies carried out within Preparatory Studies for MEPS[xxiv] for moveable and room air conditioning units <12kW. (See Section B3 for further details) The optimisation in the Preparatory Study was based on a single climate chosen to reflect the distribution of the stock of room air conditioners and used the end-user perspective and standard assumptions required by the Ecodesign Directive.

This is not to say that cost-effectiveness and cost-optimality are unimportant: clearly assessments and sensitivity studies should precede policy implementation. Both the societal and end-user perspectives are important. The societal perspective is fundamental from an economic perspective: policy instruments should lead to net gains for society as a whole. The societal perspective includes benefits to society that are not necessarily captured by market prices, and commonly justifies relatively demanding levels of energy savings. It is likely that these will not be cost-effective for some (possibly all) end-users from their narrower perspective. In particular, requirements may be seen as unduly onerous in some climates. This impacts on practical implementation and so it is important to understand the likely scope and degree of such constraints. Depending on the policy instrument and the level of requirement for product performance, assessment may need to take a national or European perspective. Requirements set at levels which are cost-effective for most applications, even if not cost-optimal, raise fewer issues of equity than more demanding requirements that are cost-effective only in some situations.

All the cases considered in this study, including BAT, are for products which are on or close to the market and, by implication, are expected by suppliers to be attractive and presumably cost-effective for some users in some circumstances. Furthermore, for cooling systems there is a growing market with significant technical potential for performance improvement, in which the cost of improved energy performance may fall significantly over a relatively short timeframe. Market transformation policies such as product MEPS can speed up this process and can additionally have an impact on pricing strategies, for example leading to lower prices for more efficient products due to economies of scale for production and more emphasis on product development to provide high performance at the lowest cost.

A3.1.4.2 Cost Effectiveness vs.Cost Optimality

A common objective of policy design is that measures should be cost-effective or cost-optimal [16] . A policy is *cost effective* if its costs are less than the value of the resulting benefits. A policy is *cost-optimal* when these net benefits are maximised. This is a stronger requirement. In addition, cost effectiveness is sensitive to the assumed prices and performance of "base case" with which potential measures are compared.

A3.1.4.3 Illustration of the Impact of Operating Conditions on Cost-effectiveness

As noted above, there is the particular complication that the cost-effectiveness of air conditioning measures is sensitive to climate, building design and building use. In consequence, setting MEPS for systems and products that have a wide range of possible applications is a difficult process. Similar problems arise when setting MEPS for buildings, which is one reason that they are set nationally or by climate zone.

Figure A3.2 illustrates this sensitivity. Simply stated, one can afford a very high efficiency air conditioner (which is more expensive) only when the cooling load is very high over a long period of time; otherwise, the savings in energy cannot justify the additional cost of the very efficient unit over the life of the unit. The detailed explanation follows:

The key parameter is annual load factor – the ratio between annual cooling demand and peak demand. This is expressed in units of "equivalent full load hours" (EFLH) and is shown on the horizontal axis. It varies with climate and building type. In Ireland, values vary between 30 for housing to 225 for retail premises, while in Cyprus the range is 600 to 800. It is not a measure of annual cooling severity, though it tends to broadly reflect it. (For example, Norway has higher figures than France due to its relatively low peak cooling loads.) Calculated values for all countries and different building types are given in section B4. The vertical axis shows the total cost savings per kW of (peak) cooling capacity compared to a reference product, including the extra cost of equipment and discounted energy costs over the life of the product. Each line represents a different SEER value.

The illustration is based on a split system. The chart shows the impact of change from an illustrative base case. The illustrative capital cost (200 Euro per kW excluding installation and trade discounts) and SEER (2.5) for the reference product and the energy costs (0.15 Euro per kWh post tax) are taken from the Lot 10 Preliminary study (ref). A product life of 12 years and a (low) discount rate of 3% pa have been used. A key factor is the degree to which extra performance implies extra capital cost. Japanese product prices reported in section B3 suggest that a 1% improvement of efficiency is associated with a 5% increase in price, but that some of this results from non-efficiency factors. Equivalent figures at less demanding performance levels from China suggest a somewhat lower effect. Engineering analysis for products in the USA [xxv] show ratios of between 0.5% and 1.5%, with the higher figures relating to higher performance equipment. The illustration here assumes 1% price increase for 1% performance improvement. Sensitivity tests show that the net savings are sensitive to the value chosen – but that the general picture illustrated remains.

[16] And improved energy efficiency should not be at the expense of other aspects of performance suchas comfort or noise.

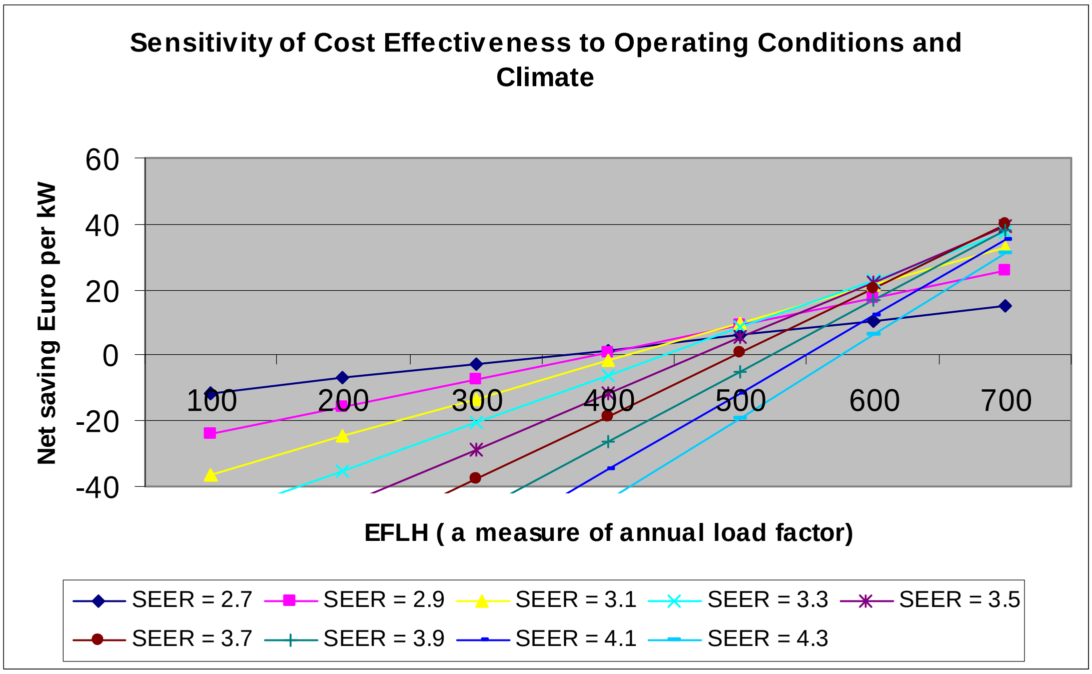

Figure 2 A3.2: Illustration of sensitivity of cost-effectiveness to operating conditions

Several points emerge (recalling that this is an illustration of principles):

§ as expected, net savings vary with equivalent full-load hours (EFLH), being higher at high values

§ at EFLH values below about 400, even small improvements in performance are not cost-effective

- o (however, at these levels of improvement there might well be no capital cost penalty)

§ Between EFLH values of 400 and 600, best value is with SEER values of around 3.1 to 3.3, with little to choose between them

§ Above ERLH values of 600 a range of SEERs becomes cost-effective but the more demanding ones are not cost-optimal (in other words, they produce net savings relative to the base case, but not relative to less demanding SEERs)

§ In particular, the highest energy saving does not coincide with the best value

The results are particularly sensitive to:

- The assumed sensitivity of cost to performance (this is not a question of whether prices in general fall, but of the additional cost associated with better performance).
  - o In the example, if the additional cost is reduced to 0.5% per 1% improvement in performance, there are net benefits at EFLH values above 200, and the highest performance levels shown become cost-optimal above about 400
- The discount rate applied
  - o From the perspective of an end-user with an opportunity cost of capital of10% pa, only situations with very high values of EFLH are attractive

Table A3.5 illustrates what this would mean for different types of application in different countries. The likelihood is based on EFLH (low < 400; medium 400 to 500; high > 500). It should also be noted that a product that is cost-optimal for the median user within any class of user will, by definition, not be cost-effective for about half of the users within the class.

Likelihood of cost justification for high efficiency cooling based on EFLH						
	Office		***Dwelling***		***Retail***	
Country	***New***	***Existing***	***New***	***Existing***	***New***	***Existing***

AT	High	Low	Low	Low	High	Low
BE	Medium	Low	Low	Low	Low	Low
DK	Low	Low	Low	Low	Low	Low
FI	Low	Low	Low	Low	Medium	Low
FR	High	Medium	Low	Low	High	Low
DE	Medium	Low	Low	Low	Low	Low
GR	High	High	Low	Low	High	High
IE	Low	Low	Low	Low	Low	Low
IT	High	Medium	Low	Low	High	Low
LU	High	Low	Low	Low	High	Low
NL	Medium	Low	Low	Low	Low	Low
PT	Medium	Medium	Low	Low	High	Medium
ES	High	High	Low	Low	High	Medium
SE	Low	Low	Low	Low	Medium	Medium
UK	Low	Low	Low	Low	Low	Low
CY	High	High	High	Low	High	High
CZ	Low	Low	Low	Low	Medium	Low
EE	Low	Low	Low	Low	Low	Low
HU	High	Low	Low	Low	High	Medium
LV	Low	Low	Low	Low	Low	Low
LI	Low	Low	Low	Low	Medium	Low
MT	High	High	Low	Low	High	High
PL	Low	Low	Low	Low	Low	Low
SK	High	Low	Low	Low	High	Medium
SL	High	Low	Low	Low	High	Low

Table 13 A3.5 Illustrative variation in the likelyhood of for high efficiency cooling being justified on cost between countries and applications

Superimposed on this idealised picture is the effect of variations of prices between countries and with time: the Lot 10 Preparatory Study showed that typical product prices varied between 139 and 350 Euro per kW for different countries. Electricity prices varied between 0.1 and 0.2 Euro per kWh.

This example only considers the cooling performance. Most room air conditioners sold in Europe also have a heating capability. Improvements to cooling efficiency are likely to also improve heating efficiency at little extra cost – but with increased benefits. In a similar way, improvements to the ventilation components of centralised systems will often also have benefits for cooling consumption.

A3.1.5 Maximum Technical Potential Savings

One set of model cases deals with the maximum technical potential for savings that would arise if “Best Available Technology” (BAT) was applied universally to all types of air conditioners. This sets limits on possible savings using current, but not generally common, technology. (A list of the cases is given in A3.1.2 above)

Combining the BAT modelling cases for each of the different system types produces aggregate potential savings of 66 TWh pa or 70% of the base case consumption for the same rate of market growth and system replacement rates. . Load reduction measures relating to the building envelope have the potential for similar saving: 54.4 TWh pa or 59% of base case consumption. The combined potential savings amount to 88% of base case consumption. Although the potential savings are very high, in practice, it is impractical to retrofit every installation with the best available technology for air conditioning, but the figure indicates the magnitude of the opportunity. In practice, equipment is replaced after it fails, becomes too expensive to repair and operate or because of building refurbishment.

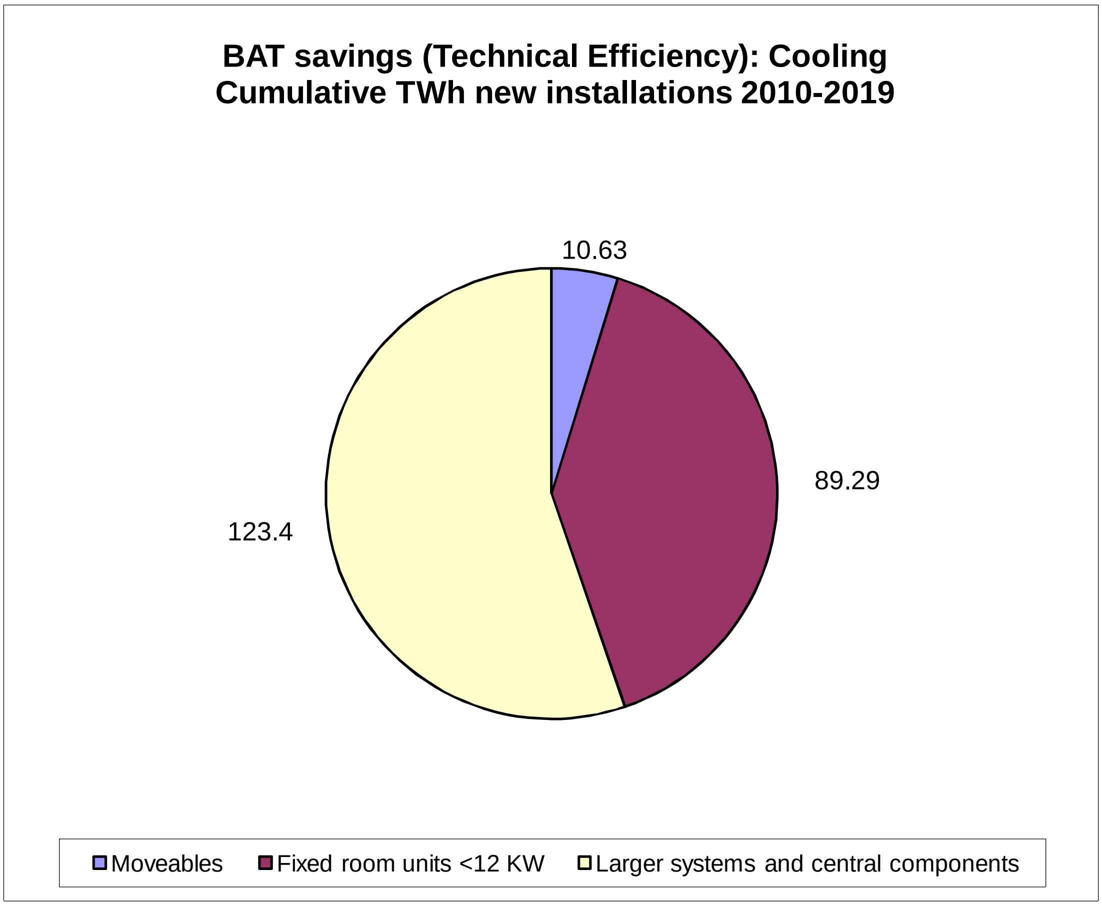

Figure 3A3.3 Distribution Potential Savings (technical efficiency) when BAT is applied to air conditioning equipment (excluding energy to move air or chilled water distribution equipment)

Figure A3.3 shows the distribution of potential savings of the energy that is used for the cooling function (that is, excluding energy used for ventilation). It broadly reflects that of existing consumption, but that the importance of central systems is greater compared to other system types. More detailed results are shown graphically on the charts below.

Figure A3.4 illustrates on the first column, the annual consumption of all air conditioners in the EU and EEA calculated by the model for the Base Case (at the current rate of consumption by existing equipment): 92 TWh/year. The second column represents the energy consumption *if the BAT were used to replace the currently operating air conditioners*: 44 TWh per year. The third column represents the annual energy consumption of all air conditioners *if the building envelope of all buildings were upgraded to the BAT*: 39 TWh per year. The fourth column represents the annual energy consumption for cooling where *the BAT was applied to both the AC equipment and to the building envelope*: 11 TWh per year. These cases illustrate the magnitude of the potential energy savings; in practice, equipment turns over as it ages and is replaced with more efficient equipment over time, according to what is offered in the market.

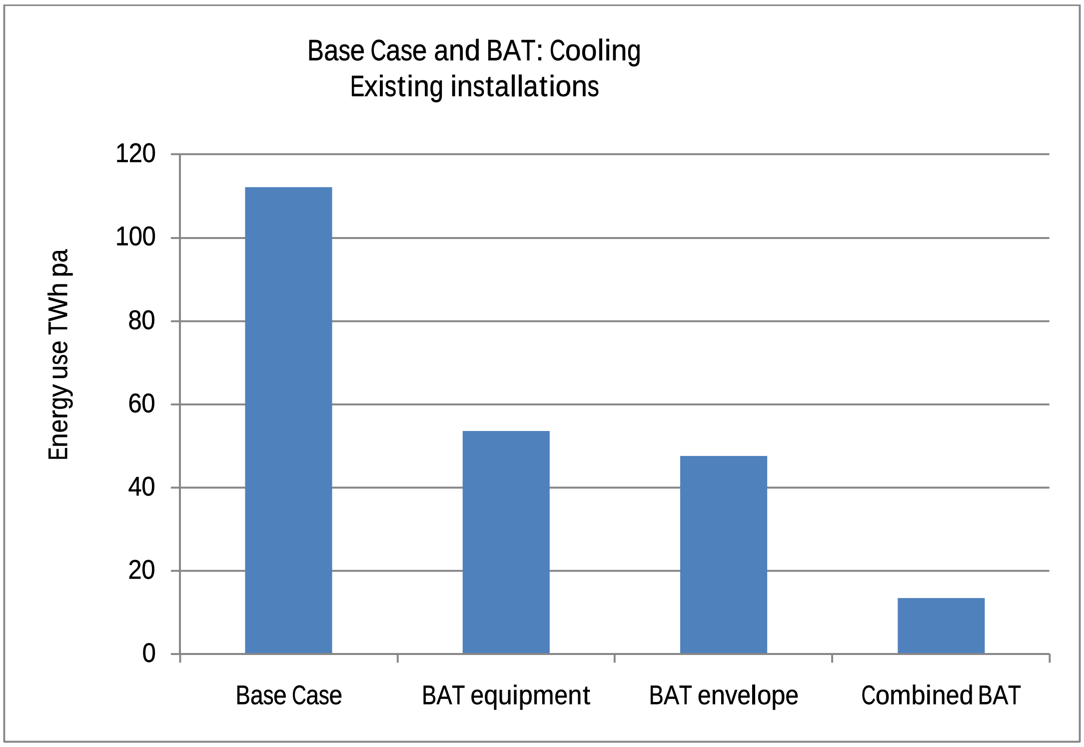

Figure 4 A3.4 Summary of BAT cases: cooling

The amount of energy consumed by air distribution systems (central systems) for moving air is very significant and is illustrated on Figure A3.4. Often, outside air is added to provide the required rate of air change for health reasons, adding to the air distribution load both in volume and in operating time of the equipment. Considering only the energy component of the air handling system associated with the air conditioning function only, the model was used to calculate the amount of energy used per annum by these systems under the following four conditions:

First column: Base case, representing the *current annual consumption of air handling systems*, about 180 TWh per year

Second column: *BAT systems applied to air handling and distribution systems*, about 55 TWh per year

Third column: *same as second case, but with reduced air flow requirement* (for non-smoking buildings), 15 TWh per year

Fourth column: annual energy consumption of *all air handling and distribution systems with BAT applied and reduced air flow requirement*, about 10 TWh per year.

Due to the impracticality of replacing all systems instantly with BAT and reducing building envelope heat gains, these calculated energy savings are indicative of the potential that exists, but will require considerable time, effort, policy interventions and money to achieve.

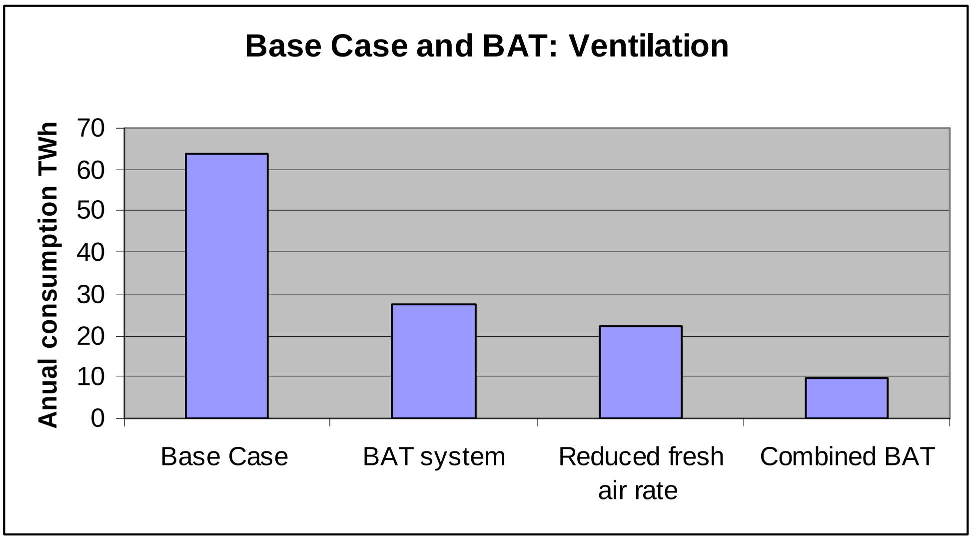

Figure 5 A3.5 Summary of BAT cases: ventilation

The potential savings that are theoretically available are considerable. The contributions of load reduction by building envelope measures (basically shading and ventilation, to a lesser extent from insulation) and by improvements to system efficiency are of very similar magnitude.

Analysis of potential energy savings in actual buildings [xxvi] suggests that there are also additional comparable levels of savings to be made from improvements to system operation. (The base case assumes well-managed systems).

Simulation studies [xxvii] show that additional but smaller savings are available from the use of more efficient lighting systems and office equipment. In broad terms, simulation showed potential air conditioning savings of around 20%. This compared to ranges of about 25% to 60% for either better shading or enhanced ventilation, depending on the technical solution chosen

There is therefore an a priori case for considering policy measures that address system efficiency, load reduction and system operation. The following sections examine the modelling results and practical considerations for each of these.

A3.1.6 Modelling Cases and Policy Measures

For air conditioning equipment and systems, modelling cases were defined to represent three groups of policy measures:

- **i.** Energy Performance Labelling and Information Provision (incl. User feedback)
- **ii.** Mandatory Minimum Energy Performance Requirements, at different levels of ambition
- iii. Incentives for Better Efficiency or Lower Consumption

Although the modelling cases are hypothetical idealisations, they have been chosen in order to inform guidance on policy-making.

For central systems, MEPS were modelled for components as well as for complete systems. MEPS applied to complete systems and to buildings (including their systems) were also modelled and the potential for savings by choosing system configurations that are inherently efficient was also investigated.

A3.1.7 Summary of Modelled Results

A total of 50 cases were modelled including a base case, BAT, and different levels of MEPS, energy labelling, financial incentives and changes in the market mix of different types of central system.

An overview of the policy measures and their respective 10-year theoretically realisable energy savings is presented graphically as a bar chart on Figure A3.5. This figure also indicates the measures that show substantial extra savings beyond the 10 year horizon ("(1)" appended). The realisable energy savings over the first 10 years were calculated using the model and the defined Cases as inputs. The realisable savings in TWh (over the first 10 years) are shown for each of the cases modelled. The lighter colour refers to savings associated with the cooling function: energy savings associated with the ventilation function of central systems are shown in a darker colour.

The largest theoretically realisable savings are from six sets of measures. These predominantly apply to central systems rather than to room air conditioners. [17] These potential savings are not simply additive. Implementation issues are discussed in section A4 below.

- Minimum performance standards for buildings and their building technical systems, with potential savings over ten years of over 180 TWh. These are already required by the Energy Performance of Buildings Directive (EPBD), but implementation requires that the building and cooling distribution system in existing buildings be upgraded and replaced to reduce the cooling demand, and that the more efficient systems be installed. Due to the long life of buildings and rather infrequent total renovation of buildings, the rate at which these measures can be implemented is relatively slow.

- Detailed cooling system audits. Research has shown that air conditioning inspections mandated by the EPBD can identify potential energy savings (and result in savings if the recommendations are acted on) but that they only identify a small part of the overall potential. Detailed but more expensive audits or equivalent measures can identify many potential savings that, if implemented, would result in savings of the order of 140 TWh over ten years.

- Minimum performance standards applied to central air conditioning systems offer potential savings totalling around 122 TWh (90 TWh from cooling and 32 TWh from air handlers) over ten years but face significant barriers to implementation, which are discussed later.

- A somewhat overlooked source of savings is a reduction in fresh air supply for buildings where smoking is no longer permitted. Potentially, this can also save about 124 TWh over ten years (100 TWh from reduced air movement and 24 TWh from reduced cooling load. This figure is somewhat uncertain since there is little information available on relative frequency of design based on smoking or no smoking assumptions.

- Demanding performance requirements for air conditioning chillers have the potential for savings of about 90 TWh over ten years. This policy option is currently being

[17] Recent increases in the market share of room air conditoners taken by highly efficient products has reduced the potential for further savings in this area.

explored in more detail in a Preparatory Study for the Energy-related Products Directive.

- Improvements in air handling subsystem efficiency (comprising both the air handling units and the associated ductwork) have the potential of saving between 35 and 52 TWh of energy the first 10 years.
- Demanding performance requirements for room air conditioners have the potential to save 40 TWh over ten years.

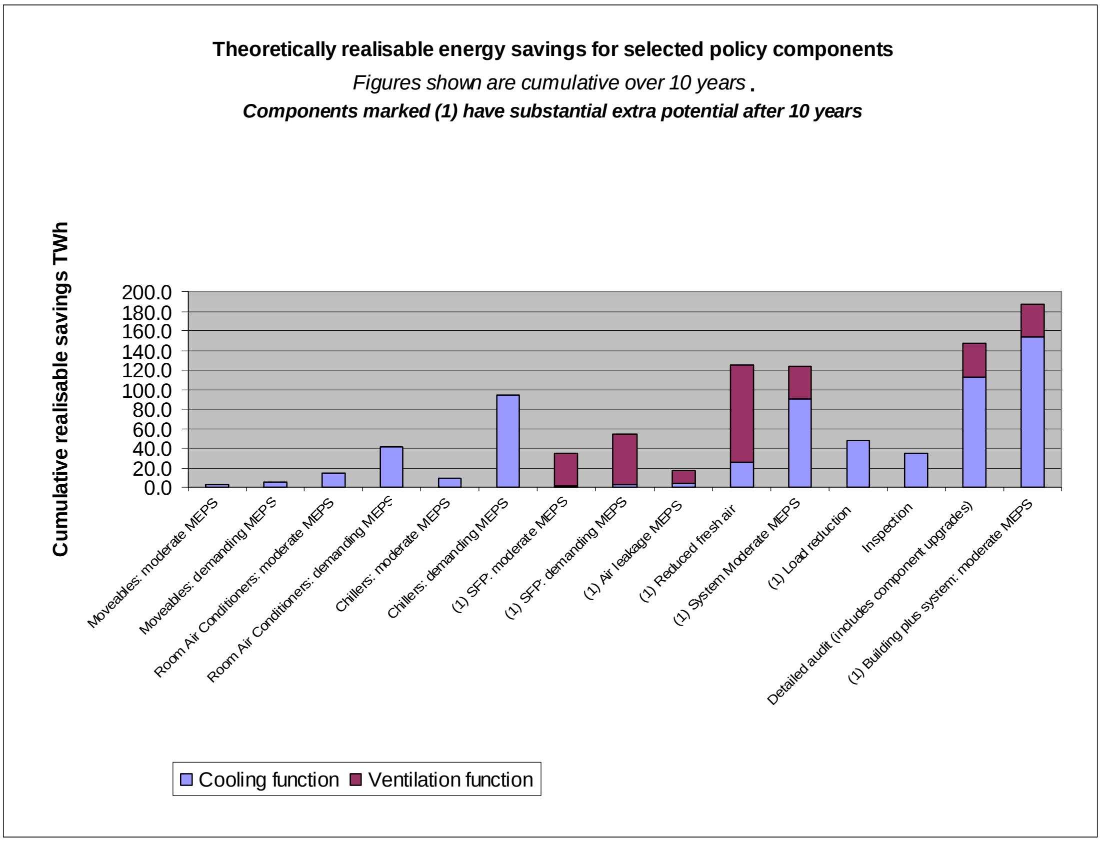

Figure 6 A3.6 Summary of realisable savings of the most significant policy measures

The following section discusses the implications of the model results and set them alongside a number of practical considerations.

A3.2 Impact of Policy Measures relating to Product Performance

This section reviews and comments on the potential impact of possible policy measures with a view to developing policy recommendations. It presents the results of the Modelled Cases and also raises some practical considerations. The detailed modelling results are contained in Section B5 of this report.

A3.2.1 Energy Performance Labelling and Information Provision for Products and Systems

The modelling results show small potential savings from Energy Performance Labelling and Information Provision for Products and Systems (beyond those already in place) (based on the assumptions made, which are discussed in Section B3). No specific policy recommendations are made, but further work to investigate the impact of these types of instruments in business-to-business supply chains is recommended. (Recommendation 20)

Modelling Results

The impact of mandatory energy labelling of moveable units and fixed room units, and the voluntary labelling of chillers and air handling units is included in the base case. The modelled savings attributable to mandatory energy labelling for the remaining products (cases C1 and C10) and systems are small. (That is less than 10 TWh over 10 years, as described earlier).

This is a consequence of the assumption that the effect of labelling to central systems would be that a 5% proportion of purchasers would switch to A-rated products.

The direct impact of MEPS on the market place is relatively straightforward to estimate, since it prevents products from being placed on the market. Assessing the likely impact is more difficult for energy labelling or financial incentives as the impact depends on changing purchaser behaviour (or manufacturers' decisions about what to place on the market).

The proportion of room air conditioners placed on the European market has certainly increased since the introduction of energy labelling as has the proportion of such products that are sold. This is especially true in Italy, where they were within the scope of a "white certificate" incentive programme. [18] These market changes have been included in the modelled base case for these classes of products.

The remaining types of air conditioning systems (central systems and large packaged units). account for the majority of the market in terms of energy consumption, and are sold via business to business supply chains. In principle, energy labelling could also have an impact in such procurement routes. For business to business transactions, this impact likely to be through procurement requirements that specify particular minimum performance levels. Energy labels can provide an easily identifiable means of checking compliance at each step in the supply chain. Such procurement requirements seem most likely to be associated with organisations that wish to establish "green" credentials (such as public bodies and organisations wishing to position themselves as being especially environmentally responsible). Given the relatively short time horizons that many businesses apply to investment decisions and the fact that the system specifier is unlikely to be responsible for the running costs this seems likely to be a relatively small proportion of specifiers. This is the pattern found with voluntary environmental labelling of buildings, which is perhaps the closest analogue or to set an example (such as government departments). In the absence of data on the proportion of the market that would specify highly efficient products, we have assumed that the energy efficiency of 5% of the products sold (drawn proportionately from the existing market mix) will be specified to be in the top performance band. [19] In the absence of empirical data, similar reasoning has been used to add a further 5% movement for "financial incentives": the actual impact of financial incentives is likely to depend on their size and accessibility.

Evidence on the impact of labelling on consumer products such as refrigerators or televisions is varied. [xxviii] In some cases (including room air conditioners) the introduction of labelling has been followed by the appearance on the market of an increased number of highly-rated products and fewer low-rated ones and, in some countries, by a significant increase in the market share of more efficient products.

[18] This is discussed in more detail in Section B3.2.5

[19] The top voluntary label class where such exists, or an equivalent category derived from market statistics: see section B3

A comparison of the modelled impact of MEPS alone and MEPS plus labelling shows that the additional impact of labelling declines as the stringency of MEPS increases. This is the result of the reduced impact of switching from the lowest permitted rating (the MEPS) to top-rated products. Removal of products from the market represents the de facto introduction of MEPS.

Practical Considerations

Despite the apparently low direct impact, energy performance labelling is an important element of policy. Information that distinguishes more- and less- efficient products and systems is necessary for other policy measures such as MEPS or financial incentives. Labelling is a familiar and easily comprehended way of providing this. For room air conditioners MEPS have tended to precede mandatory labels, although in recent years labels have tended to precede MEPS, for example, Brazil and the EU [xxix].

A rating figure based on nominal output under standard conditions can be misleading since, for air conditioning products, annual consumption is strongly dependent on part-load efficiency. Ratings based on standardised seasonal performance are preferable and will be adopted for room air conditioners in 2013. Even a single seasonal rating figure does not provide adequate information about component products (such as chillers) to system designers attempting to optimise overall system performance. For this purpose individual part-load performance figures are required. The relevant European test standard, EN14825, has recently been amended to include part-load performance testing, removing an important barrier to implementation.

A3.2.2 Energy Performance Information Provision for Complete Systems: Calculated Performance

Taken in isolation performance requirements for complete systems has significant energy saving potential. However, practical implementation faces difficulties which are described below, and much of the potential for savings overlaps with that available from other options for policy measures. Recommendations 1, 2, and 6 relate to ways of overcoming them. The provision of information would be one way of encouraging the use of higher efficiency systems. An important barrier, discussed later, is the absence of an agreed methodology for reporting the efficiency of central systems.

Modelling Results

The provision of energy performance information for complete systems was not explicitly modelled, but the impact can be assessed as being similar to the combined effect of the labelling of individual component products. As is discussed above, this is small but the approach can be seen as an essential pre-requisite for the introduction of MEPS, which have larger potential savings (and are discussed later).

Practical Considerations

For self-contained systems such as split systems this calculation amounts to the same thing as product performance labelling discussed above. For central systems it is more difficult, since these are designed specifically for particular buildings and need to be carried out for each installation.

In principle, a calculation of system efficiency is part of the implementation of the EPBD for building (plus system) energy performance requirements (and for building energy performance certification where this is done by calculation). A significant information barrier exists since there is no requirement to report the calculated air conditioning energy consumption or system performance. Some implementation software in some countries reports diagnostic information which includes this information. There is therefore an existing framework that could be used to overcome this barrier, at least for the situations where building energy performance labelling is already required. This would draw on the skills and quality assurance procedures that should already be in place for EPBD implementation.

Arguably, the main value of assessing system performance separately from whole-building performance is in applications that are not mandated by the EPBD: notably new installations in existing buildings. This could be addressed by making installation or modification of air conditioning system trigger application of elements of the EPBD (as it already triggers some elements of building energy performance standards or regulations in the UK. In this situation, the system design is more likely to be carried out by installers than by a separate design team. Currently they would be unlikely to have the appropriate training or accreditation (or perhaps independence) for regulatory purposes.

From informal discussions, it appears that the air conditioning energy calculation is rarely done convincingly within Member States' EPBD implementations at present. One serious barrier is the absence of a generally acceptable and practicable calculation methodology. Before energy efficiency indicators for complete systems (and possible system-level MEPS) could be introduced, there is a need to test and compare those methodologies that are in use, and to agree or develop a common process. A suitable vehicle for then promulgating this would be a revised version of the relevant European Standard EN 15243.

A3.2.3 Energy Performance Information Provision for complete (Central) Systems: Observed Performance

The energy performance information provision for complete (central) systems (and the closely related option of observing whole-building performance) is one of the few policy measures that can address operational energy waste and in consequence has a large potential. There are barriers related to the visibility of some information, and also the generic energy efficiency barrier of motivating organisations and individuals to taking action.

Recommendations 4 and 5 relate to inspections and audits, and recommendations 15 and 16 to different aspects of whole-building performance information. It includes two overlapping areas: basic energy benchmarking and system inspection to identify specific possible consumption reduction measures. Regular system inspection at a fairly basic level is a requirement of the EPBD for systems of over 12kW capacity but implementation is currently patchy. [xxx] Whole-building energy performance certificates (labels) are used by many Member States to meet the EPBD requirements for public display energy certificates. Voluntary use of energy benchmarks is practiced by some energy managers: detailed analysis of consumption patterns is a service that is offered by specialist companies.

Modelling Results

The policy measure "Energy Performance Information Provision for complete (Central) Systems: Observed Performance" was not explicitly modelled, as their impact has already been estimated empirically and modelling would not have materially added to this work.

For system inspection, there is empirical evidence [xxxi] that the potential savings identified by the type of inspection required by the EPBD amount to only a small proportion of the total potential savings, which amount to 34 TWh over a 10-year period. This estimate is derived by applying the proportion of possible savings from inspections that were found by the Harmonac study to the modelled estimates of potential savings in the present study. This is comparable with the potential savings from introducing moderately demanding MEPS for chillers and room air conditioners.

The same research demonstrated that it is very difficult to increase the potential savings from on-site surveys without more time-consuming, invasive and expensive system analysis. In Case Studies, detailed energy monitoring and analysis identified potential savings seven times greater than by inspection alone. This is a very large potential compared to other policy measures (but implicitly includes many of them such as replacement of existing components with high-efficiency alternatives).

Practical Considerations

There are two significant barriers to achieving energy savings from inspections: the cost of the inspection; and motivating building owners to take action on all but the most straightforward of recommendations. These are interrelated.. The market appears to have divided into owners who want a legal document to comply with EPBD requirements at the lowest possible cost and those who prefer a more expensive inspection that helps them to save energy. The supply side of the market has inevitably responded to this.

While mandatory inspection can cover all or most air conditioning systems, it only produces recommendations for action and does not guarantee savings in the way that changes to equipment efficiency can do. The actual impact therefore seems likely to be low unless combined with incentives for action. Calculations by the Auditac project [xxxii] suggested that universal inspection is probably not cost-effective. The EPBD Concerted Action reviewed this work and concluded that "... while inspections of larger installations are clearly cost-effective, inspection of smaller units, especially in moderate climates … are clearly not cost-effective". The EPBD Recast allows Member States more flexibility in this respect.

One possible option would be the mandatory metering and annual reporting of air conditioning energy consumption, with inspection or other investigations required for systems with abnormally high consumptions. This would complement the information available from on-site inspections.

Currently whole-building energy performance certificates are mainly confined to public buildings and do not separate energy use for different functions. In principle, sub-metering and reporting of specific end-use consumption could be made mandatory (perhaps limited to larger systems) and applied to a wider range of buildings. Remote recording and automated analysis and diagnosis of detailed consumption patterns to identify potential problems is being investigated by projects in Europe [xxxiii] and the USA. [xxxiv]

A3.2.4 Energy Performance Labelling and Information Provision for Buildings

Energy performance labelling and other forms of information provision for buildings have a significant potential for reducing air conditioning energy consumption if the information is acted on, since savings are available from both reduced loads and improved system efficiency. However the provision of information on air conditioning energy use within current implementations of existing EPBD requirements for building energy ratings is uneven. Recommendations 1, 2, 3, 13 and 17 relate to this measure.

Member States are already required by the EPBD to ensure that Energy Performance Certificates are produced whenever buildings are constructed, sold or let. These are based on the energy consumption of a building and its fixed building services (air conditioning, heating, lighting, hot water production). In the majority of Member States these are based on calculated consumption, although some States use measured consumption. The certificates have to be accompanied by recommendations for cost-effective improvements, which can include improvements to air conditioning systems or reductions in cooling load.

Modelling Results

This policy measure: “Energy Performance Labelling and Information Provision for Buildings” includes the effect of both load reduction measures applied to the building and improved system efficiency. The BAT modelling results reported earlier show that there are very considerable potential energy savings from load reduction measures. However, the most effective of these are applicable only to new buildings and those undergoing major refurbishment. Cost-effective recommendations are unlikely to exist for new buildings, and implementation of major changes in existing buildings is only likely (and then uncertain) at times of substantial refurbishment. In consequence, the potential impact each year is rather small. The 10-year realisable savings are estimated to be about 23 TWh.

Practical Considerations

The section addressing system-level information suggested that information on system efficiency that is used within the calculation process for building energy performance certification should be reported on the certificate. The same barriers, possible solutions and related issues apply here, but relate to air conditioning energy consumption rather than system performance. The distinction between the two is that reporting energy consumption rather than system efficiency also reflects the effect of load reduction measures applied to the building.

Limited take-up of recommendations is a generic barrier to achieving energy savings and has been discussed in many places, most relevantly in the EPBD Concerted Action. [xxxv] In the view of the national representatives, the most important actions would be “more communication”, “improve the quality of consultants” [i.e. assessors], “use other instruments”. They felt that it is particularly important to emphasise the benefits to building owners. These comments seem likely to be equally applicable to air conditioning recommendations as to other means of energy savings – possible more so since many building owners are likely to be unfamiliar with ways of reducing cooling energy consumption.

Measured whole-building annual consumption is commonly used as a means of complying with the EPBD requirement for the public display of building energy ratings for public buildings. The process of generating a rating is relatively straight-forwards as it does not require a building inspection. As a result frequent reporting is practical (in the UK annually, showing the last three years’ results). Certification based on measured consumption reflects quality of management as well as the efficiency of the building and its systems. When the information is also displayed publicly, it acts as an incentive to efficient management. Requiring or encouraging this for a wider range of commercial buildings would expand its potential impact. Ideally this would be combined with the disaggregation of air conditioning energy in recommendation 15.

A3.2.5 Policy Measure: Minimum Energy Performance Standards (MEPS) for Products

There are substantial potential savings from this policy measure, unevenly distributed between different products. Recommendations 8, 12 and 14, relate to these policy measures.

Modelling results

This subsection considers MEPs for products whether these be components of centreal systems or complete self-contained air-conditioning systems. MEPs for central systems and their sub-systems and for buildings are considered in later subsections. As can be seen from Table A3.5 above, many of the Modelled Cases were for MEPs applied at different levels to different "products" (including systems and buildings).. [20]

The Modelled Cases cover a full range of MEPS requirement levels. All Modelled Cases assume that energy labelling would also be introduced, since the majority of the implementation processes such as product test standards and compliance testing procedures and would be required for MEPS.

In the list below, the term "chillers" is used as a shorthand way of describing cold generation for all air conditioning systems other than fixed and moveable room units of less than 12 kW cooling capacity. Most of the cooling in this category is provided by chiller-based central systems but it also includes rooftop units and larger split, multisplit and VRF systems. The calculated savings are aggregate figures for all these systems.

When estimating the (realistic) market potential (sales of new efficient models), we include replacement of existing units at the end of product life and filling the demand for new units to fill the growth in the market. For a saturated market the first component could be estimated by taking the number of existing (old) units in actual use and dividing by the expected life of the product in years. The quotient would be the existing market replacement per year. Because the European market is expanding, this approach would be inaccurate and the market growth has been determined and factored into the impact using more sophisticated market modelling. These procedures were developed to support other work and are re-applied here [xxxvi]

The list below categorises product-based MEPS cases according to their theoretical realisable savings levels over a ten year period after implementation. Because of the cumulative nature of savings, the first year savings represent only between 1% and 2% of the ten-year values: 0.1 TWh for moveable units, 1.1 TWh for fixed room units and 1.6 TWh for chillers. Complete replacement of the existing stock would require approximately 12 years for moveable and fixed room units and 20 years for chillers.

Cases with High Energy-saving Impact (over 100 TWh over 10 years)

- Demanding MEPS for chillers (removes over 90% of products from current market, and therefore requires a significant lead time)

Cases with Significant Energy-saving Impact (between 10 and 100 TWh over 10 years)

[20] From a policy perspective, MEPS serve two purposes: to remove inefficient products from the market as a form of quality control on the market; and to encourage technical innovation by manufacturers of these product and by air conditioning systems designers. Only the firsy of these effects has been modelled

- Demanding MEPS for fixed room units < 12 kW (removes about 80% of products from the current market)
- Less demanding MEPS for fixed room units
- Less demanding MEPS for chillers

Other Cases (less than 10 TWh over 10 years)

- MEPS for moveable units
- MEPS for terminal units
- MEPS for pumps

The modelling results support the importance of MEPS for fixed room units and chillers as important measures of policy. The potential savings from applying MEPS to pumps, fans and terminal units used within central air conditioning systems were also assessed. By comparison with other possibilities, the impact in each case was small. However, MEPS applied to these products may be cost-effective, and the scale of savings for applications other than air conditioning may justify such measures. In this case, they should apply to air conditioning applications.

Based on the results of a Preparatory Study, [xxxvii]proposals were initially out forwards for MEPS of 3.42 (SEER) for room air conditioners and 2.19 (EER) for moveable units, to be introduced 2 and 4 years after formal adoption. These were subsequently revised to 3.60 and 2.40 to be introduced in 2013 and 2014 respectively. The Regulatory Committee has given a positive opinion on these proposals. Since the Preparatory Study was carried out, sales of A-rated products and better have increased markedly in some important countries, such as Italy and the impact of the proposed requirements will be less than initially expected. In the case of Italy and of Greece the change accompanied financial incentives [xxxviii] for the early replacement of existing systems by energy-efficient ones, and cannot be ascribed solely to the energy labelling. Progressively more demanding requirements can increase the savings without unduly restricting the range of products on the market. The limit to the requirements that could be justified would reflect a societal assessment of costs and benefits.

The levels of the originally proposed European MEPS for room units are classed as "less demanding" because changes to the market have significantly improved the aggregate energy efficiency of these products in the "base case" since the analysis underpinning them was carried out, using data predominantly from 2006[xxxix] The ten-year savings from the proposed MEPS have been modelled and are comparatively low because of the (more realistic) phased introduction compared to the theoretical instant application used for other cases. The MEPS levels adopted during 2011 are close to our modelled case for demanding MEPS and have significant realisable savings

MEPS for moveable air conditioners produce lower savings than for fixed room units or chillers, but if MEPS are introduced for fixed room units, it would seem consistent to also introduce them for moveable units. By the same token, "MEPS for chillers" implies application to the other product categories described above.

The modelling suggests that progressively tightening the proposed requirements for room air conditioners and the introduction of mandatory requirements for chillers could substantially increase the energy savings while staying within the bounds of current technology.

Practical Considerations

As noted above, the existing framework for the mandatory labelling of smaller air conditioners (up to 12 kW cooling) has recently been revised and MEPS will be introduced in 2013. The MEPS required are slightly more demanding than the "mild MEPS" case that has been modelled.

One of the modelling cases is for more demanding levels of requirements that fall short of BAT but would remove about 80% of products from the current market. Applied uniformly across countries and climates there is a risk that in some cases – less demanding climates and applications - it may impose costs that are disproportionate to the benefits. The current Regulation does not distinguish cooling performance by climate. [21] An alternative approach would be to combine uniform but less demanding European-wide mandatory requirements with relatively strong national guidance (for example in the form of "deemed to satisfy" requirements in building energy standards) to encourage the use of more efficient products in climates that justify such levels of performance. This would be more complex to administer but inherently more equitable. This option was not explicitly modelled, but the impact could be roughly estimated from the modelled country by country savings for different cases.

In the Regulation, enforcement has two main arms:

- self-declaration "The manufacturer of air conditioners and comfort fans shall provide laboratories performing market surveillance checks, upon request, the necessary Minimum Performance Requirements For sub-systems *capacities*, *SEER/EER*, *SCOP/COP* values and *service values* and provide contact information for obtaining such information."

- limited testing "The authorities of the Member State shall test one single unit."

This contrasts with the rather time–consuming and relatively expensive - but apparently more robust - independent testing of specific products and extrapolation of results to similar products of different capacity that is required by the current voluntary labelling scheme for other air conditioning products.

A3.2.6 Minimum Performance Requirements for Sub-systems

Minimum performance requirements for sub-systems offer significant potential savings. Recommendations 9, 10 and 11 relate to these policy measures. Recommendation 2 relates to coordination between national and European policy and is also relevant

Central cooling systems typically include several sub-systems in addition to the plant that generates cooling. The most important from an energy (and capital cost) perspective is the air handling sub-system. There are significant possibilities for reducing energy consumption by applying performance requirements to this sub-system. In this study fan energy consumption is divided into two parts: energy use required to provide a fresh air supply; and the additional fan energy required in systems where part of – or all – the cooling service is provide by cooling air (which may include recirculated air). In addition to reductions in fan energy consumption, more energy-efficient air distribution reduces loads on the cooling plant itself (both by reducing distribution losses and because most of the energy supplied to fans also contributes to cooling demand). In the summary below, the savings relating to the cooling and ventilation functions have been combined. In every case, the largest savings are for the energy used to support the ventilation function.

[21] Heating performance may be calculated for three climates .

Modelling Results

The modelling shows that these measures have high – in some cases, very high – potential energy savings. The list below categorises ventilation-related cases according to their savings levels over a ten-year period after implementation of the relevant policy measure.

Cases with High Energy-saving Impact (over 100 TWh over 10 years)

- Reduce ventilation fresh air rates to those needed for non-smoking premises
- Demanding MEPS for specific fan power

Cases with Significant Energy-saving Impact (between 10 and 100 TWh over 10 years)

- Less demanding_MEPS for specific fan power
- MEPS for ductwork and AHU leakage requirements

Practical Considerations

MEPS for specific fan power and for ductwork and AHU leakage already exist in national building energy standards in some Member States including the United Kingdom and Finland [22], so there is no doubt that they are possible. Most Member States do not appear to have such requirements. From a technical perspective Europe-wide requirements appear feasible. The requirements apply to parts of central air conditioning systems that vary from building to building. Air leakage from ductwork can only practicably be checked on site. For these reasons these measures can only realistically be implemented at national level through national building energy codes. The most straightforward way of implementing Europe-wide requirements would seem to be through the EPBD. Principles of subsidiarity would mean that each Member State could set requirements that best meet its local needs. Uniformity of approach could be encouraged by the publication of authoritative model codes that refer to existing European Standards that already define performance classes. Such codes could be produced by the Commission, by Europe-wide associations (such as REHVA) or jointly. .. . There are limited opportunities to implement the measures other than for new systems (including major building refurbishments), so the timescale for them to be implemented in the majority of systems would be slow – of the order of 30 to 40 years-. This has been taken into account in the figures above.

The reduction of fresh air rates for spaces where smoking is no longer permitted (but maintaining levels recommended by European Standards) would logically be implemented for new systems by reviewing – and, if necessary, revising - national engineering design codes. which specify minimum outdoor air supply rates to ensure that they reflect the different requirements for spaces in which smoking is or is not expected to take place. This might need to be supplemented by the provision of information to clients to explain the reasons for an apparent reduction in standard of service. Flow reduction should be possible in many existing systems, contingent on the possibility of maintaining adequate control and balancing. This opportunity should be highlighted within inspection and energy audit schemes.

[22] Some countries regulate one of these factor but not both. Data are not available for all countries. The assumptions used in the modelled are tabulated in Part B

A3.2.7 Minimum Energy Performance Standards (MEPS) for Complete Systems

Minimum energy performance standards (MEPS) for complete systems are called for in the EPBD Recast. [23] . The measure is closely related to that relating to energy performance labelling of complete central air conditioning systems and discussed in A3.2.3 above. The recommendations listed there (1,2, and 6) apply equally here

The overall efficiency of a central air conditioning system depends on the performance of its component parts (including those that are not series produced products) and its basic configuration. (It will also vary with weather and building use). A MEPS requirement applied at this level should still leave the system designer flexibility to trade off system type and component efficiency to produce the most appropriate or most cost-effective combination for a particular application. It also puts pressure on component suppliers to offer value for money: competition is not simply against other manufacturers of similar products, but also against competing ways of reducing energy consumption.

Modelling Results

The modelling cases separate two elements of this type of requirement, reflecting two extreme cases:

- when the type of system installed is unchanged but the system-level performance requirement results in the use of higher efficiency components
- when the type of system chosen is always the one that is inherently the most efficient for the particular application and climate (subject to some constraints)

The Modelled Cases show that the potential savings from improvements in component efficiency (without change of system type) would be large. The additional savings resulting from changes to the choice of system are also significant – of the order of 6 TWH over 10 years. Because major changes of system type are only possible in new buildings (before installation) and during major refurbishment, the potential from system changes would take several decades to be reached, and the estimated 10-year impact is rated as potentially significant (between 1 and 10 TWh). The dynamics of component replacement would be more rapid, as described under “products MEPS”. Typical product lives of chillers and air handling units are 20 to 30 years. In a steady market this would result in an annual replacement rate of 2% to 3%. In a growing market such as that for air conditioning, replacements are a smaller percentage of the installed stock. Refurbishment rates for non-domestic buildings (which contain most air conditioning systems) are rather uncertain but probably in the range of 1% to2% per annum [xl]. Only part of this will be major refurbishments that could include the replacement of complete air conditioning systems.

Practical Considerations. There are very significant practical constraints on this policy measure. Because not all systems are suitable for all applications, MEPS would need to be contingent on the type of application (which may change during the life of a building) or be set at fairly weak levels. The ranking of system switching potential savings as “significant” is contingent on the practical constraints on the interchangeability of types of system. It is possible that intangible constraints imposed by clients and their advisors (such as concerns about quality of service or property rental or resale value) could be more restrictive.

[23] Article 8 Clause 1 of the EPBD Recast states “Member States shall, for the purpose of optimising the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings.

The previous observations (under energy labelling of systems) on the barrier presented by the lack of a generally accepted methodology for calculating system efficiency apply equally here.

A3.2.8 Minimum Energy Performance Standards (MEPS) for Buildings (and their systems)

This policy measure "Minimum Energy Performance Standards (MEPS) for Buildings (and their systems)" is related to the provision of energy performance certificates for buildings and shares some barriers with that policy measure. It has a large potential for reducing air conditioning energy consumption but implementation of existing requirements for air-conditioning is uneven and levels of ambition vary between countries. Recommendations 1,2 and 13 **relate to this policy measure**

Member States are required by the Energy Performance of Buildings Directive (EPBD) to implement minimum performance standards for buildings and their associated "building technical services" (HVAC, lighting and similar services). This applies to new buildings and when buildings undergo major refurbishments. The EPBD Recast also requires minimum performance requirements to be set for replacement building elements (including systems). [xli]

This policy measure provides the designer with maximum flexibility to trade off load reduction measures against cooling system efficiency (whether achieved through component performance or choice of system type), and cooling demand against heating or lighting energy demand. It is already a requirement of the EPBD, and potential savings have to be compared to this baseline.

Modelling Results

Minimum Energy Performance Standards (MEPS) for Buildings (and their systems) encourage savings from any of: load reduction, system choice and component efficiency. Since the impact combines the savings from all these sources, the absolute potential savings are large – over 100 TWh over ten years. As with MEPS for complete systems, this approach encourages the development of cost-effective design solutions – but now including load reduction measures – and incentivises component and system providers to improve value for money in terms of energy savings in order to compete with alternative routes.

Practical Considerations

Although the potential savings are large, whole-building requirements only affect new buildings and those undergoing major refurbishment. In consequence, the time required to impact a substantial part of the building stock is long – of the order of 30 years. In that time many of the system components will have been replaced, perhaps more than once. In that sense, policy measures addressing system components (and self-contained systems) are complementary to those addressing complete buildings (or complete system). Thus the *additional* savings attributable to the whole-building (and system) MEPS are reduced to those from load reduction. These remain substantial

A4 OBSTACLES, BARRIERS AND RECOMMENDATIONS

A4.1 Scope and Overview of Section A4

Section A3 reported the main results of the modelling and other analysis in terms of realisable potential energy savings. The largest potential savings were found to result from the following measures (in order of savings [24]):

A. minimum performance standards applied at the building level but taking into account air conditioning system performance

B. detailed energy audits of cooling systems

C. minimum performance standards for air conditioning systems

D. reduction of fresh air supply in buildings where smoking is no longer permitted

E. minimum performance standards for air conditioning chillers

F. minimum performance standards for air handling systems

G. minimum performance standards for room air conditioners and other self-contained systems

Section A4 now focuses on specific obstacles and barriers that relate to the seven major opportunities listed above and on regulatory measures to reduce or overcome them.

There are significant realisable potential energy savings in each of the three main areas in which energy can be wasted: cooling demands, system efficiency and system and building operation. Lack of technically established options is not a barrier. The relationship between measures and these areas is mapped in Table A4.1 below. As can be seen, some measures impact on more than one area and two of the three areas are impacted by more than one measure.

Key	Measure	Impacts on		
		Cooling load	System efficiency	Operation
A	Minimum performance standards applied at the building level	XXX	XXX	
B	Detailed energy audits of cooling systems	XX	XX	XXX
C	Minimum performance standards for air conditioning systems		XXX	
D	Reduction of fresh air supply in buildings where smoking is no longer permitted	XXX	XX	
E	Minimum performance standards for air		XXX	

[24] The total savings is not simply the sum of the those for single measures: the introduction of some measures reduces the potential for others. For example, reducing cooling loads reduces the potential savings from higher system efficiency and vice-versa.

	conditioning chillers			
F	Minimum performance standards for air handling systems	X	XXX	
G	Minimum performance standards for room air conditioners and other self-contained systems		XXX	

Table 4.1 Showing the impact of measures by energy waste area. (More ticks means larger impact)

Table 4.2shows that there is a more consistent mapping between the measures and existing policy instruments such as the EPBD, although a few measures fall within the scope of more than one instrument. In view of this relationship, in this section, the obstacles and recommendations are grouped together according to the policy instrument to which they apply, There are also recommendations in Section A4 for actions that do not relate directly to the application of existing policy instruments.

Some smaller savings from the application of these policy instruments to components of air conditioning systems not highlighted in Section A4 (but identified in Part B of this report) may also be justified, when account is taken of their applications outside the air conditioning market.[25]

Key	Measure	Policy Instrument		
		EPBD	National Building Energy Codes	EcoDesig n Directives
A	Minimum performance standards applied at the building level	X	(Via EPBD)	
B	Detailed energy audits of cooling systems	X		
C	Minimum performance standards for air conditioning systems	X	(Via EPBD)	
D	Reduction of fresh air supply in buildings where smoking is no longer permitted		X	
E	Minimum performance standards for air conditioning chillers			X
F	Minimum performance standards for air handling systems		X	
G	Minimum performance standards for room air conditioners and other self-contained systems			X

[25] For example, the application of MEPS to pumps may well be worthwile when all pumps are considered, but the major savings will not come from air conditioning systems

Table 4.2 Mapping measures to existing policy instruments

There are many possible reasons why potential savings remain unrealised. The obstacles described in this section are those that have been identified as specifically constraining the major energy-saving opportunities listed above. The identification is based on informal discussions with stakeholders in Europe and elsewhere and published literature and the authors' experiences in supporting the implementation of air conditioning energy efficiency policy instruments.

The level of ambition that is considered economically justifiable is an over-arching, generic consideration. Notwithstanding the difficulties of determining justifiable Europe-wide levels of cost-effectiveness discussed in Section A3, the direction of travel is clear: historical trends of increasing energy prices and decreasing product prices will increasingly justify more energy-efficient ways of providing comfort. Regulatory requirements should be economically justified by the balance between life-cycle costs and benefits to society and will therefore be more demanding than at those that a "rational consumer" would perceive at current costs. The direction of travel is therefore clear, but the speed of change that can be justified is not. As is discussed in section A3, the levels of requirement that can be justified vary between countries and building types. For this reason, the Modelled Cases consider different levels of ambition for each potential measure. (Recommendation 20 is for work to investigate one aspect of this specifically in the context of air conditioning).

This generic issue underpins all aspects of regulatory policy. Additional obstacles apply to each of the three areas where air conditioning energy saving potential exists – and sometimes to specific parts of an area. These are discussed in the following subsections

Broadly, they are, by area:

Demand reduction and more effective operation. The obstacles and related recommendations relate to the provision of better information with which to identify justifiable opportunities applicable to individual buildings (recommendations 7, 15 and 16) and the implementation of the identified measures (recommendations 5 and 7). In the case of EPBD air conditioning inspections, there is also a need to explore more cost-effective ways of meeting its objectives.

Air conditioning systems and components. Provision of the information is also an issue here, typically relating to technical performance levels (recommendations 3, 8, 17), as is the implementation of identified measures. There is scope to weaken the barrier of low take-up of high performance equipment by the introduction of minimum performance requirements. In addition there are barriers relating to the need to develop procedures and model clauses for national energy performance requirements (recommendations 2, 11) and to apply them across the EU (recommendations 1, 9, 10).

Some recommendations apply to more than one area.

Several other generic obstacles to energy efficiency [26] also potentially affect air conditioning. The constraints of split incentives seem likely to be particularly important given that there is a long and somewhat complex procurement chain for most air conditioning products and systems, with no participant in the chain having responsibility for both initial and operating costs. Better product performance information (recommendation 8) would be helpful here but would be unlikely to be sufficient in itself. Recommendation 20 is for work to address this issue.

[26] A comprehensive generic set of categories of possible obstacles to energy savings is described later in Section B6 (and appendix).

The potential savings from each measure are not simply additive, especially for combinations of measures that target:

- Building design to reduce cooling demands, and system efficiency
- System efficiency and component (or sub-system) efficiency

For example the introduction of minimum performance requirements for chillers (via the EcoDesign Directives) would reduce the scope for further savings from the introduction of minimum performance requirements for buildings (including their systems) (via the EPBD). The scope of policy instruments also differs. Minimum performance requirements for buildings would not impose requirements on replacement chillers (unless such replacement was part of major refurbishment as defined by the EPBD).

The relationship between measures and the associated policy instruments is therefore rather complex. Ideally measures imposed by different policy instruments should be part of a coordinated package, with consistent criteria used to justify regulatory intervention by different instruments.

For buildings, air-conditioning systems and components an integrated package could comprise:

- Minimum performance standards applied at the building level (including system performance), allowing scope for designers to assess the least cost combinations of building and system measures. These would apply to new buildings and those undergoing major refurbishment and are within the scope of the EPBD.

- Minimum performance standards for air conditioning chillers. These are needed to capture replacement chillers that are not parts of major refurbishment and are therefore not captured by building level requirements. They would be within the scope of the EcoDesign Directives and would therefore also apply to chillers in new systems. The requirements should therefore be set at levels that permit designers of new and refurbished buildings a choice of products of different performance and cost, enabling them to search for best-value combinations of load reduction and cooling efficiency.

- Minimum performance standards for air handling systems. These are needed to capture replacement systems that are not a part of major refurbishment and are therefore not captured by building level requirements. As the requirements are placed on subsystems which are not standardised products it would be difficult to implement this requirement via the EcoDesign Directives. At present such requirements – where they exist – are implemented through national building energy codes and standards. This would seem to be the appropriate implementation mechanism. In practice similar requirements are also applied to new systems, at more demanding levels,

- Minimum performance standards for room air conditioners and other self-contained systems. These are straightforward series produced products and would be within the scope of the EcoDesign Directives. The requirements should be set at levels that permit designers of new and refurbished buildings a choice of products of different performance and cost, enabling them to search for best-value combinations of load reduction and cooling efficiency. To the extent possible, the requirements for these products should be determined by the same cost/benefit process applied to buildings.

A4.2 Energy Performance of Buildings Directive (EPBD)

A4.2.1 EPBD: MEPS for buildings and their systems

This section refers to measure A “Minimum performance standards applied at the building level but taking into account air conditioning system performance”. This is estimated to have a savings potential of 120 TWh over 10 years. It arises from considerations described in sections A4.2.3, A4.2.5. A4.2.8 and A4.2.10.

Current status

The EPBD already requires Member States to have whole-building energy performance requirements (equivalent to product MEPS) that include the effects of system and product efficiency and load reduction. Such requirements allow trade-offs to be made between different ways of reducing consumption and thus encourage the development of the most cost-effective combinations of measures for each building. An important trade-off is between energy supplied for cooling and that used for heating. Building measures to reduce cooling loads may unintentionally have a negative effect on overall annual energy use. For example, if one tries to reduce winter-time solar gain by using fixed shading and overhangs in buildings, the result may be an increase in the need for space heating due to reduced solar gain in winter; some forms of window shading may decrease solar gain and cooling requirement, but also may increase the need for artificial lighting.

Most room air conditioners currently sold in Europe are reversible: they can also operate as highly efficient heating systems (compared to electric resistance heating), often at lower carbon intensities than fossil-fuelled systems. Some other systems – notably VRF systems and water loop heat pumps – have the ability to transfer surplus heat from one part of a building to other parts that may require cooling. Heat rejected from chillers may also be used for space heating for other zones or to preheat domestic hot water. Generally, the more efficient an air conditioner is in cooling, the more efficient it is in heating also. Therefore efficiency improvements in reversible air conditioners can save energy on a year-round basis.

Interaction with other possible policy instruments

If product MEPS are in place, they will reduce the additional potential impact of whole building requirements.

Other features

The EPBD mechanisms relate to new buildings and major refurbishments and therefore have a slow cumulative impact. There will be additional longer-term savings beyond the 10-year modelling horizon.

Barriers and Recommendations

The current state of implementation of the whole-building performance requirement presents several barriers to achieving savings in air conditioning energy consumption:

Barrier to improved efficiency: *Implementation of the requirements for air-conditioning is patchy, especially with regard to the methods of calculating system efficiency*

In a survey by the EPBD Concerted Action[xlii], only 5 of the 15 respondents claimed to have a calculation method that included air conditioning system performance. The survey did not look into what the methods were.

> ***Recommendation 1**: Member States that do not have such procedures should be required to implement them.*

There is further barrier to implementing this recommendation: there is little prior art in the use of calculation methods for air conditioning energy consumption that are both technically convincing and appropriate for regulatory application to the wide range of applications that need to be covered. [27] As noted above, at least 5 countries claim to have procedures, but little detail is known about them.

***Barrier to improved efficiency:** Lack of a recognized standard for the calculation procedure.*

This should be supported by

> ***Recommendation 2**: A consensus should be developed for a generally acceptable calculation procedure. Ideally this should be consistent with the procedures that are already in place in several Member States. This is likely to require resources for testing existing procedures and, if necessary, the development of improved ones. (Such a procedure would also be a necessary precursor to system-level MEPS, should they be judged desirable.).*
>
> In principle, this might be expected to fall within the remit of the mandated revisions to EPBD-related CEN standards, but it is unlikely that the timescale or funding mandated would allow the research and development necessary to reach a robust procedure. A more practicable approach could be to develop and test a methodology outside the CEN framework – perhaps within European programmes such as those managed by EACI – with the possibility of adopting it as a formal standard in due course.

A4.2.2 EPBD: Information – System Inspections and Audits

> This section refers to Measure B “Detailed energy audits of cooling systems”. The estimated energy savings if improvements identified by inspections are implemented is 30 TWh over 10 years. Research has shown that most of these are low-cost measures that could, in principle be implemented quickly. Actual implementation rates are not known. Detailed audits can identify more savings but are expensive to carry out and only cost-effective where they identify affordable savings that are actually implemented.

Current status

The EPBD requires the mandatory regular inspection of a/c systems > 12kW. The Recast permits the frequency of inspection to be varied and allows Member States to opt for information campaigns in place of mandatory inspection. The Recast also encourages the use of electronic data collection to assist diagnosis

[27] Most existing calculation tools were either developed for design purposes, requiring high levels of skill and large amounts of data, or are little more than rues of thumb

Features

The requirement for mandatory inspections is one of the few policy instruments that address operational energy wastage. Even though the system is working as intended, the operation of the building and occupant behaviour can have a severe impact on operating cost. For example, open doors, windows, incorrect settings, extensive interior heat gains, air movement between controlled and uncontrolled zones, cooling during unoccupied periods, etc. can have a very significant impact on energy consumption (and operating cost).

Barrier to improved efficiency: Weak *implementation of the requirement for regular inspection (but data on this are sparse).*

An EPBD CA report [xliii] found that 40% (of 20 respondents) had inspection system in force or in preparation, a similar number rely on existing systems and 20% have no regulations. It also found that “most MS are convinced that there is room for improvement in their inspections scheme” (this applies to boiler and air conditioning inspections). At least three Member States have indicated that they intend implement information campaigns instead of inspections.

> ***Recommendation 5:*** *Encourage Member States to strengthen implementation where necessary.*
>
> For example, there are business opportunities in remedying existing efficiency defects or avoiding future ones (subject to effective quality assurance and independence of the inspectors). The supporting analysis to this recommendation is discussed in section A4.2.4.

The uncertain cost-effectiveness of mandatory inspection comprises a barrier to active implementation of the policy instrument.

Barrier to improved efficiency: *Doubtful cost effectiveness of universal) inspection of air conditioning systems deters active implementation of policy.*

While mandatory inspection is likely to be cost effective for poorly managed systems where the manager takes action in response to recommendations, cost-effectiveness will be low where systems are already well-managed or recommendations are not acted on. This was the conclusion was reached by the EPBD Concerted Action [xliv], having reviewed research results and may be the reason why several Member States have opted instead for information campaigns. Selective inspection would be likely to improve the value for money of an inspection requirement, providing that the initial screening process is effective and inexpensive. The following four recommendations address this issue

> ***Recommendation 4:*** *The potential use of electronic monitoring of air conditioning systems to improve the cost-effectiveness of inspection should be investigated.*
>
> Article 15, Clause 2 of the EPBD Recast acknowledges that electronic monitoring of systems could be justify more selective inspection: “Member States may reduce the frequency of such inspections or lighten them, as appropriate, where an electronic monitoring and control system is in place”. Remote monitoring of building energy consumption is an established technology, but has not been used to identify priorities for inspection. A project supported by European funding to develop and test such an application is currently under way. [xlv] .

A4.2.3 EPBD: Information – Building Energy Performance Certificates

The EPBD requires the provision of a whole-building energy performance certificate (EPC) whenever a building is constructed, sold or let. It must be accompanied by recommendations for measures to improve consumption. Most EPCs are based on calculated rather than measured consumption but many countries do use measured consumption for those buildings where public display certificates are required and a few use measured consumption more widely. [28]

Existing energy performance certification processes contain – or could contain – information that would identify systems with particularly high consumption or apparently low efficiencies and which could therefore be prioritised for inspection. Since building energy performance certification is required whenever buildings are sold, let or constructed they have a much wider application than building energy codes, which only apply to new buildings and major renovations.

The following recommendations address existing barriers to the use of information from the building energy certification process.

A4.2.3.1 Certification based on measured energy consumption

Certification based on measured consumption one of the few regulatory opportunities to address poor energy management. There are two significant barriers to achieving this for air conditioning.

Certification based on measured consumption reflects the quality of management as well as the efficiency of the building and its systems. The process of generating a rating is relatively straight-forward as it does not require a building inspection. When the information is also displayed publicly, it acts as an incentive to efficient management.

The supporting analysis to this recommendation is discussed in section A4.2.5.

Barrier to improved efficiency: *Lack of disaggregated energy end-use data makes it difficult for the user to identify AC electricity consumption*

The primary source of data for building energy performance certification based on measured consumption is the output of utility meters. In some larger buildings utility electricity consumption may be broken down into hourly or shorter time steps but for billing purposes it is aggregated over a complete building or part of a building. It is therefore difficult to identify air conditioning consumption separately.

> ***Recommendation 15:*** *Require the separate metering and reporting of electricity consumption of major items of air conditioning equipment and reported in energy performance certificates.*
>
> Disaggregated information would identify unusual consumption levels. Ideally the information should be lodged in a central data base that can identify such situations automatically. The information would also add value to universal mandatory inspection by helping an air conditioning inspector to judge whether to recommend further investigations beyond a basic inspection.
>
> The supporting analysis to this is discussed in section A4.2.5.

[28] Notably Norway and, for some types of building buildings,France.

Barrier to improved efficiency: *Many buildings are not certified on the bases of measured consumption*

In most Member States, certification based on measured consumption is confined to public buildings. Even with disaggregated consumption reporting, as recommended above, diagnostic information can only be available for part of the market.

> ***Recommendation 16:*** *Encourage Member States to expand the use of measured energy ratings to a wider range of buildings: notably those with air conditioning.*
>
> For example, Energy Performance Certificates could usefully show both calculated and measured performance levels. Calculated performance is an indicator of the (theoretical) energy efficiency of the building and system: measured performance complements this by reflecting actual use and construction. (See also recommendation 17 below)

A4.2.3.2 Certification based on calculated consumption

Standardised calculated energy consumption is the basis of energy performance certification for the majority of buildings in Europe. The calculation process requires the calculation of air conditioning energy use. (But see 1 and 2 above concerning the potential to improve this). Information on the expected overall energy performance of the air conditioning system, based on declared system design and component performance is therefore determined. However, explicit declaration of this on the certificate appears to be rare.

Barrier to improved efficiency: : *The calculated air conditioning system energy performance carried out as part of building energy performance certification is not reported.*

> ***Recommendation 17:*** *Calculated air conditioning energy consumption and overall system efficiency - should be reported in building energy performance certificates.*
>
> Access to calculated efficiency and consumption data would identify air conditioning systems with low inherent efficiencies that would be likely to justify further investigation and possible upgrading. Ideally the information should be lodged in a central data base that can identify such situations automatically. The information would also add value to universal mandatory inspection by helping an air conditioning inspector to judge whether to recommend further investigations beyond a basic inspection. The cost of making existing information accessible should be low.

The supporting analysis to these recommendations is discussed in section A4.2.5.

A4.3 National Building Energy Codes, Standards and Regulations

Some requirements for air conditioning systems can only realistically be implemented as part of the building permitting and control system, (though the EPBD can encourage such implementation). Such requirements include those applying to elements of central systems such as air distribution systems that are specifically designed for each building- essentially bespoke subsystems (though built from mostly standardised components). (System components that are traded products can be addressed through the EcoDesign Directives and are discussed later).

A4.3.1 Air Handling Subsystems: specific fan power and air leakage

An air handling subsystems comprises the combination of ductwork, air delivery terminal and the fans, filers and heat exchangers that are usually containing in an air handling unit (but may be separate components). Such a subsystem has two significant aggregate energy performance characteristics: specific fan power (SFP: which, despite its name, is influenced by all the components of the subsystem) and air leakage. Performance requirements for both leakage and SFP have been judged cost-effective and implemented by several, mainly Scandinavian, countries but are not implemented in other Member States. The potential realisable energy savings over 10 years from the universal introduction of requirements at the same level as those already in place in some countries are 55 TWh for SFP and 30 TWh for air leakage.

Barrier to improved efficiency: *Lack of performance requirements for Air Handling Subsystems in many Member States*

> ***Recommendation 9:*** Minimum energy performance requirements for specific fan power should be introduced in those Member States that do not already have such requirements.
>
> ***Recommendation 10:*** Minimum energy performance requirements for ductwork and air handling unit leakage should be introduced in those Member States that do not already have such requirements.
>
> ***Recommendation 12:*** To assist Member States to introduce these requirements, model clauses and guidelines should be developed, based on the experience of those that already have them.
>
> The supporting analysis to these recommendations is discussed in section A4.2.7.

A4.3.2 Air Handling Subsystems: outdoor air supply rates

There are also substantial potential savings associated with reducing outdoor air requirements for spaces in which smoking is no longer allowed. This is likely to be cost-effective in new installations and in existing ones where the system configuration (and application) permits it. The potential savings over 10 years are tentatively estimated to be 120 TWh, but shortage of information on current national constraints on smoking – and their complexity - and on the extent to which air handling subsystems have already been adjusted to reflect them, mean that this may be an overestimate. Minimum fresh air rates may be defined in national building codes or design conventions.

Barrier to improved efficiency: : *An opportunity exists to reduce energy consumption by reducing outdoor air supply rates in spaces where smoking is no longer permitted does not appear to be widely recognized.*

> ***Recommendation 7*:** Fresh air design rates and regulatory requirements should be reviewed in the light of smoking legislation and amended where appropriate (retaining compliance with relevant European standards
>
> Air conditioning inspectors should also be reminded of the savings potential.
>
> The supporting analysis to this recommendation is discussed in section A4.2.3.

A4.3.3 System-level MEPS

In theory, system-level MEPS have a significant energy saving potential, estimated at 30 TWh over 10 years. However, most of this potential can be achieved by other policy instruments that appear easier to implement, including as requirements for product, subsystem and whole-building performance.

Current status

The EPBD Recast calls for the introduction of MEPS for technical building systems [29]. As far as is known no Member State currently applies a whole-system energy requirement.

Implementation of recommendation 2 (for the development of a generally acceptable calculation procedure for characterising air conditioning system energy performance) would be a necessary prior step to the introduction of system-level performance requirements. The procedure recommended in recommendation 2 would need to be extended to include a practical performance metric (or metrics) that aggregates heating, cooling and ventilation energy use. In principle compliance could then be checked as part of national building energy codes (for new buildings and major refurbishments). However, many air conditioning systems are installed in existing buildings where building energy codes do not normally require a whole-system calculation, and where installation contractors are therefore not familiar with such processes. The high potential for savings suggests that the issue should not be forgotten, however.

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> ***Recommendation 6:*** *System-level performance requirements for air conditioning systems should not be treated as priority issue, but the case for them should be reviewed from time to time.*
>
> The supporting analysis to this is discussed in section A4.2.3 and is in the light of progress on recommendations 1 and 2.

A4.4 Energy-related Products Directive

A4.4.1 Energy-related Products Directive: Chillers

The modelling results show potential realisable savings over 10 years of up to 90 TWh from demanding levels of MEPS, with a figure of 25 TWh for less demanding levels of requirements (which would remove fewer products from the market and would therefore be more practicable in the short run).

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[29] Article 1 (c) the application of minimum requirements to the energy performance of: ……
(iii) technical building systems whenever they are installed, replaced or upgraded;
Article 8 1. Member States shall, for the purpose of optimising the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings.
System requirements shall be set for new, replacement and upgrading of technical building systems and shall be applied in so far as they are technically, economically and functionally feasible.
The system requirements shall cover at least the following:
(a) heating systems;
(b) hot water systems;
(c) air-conditioning systems;
(d) large ventilation systems;
or a combination of such systems.

Current status

There are no European minimum performance requirements or mandatory energy labels: a Preparatory Study is under way. MEPS for chillers are well-established in other parts of the world. The seasonal performance of many chillers is known through the existence of a voluntary energy labelling scheme which covers many but not all chillers.

> ***Barrier to improved efficiency:*** *The absence of MEPS and mandatory energy labels for chillers obstructs the achievement of energy savings.*
>
> ***Recommendation 8:*** *Introduce mandatory energy labelling and MEPS for chillers*
>
> Since MEPS are assessed from an end-user perspective within the Ecodesign Directive - and in order to allow time for the supply chain to adapt – the initial proposals seem likely to be at "moderate" levels. More demanding requirements are likely to be cost-effective to society as a whole, though not to all end-users - cost-effectiveness will vary from country to country. It would therefore be desirable, after initial introduction, to review requirement levels with a view to progressively making them more demanding, should this be justified.
>
> The supporting analysis to this recommendation is discussed in section A4.2.6.

A4.4.2 Energy-related Products Directive: Room Air conditioners < 12kW

The modelling results show potential realisable savings over 10 years from the introduction of MEPS for these products in the range 15 to 20 TWh, depending on the level of requirements set

Current status

Based on the results of the Lot 10 Preparatory Study, proposals were initially put forwards by the Commission for MEPS of 3.42 (SEER) for room air conditioners and 2.19 (EER) for moveable units l. These were subsequently revised to 3.60 and 2.40 which will be introduced in 2013 and 2014 respectively. Since the Preparatory Study was carried out, sales of A-labelled products and better have increased markedly in some important countries, such as Italy. As a result, the impact of the MEPS will be less than initially expected.

> ***Barrier to improved efficiency:*** *Because of changes in the market since the development of the MEPS criteria, the levels to be introduced from 2013 now look weak.*
>
> ***Recommendation 12:*** *Develop proposals to progressively make MEPS more demanding.*
>
> Progressively more demanding requirements can increase the savings without unduly restricting the range of products on the market. Since MEPS are assessed from an end-user perspective within the Ecodesign Directive, more demanding levels are likely to be cost-effective to society as a whole, though not necessarily to all end-users.. (See also Recommendation 3 below for a possible alternative approach to implementation).
>
> The supporting analysis to this recommendation is discussed in section A4.2.6.

A4.4.3 Energy-related Products Directive: Other Components

The savings achievable by MEPS on other components of central air conditioning systems have been found to be relatively small, except for air movement subsystems (which are addressed above in the section on national building codes).

There is therefore no compelling case for introducing MEPS for other components of central air conditioning systems. This does not preclude the introduction of MEPS for components such as pumps and fans which are also used in other applications, if the wider perspective justifies this

The supporting analysis to this recommendation is discussed in section A4.2.6.

A4.4.4 Energy-related Products Directive: Provision of Information

A seasonal performance value that reflects the variability of efficiency at different loads and operating temperatures is a more robust metric for MEPS and energy labelling than a standardized "at design" value. Standards for test conditions and suitable metrics exist, are used in voluntary energy labelling schemes, and may be used to comply with the forthcoming MEPS for fixed room air conditioners [30](and possibly for other products). The whole-system calculation procedures (as referred to in 1,2 and 6) require the individual part-load performance values: they are combined local climatic and application data to generate system efficiencies that relate to local conditions. However, the individual test results are not required to be reported by the Energy-related Products Directive.

> ***Barrier to improved efficiency:*** The calculation of system energy efficiency is impeded by the absence of part-load performance data in energy labelling information.
>
> ***Recommendation 3:*** *Product Information sheets for air conditioning products should contain the key part-load performance data used in the ratings.*
>
> This is a low-cost measure that supports the implementation of recommendations 1 and 2 (and potentially 18).
>
> The supporting analysis to this recommendation is discussed in section A4.2.5.

A4.4.5 Energy-related Products Directive: General

The cost effectiveness of MEPS varies with application and climate. Demanding performance requirements may be unnecessarily costly in milder climates, but less demanding ones may be suboptimal in hotter ones. A combination of less demanding Europe-wide requirements with country- (or climate-) specific ones could provide a better value for money option, and perhaps greater overall savings than would be possible from a practicably high Europe–wide requirement.

Barrier to improved efficiency: : *If MEPS are set at demanding levels uniformly across Europe, some countries will be obliged to use products that are more efficient than is cost-effective for them.*

> ***Recommendation 14:*** *Before introducing demanding Europe-wide levels of product MEPS, consideration should be given to implementing them via national building codes, possibly accompanied by an over-riding European MEPS.*

[30] The calculation of seasonal efficiency for the MEPS may alternatively be based on other manufacturers information

Although national variations would result in a lower potential saving than imposing a demanding level of mandatory European MEPS, the requirements could better reflect national cost-effectiveness. This should reduce barriers to implementation and, in terms of what is practically possible achievable (rather than theoretical) savings could be higher. This approach clearly has implications for the levels of Europe-wide MEPS that are applied, and requires more actions by Member States. From modelling results achievable savings could be around 25 TWh over ten years as with recommendation 8. The supporting analysis to this recommendation is discussed in section A4.2.6. An alternative approach would be to impose different levels of MEPS in different regions. This may be more complex to implement.
This would only be appropriate for fixed air conditioning systems which are covered by EPBD.

A4.5 Other Recommendations

A4.5.1 Take up rates for recommendations

A generic problem (and the binding constraint) for energy efficiency policy instruments that provide information is the need to persuade recipients to take action. For air-conditioning, this applies specifically to recommendations arising from air conditioning inspections and from energy performance certificate assessments.

Barrier to improved efficiency: *Poor take-up of recommendations*

> ***Recommendation 18:*** *introduce measures to incentivize the implementation of recommendations.*
>
> Such measures could include training for assessors in communicating the results to building owners, support measures from Energy Agencies to facilitate implementation of recommendations, or financial incentives such as low cost loans.
>
> . The supporting analysis to this recommendation is discussed in section A4.2.5.

A4.5.2 Consistency and coordination between policy instruments

It is apparent from the preceding section that air conditioning energy consumption is the subject – but not usually the only target – of a number of policy instruments, operating at different levels: building, system, subsystem, product, end-user. If one looks at air conditioning in isolation from the building shell, interior structure, intended use, the heating system, ventilation and exhaust, etc., there is a risk that the performance of other building systems will be affected as well because of interactions among the measures.

At present, different areas of end-use efficiency policy are assessed using different criteria, and to a large extent, independently. In particular, building energy requirements are set at national level within the European EPBD framework, while product policy is determined centrally as part of single-market policy. Section A4.4.4 above identifies a specific area where there is an opportunity for different instruments to support each other more effectively.

The most fundamental example of inconsistency is in the differences of perspective for defining “cost-effectiveness”. The Preparatory Studies for the Energy-related Products Directive use a well-defined methodology that takes an essentially end-user perspective, Many Member States base energy policy on more demanding societal tests of benefit. The EPBD Recast proposal for a cost-optimality test takes an end-user perspective (but permits the additional use of the societal perspective). Since the end-user perspective almost always leads to lower savings than would be achieved than if cost effectiveness was judged from a societal perspective, this inconsistency results in different ambition levels between Member States and, in particular, between product and building (and renewable energy) policy. :

In principle, the fundamental perspective for assessing policy options should be societal, including the (shadow) costs and benefits of externalities, ignoring internal transfers such as taxation and subsidies and applying a social discount rate. The fundamental economic justification for intervention is often that there is a societal net benefit that even a “perfect” market will not capture. The end-user perspective is also important to assess whether some parts of society will bear an unreasonable burden.

The potential savings have not been explicitly estimated. From a societal perspective “demanding” product MEPS these would probably be cost-effective, while from the end-user viewpoint many of them may not be. Based on the overall potentials for the application “demanding” product MEPS and equivalently requirements for buildings, the potential extra justifiable savings seem likely to be of the order of 100 TWh over 10 years.

Barrier to improved efficiency: *The use of end user cost effectiveness criteria to assess some policy options reduces the level of ambition and therefore the potential savings*

> ***Recommendation 13***: *All assessments of policy instruments should be based on a common approach which reflects the costs and benefits to society.*
>
> In particular, the procedures required by the Eco Design Directive should be reviewed to include (standardized) values for impacts on society in addition to the present end-user perspective. The cost-optimal test process called for by the EPBD Recast should also take this perspective.
>
> The background to this recommendation is discussed in section A4.2.5.

A4.5.3 The effectiveness of energy efficiency information-provision mechanisms in business-to-business supply chains.

The air conditioning market for non-moveable units is characterized by (sometimes lengthy) business-to-business supply chains. Inferences from the impact of energy labelling of consumer products may not be applicable. This leads to considerable uncertainty about the impact of information-provision instruments for air conditioning.

Barrier to improved efficiency: : *Significant uncertainty about the impact and cost-effectiveness of energy labelling and similar instruments for business-to-business supply chains leads to equally uncertain recommendations for the value of policy instrument .*

> ***Recommendation 20:*** *Investigate the effectiveness of energy efficiency information-provision mechanisms in business-to-business supply chains.*
>
> Most studies of the impact of energy labelling deal with consumer products. Although some air conditioners fall into this category, in Europe most – including most fixed room air conditioners – do not. The impact – and the most appropriate form – of information-providing instruments for businesses is likely to be different from those directed at the individual private consumer It is not obvious that the results of these studies apply equally to business to-business supply chains where split incentives at each stage of supply seem likely to dilute the impact of product information. For example, performance information may need to suitable for incorporation in explicit procurement requirements set by the ultimate purchaser (or on his behalf) that can be made visible at each transaction in the supply chain. For central system components (especially) these requirements may need to be more complex than simple performance labels and the corresponding product information would also be more complex.
>
> This recommendation would also be pertinent to whole-building performance information and other products
>
> The supporting analysis to this recommendation is discussed in section A4.2.2.

A4.5.4 Causality and scale of the relationship between the introduction of MEPS (or labelling) and subsequent product cost increases

The impact of the introduction of energy performance requirements on product price is central to any evaluation of cost-effectiveness, and thus to justifiable levels of ambition. From a purely technical perspective, increased efficiency almost always incurs additional direct manufacturing costs. On the other hand, increased volumes are likely to decrease costs per unit along the supply chain. Superimposed on this, there may well be an underlying reduction in the real price of products that is not linked to the level of performance.

Thus, simply observing that prices continued on a downward trend after the introduction of, for example, MEPS does not necessarily provide much information: they may have fallen more rapidly without the MEPS. Equally, if prices are likely to continue to fall, this should be reflected in estimates of cost-effectiveness. [31]

***Barrier to improved efficiency:* Uncertainty about the relationship between the introduction of MEPS (or labelling) and subsequent product cost increases (if any) causes uncertainty about justifiable levels of ambition and levels of energy saving**

> ***Recommendation 20:*** *Investigate the relationship between product price trends, energy performance and the introduction of labelling or MEPS for air conditioning products and systems.*

[31] It may be, for example, that delaying the implementation of MEPS until prices have fallen may be the most cost-effective option

A5 OTHER IMPORTANT ISSUES

In this chapter we briefly address significant policy issues that are relevant to cooling energy use.

A5.1 Electricity Pricing

The price of electricity can potentially impact on the energy use for cooling in two ways. Firstly, high electricity prices are likely to encourage purchasers of cooling systems towards the use of more efficient models (which are more likely to become cost effective under higher electricity prices) or design buildings which rely on passive cooling technologies such as natural ventilation, fixed shading, moveable shading, etc. Secondly higher electricity prices are more likely to make building users and managers take actions that make installed cooling systems more efficient, such as superior controls, lower air leakage, increased use of free cooling, reduced ventilation, use of heat recovery for exhaust air, etc.

These effects are reflected at the macro level by concept of price elasticity, which quantifies the way in which demand is modified in response to price changes and is likely to be affected by the different elements of electricity cost: such as variation of cost with short-term demand (especially peak demand) and the overall commodity price .

A5.2 Product Price Impacts from Regulation

MEPS may also impact on product prices. For mild MEPS it seems likely that putative purchasers of low efficiency products will trade up to broadly similar products. A price increase can be expected, but might be mitigated by market forces acting on the supply chain. The additional sales are of products that are likely to already be in series production, so additional "learning by doing" economies seem unlikely.[32] Since the change will only affect a relatively small part of the market, average prices are unlikely to change significantly.

For very demanding MEPs there is likely to be a need for the greater use of higher efficiency, less common technologies such as variable or multiple speed compressors, oversized coils for lower temperature differences, variable speed fan motors, specialized high surface area tubing for heat exchangers, etc. In the short run this is likely to increase costs and prices, but over time these increases may be mitigated by improvements in design or production or by economies of scale in distribution and market positioning.[33] Anticipating the scope for this mitigation is a difficult challenge for analysts (and manufacturers).

An IEA report [xlvi] (not specifically dealing with air conditioning) concluded that "Although there appears to be no correlation between price and energy efficiency and the average price of appliances has been falling consistency, there is evidence that the most efficient products in some categories are more expensive than products which are less efficient." Some of this increase was thought likely to be due to the inclusion of non-energy-related features in "premium" products. However, "the commercially sensitive nature of pricing policies, together with the complexity of separating out pure efficiency costs from other appliance features, makes it difficult for an outside observer to understand how prices relate to costs of manufacture"

[32] That is to say beyond any existing "learning by doing" improvements

[33] For example, Japanese products meeting Toprunner requirements were initially larger, and heavier than their predecessors because of the need to increase heat transfer area. Over time more sophisticated heat exchanger design reduced the material content – albeit at the expense of more complex manufacturing processes

This issue is also addressed in section A4.1.4.

A5.3 Possible Role of Demand Side Reduction

Demand Side Management (DSM) refers to measures that can be taken by utilities to influence the amount or timing of customers' energy demand. This is beneficial for electricity utilities to ease system constraints, to reduce the need to build additional generation capacity, to reduce resource requirements and to increase the economic efficiency of electricity generation. There are several different types of demand reduction programmes;

> **Direct load control and curtailment:** Here there is an agreement between the supplier and the end user that when certain criteria are reached (i.e., wholesale pricing or network constraints) electricity supply with be either reduced or switched off.
>
> **Emergency demand response programmes:** This refers to a package of measures that will be applied only where there are severe supply constraints e.g., a risk of brown outs and/or blackouts
>
> **Demand side bidding:** Here consumers can be paid a market price for load withdrawal
>
> **Time of Use (TOU) Tariffs:** Here the retail price is different for certain blocks of time, generally relating the time of day and corresponding to on-peak, mid and off-peak electricity demand[34],
>
> **Real Time Pricing:** Here the pricing varies over short intervals to reflect the marginal cost of generation.

For cooling demand side management programmes can only be effective where the end user is able to either reduce the overall efficiency of the their cooling system, or by partially offsetting the timing of electricity consumption from that of the cooling demand, for example, by pre-cooling a building at a time of low peak demand for electricity.

A5.4 Peak Power Demand and Smart Grids

The current capital cost of peak-lopping power generation plant (taken as conventional gas turbine) is about 700 Euro per kW, projected to fall to under 500 Euro per kW for advanced turbine technology. [xlvii]

This is the maximum cost that can be assigned to an additional kW of electricity demand for cooling. A lower figure applies per kW of cooling demand, depending on the plant EER, for an EER of 2.5 the figures would be 280 to 200 € per kW, and for an EER of 3.5, 200 to 140 € per kW. An improvement of EER from 2.5 to 3.5 therefore has a maximum implied value of 60 to 80 € per kW.

In practice the impact on the peak load of the generation system will normally be less than these figures because of diversity between different loads, availability of pumped storage and the possibility of electricity trading with grid system which do not have coincident peak demands. In general, only Southern European grid systems are currently summer-peaking, though the growth of air-conditioning use could, in principle, move some systems into this class.

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[34] Time of use tariffs are common across Europe, particularly for larger consumers which would cover the majority of cooling system installations.

In the longer-term the growth of intermittent renewable generation is creating a need for increased storage capacity (or generator margin) and is a factor in the development of “smart grids” with the capacity for active load management. At the level of individual air conditioning systems, this can include load reduction by allowing short-term indoor temperature fluctuations – possibly coupled with some initial “over-cooling” to avoid unacceptable temperature rises – and the incorporation of physical energy storage in systems. This is an established technology, motivated by the cost of peak demand charges, and is typically provided by phase-change materials such as ice slurries. As is explained in Section B1.3.4, thermal storage can increase or decrease annual system efficiency depending on the difference in operating temperatures conditions of the refrigeration equipment between build-up and drawdown of thermal storage; the off-peak operation tends to reduce the operating cost, but not necessarily the total energy consumption.

Study to assess barriers and opportunities to improving energy efficiency in cooling appliances/systems

SECTION B

Supporting information and assumptions

Introduction to Part B of the report

Part B of this report contains details of the assumptions, processes and market context on which the analysis and recommendations reported in Section A are based.

Context

Sections B1 and B2 provide context for the study. Section B1 "Cooling Systems and their Applications" describes the different types of air conditioning system that are used in buildings in Europe, their characteristics and most common applications. It also summarises the current market shares and trends. Section B2 summarises existing European and national policies that impact on the energy performance of cooling systems, where appropriate distinguishing between different types of system.

Modelling

Sections B3 and B4 relate to the modelling process used to estimate energy consumptions and savings, and its application. Section B3 "Definitions of Modelled Cases and Input Values" explains which situations ("Modelled Cases") were examined and how the data were obtained. Generally, available data had to be processed to provide parameter values for the model and the procedures used are explained, together with the resulting values. Section B4 "Modelling Process and Additional Input Values" explains the structure of the model together with the source of internal parameter values.

Results

Sections B5 and B6 deal with results and their implications. Section B5 "Modelling Results" presents detailed model outputs. These are provided to allow interested readers to examine them in greater granularity than is shown in Part A. As a result, there are many tables of figures, which are not easy to digest. Readers who wish to compare the results at a more directly usable level are advised to focus on the first part of Section B6 and the more accessible descriptions in Part A. Section B6 "Opportunities and Possible Policy Measures" brings together the modelling results and estimates of non-modelled potential savings based on the reanalysis of published studies to identify the areas which offer the largest potential savings. It also summarises the types of barrier that need to be considered and discusses the policy measures that it seems most appropriate to consider.

Appendixes

Two appendixes: "Appendix B1: Barriers, Policy Instruments, and Air Conditioning" and "Appendix B2: Selection of Assumptions for Demand Reduction Through Improved Building Design and Better Operation and Maintenance" provide detailed discussion of the issues described in their titles.

B1 COOLING SYSTEMS AND THEIR APPLICATIONS

B1.1 Application and Markets of Air Conditioning Units and Central Systems

There is a wide range of methods for classifying cooling systems, e.g., based on how the system components are packaged, the distribution and heat rejection medium, and the basic system configuration. Some features are present in all cooling systems, e.g., cool generation, transfer of "coolth" into a room, removal of heat from the room and heat rejection[35], but there are a multitude of different types of air-conditioning system currently in use in Europe. For this study it was important to ensure that the most important systems types were modelled and that the categorisation used could be mapped against the potential for energy efficiency improvements and available policy intervention opportunities. The approach adopted was also influenced by the extent and quality of available data.

Taking into account the above, three broad classes of cooling system were considered separately for this study (although there is some potential overlap):

1. **Moveable units.** These are appliances bought over the counter or through internet suppliers and do not generally require any installation expertise.

2. **Room air conditioners/Packaged systems.** These are series-produced self-contained units or systems comprising a unit that conditions a single room. They generally require professional installation[36].

3. **Central systems.** These are larger systems that require professional installation and serve more than one room (often large numbers of rooms). They are typically bespoke systems designed for specific buildings, but are largely composed of standardised component products.

To put the above categorisation in context, moveables account for only about 4% of annual sales in the EU (expressed as rated cooling capacity rather than number of products). Fixed room conditioners account for just under 50%, with central systems providing the remainder. It should be noted that there is a potential overlap between room air conditioners and central systems in terms of both their application and the potential policy interventions. This particularly applies to split systems. For the purpose of this study single split systems <12kW were considered to be room air conditioners, whilst larger single split systems (>12kW) and multisplit systems were included in the central system category. This division coincides with the boundary adopted for the Lot 10 study and subsequent introduction of minimum performance requirements and revised energy labelling.

Within each of these broad categories, there are variations in the mix of system types installed in different building types and different applications. This can be important for regulatory purposes as different policy instruments apply in different ways:

- **Residential and non-residential:** although more moveables are sold into housing than into other building types, over 80% of systems (by number) in dwellings are fixed room air conditioners: central systems are predominantly installed in other types of building. In consequence, about 60% (by capacity) of non-domestic air conditioning is in the form of central systems.

- **Existing buildings:** about 60% of new systems (by cooling capacity) are installed in existing buildings. Of these over 60% (of capacity) is in the form of fixed or moveable

[35] Section B1 provides more detailed descriptions of the operation and classification of cooling systems.
[36] Some units have "quick couplings" designed for non refrigeration/DIY installers.

room air conditioners. Central systems are less likely to be installed in existing buildings than in new buildings but still account for just over 40% part of new capacity.

- **New buildings:** in new buildings, over 55% of new systems (by capacity) are central systems.

- **Replacement equipment:** this accounts for about 10% of moveable sales, 20% of room air conditioners and 30% of chillers[37].

In addition to differences between types of buildings that affect system type or configuration preferences, there are three main market sectors for comfort cooling:

3. Installation in new buildings

4. First-time installation in existing buildings

5. Replacement of systems (or, especially in the case of central systems, of components)

In summary, the current *sales* (measured by rated cooling capacity) divide is shown in Figure B1.1 and Tables B1.1 and B1.2. Because of differences in market penetration trajectories and different equipment life expectancies, the *installed stock* is believed to contain a larger proportion of central systems[38].

Overall, more than 80% of sales into dwellings are of room air conditioners. In contrast around two thirds of installations in non-residential buildings are central systems (chiller based systems and packaged systems of over 12kW cooling capacity).

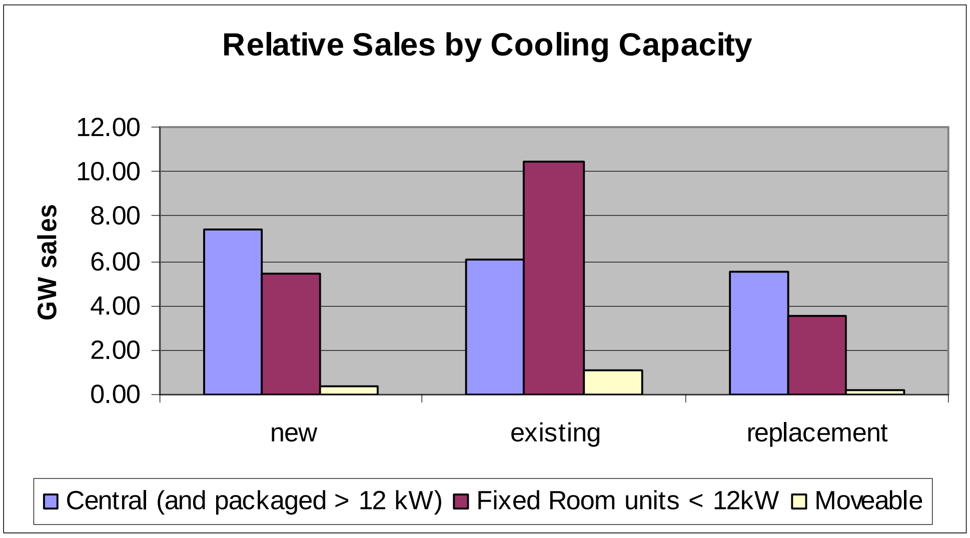

Figure 7: B1.1: Relative sales by cooling capacity for each system split into new buildings, existing buildings and replacement units.

Summary of Market for Air Conditioning (by cooling capacity)			
	New Buildings	Existing Buildings	Replacement Products

[37] The longer historical use of central systems and the long life time of some central plant components means that a greater proportion of sales are for replacement than for the other equipment types
[38] Replacement sales clearly do not add to the stock, although in the case of replacements that are not "like for like" they may alter its composition.

Central Systems	18%	15%	14%
Fixed Room Units	14%	26%	9%
Movables	1%	3%	0%

Table 14: B1.1: Sales (by cooling capacity) for each system type split into new buildings, existing buildings and replacement units.

As can be seen from Figure B1.1 and Table B1.1, the market for new AC units is spread fairly evenly across new buildings, existing buildings and replacements for failed units in existing buildings. Therefore from the point of view of effective energy efficiency initiatives, new buildings, existing buildings and replacement units are equally important markets.

In terms of which market accounts for the largest portion of the energy use, Table B1.2 presents the breakdown of sales of room AC units and central AC systems into the residential and commercial markets. It is clear the central AC systems represent the majority of sales (in terms of rated cooling capacity). Central systems come in a variety of configurations involving the distribution of cooled air, chilled water, or refrigerants to various zones of the building. Others use a water loop, distributed water-to-air heat pumps and a central chiller to provide both heating and cooling (even simultaneously).

Partition of sales (by cooling capacity)		
	All Room Units	Central Systems
Residential	20%	0%
Commercial	33%	47%

Table 15: B1.2: Sales (by cooling capacity) split into residential and commercial buildings by type

The broad categorisation of system types shown in the table above is useful because it relates the system types to applications, but also to potential policy instruments. However, to examine the potential for improving energy efficiency a more detailed breakdown is needed for each of the three types described earlier, moveables, room ACs and central systems. These are further broken down below in Table B1.3, which also shows the modelled categories.

Moveable systems		**Modelled category**
Single Duct	A single moveable unit contains both sides of the refrigeration cycle (the release of heat to the outside and provision of cooling inside) with a fan to distribute the cool air inside and a single outlet duct which discharges waste heat air to the outside air via a flexible hose. These systems are fundamentally different from others in that the inlet air is taken from within the cooled space and ventilation through the building fabric will be required to make up for the air extracted by the system. This makes it difficult to measure and compare the energy performance of single duct moveable units.	Single duct
Double Duct	Similar to a single duct unit except these units have both an outlet and an inlet duct which may be either temporary flexible hoses or semi permanent ducts.	Double duct
Room air conditioners		
Window/Wall Units	Both sides of the refrigeration cycle are housed in a single unit which is installed through a window or wall so that the heat rejection side of the system is on the outside of the	Window / wall

	building and the cooling side is on the inside. There is a fan in each side of the unit to facilitate the transfer of heat into the refrigerant on the inside, and into the air on the outside. This category also includes fixed dual duct systems which are functionally very similar except that the unit is housed wholly within the building and is connected to the outside via an inlet and an outlet duct.	
Single Split Systems <12kW	The single split system has an outdoor unit which contains the condenser and compressor, and discharges heat to the outside air. This is linked via the refrigerant pipework to a single indoor unit which contains the evaporator and a fan which delivers cooling within the room and can be ducted or non-ducted.	Single split <12kW
Central plant systems		
Larger Split Systems	This category comprises both larger >12 kW single splits systems and multisplit systems. Multisplit systems are similar to single split systems except that there are multiple indoor units which serve separate rooms or zones. These are individually connected to a single outdoor unit via refrigeration pipework. The system can usually operate in cooling only mode or in heat pump mode for heating.	Split systems >12kW
VRF	VRF (Variable Refrigerant Flow) multisplit systems are a more sophisticated version of the multisplit system. These systems supply heating and cooling and can have 2-pipe refrigerant pipework, or 3-pipe refrigerant pipework that enables heat to be transferred from a room that requires cooling to another within the same building that requires heating. A variable speed compressor allows the system capacity to be varied to accurately match the building heating and cooling loads.	VRF
Rooftops	These are packaged units where both sides of the refrigeration cycle are housed in a single unit which is located on the outside of the building (often on top of the roof) together with an air handling unit which supplies the conditioned air to the building via ducts.	Rooftop
All Air Constant Volume (CAV)	These systems provide a constant volume air supply at a single temperature. Cooling of the air is normally provided by a chilled water or direct expansion (DX) cooling coil in an air handling unit (AHU) which distributes the cooled air to rooms via ductwork. The air handling unit is usually able to vary the proportion of fresh to recirculated air to meet the ventilation requirements of the building and to minimise cooling requirements. Some systems also include terminal reheat coils to allow different air supply temperatures in different rooms or zones.	All air constant volume
All Air Variable Air volume (VAV)	As above but different cooling requirements of individual rooms or zones can be accommodated by varying the volume of air supplied to each room or zone. The AHU fan speed is varied to match the overall supply air flow rate and therefore significant fan energy savings are possible when the overall cooling requirement is low.	All air VAV
Water based fan coil unit (FCU)	Chilled water (and sometimes also hot water) is circulated around the building to supply terminal units in the rooms where a fan blows room air over a cooling coil. Most fan coil systems are also supplied with conditioned fresh air from a central AHU. The room air and ducted fresh air are mixed at the inlet to the FCU.	Water based fan coil
Water based induction	Similar to the above except that a minimum quantity of conditioned fresh air from an AHU is injected through	Water based induction

	nozzles to induce a flow of room air over a chilled water coil before the mixed air flow is supplied to the room.	
Heat Pump Loop	This system is based on a constant temperature water loop circulated around the building with self contained heat pumps providing either heating and cooling of individual rooms or zones by transferring heat from or to the water loop. These systems are sometimes referred to by their historical trade name "Versatemp". Some versions are also fed with ducted conditioned fresh air from an AHU which is mixed with room air at the inlet to the unit. The water loop is kept cool by a central chiller, cooling tower or dry air coolers.	Heat pump loop
Chilled Ceiling/Passive chilled beam/other construction embedded cooling	High temperature chilled water is circulated through embedded cooling pipes, passive coils or cooled ceiling panels to provide cooling by conduction and natural convection.	Chilled ceilings and passive chilled beams with displacement ventilation
Active chilled beam	As with passive chilled beams, high temperature chilled water is circulated within cooling coils but room air flow is induced through the coils by a minimum quantity of conditioned fresh air supplied from a central AHU and injected through nozzles but at a lower pressure than with induction units.	Active chilled beam

Table 16: B1.3: Description of various types of moveable, room and central air conditioners in use in EU and EEA Member States and considered in this study

The room air conditioner and central plant types align with those identified in the draft European Standard EN15243[39] which deals with the calculation of HVAC system efficiencies. This standard identifies around 40 mechanisms that can affect the relationship between the cooling demand of a building and the energy used by the air conditioning system to meet this demand. The standard identifies several different approaches to calculating system energy consumption all of which have disadvantages and advantages and make assumptions that may be quite different to reality such as perfect control. A more detailed discussion about EN15243 is provided in Section B2.1.2, which concludes that much more work is required before recommendations can be made on a common calculation procedure.

B1.2 Applicability of Central Systems to various types of Buildings

The choice of cooling system (including the type of distribution of cooled air for a building), depends on a number of factors that impact on the actual design of the building, end-user requirements (level of control, humidity control, noise level, fresh air requirement, zoning, etc.), the availability of space for the cooling equipment and the associated distribution system, capital cost, operating cost, etc. Table B1.4 below illustrates the technical merits of the various types of cooling systems in buildings.

It is normal practice to classify systems based on how cooling is delivered to the space as this largely determines the applicability of different system types to different types of buildings. In some cases this also defines the cooling generation process, which in the case of VRF/multi-split, packaged room units and rooftop units is an integral DX vapour compression refrigeration cycle with air-cooled condensers. In the majority of centralised systems the cold generation is provided by air-cooled chillers. Very rarely all-air systems use DX cooling coils

[39] EN 15243:2007 "Calculation of room temperatures and of load and energy for buildings with room conditioning systems"

in the air handling units but the majority use air cooled chillers with chilled water cooling coils. The modelling assumes that all these systems are chilled water based.

The majority of chillers sold in Europe are air-cooled but around 20% of total chiller sales are water cooled, increasing in proportion with cooling capacity. This is unsurprising because at high cooling capacities the extra complexity and cost of water cooled chiller systems offsets the higher space requirement of air cooled systems. A significant proportion of larger chillers are used for industrial cooling applications which are outside the scope of this study, although there is currently no data on the actual stock or destination of product sales. In many countries, including the UK, concerns about the risk of Legionella spread by cooling towers have significantly reduced their use in building cooling systems. Water cooled chillers consume less energy than air cooled chillers, but at the system level the energy consumption of condenser pumps (and in closed systems additional secondary pumps); cooling tower fans and trace heating in winter must be added. Consequently the difference in system energy consumption is assumed to be relatively small.

System type	Advantages	Disadvantages	Comments
		All-air systems	
Constant volume	Relatively simple system. No pipework in space	Difficult to serve spaces with different uses from a central unit. High fan energy consumption. Space requirements for ducts and air handling units. Potential for high air leakage	Suitable for large spaces
Variable air volume	Lower fan energy consumption than constant volume. Can serve spaces with different demands. No pipework in space	Space requirements for ducts and air handling units. Non-optimal humidity control. Relatively complex design and control and difficult to commission. Potential for high air leakage	Better for large buildings with extensive internal zones with varying cooling loads than buildings with large perimeter zones subject to widely varying heat losses and solar heat gains
Dual duct	Can serve spaces with different demands. No pipework in space	High space requirements for ducts and air handling units. High fan energy consumption. Poor cooling efficiency. Expensive. Potential for high air leakage.	?
Multi-zone	Can serve spaces with different demands. No pipework in space	Complex central units. Space requirements for ducts and air handling units. Potential for high air leakage	?
Terminal reheat	Can serve spaces with different demands.	Space requirements for ducts and air handling units. Poor cooling efficiency. Potential for high air leakage	Very wasteful of energy
		Air/water	

Fan coil – 2-pipe	Can serve spaces with different demands. Limited requirements for ductwork and reduced air handling unit size. Relatively low fan energy consumption.	Not well-suited to climates without well-defined cooling seasons. Need to arrange for condensate disposal within room	
Fan coil – 3-pipe	Can serve spaces with different demands. Limited requirements for ductwork and reduced air handling unit size. Relatively low fan energy consumption.	Proved to be inefficient in European conditions. Need to arrange for condensate disposal within room	
Fan coil – 4-pipe	Can serve spaces with different demands. Limited requirements for ductwork and reduced air handling unit size. Relatively low fan energy consumption.	More expensive than 2-pipe. Need to arrange for condensate disposal within room	Very versatile and can be used in a very wide range of building types with a wide range of loads, including simultaneous heating and cooling in different zones
Induction	Can serve spaces with different demands. Limited requirements for ductwork and reduced air handling unit size.	High fan energy consumption if (as was usual) high pressure operation. Need to arrange for condensate disposal within room, and noise	
Chilled ceiling / passive chilled beam	Can serve spaces with different demands. Limited requirements for ductwork and reduced air handling unit size. Relatively low fan energy consumption. Frees floor space.	Limited cooling capacity. Care needed to avoid condensation. Limited ability for humidity control	Best for spaces without large solar gains due to limited cooling capacity
Active chilled beam	Can serve spaces with different demands. Limited requirements for ductwork and reduced air handling unit size. Relatively low fan energy consumption. Frees floor space.	Care needed to avoid condensation.	
		Direct Expansion	
Room units	Can serve spaces with different demands. Can be used with natural ventilation.	Poor selection may lead to noise or comfort constraints. Condensation likely in units. Poor humidity control	

VRF	Can serve spaces with different demands. Can be used with natural ventilation.	Condensation possible in units. Poor humidity control Relatively high refrigerant charge	Limit to the number of storeys served by each system
Multi-split	Can be used with natural ventilation.	Condensation possible in units. Poor humidity control Relatively high refrigerant charge	
Rooftop	Can serve spaces with different demands. Frees floor space	Best suited to single story buildings only.	

Table 17: B1.4: Technical merits of the various types of central cooling distribution systems in buildings

As a result of the merits and disadvantages presented in Table B1.4, certain system types are more likely to be found in specific situations. Table 18: B1.below summarises the likelihood or probability of different types of air conditioning systems being used in specific types of buildings. The probabilities are based on limited market research data and the authors' expert opinion of current usage in Europe and therefore reflect current market trends and preferences, economics and industry practice. Consequently, it does not show the full range of technical possibilities (see Table B1.6).

		All air		Air/water			DX		
Building type	Sub-type	Constant volume	VAV	Fan coil, induction & WLHP	Chilled beam/ ceiling	Active chilled beam	Room unit	VRF/ multi split	Rooftop
Offices	Shallow plan*		XXX	XXX	XXX	XXX	XX	XXX	X
	Deep plan	X	XXX	XXX	XXX	XXX		XX	
Retail	Small shop						X	XXX	XX
	Large store/ dept store	XXX		X					XX
	Supermarket	XXX		X				X	XXX
	Mall	XXX							XX
Hotels	Public areas	XXX						X	XX
	Bedrooms		X	XX			X	X	
Hospitals	Core zones	XXX							X
	Operating theatres	XXX							X
	Treatment/diagnostic rooms	XX					XX	XX	X
Theatres/cinemas		XXX		X					XX
Exhibition halls		XXX		X					XXX
Night clubs/large venues		XXX		XX				XX	XX
Airport/ transport terminals		XXX		XX					XX
Residential					X		XXX	XX	

Table 18: B1.5. Probability of different types of air conditioning system being used in specific building types. (N.B. This is not intended to be a guide on system recommendation, but rather a reflection of the current situation in European buildings.)

*Shallow plan means that windows are not far away from any location on the floor

WLHP = water loop heat pump system

X = system type sometimes found

XX = frequently used system type

XXX = very frequently used system type

The technical possibility of different systems being used in specific building types (by % probability) is shown in Table B1.6. It is based on the authors' experience and expert opinion and knowledge of the practical limitations of specific air conditioning systems in specific building types. It disregards current markets trends, preferences and cost factors and what is installed today but takes account of practical and performance based constraints. For example VRF/multisplit systems could be used in all residential buildings but in reality they are more expensive than simpler room units and they may also be objected to on safety and environmental grounds because there is the potential to leak larger volumes of refrigerant into occupied rooms. All-air systems are assumed to be unsuitable for residential buildings due to practical difficulties of incorporating ductwork into European dwellings, which are often multi-storey, concrete, or masonry construction and lack sufficient space. All-air systems are also not suitable for multi-tenanted buildings (residential and commercial) due to the difficulty in apportioning energy costs and the need not to mix air between suites. Chilled ceiling and chilled beams systems have relatively limited cooling capacities and are less suitable for larger spaces such as those that have very high occupation densities. These systems are also not suitable for use in high areas with humid summer climates due to the lack of indoor humidity control.

Climatic factors could potentially influence the technical possibility of using different systems in different geographical regions but the likely effect of this within Europe is considered to be relatively slight and could be easily overcome through appropriate building design. It is possible that certain systems, chilled beams for example, may be less applicable to hot southern European regions but there is no evidence for this. The use of chilled beams may be suitable for very hot, dry climates like deserts, and their use appears to be growing in the Middle East). By far the greatest effect of climate is on system run hours and efficiency, both of which are already included in the model.

		All air		Air/water			DX			
Building type	Sub-type	Constant volume (in %)	VAV (in %)	Fan coil & induction (in %)	Chilled beam/ ceiling (in %)	Active chilled beam (in %)	Room unit (in %)	VRF/ multi split (in %)	Roof top (in %)	Water loop heat pump (in %)
Offices	Shallow plan	50	50	100	50	50	100	100	10	100
	Deep plan	50	50	100	75	75	25	100	10	100
Retail	Small shop	50	50	25	25	25	100	100	10	25
	Large store/dept store	100	100	100	50	50	25	100	25	100
	Supermarket	100	100	100	50	50	15	100	100	100
	Mall	100	100	100	50	50	5	50	25	100
Hotels	Public areas	50	50	100	75	50	25	100	20	100
	Bedrooms	0	0	100	25	10	100	100	0	100
Hospitals	Core zones	100	100	100	75	75	0	100	10	100
	Operating theatres	100	100	0	0	0	0	0	10	0
	Treatment/ diagnostic rooms	50	50	100	25	25	75	100	10	100
Theatres/ cinemas		100	100	50	25	25	25	25	50	50
Exhibition halls		100	100	80	25	25	25	25	75	80
Night clubs /large venues		75	75	100	25	25	25	50	50	100
Airport/ transport terminals		100	100	80	75	75	25	25	75	80
Residential		0	0	75	25	10	100	100	0	50

Table 19: B1.6: Technical possibility of different systems being used in specific building types by probability (%)

The percentages shown on Table B1.6 above are used as the basis for system applicability to building type in the modelling.

B1.3 Relative Efficiency of Various Distribution Systems

The total amount of energy consumed by a central cooling system is composed of three components: energy consumed by the refrigeration compressor, energy consumed by the auxiliary equipment (such as fans and pumps) and energy consumed by the controls. Due to the variety and sizes of distribution systems for chilled air, water or refrigerant, cooling towers, fans and pumps combinations and control components such as dampers, valves, thermostats, times, etc., the relative size of the three components can vary considerably from one type of system to another. The European standard EN 15243 lists many configurations of components and various mechanisms in air conditioning systems that cause more energy to be used than is theoretically needed. This is particularly true in the case of adjusting flows via the use of dampers rather than by variable speed fans and pumps for much more efficient control of flow, as an example. The principal culprits are discussed later in this section.

Cooling energy may be distributed as chilled air, chilled water (or other fluid) or as liquid refrigerant. For a given amount of energy transported, considerably more energy is required using air than water or refrigerant. Systems that only use air as a distribution medium - “all-air systems” – require significantly more “auxiliary energy” (energy for fans and pumps) than do systems that only use smaller volumes of air to provide ventilation, or rely on natural ventilation.

The choice of cooling distribution system in practice is not solely based on energy efficiency as other practical factors including comfort criteria (temperature, humidity and draught), noise criteria, space requirements, cost and sometimes environmental factors (refrigerant type) are also taken into account. Air distribution ductwork is usually cheaper than chilled water distribution pipework but takes up more interior space. Refrigerant distribution pipework takes up least space but may be objected to on the grounds that most refrigerants are toxic, some are flammable and others can be harmful to the environment if the pipework or terminal units leak or are damaged.

B1.3.1 All-air distribution systems

One form of all-air system is the constant-volume (CAV) system, in which room temperature is controlled by altering the supply air temperature. This configuration is not able to adequately serve spaces that have different and variable amounts of heat gain because there is not a practical method of supplying air at different temperatures in a single system. A common method is to use dampers to control the amount of cooled air delivered to a zone. Several variants of the all-air system can provide alternative temperature control methods.

The most relevant all-air distribution system to the current study is the variable air volume (VAV) system. Room temperature is controlled by altering the supply volume of air rather than its temperature. Each air supply terminal has the ability to throttle the supply airflow, and fan speed is adjusted to ensure that all areas are appropriately cooled. By avoiding overcooling, this type of control has the effect of reducing fan energy use and improving energy efficiency. On the other hand, controlling air flow through the use of dampers is not an efficient method of control, as fans require to operate against a higher pressure when dampers are partly closed. Care has to be taken to ensure that comfortable conditions are maintained at the lower air flow rates (at low flows there is a risk of cold air from ceiling terminals falling directly onto occupants without first being mixed with room air, as would happen at higher flow rates) and that sufficient fresh air is still provided. For this reason some VAV terminals are provided with fans to ensure good mixing – at the expense of some additional energy consumption. VAV systems serve multiple spaces, and the unpredictable fluctuations of air pressure within the ductwork system mean that, in practice, the fan energy savings, though substantial, fall short of theoretical expectations. It is generally acknowledged within the industry that VAV systems are relatively difficult to design and commission.

VAV (and CAV) systems have no inherent means of providing heating to some rooms and cooling to others. Heating can be provided by separate systems – ideally (but by no means universally) with control interlocks that prevent energy wastage from attempts to simultaneously heat and cool the same space.

There are other ways of providing heating. Terminal reheat systems were used many years ago when the cost of energy was much lower than today and at that time, operating cost was not as important as capital cost or as maintaining the desired comfort levels. This type of system used reheaters installed in the terminal units, hence the name: terminal reheat air distribution system. Since these reheat cooled air which may be below ambient temperature (albeit at the lowest flow rate) there is wastage of both cooling energy and heating energy. However, the controls for these reheat terminals are easy to implement and a wide range of room loads in different areas of the building can be met simultaneously, while maintaining the target absolute humidity in the indoor air through the control of the chiller temperature. Reheaters can be electric but commonly use hot water.

An alternative configuration to reheat terminals is the double-duct (CAV or VAV) system. In this configuration, separate ducted supplies of hot and cold air are provided to each room and mixed to the desired supply temperature. This system has low energy efficiency because it generates more heating and cooling energy than is actually needed in each space and even when there is no requirement for heating or cooling, heated and cooled air is still produced and mixed to maintain room conditions. It also requires a lot of duct space and care is needed with duct balancing.

A further variation on the all-air configuration is the multi-zone system. This provides a supply of air to each space through ductwork dedicated to that space. This permits good control of the temperature in each space, but requires complicated ductwork layouts unless the plant room can be located close to all the spaces served.

The pressure required – and therefore the energy needed – to transport air through ductwork, filters etc is especially sensitive to airflow velocity. If space constraints impose small duct sizes and therefore require high airflow velocities, the auxiliary (fan) energy will be especially high. For obvious reasons, air leakage from ductwork and air handling units has a larger impact on the energy efficiency of all-air systems than on systems that use other distribution media. A partially offsetting factor is that, in suitable climates, outdoor air is sometimes sufficiently cool to provide “free cooling” without operating the cold generator.

Although text books still describe the design and operation of terminal reheat and double-duct systems, it is felt that new terminal reheat installations in European comfort cooling applications have been virtually unknown during the last 30 or 40 years and they are therefore not included in the modelling. They may still be used in some other applications such as the industrial and manufacturing sectors.

B1.3.2 Air-Water Distribution Systems

Systems that distribute most of the cooling energy by water have inherently lower “auxiliary energy” consumptions. The reason is that the amount of pumping energy required to move chilled water through a pipeline is much lower than the amount of fan energy required to move and equivalent amount of energy in chilled air through a system of air ducts. In practice, most centralised air conditioning systems also provide mechanical ventilation and use this ventilation air as a “free” resource for transporting some of the cooling energy. [40]

[40] In this study, energy used to transport this air has been assigned to the ventilation function which operates on a year-round basis: the additional energy required by fans in all-air systems has been allocated to the cooling function, which operates for a number of weeks per year.

There is a variety of water-based terminal units than can be used in such systems. These can be classified as those which operate at relatively high temperatures (and therefore require relatively large surface areas): chilled ceiling and chilled beams; and those that operate at relatively low temperatures: fan coil units and induction units.

The most common terminal units today are fan coil units, in which a fan blows room air over a (water cooled) cooling coil in response to room cooling demands. Heating can also be provided in the same terminal units, either by electric heaters or heating coils using hot water. In the latter case, and largely depending on climate, the fan coil may be two-pipe (in which the whole system operates either in heating or cooling mode), four-pipe (which allows simultaneous heating and cooling of different spaces) or three-pipe (which needs less pipework but has proved problematic in operation). Differences in energy efficiency between these options are small, provided that steps are taken to prevent simultaneous heating and cooling in the same zone.

Systems using high temperature emitters, such as chilled ceiling and chilled beams, are inherently more efficient. The higher operating temperature allows cold generators to operate more efficiently – theoretically up to 20% more efficiently. In practice this saving can be lost if, for example, cooling coils serving the ventilation air part of the system are designed to operate at lower temperatures.

Systems using chilled ceilings have a second potential advantage relating to ventilation efficiency. With chilled ceilings, and also often with passive chilled beams, ventilation is generally designed to remove air-borne contaminants rather than provide any significant amount of heating or cooling. The low air flow rates required are compatible with displacement ventilation, in which smaller volumes of air are introduced at low level at low velocities. Lower air volumes translate into lower fan energy consumptions.

B1.3.3 Heat Recovery Effects

Some systems have the ability to recover heat gains from one space or room and to use them to heat another space or room, thus reducing net energy demand. This is specifically the case with some VRF systems and with water loop heat pumps. In addition, one of the consequences of systems that control the average temperature of several spaces is that the inevitable differences in room temperature can have a similar effect. The magnitude of these effects is not well understood but certainly is dependent on the building and climate of an application. It should be noted that there may be an underestimate of the energy efficiency of these systems as they have not been represented in our modelling.

B1.3.4 Water loop and distributed heat pumps system

These systems comprise a constant temperature water loop circulating around the building with individual self-contained reversible heat pumps that can source or sink heat from the water loop. These systems were originally designed to reject heat from the water loop via evaporative cooling towers. However, the current aversion to the use of cooling towers on account of the Legionella risk means that most of these systems are used with a central chiller or dry air coolers. The use of a chiller introduces a second level of refrigeration into the system which introduces additional inefficiencies. The alternative is to use dry air coolers, but this requires the water loop temperature to be raised to around 35°C or higher (compared to say 30°C for a cooling tower) depending on climate. In cooling mode this will raise the heat pump condensing temperature and reduce efficiency.

B1.3.5 Thermal Storage

Seasonal thermal storage is an element of “geothermal” systems. Most systems use ground coupling with reversible ground source heat pumps to provide a heat source in winter and a sink in summer. Where available inland lakes, rivers and ground water can also be used although the applicability is very limited and there are usually constraints on maximum allowable temperature rise in summer. The applicability of ground coupled systems is also limited in existing buildings due to the lack of space and impracticality of installing ground heat exchangers around or below existing buildings. For these reasons such systems were not modelled.

Short-term thermal storage (by chilled water storage, ice generation, for example) is practiced in some systems to avoid peak demand charges for electricity but does not contribute to energy efficiency per se. The energy storage/recovery cycle introduces additional energy losses and in ice storage systems the temperature range that the refrigeration or cooling system must operate is increased which reduces EER. These losses will be offset by lower night time air temperatures for systems that generate ice or other forms of stored “coolth” overnight. However the overall impact on energy efficiency depends on climate and loads and may be quite small (savings in UK are often very small but may be higher in hotter climatic regions). In addition in many buildings the additional space and weight required by the thermal store, especially chilled water, is a barrier to their use as is the additional cost of the system. This is especially the case in residential buildings and small commercial premises.

A theoretical analysis of a US ice thermal storage product showed a wide range of results including typical energy savings of about 20% in a retail application. In residential buildings the savings were highly climate and cooling load dependent and ranged from negative up to about 50%[41]

The interest and popularity of ice thermal storage in other countries, such as the USA and also parts of the Middle East, where peak day-time cooling loads can be very high, was driven more by the ecological and political problems of building new generating plants than by energy efficiency concerns [xlviii].

Some of the more successful cold thermal storage systems in the UK have been chilled water storage systems as part of large district cooling and combined heat and power (CHP) systems. In these systems the size, weight and cost of the thermal storage plant is less of an issue and the storage and load smoothing feature may be a positive benefit to the system. Examples include Heathrow Airport Terminal 5 (chilled water) and Citigen in the City of London (chilled water).

The incorporation of compact ice thermal storage systems into packaged air conditioners has been demonstrated recently in North America [xlix] and its potential application and energy savings in Europe should be investigated. These systems are not popular in Europe and there is no data available on their performance locally, therefore this type of system was not modelled.

B1.4 Configuration and Relative Energy Efficiency of various types of Central Distribution Systems

This section focuses on the impacts of system configuration on energy requirements of the distribution system.

[41] Ice Storage Air Conditioners California Energy Commission 2006 http://www.energy.ca.gov/2006publications/CEC-400-2006-006/CEC-400-2006-006-SF.PDF

Many different combinations of components – system configurations - are possible with centralised air conditioning systems. The choice of system configuration may be determined by the building owner, architect or professional building services engineer taking into account available technology, cost, energy efficiency and practical suitability for the particular building and expected occupancy. The choice of components may be made by the building services engineer or the M&E installation contractor. The components may be supplied by different manufacturers based on a range of factors including familiarity, cost and availability.

Different configurations have different advantages and disadvantages, including inherently different energy efficiencies.

The overall efficiency of a centralised system depends on the:

- inherent efficiency of its component parts;
- configuration of the system;
- correct matching of component parts (a component may be inherently efficient but, if undersized, may impose additional loads on other parts of the system. If over-sized, it may have higher energy consumption than is necessary – albeit at high component efficiency; and the
- pattern of loads placed upon it (and the ability to reject heat effectively).

B1.4.1 Sensitivity of energy consumption of AC systems to efficient design by system type

The model in this study was used to test the sensitivity of the energy use index for a typical building in London to various types of distribution systems, as well as to different levels of *efficient* designs, some more efficient than others, considering typical variations in the selection of components.

Figure B1.2 presents graphically the range of annual energy consumption indices (in kWh/m^2) obtained from modelling an office building in the London area equipped (sequentially) with the following types of distribution systems for air conditioning:

1. Chilled ceiling and displacement ventilation
2. Split system and natural ventilation
3. Fan-coil system
4. Variable air volume
5. Constant air volume (variable recirculation)
6. Terminal reheat

For each configuration, the lowest consumptions resulted from the assumed high efficiency components and careful component matching, while the higher consumptions represent the assumption that less efficient components and poor matching was used.

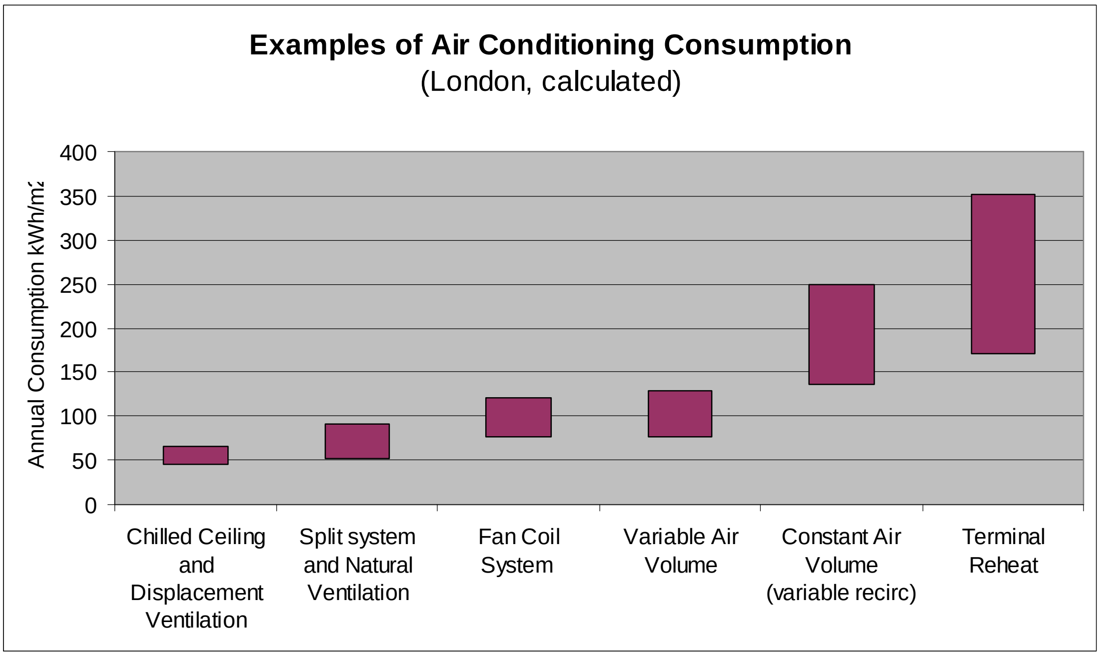

Figure 8: B1.2: Calculated energy consumption ranges for a sample of system configurations (for offices in London)

Figure B1.2 shows calculated energy consumption indices for the indicated configurations and component efficiencies for the same building, climate and usage assumptions

The calculation procedures are the same as those used in the modelling that underlies this study – see Section B4. It can be seen that, while some configurations are inherently more energy-efficient than others, there is not an unambiguous trend that central air conditioner systems involving central air distribution systems consume considerably more energy than the others types of systems.

B1.4.2 Share of energy use between cooling and distribution for typical systems

The model of the same six systems was further analyzed to determine the distribution of energy use between the refrigeration machine and the auxiliaries (distribution system). The results are plotted for both the high and low distribution efficiency cases on Figure B.1.3

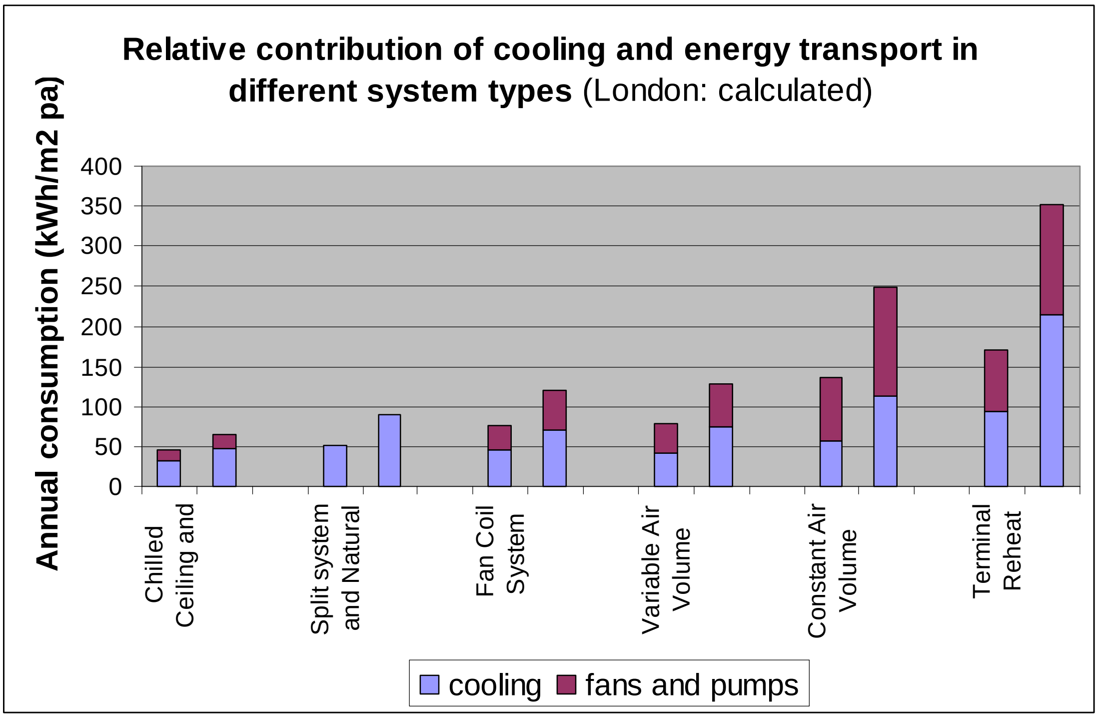

Figure 9: B1.3 Calculated energy consumption for a sample of system configurations broken down according to cooling energy and transport energy (fans and pumps) (for offices in London)

It is important to note that for the less efficient distribution systems there is a significant additional cooling load associated almost entirely with the additional amount of energy that was in effect injected into the cold air stream by the fan motors and by the added friction in the less efficient distribution systems. Inefficiency of distribution has a doubling effect on the deterioration of overall system efficiency.

Figure B1.4 shows the same results with the energy demands broken down according to cooling energy and transport energy (fans and pumps - in practice mostly fans[42]).

B1.4.3 Comparison between Water and Air distribution systems

The same model was used to compare the relative energy use by system component for the same office building first modelled with a water distribution system with fan-coil units and next with a constant air volume distribution system. The simulated weather conditions for three different cities were used (Seville, Milan and London) in order to demonstrate the sensitivity of the cooling energy index to different weather conditions. In addition, the energy consumed by each sub-component has been separated out on each column into different colours to show the relative contribution of each to the total load. The results are presented graphically on Figure B1.4.

[42] Other than "all-air" systems, most of the fan energy is attributable to the ventilation function.

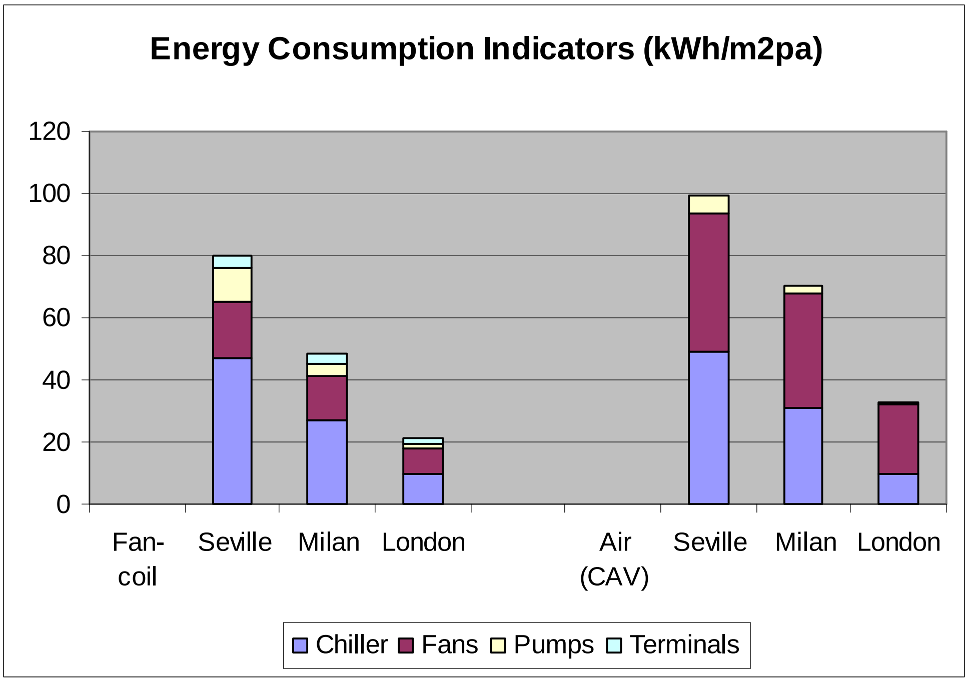

Figure 10: B1.4: Calculated energy consumption broken down according to cooling energy and transport energy (fans and pumps) for two system configurations in three climates [l]

In this set of models, the additional energy requirement of the constant air volume system is clear. This component increases as the air conditioning demand increases

Consumption, especially for cooling, depends on the climate as shown in Figure B1.4 (taken from the EECCAC project), which illustrates the variation of calculated breakdown for two system types in three different climates[43].

B1.5 Prices and Cost-Effectiveness of System Types

The comparisons of energy consumption made above are calculations (using the same system efficiency methodology as used in the Modelled Cases in this study). They are therefore on a strictly like-for-like basis. In practice, system design and performance varies from building to building because of differences in building design and use. The following analysis is based on capital and running costs reported by large UK quantity surveying practices, drawn from their databases of project costs[li] [44]. It includes both central systems of various types, room units (referred to in the chart as "packaged heat pumps") and systems that serve multiple spaces but which are not always categorised as "central systems"[45].

This type of information, disaggregated by system type is rare. Some of the results are a little surprising, for example that 4-pipe fan coil systems have consistently higher running costs than 2-pipe systems. Additional information and analysis would add confidence to the conclusions drawn from the results. The running cost data for 4-pipe fan coil systems may incorrectly include heating energy and it is also likely that non-optimal control may cause simultaneous heating and cooling between adjacent zones or overheating and overcooling effects in the same zone.

[43] This is not for the same building
[44] Other information shows that "displacement ventilation" costs include cooling. We assume that this is by chilled ceiling as this would be the usual situation for using displacement ventilation in the UK
[45] VRF (and multisplit) systems and water loop heat pumps fall into this category. We have classed them as "central" systems in this study.

Figure 11: B1.5: Indicative capital and running costs for different system types (for offices in London) in 2008[lii] In 2008 £1 was equivalent to approximately 0.9 Euro

Figure B1.5 illustrates the range of costs that is found in practice. The range of capital cost for each of the 11 systems modelled is represented by the horizontal sides of each rectangle, while the range of running cost in £/m^2 of gross building floor area per annum is represented by vertical sides. It can be seen that VRF heat recovery systems have one of the lowest system operating costs, but that they are also one of the most expensive to install on a per square meter of floor space basis. The fan-coil 2-pipe systems have some of the lowest capital costs, but have running costs that are far from the lowest of the systems. Converting these results to net present values in £/m^2 for each system type, produces Figure B1.6. Converting these results to net present values produces Figure B1.6. It can be seen that the system with the theoretically lowest consumption is not necessarily the one with the lowest life–cycle cost. The differences between system types are only slightly more than the variations for systems of similar type. However, some system types, including VRF, 2-pipe FCU, packaged units and displacement ventilation do appear to typically have lower NPVs than others. Chilled beams have high NPV values due to their relatively high capital cost. This requires more data and further analysis but a factor might be their low relative cooling capacity resulting in a low specific capacity relative to heat exchanger surface area.

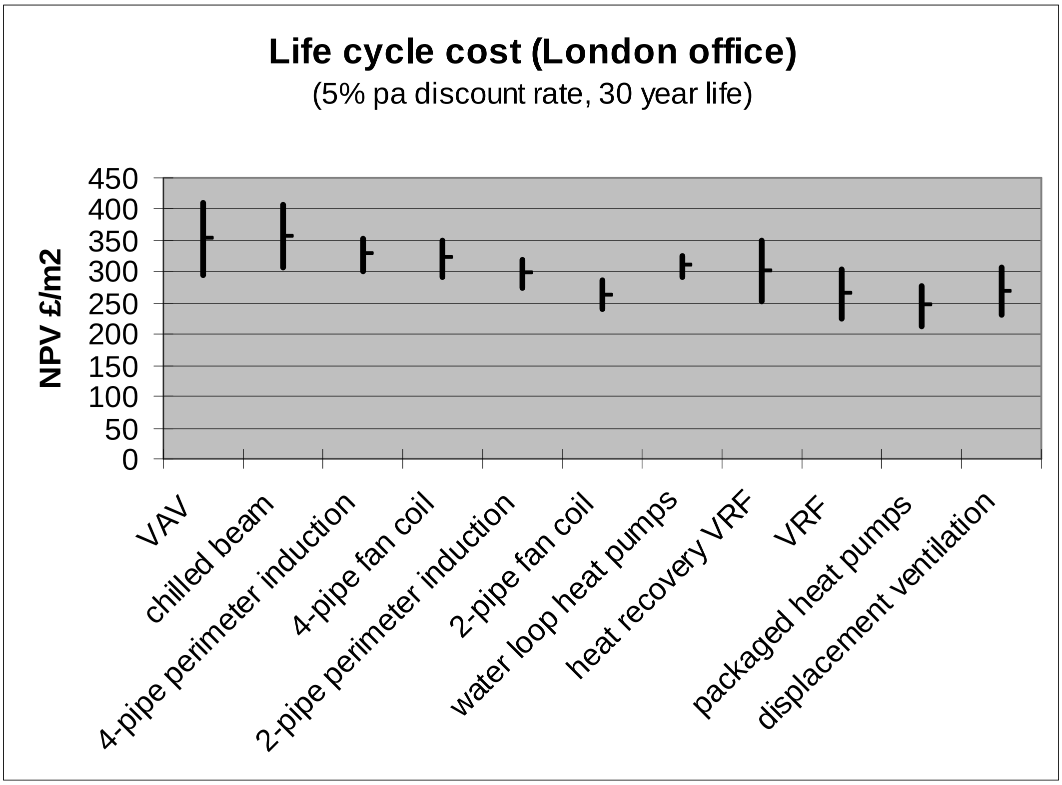

Figure 12: B1.6: Indicative life cycle costs for different system types (for offices in London) in 2008[lii]

Similar information could not be found for other countries. As an indication of the impact of climate on running costs and consequent higher life-cycle costs, the cooling demand modelled was increased by a factor of 3. Figure B1.7 shows the impact if the increased energy cost on the life cycle cost of each system. (A three-fold increase of running costs for other reasons would obviously have the same effect). In these conditions a somewhat clearer picture emerges. Decentralised room cooling and VRF systems that use refrigerant rather than water or air for cooling distribution, and displacement ventilation (assumed to be used with a chilled ceiling) have the lowest life-cycle costs Figure B1.7 shows, these are not generally the systems with the lowest capital cost, so procurers who emphasise first cost will tend to favour some of the systems with higher life-cycle costs. As is explained earlier in this section, the systems with the lowest life-cycle costs have constraints on their applicability[46].

[46] for example 2-pipe systems are only suitable for climates where there is a clear distinction between cooling and heating seasons or applications where a heating service is not required.

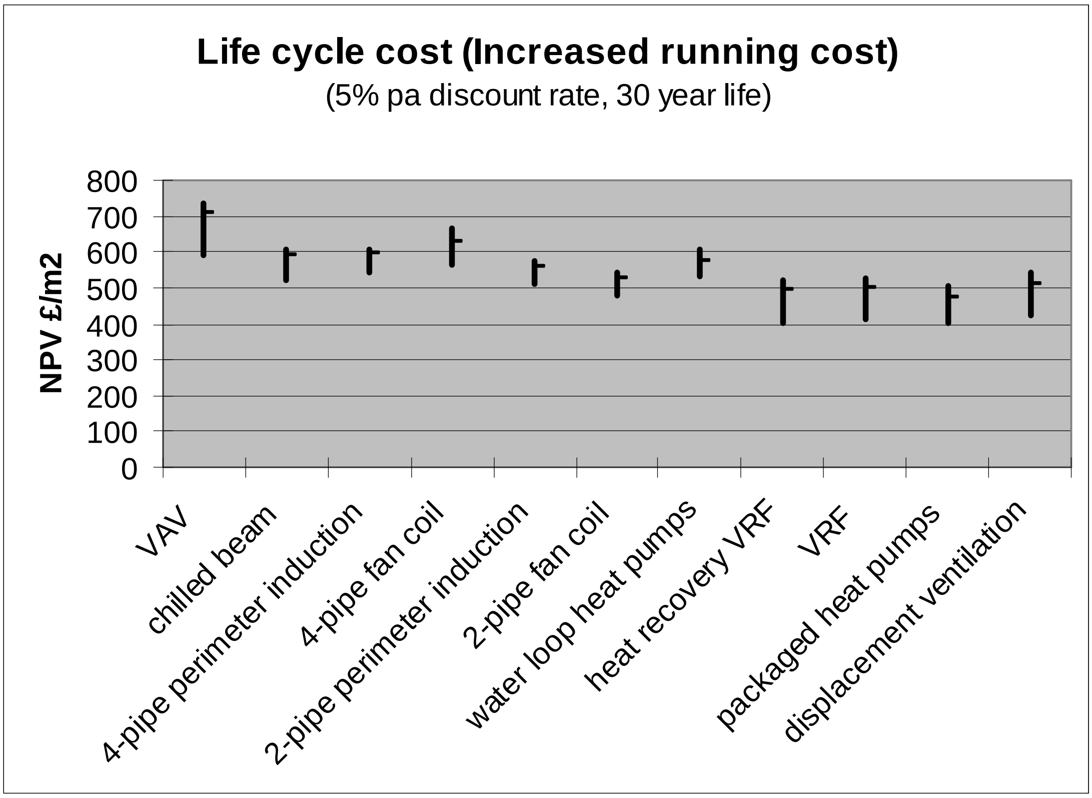

Figure 13: B1.7: Indicative capital and running costs for different system types (for offices in London) in 2008[lii] In 2008 £1 was equivalent to approximately 0.9 Euro

Cooling energy distribution not only incurs energy losses and pump and fan operation costs, which are reflected in higher energy use and running costs, but the cost of pipework and ductwork also contributes significantly to capital cost (and indirectly to lost usable space). Figure B1.8 [liii](from a different database) shows the cost breakdown for a typical 4-pipe fan-coil system in a London office. Much of the cost is associated with components that do not use energy directly. It can be seen that those components that directly use energy account for only a small proportion of the system cost: 4% for the chillers, 4% for the air handling units and 11% for the fan coil units. Distribution systems (ductwork, chilled water pipework, heating pipework plant room equipment) accounts for nearly 2/3 of the total system cost.

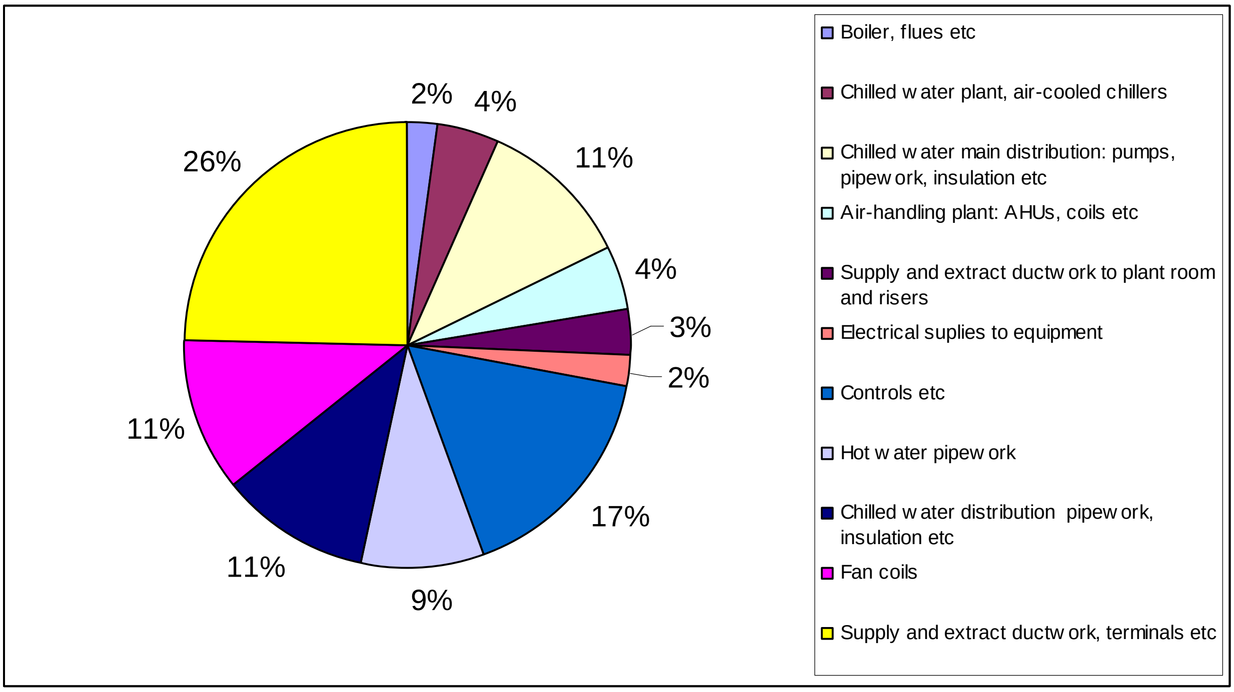

Figure 14: B1.8: Cost breakdown for a typical 4-pipe fan-coil system (London office building)

The importance of the cost of air distribution and its variation with system type, are illustrated in Figure B1.9 below, which breaks down the average capital costs used in the life-cycle cost analysis by function. However, some of the figures are rather surprising (notably the apparently high ventilation cost for VRF and packaged systems) and they are shown here as an illustration of information that is presented to designers and their clients. The precise definitions used are not known, but it appears that "ventilation" does not distinguish between components provided purely for ventilation and those which are sized primarily to transport cooling energy. Differences in "cooling" cost appear to reflect the choice of terminal. Further information and analysis is needed in this area.

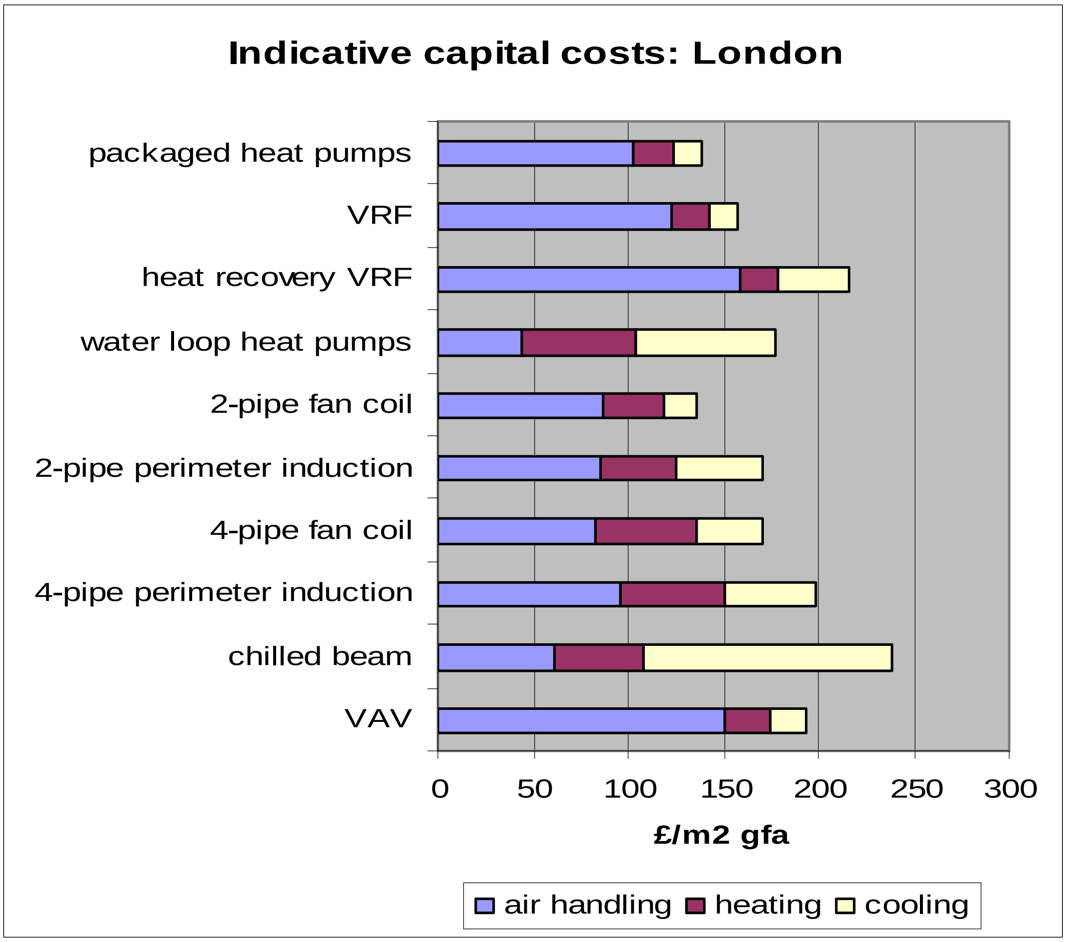

Figure 15: B1.9: Breakdown of capital costs according to function (for offices in London) in 2008[lii]
(Note GFA = gross floor area of the entire building (measured to internal face of external walls))

B1.6 Cooling Equipment Market Trends

In new buildings about 55% of sales (by kW of cooling) are of central systems, with just over 40% being fixed room units. In existing buildings, room units account for 65% of new installations (by capacity). This is partly due to the ease of installation and low installed cost, particularly in smaller existing buildings, and the fact that many older buildings in Europe were not originally designed or built with air conditioning.

This section looks at current market trends for cooling systems in more detail.

As a starting point, the destinations of different types of systems are considered. As can be seen in Figure B1.10, chiller-based central systems are overwhelmingly used in non-residential buildings. Within the non-residential sector, three sub-sectors stand out: offices, retail and leisure and hotels (Figure B1.10). These sub-sectors also account for the largest shares of most other systems, although the retail sector has a relatively large share of rooftop units (though there are still more chiller systems).

The distribution of these products is shown in Table [include #]:

Product	New Residential	New Non-residential	Existing Residential New units	Existing non-Residential New units	Replacement Residential	Replacement Non-residential	Total
Moveable ACs	21%	2%	61%	5%	10%	1%	100%
Fixed room ACs (wall/window or splits <12 kW	10%	18%	20%	34%	7%	11%	100%
Central AC systems >12 kW	< 1%	39%	< 1%	32%	< 1%	29%	100%

Table 20: B1.7: Distribution of Various types of Air Conditioners by Market

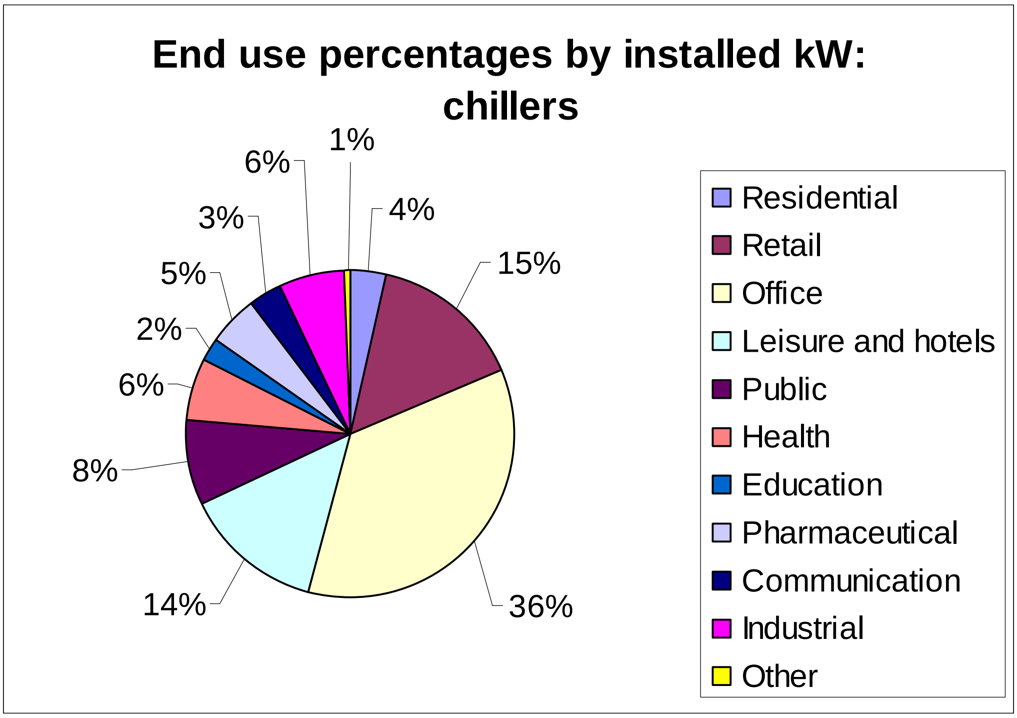

Figure 16: B1.10: Distribution of installed kW (chillers) by end use type

In dwellings, on the other hand, most systems[47] are single room split systems; although on a capacity basis, more split systems are sold into non-residential buildings (Figure B1.11).

[47] In Europe, North America is different

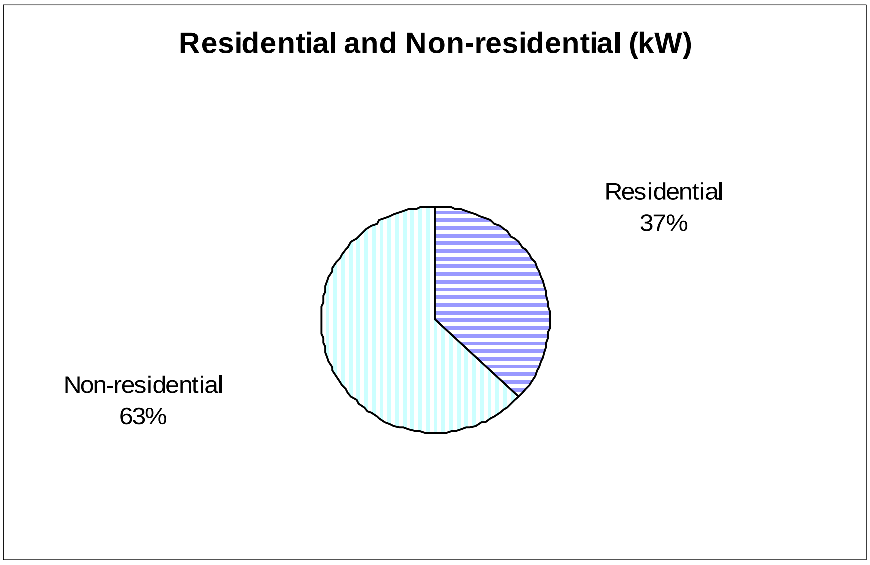

Figure 17: B1.11: Distribution of kW room unit (< 12 kW) sales in 2002 between residential and non-residential

There are a wide range of air-conditioning system types and configurations. Historically, air conditioning has been provided by centralised systems although in the last two decades decentralised packaged equipment have been used widely in smaller buildings and sometimes in the refurbishment of older large buildings. The wide range of possible systems partly reflects the historical development of the technology, newer configurations offering features that allow them to take market share from older ones. However, older configurations retain advantages for some applications.

Statistics are sparse but, broadly speaking (and based largely on subjective review of technical papers and recollections), the trend in central air conditioning in offices in Europe over the last 60 years has been:

- 1950s: constant volume all-air systems in core areas plus induction or dual duct systems in perimeter areas.
- 1960s and 1970s: broadly similar but some new systems introduced in small numbers: variable volume all-air, water loop heat pumps, fan coils, terminal reheat, chilled ceilings with a consequent slight reduction in market share other systems.
- 1980s: growth in use of fan coils and variable volume all-air. First appearance of VRF. Decline of other systems.
- 1990s: continued growth of fan coils, increasing use of VRF, chilled ceilings and chilled beams.
- 2000s: growth in use of fan coils, VRF, chilled ceilings and beams; declining use of variable volume all-air.

Currently, it is estimated (preliminary Ecodesign Lot 6 end-use statistics for Europe[liv]) that the majority of new central systems use fan coil units, followed by VRF and chilled beams and ceilings.

Variable volume all-air systems became synonymous with high quality air conditioning in large buildings during the 1980s, despite difficulties with commissioning and control. Its popularity declined in the 1990s when the benefits of air/water systems, especially their flexibility and the reduction in plant and duct space, became more important.

A significant aspect to the popularity of fan coil units is that they minimise the size of air handling units and distribution ductwork and suit a wide range of loads. They are therefore favoured by commercial office developers who are concerned about flexibility and maximisation of lettable floor area. Fan coil units have largely superseded induction units.

The market for moveable and room air conditioners in Europe was very small before the 1980s and significant growth did not occur until the mid 1990s. There has been significant growth in single split systems and moveables, but declining use of window/wall units in those countries with sufficiently long-established air conditioning markets to have supported them in the first place. . Of these system types single split systems are most prevalent.

B1.7 Controls

There are two categories of controls: functional controls necessary for the system and component operation, and zone time and temperature controls. Zone time and temperature controls are usually zone or room based and are concerned primarily with temperature (and sometimes humidity) control to meet the end-user conditions (usually related to occupant comfort requirements), and energy efficiency by switching the system off outside pre-set occupancy hours. In many systems these controls are also required to switch between heating and cooling and to prevent simultaneous provision of heating and cooling. Energy efficiency savings can be achieved by the correct application and settings of these controls but also by manipulation of control set points such as raising cooling temperature set points several hours before the end of the occupied period.

System controls are required to control intermediate operating conditions and individual components or parts of the system. Examples include mixing of intermediate hot and cold air flows, off-coil air temperatures, control of the relative proportion of fresh air and recirculated air in air handling units and the control of fan and pump speeds to match airflow and chilled water flow rates to cooling loads. Some of these controls can have a predictive element in their algorithms. Intermediate controls can influence the energy efficiency of the system without compromising the end-user conditions. In many buildings most of these controls are integrated into Building Management Systems and can be highly complex. However, experience shows that the complexity of these systems does not necessarily guarantee good control or energy-efficient operation of the air conditioning system. Key factors related to the effectiveness of controls include user understanding, correct commissioning and temperature and humidity sensor accuracy.

Useful information and statistics on controls and the possible energy efficiency improvements with improved technology is sparse and more research is needed in this area. Robust technical measurement of claimed savings (which are typically in the range of 10-15%) is extremely difficult but the controls provided with many room units are relatively poor and there may consequently be scope for significant energy savings. The capital cost ranges from very low to significant for variable volume chilled water systems and air distribution systems.

Regarding “Summary” below: What does it summarize and what purpose does it serve? Please describe in text. I also don’t understand why it appears in a box.

A summary should provide a synthesis of the main issues and based on those you should be able to point to conclusions, which should appear at the end of each chapter.

Summary

1. The air conditioning market across Europe is diverse in terms of types of systems and appliances, sales channels and the methods and criteria used in the design and selection of systems.

2. The classification of systems and appliances has been selected to permit quantification of sales in terms of installed capacity for new, existing and replacement markets.

3. The different types of systems and appliances in the European market and their inter-relationship with building ventilation systems have been described, as well as their advantages and disadvantages and their applicability to different building types.

4. Overall the majority (80%) of new residential systems (by number) are room air conditioners whereas in commercial buildings the majority (60%) are central systems (by capacity).

5. For central systems, the efficiency depends on a large number of factors related to system design and component selection, performance requirements related to temperature and humidity control and fresh air requirements and load characteristics including the size and spatial and temporal variation in internal and external loads.

6. Many factors influence the determination of the “best” system for a new building and the most efficient system may not be optimal for the building or the user. Factors include physical constraints such as available space for cooling plant and distribution systems and noise criteria, and economic and lifecycle related factors.

7. Heat recovery systems may be appropriate in buildings with simultaneous heating and cooling requirements, and thermal storage systems allow management of peak load demands and exploitation of lower cost power tariffs. However, the higher cost and complexity of current systems may be difficult to justify in terms of overall lifecycle costs. Future smart grids and smart cities may significantly alter the economics of thermal storage systems.

8. In central systems the cost of replacing air handling plant and chillers is lower and more practical than replacing an air or water based distribution system. Therefore replacing chillers and air handlers in existing buildings at the end of life with more efficient equipment should be considered as an option whereas replacing the distribution system is unlikely to be viable unless a building is undergoing major refurbishment.

9. The complexity of many central systems and the wide spatial and temporal variation in heat and ventilation loads in many larger buildings means that controls are critical to efficient operation and meeting performance and comfort criteria. Therefore improved controls linked to better commissioning and maintenance has the potential to significantly improve energy efficiency as well as provide optimal comfort and air quality.

B2 EXISTING POLICIES THAT IMPACT ON THE ENERGY PERFORMANCE OF COOLING SYSTEMS

B2.1 Introduction

This section summarises existing, expected and past air conditioning energy performance policies and discusses their evolution. It provides the context for policy development in terms of historical developments and the current policy landscape. It identifies which instruments have been implemented and their evolution over time. Currently there is a mixture of Europe-wide and national policy instruments affecting air conditioning in Europe. There are also relevant precedents in non-European countries.

This section reviews existing policy instruments (and some that have been suggested but not implemented) which impact on the energy performance of cooling systems. It has two purposes: information from EU and EEA countries provides a context for later discussion of possible new or modified policies applicable in those countries and, more generally, knowledge of measures that are already in place outside Europe illustrate precedents for possible new European policy instruments. While trends in the market mix for room air conditioners have been reported, there do not appear to be any post-implementation studies that identify the impact of specific air conditioning policy measures, though parallel CLASP study has been proposed. [48] [lv].

Policy instruments aimed at limiting air conditioning energy consumption may be applied at several levels. At the most general level, they can apply to energy pricing or whole-building energy consumption. At the other end of the spectrum are product performance requirements (or limitations on the use of air-conditioning in certain types of buildings or climates[49]).

This section starts with energy efficiency requirements for products, moving to increasingly broad-based instruments such as instruments applied to whole systems, to buildings, and to product and energy pricing issues. It first addresses energy performance labels, before considering minimum energy performance requirements.

The broad international picture for air conditioning MEPS and energy labels is that countries such as Korea and Japan with warm climates and large or potentially large air conditioning energy demands have prioritised equipment labelling and MEPs above building-related measures that also reduce loads . Other countries – especially those where heating is equally or more important (including most of Europe) - have placed more emphasis on building-level requirements that include air conditioning, heating and lighting. Product (and building) MEPs have generally been initially introduced at relatively undemanding levels but, over time, the requirements have been made progressively more demanding. At the European level, the key Directives are the Energy-related Products Directive (formerly the Energy-using Products Directive,. the Energy Labelling Directive and the Energy Performance of Buildings Directive. The national instruments with the most direct impact are Building Energy Regulations (or Building Energy Codes and Standards), latterly influenced by the EPBD. Tax incentives, energy taxation and related measures and also have an influence on decisions.

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[48] The scope this study "to compare the performance of energy efficiency standard and labelling programs conducted by countries around the world for air conditioners" has now been reduced
49 This has reportedly been implemented in parts of Switzerland, but would have health implications for climates where extended heat waves are possible

Performance Metrics

For cold generators (including chillers), the ideal metric from the consumers point of view would reflect overall annual performance in the specific climate and application under consideration. Even if it was technically possible, this would conflict with the objective of labelling (or applying MEPS to) products which may be used anywhere in Europe.

The majority of existing labelling and MEPS schemes – and certainly the initial ones – have used performance measured in the laboratory under standard rating conditions. These are almost always at nominal full output under standardised design conditions (temperature, moisture content, and so on). This is the basis of the current European labelling schemes for products of up to 12kW cooling capacity.

Standardised "seasonal" performance based on a weighted (harmonic) mean of laboratory test under a number of different operating conditions is a more satisfactory metric, though it requires additional testing and is climate-dependent. It was initially applied to chillers and other systems in the USA. A similar approach was proposed by EECCAC and adopted by Eurovent for chillers and is now the proposed basis for the new European energy labelling scheme for air conditioners of up to 12kW capacity (apart from moveable units, which will still be based on EER).

B2.2 Energy Labelling and Information Provision: Product Level

The efficiency of many air conditioning products varies with load and with outdoor temperature. As a result, a single efficiency based on measurements under standard test conditions may not be a reliable indicator of in-use performance. This is discussed further in the box above**.**

Much of this section deals with energy labelling, which is a familiar concept for consumer goods in Europe and elsewhere. Energy performance labels are an example of the more generic set of policy instruments that aim to influence purchaser choice by providing information. Most air conditioning is specified through a business to business supply chain, where procurement requirements by the ultimate customer may be more effective than labelling products which only influence the initial purchaser.

B2.2.1 Room Air Conditioners

There is a history of energy labelling for air conditioners from at least 1975 (in the USA). Performance class labelling is also in place in China, India and South Korea, so this is a well-established policy instrument. The processes and issues are comprehensively addressed in the CLASP Guidebook[lvi] and the relative merits of application to different types of product are discussed later in this report. Energy labelling for air conditioners is now required in a number of countries including the USA, Canada, North America, India, China and South Korea. It was introduced in Europe in 2002 for air conditioners of up to 12kW cooling capacity. European labels are currently based on performance at nominal cooling capacity rating via the EER (Energy Efficiency Ratio), though there is a move to adopt a seasonal performance (SEER) metric which incorporates performance at part-load conditions (See Performance Metrics box at the end of this section)[50]. While the claimed performance class for a product is published,

[50] The analysis in this report assumes application of standard Europe-wide criteria for labels and MEPS based on EER or SEER. The latest version of EN 14825 contains procedures for calculating SEER for

presentation of the actual data (including part-load efficiencies where appropriate) is not mandatory.

The original European cooling and heating efficiency requirements for energy labelling classes are shown in Table 21: B and Table B2.2.

Cooling: Air-cooled			
Energy Efficiency Class	Split and multi-split appliances	Packaged (through the wall)	Single duct and double ducts
A	3.2 < EER	3.0 < EER	2.6 < EER
B	3.2 ≥ EER > 3.0	3.0 ≥ EER > 2.8	2.6 ≥ EER > 2.4
C	3.0 ≥ EER > 2.8	2.8 ≥ EER > 2.6	2.4 ≥ EER > 2.2
D	2.8 ≥ EER > 2.6	2.6 ≥ EER > 2.4	2.2 ≥ EER > 2.0
E	2.6 ≥ EER > 2.4	2.4 ≥ EER > 2.2	2.0 ≥ EER > 1.8
F	2.4 ≥ EER > 2.2	2.2 ≥ EER > 2.0	1.8 ≥ EER > 1.6
G	2.2 ≥ EER	2.0 ≥ EER	1.6 ≥ EER

Table 21: B2.1: Previous European cooling efficiency requirements for each energy labelling class

Heating: Air-cooled			
Energy Efficiency Class	Split and multi-split appliances	Packaged (through the wall)	Single duct and double ducts
A	3..6 < COP	3.4 < COP	3.0 < COP
B	3.6 ≥ COP > 3.4	3.4 ≥ COP > 3.2	3.0 ≥ COP > 2.8
C	3.4 ≥ COP > 3.2	3.2 ≥ COP > 3.0	2.8 ≥ COP > 2.6
D	3.2 ≥ COP > 2.8	3.0 ≥ COP > 2.6	2.6 ≥ COP > 2.4
E	2.8 ≥ COP > 2.6	2.6 ≥ COP > 2.4	2.4 ≥ COP > 2.1
F	2.6 ≥ COP > 2.4	2.4 ≥ COP > 2.2	2.1 ≥ COP > 1.8
G	2.4 ≥ COP	2.2 ≥ COP	1.8 ≥ COP

Table 22: B2.2: Previous European heating efficiency requirements for each energy labelling class

These labels have been revised, with separate ratings for single duct, double duct and all other room air conditioners (split systems) with a rated capacity of up to 12 kW.[lvii] EER are retained for moveable units but seasonal energy efficiency ratios are required for split systems [51] . It would appear that this categorisation reflects the fact that current moveable units have simple on/off control – and perhaps the costs and complexities of part-load testing relative to the potential energy savings. Ten ratings, (seven of which will be displayed on the label depending on the rating) from A+++ to G are proposed, with separate ratings for cooling and heating for reversible units. The SEER of the heating function will be calculated based on different climate zones, but for cooling this will be based on a single climate zone. The new

different climate regions, which opens the technical possibility of different requirements in different climate zones. It may also be noted that the Boiler Efficiency Directive uses part-load efficiencies in a different way, requiring minimum performance at each condition tested rather than a weighted average.

[51] However, there is considerable flexibility about how this is calculated

requirements are summarised in Table 23: and Table 24: . The proposed Labelling regulation was adopted on 4 May 2011 and came into force on 26 July 2011[52].

[52] COMMISSION DELEGATED REGULATION (EU) No 626/2011 of 4 May 2011 supplementing Directive 2010/30/EU of the European Parliament and of the Council with regard to energy labelling of air conditioners, OJ L 178 6 July, 2011

Cooling: Air-cooled			
Energy Efficiency Class	Room Air Conditioners	Double Duct	Single duct
A+++	≥7 SEER	≥4.1 EER	≥4.1 EER
A++	≥6.1 SEER	≥3.6 EER	≥3.6 EER
A+	≥5.6 SEER	≥3.1 EER	≥3.1 EER
A	≥5.1 SEER	≥2.6 EER	≥2.6 EER
B	≥4.6 SEER	≥2.4 EER	≥2.4 EER
C	≥4.1 SEER	≥2.1 EER	≥2.1 EER
D	≥3.6 SEER	≥1.8 EER	≥1.8 EER
E	≥3.1 SEER	≥1.6 EER	≥1.6 EER
F	≥2.6 SEER	≥1.4 EER	≥1.4 EER
G	<2.6 SEER	<1.4 EER	<1.4 EER

Table 23: B2.3: current European cooling efficiency requirements for each energy labelling class

Heating: Air-cooled			
Energy Efficiency Class	Room Air Conditioners	Double Duct	Single duct
A+++	≥5.1 SEER	≥4.6 EER	≥3.6 EER
A++	≥4.6 SEER	≥4.1 EER	≥3.1 EER
A+	≥4.0 SEER	≥3.6 EER	≥2.6 EER
A	≥3.4 SEER	≥3.1 EER	≥2.3 EER
B	≥3.1 SEER	≥2.6 EER	≥2.0 EER
C	≥2.8 SEER	≥2.4 EER	≥1.8 EER
D	≥2.5 SEER	≥2.0 EER	≥1.6 EER
E	≥2.2 SEER	≥1.8 EER	≥1.4 EER
F	≥1.9 SEER	≥1.6 EER	≥1.2 EER
G	<1.9 SEER	<1.6 EER	<1.2 EER

Table 24: B2.4: Current European heating efficiency requirements foreach energy labelling class

B2.2.2 Chillers

Eurovent Certification operates a voluntary certification system (which is mandatory for its members - who represent a large part of the market) for chillers (and other air conditioning products)[53] [lviii] (see Table 25:). The website also usefully provides access to information on products that have been certified in the past, but are no longer on the market. For chillers, this is linked to an energy performance labelling scheme. The labelling classes are based on EER values at rated output, but Eurovent also certifies standardised seasonal performance values for certified chillers using the ESEER procedure[54]. As explained elsewhere in this report, water-cooled and remote condenser chillers have higher nominal EERs an than air-cooled chillers, but values used in energy classes and for MEPs need to reflect the extra energy required for heat rejection by these products.th

[53] This is based on (relatively expensive for manufacturers) independent product testing. Many member market surveillances of the mandatory scheme for room air conditioners are based on self-declaration, supported by random checks.

[54] ESEER follows the same general principles as the US “Integrated Part-Load Value” method, which has been in use since 1998.

EER Class	Air cooled	Water Cooled	Remote Condenser
A	>3.1	> 5.05	> 3.55
B	2.9 to3.1	4.65 to 5.05	3.4 to 3.55
C	2.7 to 2.9	4.25 to 4.65	3.25 to 3.4
D	2.5 to 2.7	3.85 to 4.25	3.1 to 3.25
E	2.3 to 2.5	3.45 to 3.85	2.95 to 3.1
F	2.1 to 2.3	3.05 to 3.45	2,8 to 2.95
G	< 2.1	< 3.05	< 2.8

Table 25: B2.5: Eurovent certification - standardised seasonal performance values for certified chillers. Source: Eurovent Certification

French, Spanish and UK building standards and regulations set out minimum backstop (EER) performance requirements for chillers. The legal status of technical documents supporting building standards and regulations varies between Member States. Typically, they have the status of "deemed to satisfy" guidance, which, while not strictly legally binding, are widely treated as if they were.

Australia proposes to introduce a "recommended high efficiency level" with an EER of 3.20 (which would fall in Eurovent class A) in addition to MEPS.

B2.2.3 Air Handling Units

There are currently no Europe-wide mandatory MEPS or energy labels for air handling units[55]. A Preparatory Study covering central air conditioning and ventilation systems for the Ecodesign Lot 6 is currently being prepared, but has not yet developed proposals for air handling units[lix].

Eurovent Certification has developed a voluntary (mandatory for the air handling units that it certifies) set of energy performance classes for air handling units, in use since 2009.

The basis of classification is the European Standard EN 13053, which defines classes based upon the following criteria[lx]:

- Average air velocity through the casing
- Heat recovery figures, minimum efficiency and maximum pressure drop depending on air flow rate and annual operating time
- For the absorbed motor power a reference is made to the maximum allowable absorbed motor power in using a formula

While the classification identifies products of inherently higher or lower energy efficiency for a given application, the energy use for air movement is more strongly dependent on the specific fan power, which itself is largely determined by the characteristics of the ductwork system which is served by the AHU. [56]

[55] There do not appear to be such systems anywhere else.

[56] Implementation of the EPBD has been accompanied by the training of designers and EPC assessors on the use of compliance tools. This – and the availability and mandatory use of tools to calculate

A number of European countries (Finland, France, Germany, Ireland, Norway, Poland, Spain, UK at least) have limits to acceptable specific fan powers (SFP) for ventilation systems within their building energy standards or regulations. SFP depends on pressure drop, fan efficiency and design of the motor and drive system. European standard EN 13779 contains a set of SFP classes and recommended allowances for additional components such as the provision of heat recovery (see B2.6).**Error! Reference source not found.**

Table 26: B2.6: Classes for Specific Fan Power

B2.2.4 Pumps

Minimum energy performance requirements for glandless standalone circulators come into force under the Ecodesign Directive in 2013 and will be made more demanding from 2015. At this date, Circulators integrated into products (including heat pumps) will also be included. The nameplate on circulators will also be required to show the energy efficiency index (EEI). The EEI is a weighted average of electricity consumption under a range of part-load conditions.[lxi]

B2.3 Energy Labelling and Information Provision: System Level

There do not appear to be any examples in place of system-level air-conditioning energy performance labels[57]. Although desirable in principle, there are substantial practical problems that need to be overcome with respect to central systems. Realistically, standardised system efficiency has to be determined by calculation – on-site measurements may identify faults, but the operating conditions are too uncontrollable to yield reliable comparisons. In addition, different systems have different configurations and sometimes functions, e.g., ventilation, humidification, etc., which further complicate comparison.

These types of calculations are required for implementation of the EPBD, which requires building energy standards to take account of the efficiency of "building technical systems" (including air conditioning). The EPBD calls for the introduction of minimum performance requirements for technical building systems,[58]. Because of this, attempts have been made to produce a European Standard for such calculations: EN15243[lxii]. It was concluded that there was insufficient experience to identify recommended procedures. The standard identifies different approaches that are used – notably the choice between explicit hour by hour (or more frequent) modelling and parametric models that use longer time periods (in particular

annual building energy consumption has had the effect of increasing their understanding of the importance of different factors, including system components.

[57] Other than for self-contained systems such as split systems

[58] Article 8 Clause 1 of the EPBD Recast states "Member States shall, for the purpose of optimising the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings.

monthly calculations that are consistent with equivalent load calculations that are widely-used in Member States regulatory calculations). Each of these has advantages and disadvantages. Detailed simulation is more explicit, but requires large amounts of data which are not easily obtained, requires simulation tools that are outside the experience of many system designers, and current simulation practice usually assumes ideal control (and often ideal component performance. Parametric models are generally less transparent and less flexible (though this may be acceptable in a regulatory context), but less demanding of data, and better able to accommodate generic adjustments to reflect empirical measurements (such as “imperfect control”). Within the EU, different Member States use each of these approaches to calculate building energy demand. Detailed modelling of air conditioning system performance does not appear to be used[59].

The standard EN 15243 contains extensive tables of air conditioning system types, and energy wastage mechanisms that may be present in each system type. It requires system performance models to state which system types they claim to be able to represent and to also state how they address each of the relevant energy wastage mechanisms[60].

A survey, carried out by the EPBD Concerted Action, identified only six Member States that claimed to include overall air conditioning efficiency in their building energy requirements.[lxiii] At least three of these use the methodology employed in this study (a fourth is implementing it, but may not have responded to the survey). It is believed that some other Member States account for system efficiency in a more simplified manner[61].

The development of calculation methods that are sufficiently robust and straightforward to apply (and check) to serve as regulatory instruments is an area that requires a significant amount of further investigation. EN 15243 was produced to support the EPBD, and will be considered for review within the EC mandate given to CEN in the context of the EPBD Recast to improve such standards. It appears unlikely that the available financial resources or timescale provided under the mandate will be sufficient to support what seems likely to be a significant research activity to develop such procedures. 2.4 Energy Labelling and Information Provision: Building and System Level

At the building level, the Energy Performance of Buildings Directive requires Member States to introduce Energy Performance Certificates (EPCs) for use whenever a building is constructed sold or let. It therefore applies to all new buildings and to the majority of existing ones. There is a separate requirement for public buildings to prominently display energy performance ratings. For new buildings, this can only be based on calculation and many European countries have also to use calculated performance as the basis for EPCs for existing buildings. Others use measured energy consumption as the basis of EPCs for existing buildings, and most use measured consumption as the basis of the Display Energy Certificates required for public buildings[lxiv].

Public access to EPCs varies between countries. Detailed information is not available but in some countries it is considered public information, while in others it is treated as private information that can be demanded only in certain circumstances, such as a serious interest in purchase. The EPBD Recast requires the energy rating to be displayed on all advertisements for sale or rent.

[59] Detailed simulation is sometimes used for design purposes, but this is not a legal requirement

[60] The system performance calculation used in this study is a parametric method that is compliant with these requirements, and is a derivation of the procedure used for building regulation compliance and building plus system energy labelling in a number of European countries, including the UK.

[61] Private communications

The underlying information behind the calculations is generally not readily available, though recommendations for potential improvements are required. Some certification software provides diagnostic information that identifies the (calculated) air-conditioning energy consumption. Subject to the caveats expressed above regarding system efficiency calculations, this could be the basis for – for example – air conditioning performance metrics. The calculated air conditioning consumption relates to standardised patterns of use (which will vary according to the building type), and standard weather. It reflects not only system efficiency but also building features such as window design and shading. For the building design team it allows cost assessments (whether of life cycle cost or first cost) to be optimised over the "building plus system" domain. This approach deserves further investigation.

Measured energy consumptions further broaden the scope to include the impacts of operation and management and therefore have the potential to identify additional energy wastage. While regulatory requirements are currently based on annual whole-building consumptions (and comparisons with generic benchmarks), there are a well-established commercial energy management programmes based on much finer-grain information. Some Member States such as Portugal use high annual consumption (relative to a benchmark) data to trigger a requirement for a full energy audit. The use of a central database of regulatory measured energy consumption levels should improve the reliability of benchmarks – but is not in place in all Member States. Existing regulation based on benchmarks is based on all energy use by a building, or an organisation. While high consumption may indicate high air conditioning energy use, it may have other causes. Only further investigation or more disaggregated reporting can identify which end-use is the cause. Some countries, such as the UK, require sub-metering of electricity on new installations. This is an important enabling requirement for energy management, but only has an impact if the information is acted upon[62]. There is an extensive discussion on energy benchmarking of buildings in the EPBD Concerted Action report of 2010.[lxv] Key conclusions include:

- Guide for installation of meters and sub-meters is needed
- Guide for in situ measurements is needed
- Benchmarks for a variety of uses are urgently necessary
- There is a need to investigate the energy consumption of the existing building stock statistically … to enable a set of valid benchmark criteria [to be developed]

In principle, additional information on air conditioning systems above 12 kW capacity is available from EPBD-mandated inspections. However, these are normally based on a visual inspection without quantified performance data.

Financial incentives linked to performance are rare. (The original conception of the UK's Carbon Reduction commitment was for a revenue-neutral recycling of money to organisations whose carbon efficiency was improving from those whose was not[63]).

B2.5 Minimum Energy Performance Standards: Products

Minimum Energy Performance Standards may be introduced with the aim of removing products of low efficiency from the market on the basis that purchasers may not recognise

[62] A research project supported by the EU's Intelligent Energy-Europe programme.– iSERV – began in 2011 aimed at refining the analysis of on-line air conditioning energy reporting to identify the likelihood of specific energy saving opportunities as well as reporting comparative benchmarking

[63]The recycling of revenue aspect of this policy instrument will not now go ahead so this is effectively a form of carbon tax.

that they represent poor value. Alternatively, they may be introduced at rather demanding levels with the dual aims of reducing energy consumption despite possible cost increases for certain product groups, and of forcing the pace of product development. The signposting of future tightening of requirements allows manufacturers time to develop least-cost compliant products

B2.5.1 MEPS Room Air Conditioners

MEPS for air conditioners are in place in a number of countries in North America and Asia. They are generally based on full-load ratings and are set at levels that are around the middle of the range of performance of European energy labels. However, Japan's "top-runner" requirement matches the performance of the best products available at the time the analysis was carried out – above that of most products on the European market. Typically there is a five-year period between the announcement of requirements and their coming into force. In Japan, the market for small domestic air conditioners is very competitive and this period would typically include at least one product redesign. This would not necessarily be the case for all products in all countries.

B2.5.2 MEPS Room Air Conditioners - Europe

Voluntary MEPS for room air conditioners have been in place in Europe since 2004 and proposals for mandatory requirements have recently been adopted. These proposals are described later in this section.

Eurovent Certification, representing the manufacturers of the majority of air conditioners sold in Europe, removed products with a G label from its directory from 2004. Further removals were intended, but it became clear that the technical testing tolerances that Eurovent demands for certification were more demanding than those required for European labelling, leading to the possibility of inconsistencies[64]. In the UK and some other countries, building regulation advisory documents set "backstop" performance criteria for many building elements (within an overall carbon emissions constraint for the building and systems). The 2010 level for this for split systems is in the middle of the F range.

Figure 2.1 below shows the evolution of the range of EERs of Eurovent-certified split systems. It is clear that the performance of the best equipment on the market rose markedly in about 2006 as products that were already available in other parts of the world appeared on the European market. The change in the worst certified products is much less marked, but the average EER of certified products has risen steadily.

[64] The (self-declared) measurement tolerances that are acceptable for European labelling are sufficiently wide that products can legitimately be placed in more than one class. Eurovent Certification imposes stricter (more expensive) requirements for independent testing to tighter tolerances, which reduce this effect.

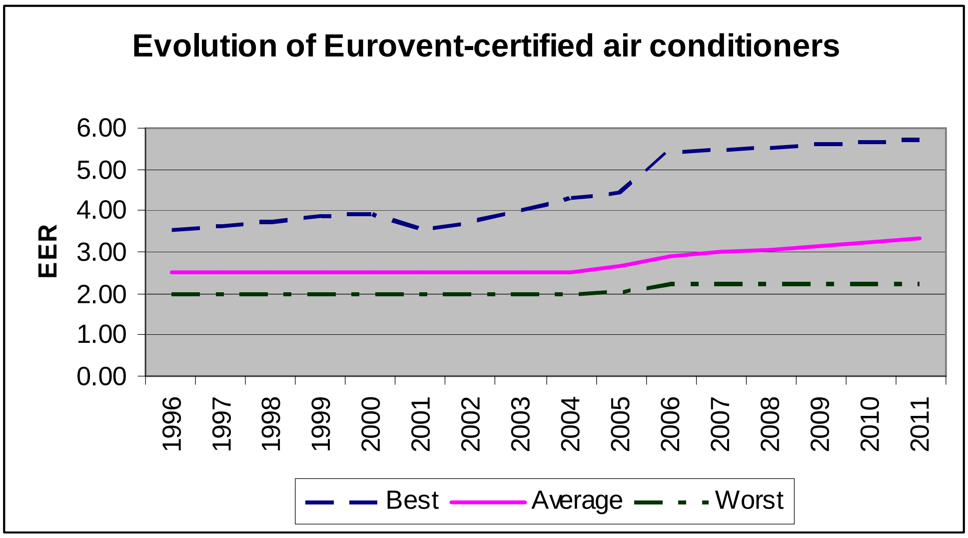

Figure 18: B2.1: Evolution of the range of EERs of Eurovent-certified split systems. Source: Preparatory study for Lot 10 to 2006. Eurovent data for 2011, interpolated between 2006 and 2011

These changes are shown more clearly below in the distribution of certified split systems (by product number, not by market share) in 2002, 2006 and 2011 (Figure B2.2).

Since 2002 (when mandatory energy labelling was introduced) the proportion of A-rated products has steadily risen. In 2006, the percentage of products on the market in Classes A, B and C increased compared to 2002 and the percentage of number of products in Classes D, E and F declined. By 2011, most products were in class A (and many will fall into the new classes A+ and above when these are introduced). Thus the range of performance levels on the market has extended upwards, providing possible technical “headroom” for future MEPS.

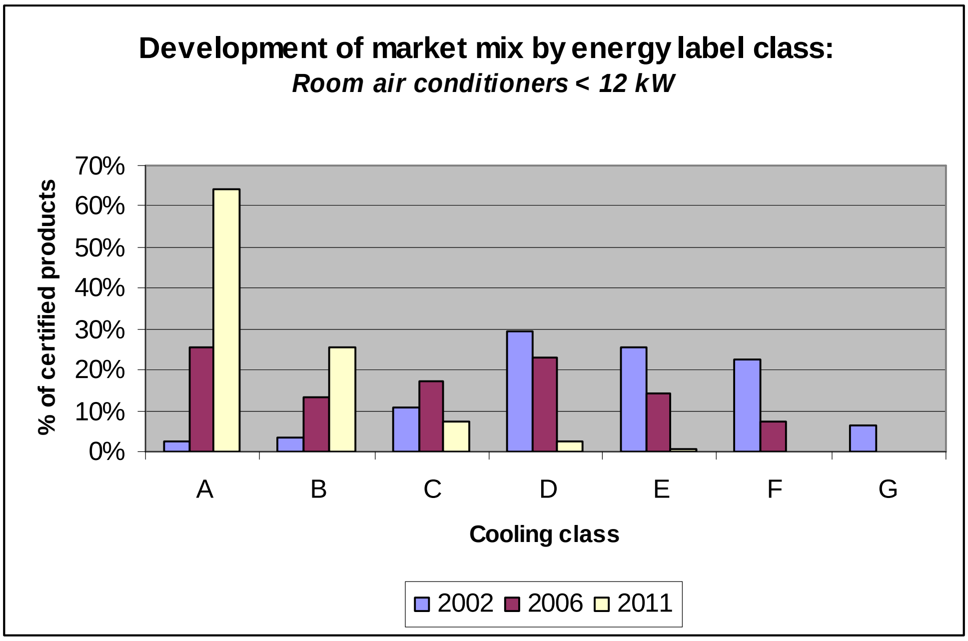

Figure 19: B2.2: Distribution of certified split systems (by number of products). Source: Eurovent database 2002 and 2006 and 2011

The proposals for mandatory requirement arise from the Ecodesign Directive (2009/125/EC), which requires ecodesign requirements to be set for energy related products which "... result in a significant environmental impact [and] where the impact can be reduced without incurring excessive costs."

A preparatory study (Lot 10) has been carried out for air conditioning of less than 12kW cooling power (excluding air to water systems). Following this minimum performance levels for cooling and heating functions and requirements for power consumption in the off mode and in standby modes were put in place. The requirements also demand that a power management function is provided that will switch the appliance automatically into standby or off modes within the shortest appropriate time. As well as energy use the requirements extend to internal and external noise levels. Subsequently, slightly more demanding MEPS for room air conditioners were accepted at the end of May 2011.

The Ecodesign requirements correspond to the life-cycle optima for typical users and a standardised European climate determined by the Preparatory Study. They were based on seasonal performance except for moveable units (for which requirements are based on EER) and so are not directly comparable with those currently in force in other countries. This follows the extension of the relevant European Standard (EN14825[65]) to include part-load tests and weighting formulae for standardised seasonal efficiency calculations. Seasonal performance information also has to be provided for different climate zones, as specified in the standard. To allow time for manufacturers to adapt to the new requirements, it is proposed that they will be introduced progressively over a 4 year period. The seasonal energy efficiency ratio or energy efficiency ratio for single and double duct appliances must be verified by Member States by testing one unit which must be +/- 8% of the stated value. If this test is not met then further testing will be required to determine whether the product complies with the regulations[66].

The proposed European MEPS for air conditioners are shown in the threeTables below. They differ according to the global warming properties (GWP) of the refrigerant used.

Minimum energy efficiency performance requirements: refrigerants with GWP>150						
	Room air-conditioners ≤12kW output power and double ducts >1kW input power		Double ducts ≤1kW input power		Single ducts ≤12kW output power	
Parameter	SEER	SCOP(A)	EER	COP	EER	COP
2 years after entry into force	**3,60**	**3,20**	**2,10**	**2,36**	**2,30**	**1,80**
4 years after entry into force	**4,30**	**3,50**	**2,45**	**2,60**	**2,60**	**2,04**

Table 27: B2.7: European MEPS for air conditioners – refrigerants with GWP>150

[65] It is understood that this standard has passed formal vote but not yet been formally published (this typically takes 6 – 12 months).

[66] As noted above, this tolerance is less strict than that of the existing voluntary scheme.

Minimum energy efficiency performance requirements: refrigerants with 1<GWP≤150						
	Room air-conditioners ≤12kW output power and double ducts >1kW input power		Double ducts ≤1kW input power		Single ducts ≤12kW output power	
Parameter	SEER	SCOP(A)	EER	COP	EER	COP
2 years after entry into force	**3,42**	**3,04**	**2,00**	**2,19**	**2,19**	**1,71**
4 years after entry into force	**4,09**	**3,33**	**2,33**	**2,47**	**2,47**	**1,95**

Table 28: B2.8: Proposed European MEPS for air conditioners – refrigerants with 1<GWP≤150

Minimum energy efficiency performance requirements: refrigerants with GWP≤1.						
	Room air-conditioners ≤12kW output power and double ducts >1kW input power		Double ducts ≤1kW input power		Single ducts ≤12kW output power	
Parameter	SEER	SCOP(A)	EER	COP	EER	COP
2 years after entry into force	3,06	2,72	1,79	1,99	1,99	1,53
4 years after entry into force	3,66	2,98	2,08	2,21	2,21	1,73

Table 29: B2.9: European MEPS for air conditioners – refrigerants with GWP≤1

The working document also identifies the following benchmarks for best available technology (BAT). There is a large difference between room air conditioners and single/double ducts. This is believed to be because less development effort has been put into the latter products. When they have manual on/off control, part-load performance is not a useful concept. .[67] Furthermore, it should be noted that the best Japanese room air conditioners have EER's in excess of 7.0W/W (See Table B2.1 below).

Room air conditioners ≤ 12 kW output and double duct > 1kW input	SEER 7.0
Double ducts ≤ 12 kW output ≥1kW input power	EER 3.0
Single ducts ≤ 12 kW output	EER 3.15

Table 30: B2.10: Benchmarks for BAT contained in the Regulation[20]

B2.5.3 MEPS Room Air Conditioners International

Table B2.11 below summarises the history of MEPS applied to split systems (the national requirements have been assigned to current European energy label classes for clarity)[lxvi lxvii].

Several features are apparent:

- initially, requirements were typically at the lower end of the performance range

[67] EER values of 7.0 have been quoted elsewhere. These refer to the SEERon metric rather than the more usually quoted SEER. SEER latter includes standardised contribution from energy consumption when the air conditioner is not cooling: SEERon omits them and therefore has a higher value. However products with EER levels of 6.5 are certainly on the market. See EN 14825 for definitions.

- subsequently, these were increased and many are now at the top end of the range
    - this coincided with product technical developments)
    - many of the countries have high cooling requirements compared to much of Europe
- requirements for lower capacity products are typically more demanding than for larger ones

In part, this reflects the more competitive market and more frequent product redesign in those countries with large markets in housing.

Evolution of cooling MEPS for reversable split systems				
Country	**Capacity Band kW**	**Date**	**EER**	**European label equivalent**
Japan	<4	1997	2.67	E
	4 to 7.1	1997	2.34	G
	> 7.1	1997	2.45	F
China	< 2.5	2001	2.85	C
	2.6 to 4.5	2001	2.7	D
	> 4.5	2001	2.55	E
Chinese Taipai	< 4.1	2002	2.97	C
	< 4.1 with inverter	2002	2.77	D
	> 4.1	2002	2.73	D
Australia (and New Zealand)	< 4	2004	2.3	F
	4 to 7.5	2004	2.3	F
	7.5 to 10	2004	2.3	F
	10 to 18.9	2004	2.3	F
Korea	< 4	2004	3.37	A
	4 to 10	2004	2.97	C
	10 to 17.5	2004	2.76	D
China	< 4.5	2005	3.2	B
	4.5 to 7.1	2005	3.1	B
	7.1 to 14	2005	3	B
Australia	< 4	2006	3.05	C
	4 to 7.5	2006	2.75	D
	7.5 to 10	2006	2.3	F
	10 to 18.9	2006	2.3	F
Canada	All	2006	3.8	A
Australia	< 4	2007	3.05	C
	4 to 7.5	2007	2.75	D
	7.5 to 10	2007	2.75	D
	10 to 18.9	2007	2.75	D
Japan	< 2.5	2007	3.64	A
	2.5 to 3.2	2007	3.64	A
	3.2 to 4	2007	3.08	B
	4 to 7.1	2007	2.91	C
	> 7.1	2007	2.81	C
Australia	< 4	2008	3.33	A
	4 to 7.5	2008	2.93	C
	7.5 to 10	2008	2.93	C
	10 to 18.9	2008	2.75	D
Taiwan	< 4	2011	3.45	A
	4 to 7.1	2011	3.2	A
Taiwan	< 4	2015	3.85	>A
	4 to 7.1	(proposed	3.55	>A

Table 31: B2.11: Evolution of cooling MEPS for reversible split systems

B2.5.4 MEPS Chillers

In the US, ASHRAE standard 90.1[lxviii] contains minimum EER and IPLV (a standardised SEER calculation) efficiency requirements for chillers. State and local governments are required to have building energy codes for commercial buildings that are at least as stringent as the 1999 version of the standard. Some states have implemented the 2004 version (in which the requirements for chillers are the same as in the 1999 version). Canada and Chinese Taipei also use the figures in this standard and Australia is proposing to do so[lxix].

The 2010 version of the standard retains the same EER values but slightly tightens the seasonal performance requirement (IPLV). The figures for 2010 are shown in Table B2.12. They are equivalent to energy class C in the Eurovent Certification scheme.

Original requirements from ASHRAE-90									Converted to European units					
			Before 1/1/2010		As of 1/1/2010				Before 1/1/2010		As of 1/1/2010			
					Path A		Path B				Path A		Path B	
Equipment Type	Capacities	Units	Full Load	IPLV	Full Load	IPLV	Full Load	IPLV	Full Loa	IPLV	Full Loa	IPLV	Full Loa	IPLV
Air Cooled Chillers	<150 Tons	EER	≥ 9.562	≥ 10.42	≥ 9.562	≥ 12.500	N/A	N/A	≥ 2.80	≥ 3.05	≥ 2.80	≥ 3.66	N/A	N/A
	≥ 150 Tons	EER			≥ 9.562	≥ 12.750	N/A	N/A			≥ 2.80	≥ 3.74	N/A	N/A
Air Cooled without Condenser	All	EER	≥ 10.59	≥ 11.78	Must be match with condenser				≥ 3.10	≥ 3.45	Must be match with			
Water Cooled Recip	All	EER	≤ 8.37	≤ 0.696	Must comply with W/C				≤ 2.45	≤ 0.20	Must comply with W/C			
Water Cooled Positive Displacement	< 75 Tons	kW/ton	≤ 0.79	≤ 0.676	≤ 0.780	≤ 0.630	≤ 0.800	≤ 0.600	≤ 4.45	≤ 5.20	≤ 4.51	≤ 5.58	≤ 4.40	≤ 5.86
	≥ 75 Tons & < 150 Tons	kW/ton	≤ 0.79	≤ 0.676	≤ 0.775	≤ 0.615	≤ 0.790	≤ 0.586	≤ 4.45	≤ 5.20	≤ 4.54	≤ 5.72	≤ 4.45	≤ 6.00
	≥ 150 Tons & < 300 Tons	kW/ton	≤ 0.717	≤ 0.627	≤ 0.680	≤ 0.580	≤ 0.718	≤ 0.540	≤ 4.90	≤ 5.61	≤ 5.17	≤ 6.06	≤ 4.90	≤ 6.51
	≥ 300 Tons	kW/ton	≤ 0.639	≤ 0.571	≤ 0.620	≤ 0.540	≤ 0.639	≤ 0.490	≤ 5.50	≤ 6.16	≤ 5.67	≤ 6.51	≤ 5.50	≤ 7.18
Water Cooled Centrifugal	< 150 Tons	kW/ton	≤ 0.703	≤ 0.669	≤ 0.634	≤ 0.596	≤ 0.639	≤ 0.450	≤ 5.00	≤ 5.26	≤ 5.55	≤ 5.90	≤ 5.50	≤ 7.81
	≥ 150 Tons & < 300 Tons	kW/ton	≤ 0.634	≤ 0.596	≤ 0.634	≤ 0.596	≤ 0.639	≤ 0.450	≤ 5.55	≤ 5.90	≤ 5.55	≤ 5.90	≤ 5.50	≤ 7.81
	≥ 300 Tons & < 600 Tons	kW/ton	≤ 0.576	≤ 0.549	≤ 0.576	≤ 0.549	≤ 0.600	≤ 0.400	≤ 6.10	≤ 6.40	≤ 6.10	≤ 6.40	≤ 5.86	≤ 8.79
	≥ 600 Tons	kW/ton	≤ 0.576	≤ 0.549	≤ 0.570	≤ 0.539	≤ 0.590	≤ 0.400	≤ 6.10	≤ 6.40	≤ 6.17	≤ 6.52	≤ 5.96	≤ 8.79

Table 32: B2.12: Figures for US standard ASHRAE-90 – minimum performance requirements for chillers - 2010

B2.5.5 MEPS Rooftop units

The USA has MEPS for Rooftop units. Table B2.13 below excludes sizes typical of residential applications since this application is very rare in Europe.

	EER (converted to European units and rounded)	
Date	**2008**	**2010**
19 to 40 kW	2.6	3.3
40 to 70 kW	2.5	3.2
Above 70 kW		3.1

Table 33: B2.13 US MEPS for Rooftop units

B2.5.6 MEPS Air Handling Units

Currently, no mandatory MEPS for air handling units exist in Europe. As noted above under “labelling”, studies are underway that may lead to European proposals. A fundamental issue is whether an energy performance requirement should relate to the product tested under standard conditions that may not represent the actual usage, or whether it should be a system metric that also reflects the effects of the associated ductwork system. As noted in section B3, several countries have national requirements for specific fan power (including the impact of the ductwork) in their national building energy regulations[68].

B2.5.7 MEPS Non-energy-using components

Energy-related performance requirements for these components are rather uncommon. As already noted, specific fan power is strongly influenced by ductwork design. Several European countries have national requirements for duct leakage [69].

Eurovent certifies filters (claimed initial pressure drop is verified, but is not reported in the Eurovent database) and other energy related products.

B2.5.8 MEPS Systems

As has already been noted, calculations of EPBD building and system level performance requirements can only be carried out by including system performance. In practice, system performance metrics do not seem to be generally reported in Energy Performance Certificates[70]. Many implementations of the EPBD by Member States do not consider air conditioning system performance in any detail[lxx]. As discussed above under "labelling," a minority of European countries claim that their procedures include overall system efficiency, but it seems that in practice this often takes the form of MEPS applied to system components and the mandatory provision of certain features (such as controls).

On the other hand, the Ecodesign Lot 1 proposals for boilers were originally based on the concept of energy performance for complete heating systems. These attracted criticism from the HVAC industry on the grounds that manufacturers generally produce products that form part of systems and cannot reasonably be expected to provide system-level information. In the latest proposals (as of June 2011) it is proposed that requirements be applied to "self-standing" products.

The EPBD Recast also requires the introduction of minimum performance requirements for HVAC systems, particularly for new systems in existing buildings[71].

B2.5.9 MEPS Buildings (including their HVAC systems)

Whole-building (and system) energy performance standards are, in principle, universal through the EU since they are mandated by the EPBD. In practice, Member States are at differing levels of implementation, especially when it comes to the treatment of air conditioning systems. Such standards are also used elsewhere in the world. There is therefore a significant body of experience and existing application infrastructure (including

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[68] A possible approach would be to use product MEPS (under standard conditions) as a base requirement, supplemented by national requirements that include ductwork impact

[69] More detail is provided in section B3.

[70] But are accessible in some regulatory software in some countries

[71] Article 1 "Member States shall, for the purpose of optimising the energy use of technical building systems, set system requirements in respect of the overall energy performance, the proper installation, and the appropriate dimensioning, adjustment and control of the technical building systems which are installed in existing buildings. Member States may also apply these system requirements to new buildings". Article 8 expands this.

calculation tools, and cadres of trained assessors), and enforcement processes (including quality assurance auditing, penalties etc).

The concept of "building energy efficiency" is somewhat misleading, in that it implies that it is possible to define an ideal (non-zero) level of demand. For this reason, building energy indicators are usually defined in terms of (normalised) consumption per unit of floor area. [72].In national building energy codes the calculated energy consumption of a building design is compared with that of a "reference building" (typically of identical geometry and use, and exposed to the same climatic conditions as the building under consideration). This approach allows whole-building consumption targets to reflect the mixture of activities taking place within a building. This is especially important for buildings that are not dwellings, which may contain spaces with very different uses.

The form in which energy is supplied – as electricity or by different fuels -has different implications for policy, total delivered energy is not a useful metric. For meaningful regulation each energy source needs to be converted to a common metric. In most Member States this is "primary energy", typically based on the calorific value of the fuel, but modified for electricity to take account of the conversion efficiency of fossil fuelled generation plant. Conversion factors for electricity vary from country to country to reflect differences of fuel use for electricity generation and other, less tangible factors. In the UK, the consequent carbon dioxide emissions are used[73].

Member States differ in their approach to setting building-level requirements, both in processes applied and the economic perspective used to set the levels. Some countries assess net societal benefits (including for example shadow prices for environmental damage), while others consider the end-user perspective. In practice the former results in more demanding standards. Other countries consider both perspectives.

The EPBD Recast requires Member States to demonstrate that whole building (and elemental) minimum performance requirements are "cost-optimal". This is easier said than done and the definition of the process is currently still in progress. The wording of the Recast requires that the "cost-optimal" will be viewed from the perspective of the end-user rather than that of society.[lxxi]

B2.6 Product pricing and incentives (access to capital)

Several countries provide tax incentives (typically increased write-down rates) for approved energy-efficient products. Some of these (in the UK or Ireland, for example) include air-conditioning equipment[lxxii]. The UK scheme provides a tax incentive to businesses that invest in equipment that meets published energy-saving criteria. An Energy Technology List (ETL) details the criteria for each type of technology, and lists those products in each category that meet them. The incentive Provides 100% first-year capital allowances on investments in energy-saving equipment against taxable profits of the period of investment, thus improving cash flow.

Scrappage schemes are most familiar applied to cars, but have also been used with domestic appliances, usually financed by energy supply companies. The UK also had a boiler scrappage scheme (A boiler rating system has been in place for a sufficiently long period to

[72] As more energy-intensive but smaller buildings may result in lower total consumption by a business, a more fundamental measure would be energy consumption per unit of economic output.

[73] This is useful for some purposes but clearly does not allow the implications for the electricity supply system to be isolated.

enable the identification of qualifying boilers). During 1988-90 a Spanish utility offered residential customers rebates to install high-efficiency air-conditioners. However this appears to have been intended to promote new ownership rather than replacement of less efficient appliances[lxxiii] . More recently, Greece operated an air–conditioning scrappage scheme.[74].

Low interest loan schemes for energy saving exist - in the UK, air conditioning and refrigeration have been stated to be among the most popular choices for businesses that have taken Carbon Trust (interest-free) loans.

See Appendix B1 for further discussion of policies related to product pricing and incentives.

B2.7 Prohibition of Smoking

Although not an energy policy measure, smoking bans do have an impact on energy consumption. The required supply of fresh air energy – and hence the energy consumption for ventilation (determined by the total airflow) and for cooling (because larger fresh air flows mean bigger cooling demands when the fresh air is warmer than the room air) depends on the amount of smoking that is expected in the space served. National building codes and similar documents generally specify minimum rates for non-smoking applications, whereas design practice should consider (in consultation with the client) the likely level of smoking.

Many countries now prohibit smoking in some or all public indoor spaces including work places. It is not clear to what extent design guidance and practice for ventilation now reflects this, but it is clear that many existing systems will have been designed in the expectation of smoking that is now prohibited.

B2.8 Summary Table

Potential policies and the extent to which they have been implemented both within and outside of Europe are summarised in Table B2.14.

Level of application	Overseas Precedents	European Precedents	Comments
		Energy labelling and information provision	
Products and components	Well established	Mandatory for room air conditioners and movables, voluntary for chillers	Usually packaged with MEPS
Complete (Central) Systems	No known examples	Regular inspection and report required by EPBD	Experience shows that only a proportion of potential savings are identified
Building (and systems)	??	Required by EPBD	Implementation patchy for air conditioning
		MEPS	
Products and components	Well established	Agreed for room air conditioners and movables	Overseas practice has been to introduce at relatively undemanding levels and progressively tighten
Complete (Central) Systems	No known examples	Suggested by EPBD recast	Significant technical implementation issues
Subsystems	??	Some national requirements for specific	Demonstrably possible but not widespread

[74] A scrappage scheme for inefficient air conditioners also operates in Mexico

		fan power and ductwork leakage	
Building (and systems)	Well established for buildings but less so for systems	Required by EPBD	Implementation patchy for air conditioning
Incentives and Pricing			
Products and components	??	Tax incentives in some countries	Perceived value may be less financial than in the establishment of an "approved list" of products
Products and components	??	Scrappage scheme in one country (Italy)	Also applied to boilers in one country (UK)
Supply chain	Procurement programmes well established for other products	Procurement programmes for other products in some countries	Only apply to part of the market
Supply chain	Green leases in some countries	Green leases in some countries	Appear to have limited take-up
Building (and systems)	??	High energy taxation in at least one country (Denmark)	Politically sensitive

Table 34: B2.14: Summary of Existing Policies within and outside of Europe

B3 DEFINITIONS OF MODELLED CASES AND INPUT VALUES

B3.1 Introduction

The assessment of the potential for reducing the energy consumption of air conditioning equipment in Europe requires looking at the current level of consumption in existing buildings as well as in new buildings that will be coming into service in the future. Whilst it may not be feasible to replace cooling systems in existing buildings with more efficient types until they are totally refurbished, it is useful to determine the potential savings in cooling energy through the application of three types of measures that:

1. Reduce cooling demands (by improvements in the building shell characteristics and internal gains from people and equipment)

2. Improve the average efficiency of air-conditioning systems (installed plant)

3. Improve the quality of operation and management of air conditioning systems (via improvements in operation and maintenance)

Since the vast majority of cooling consumption in Europe is attributed to existing buildings (new buildings represent a small percentage of the total stock), any model used to estimate the impact of measures to reduce cooling energy consumption must consider options that are feasible in existing buildings as well as for new buildings. Although some of these options are likely to be easier to implement in new buildings.

This chapter describes in detail the Modelled Cases chosen for this study. It discusses the rationale for the choice of cases and identifies the data sources and assumptions used, as well as presenting the data inputs used in the modelling. The system types and range of energy performance levels of cooling products on the market, the operating characteristics of central systems and describes the limitations of various system types and their inter-changeability are described in Section B1 of this report.

The energy saving opportunities, or intervention points, for cooling systems were identified at four different levels:

- Product and component energy performance

- System energy performance, which incorporates component energy performance

- Building energy performance, which relates to building design

- Operational energy performance, i.e., how effectively the system is controlled to meet cooling

The Modelled Cases defined here address product, systems and building level energy performance measures and consider the potential savings for a selection of different policy components:

- Labelling and information

- MEPS

- Financial incentives, and

- Improved building design, including fabric measures, such as solar shading, and more energy efficient lighting and appliances

A variety of cases were defined for covering these policy components applied at the appropriate levels to the 14 system types identified in Chapter B1. These provided an assessment of the potential savings from within system improvements.

In addition, a separate analysis considered the potential savings that could be achieved from system switching.

The cases that have been modelled for this study explored the potential savings that can be achieved for each of the individual detailed system types identified in Section B1. In addition, the potential savings that could be achieved by system switching *within* each of the main system categories and from system switching *between* the main system categories were also explored.

The modelling process used to explore these Modelled Cases is presented in Section B4 of this report and the potential savings identified are presented in Section B5. Subsequently the extent to which these savings could be realised by cost effective policy options is considered in section A4, whilst the resultant policy recommendations are presented in section A3.

The maximum savings that would be achieved by implementing the current best available technology (BAT) in all feasible instances, regardless of cost considerations, was modelled to establish a limiting yardstick. Whilst current BAT technology is unlikely to be cost effective, even at the societal level, it is not unreasonable to assume that current BAT might be nearly cost effective in a few instances; it would be unlikely to be on the market in the first place if this was not the case. Furthermore, for cooling products the cost of current BAT technology is liable to decrease rather than increase so it may become cost effective in more instances in the future. Therefore it is reasonable to assume that current BAT technology has the potential to become cost effective (at least at the societal level) in the future.

In addition to BAT, the savings that would arise from applying the following policy levers at each of the three intervention points (product, system or building) were considered:

- Labelling and information – which encourages decision makers to choose more efficient options.
- Financial incentives – which would boost the uptake of higher efficiency options.
- Minimum Energy Performance Standards (MEPS), which would cut out the least efficient options.

Generally at least two different savings levels were considered:

- Light: This is representative of policies that would be defined as “backstop” requirement or only slightly above. These are likely to be cost effective from the end user perspective in almost all applications.
- Moderate or demanding : This relates to a more substantial level of savings that might be expected to be cost effective from the societal perspective, and typically has the objective of forcing the pace of technical development.

In many cases additional savings levels were also modelled, particularly for product MEPS, in order to provide a better understanding of the sensitivity of potential savings to regulatory performance requirements.

As well as modelling the effect of efficiency improvements that might be achieved for each system sub-type[lxxiv] (individual system level), the energy savings that could be achieved by switching to more efficient system sub-types both within and between each of the main system categories were considered. For the system switching analysis two cases were considered, one of which examined the effect of replacing a system by a typical example of the most efficient system sub-type. The second case considered the extreme case of replacement with the most efficient system sub-type with BAT levels of performance.

B3.2 Summary of the Modelled Cases (Individual System Level)

The Modelled Cases for the individual system analysis take account of the point at which a potential policy intervention could be made, e.g., for products this would generally be related to sales, whereas for systems and buildings it may also relate to the existing stock. Accordingly the Modelled Cases have been applied to new installations only, for product level interventions and to both new and existing installations for system and building level energy saving options.

The Modelled Cases for moveable units and room air conditioners were essentially either product related or building related as the cooling system is a self contained product. However, for larger and centralised systems the Modelled Cases considered both products, which will be the components which comprise the system, the system as a whole and the building.

Each of the specific cases that were explicitly modelled for this study for each of the three main system types are referenced by a unique alphanumeric code which is referred to throughout this report and termed “case number”.

B3.2.1 Modelled Cases Moveable Units

The following cases were modelled for moveable units, product level cases were modelled for new installations only as existing systems are not likely to be affected by product level policies and replacement systems were included under new installations. Building envelope saving measures could potentially be applied to all buildings so these measures were applied to both new and existing installations and will result in a reduction in the hours that the cooling system is required to operate. They may also reduce the number of units sold, but this was not modelled.

Case no.	Description	Installations
M0	Base case (labelling + existing building regulations)	All
M1	(Product) proposed MEPs	New
M2	(Product) MEP 1	New
M3	(Product) MEP 2	New
M4	(Product) proposed MEPs + financial incentives	New
M5	(Product) MEP 1 + financial incentives	New
M6	(Product) MEP 2 + financial incentives	New
M7	(Product) BAT	New
M8	(Building) acheivable envelope savings	All
M9	(Building) BAT envelope savings	All

Table 35: B3.1: List of Modelled Cases for mobile units (individual system level)

B3.2.2 Modelled Cases and Inputs for Room Air Conditioning Units

The following cases were modelled for room air conditioning units, product level cases were modelled for new installations only as existing systems are not likely to be affected by product level policies and replacement systems are included under new installations. Building envelope saving measures can be applied to all buildings so these measures were applied to both new and existing installations and will result in a reduction in the hours that the cooling system is required to operate. They may also reduce the number of units sold, but this impact has not been modelled.

Case no.	Description	Installations
RAC0	RAC (Base case) labelling + existing building regulations	All
RAC1	RAC (Product) proposed MEPs	New
RAC2	RAC (Product) MEP 1	New
RAC3	RAC (Product) MEP 2	New
RAC4	RAC (Product) MEP 3	New
RAC5	RAC (Product) MEP 4	New
RAC6	RAC (Product) proposed MEPs + financial incentives	New
RAC7	RAC (Product) MEP 1 + financial incentives	New
RAC8	RAC (Product) MEP 2 + financial incentives	New
RAC9	RAC (Product) MEP 3 + financial incentives	New
RAC10	RAC (Product) MEP 4 + financial incentives	New
RAC11	RAC (Product) BAT	New
RAC12	RAC (Building Envelope) acheivable envelope savings	All
RAC13	RAC (Building Envelope) BAT envelope savings	All

Table 36: B3.2: List of Modelled Cases for room air conditioning units (individual system level)

B3.2.3 List of Modelled Cases and Inputs for Central and Larger Systems

The following cases were modelled for central and larger systems, product level cases were modelled for new installations only as existing systems are not likely to be affected by product level policies and replacement systems were included under new installations. Building and system level cases are modelled for both new and existing systems. Building envelope saving measures could potentially be applied to all buildings so these measures were applied to both new and existing installations and will result in a reduction in the hours that the cooling system is required to operate. They may also reduce the number of systems installed and perhaps the choice of system type, but these effects were not modelled.

Case no.	Description	Installations
C0	Central (Base case) voluntary labelling and existing building regulations	All
C1	Central (Product (Chillers and Packaged Units)) labelling	New
C2	Central (Product (Chillers and Packaged Units)) labelling + financial incentives	New
C3	Central (Product (Chillers and Packaged Units)) MEP1 + labelling	New
C4	Central (Product (Chillers and Packaged Units)) MEP2 + labelling	New
C5	Central (Product (Chillers and Packaged Units)) MEP3 + labelling	New
C6	Central (Product (Chillers and Packaged Units)) MEP1 + labelling + financial incentives	New
C7	Central (Product (Chillers and Packaged Units)) MEP2 + labelling + financial incentives	New
C8	Central (Product (Chillers and Packaged Units)) MEP3 + labelling + finacial incentives	New
C9	Central (Product (Chillers and Packaged Units)) BAT	New
C10	Central (Product (AHU)) labelling	New
C11	Central (Product (AHU)) labelling + financial incentives	New
C12	Central (Product (AHU)) MEP1 + labelling	New
C13	Central (Product (AHU)) MEP1 + labelling + financial incentives	New
C14	Central (Product (AHU)) BAT	New
C15	Central (Product (Fan coil terminal units)) MEP1 + labelling	New
C16	Central (Product (Fan coil terminal units)) MEP1 + labelling + financial incentives	New
C17	Central (Product (Fan coil terminal units)) BAT	New
C18	Central (Product (Pump)) MEP1 + labelling	New
C19	Central (Product (Pump)) MEP1 + labelling + financial incentives	New
C20	Central (Product (Pump)) BAT	New
C21	Central (System (air leakage)) MEPS	All
C22	Central (System (air leakage)) BAT	All
C23	Central (System (AHU)) reduce fresh air flow rate	All
C24	Central (System (rigourous A/C inpection)	All
C25	Central (System (All components)) MEPS	All
C26	Central (System (All components)) BAT	All
C27	Central (Building Envelope) acheivable envelope savings	All
C28	Central (Building Envelope) BAT envelope savings	All

Table 37: B3.3: Modelled Cases for central and larger systems (individual system level)

Table B3.4 maps the within system Modelled Cases according to the policy components and implementation levels that they relate to (e.g., light, moderate or BAT). The table also indicates the extent to which these policy components are expected to be cost effective.

Policy Component	Main System Type			Installations	Cost Effective
	moveables	RAC	Central and larger		
Base case	MO	RAC0	C0	All	almost always
Proposed Product MEPS	M1	RAC1		New	almost always
Labelling and Information			C1 (Chiller)	New	almost always
			C10 (AHU)		almost always
Labelling and information + financial incentives			C2 (Chiller)	New	almost always
			C11 (AHU)		almost always
Light Product MEPS	M2	RAC2	C3 (Chiller)	New	almost always
		RAC3	C4 (Chiller)	New	
Moderate Product	M3	RAC4	C5 (Chiller)	New	on average
			C12 (AHU)		

MEPS		RAC5	C18 (Pumps)		
			C15 (Terminal)		
Light Product MEPS + financial incentives	M4	RAC6	C6 (Chiller)	New	almost always
	M5	RAC7	C7 (Chiller)		
		RAC8			
Moderate Product MEPS + financial incentives	M6	RAC9	C8 (Chiller)	New	on average
			C13 (AHU)		
		RAC10	C19 (Pumps)		
			C16 (Terminal)		
BAT product MEPS	M7	RAC11	C9 (Chiller)	New	potentially
			C14 (AHU)		
			C20 (Pumps)		
			C17 (Terminal)		
Moderate System MEPs and Labelling			C21 (Ductwork Leakage)	All	on average
			C23 (System Performance)	All	
			C24 (System Performance)	All	
			C25 (System Performance)	New	
BAT System MEPs and labelling			C22 (Ductwork Leakage)	All	potentially
			C26(System Performance)	New	
Moderate Building MEPs	M8	RAC12	C27	All	on average
BAT Building MEPs	M9	RAC13	C28	All	unlikely

Table 38: B3.4: Summary of within system Modelled Cases indicating installations addressed and potential cost effectiveness

Blanked out cells indicate that these cases were not modelled. They were excluded because:

- For central systems there are currently no proposed product MEPS.
- Product labelling for Moveable and Room Air Conditioning units are already mandatory under the Energy Labelling Directive[lxxv].
- Product rather than system level MEPS and Labelling are relevant for Moveable and RAC units.

The remainder of this section outlines the rationale for choosing these specific modelling cases for the within system analysis and the choice of performance level(s) and then summarises the inputs used in the modelling.

B3.3 Overview of the Modelling Options at the Individual System Level and the Rationale behind These Choices

B3.3.1 Background

Existing studies show that each of the three areas for potential savings mentioned above has a comparable magnitude as shown in the figure below. This is derived from information collected by the Harmonac project[lxxvi]. (More detail on this is provided in Appendix B2).

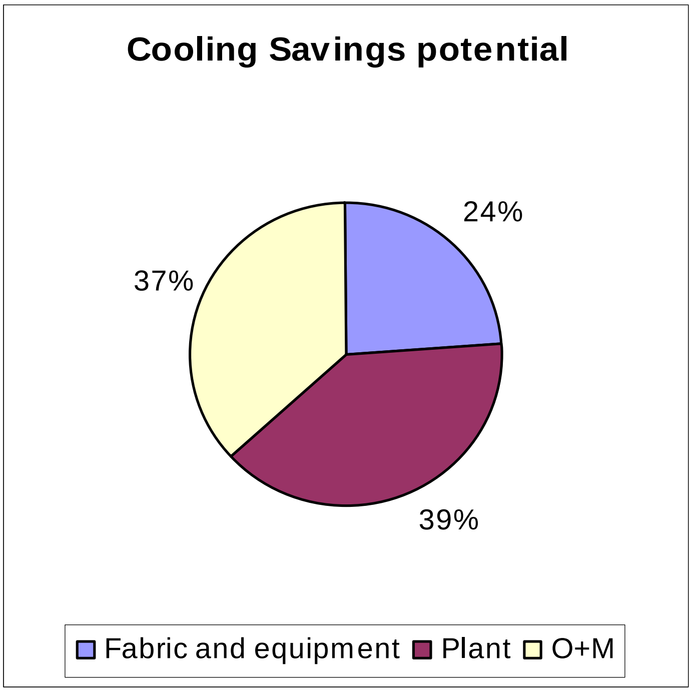


Figure 20: B3.1: The relative contribution of different types of measure for saving energy use (Source: Harmonac study)

The Modelled Cases therefore considered only plant (system energy performance) and fabric and equipment[75] measures, and looked in most detail at potential savings from measures to improve average system efficiency (plant), as:

- this is an area where Europe has few mandatory requirements
- product policies in this area are currently
    - being put in place for room air conditioners[lxxvii]
    - being examined for products that form part of central systems under the Ecodesign Directive[lxxviii]
    - proposed for systems in the EPBD Recast[lxxix]
- there is a wide range of potentially interacting possible policy options: minimum performance requirements (potentially applied to individual products or complete systems); energy performance labels; financial incentives applied to products or buildings

[75] In this context equipment refers to energy using equipment within the building that contribute to internal gains, e.g., lighting, office equipment, etc.

For the individual system analysis a range of modelling options were selected that reflect both the technical potential for savings that could be achieved by the deployment of current best available technologies (BAT), and also the levels of savings that might potentially be achieved with more realistic assumptions that reflect (to a greater or lesser extent) the constraints of costs (cost effectiveness) and practicability.

Later sections describe how the product/component performance levels for MEPS, labelling and financial incentives were chosen and how the associated market average performance (SEER values) were calculated.

In the modelling, these calculated market aggregate SEER values were applied to each country individually as default assumptions. Where there is information to show that a country has a different distribution of product efficiencies, these over-rode the default values. This process is described in more detail in section B4 and the input SEER values used in the modelling are provided at the end of this Chapter.

The savings calculated for each modelled case relate to the ultimate potential if measures were applied in all applicable instances, i.e. the energy saving option was implemented in 100% of cases where the measure could feasibly be applied and takes no account of compliance failures or technical and market imperfections. They provide one, important, dimension against which to assess policy options. Realisable savings will be lower as they are constrained by practical implementation, financial and other considerations, discussed in Section A4 of this report. The rate with which they can be achieved will also be constrained by such factors as stock turnover (which were modelled) and time to set up implementation frameworks (which were considered outside of the modelling analysis).

System types

Moveable units are straightforward to define, but the line between room air conditioning units and central systems is harder to draw. For this study, room air conditioners are taken to be those with a cooling capacity of <12 kW, which covers wall/window units and small single split systems, whilst all units that are 12 kW or larger have been included in the central systems category as units of this size will generally serve more than one room. These categories relate to different markets and the 12 kW cooling division is consistent with that used in the Ecodesign Directive and (for inspections) in the Energy Performance of Buildings Directive.

As the three main system types identified in Section B1 and the text below (moveable units, room air conditioning units and central systems) relate to largely separate markets, the savings potential for each was modelled separately.

The options modelled for this study assessed the savings potential for each of the system sub-types at the product, system and building level (for moveable and room air conditioning units, product and system are one and the same).

The following sections describe how the minimum energy performance levels and other modelling cases were determined.

B3.4 Introduction to Setting Minimum Energy Performance Standards for Products and System Components

MEPS are one means by which the aggregate energy efficiency of products can be improved and savings made. MEPS can be set at any performance value within the range available in the market place. At one extreme, they may be set in order to simply remove the least efficient products from the market, on the basis that they offer poor value in terms of energy efficiency[76]. Or they may be set at more demanding levels that have a greater impact on the market. Such levels seem more likely to generate pressure for technical development by manufacturers who wish to maintain market differentiation in terms of energy efficiency. An example of this is the Japanese "Top Runner" programme, which sets future (fleet) MEPS at levels which correspond to current best available technology.

Commonly, MEPS are set as the result of techno-economic assessments of optimum life-cycle cost. These are usually based on "typical" usage assumptions that do not distinguish between differences of usage or cost faced by different users. Such assessments may be made from the perspective of society as a whole (the societal perspective) – including shadow prices for externality costs, ignoring subsidies and taxes and using (low) social discount rates - or from the perspective of the end-user. In the latter case, prices include taxes and subsidies, and externalities are not included (unless they are priced in through taxation). Logically, discount rates should reflect costs of capital, but this is often not the case.

As a broad generalisation, the societal perspective justifies more demanding MEPS than the end-user one. European practice is to use the end-user perspective when setting appliance MEPS in the Ecodesign Directive. For building (and building + system) MEPS – "building energy standards" – the picture is more mixed. Most (but not all) Member States use a societal perspective when setting these requirements. Many also consider the end-user perspective in order to identify sectors that may be disproportionately affected.

In terms of the modelling, separate cases were considered that represent relatively mild MEPS, characteristic of end-user based assessments, and more demanding MEPS that might arise from societal perspectives. Where there are existing or planned energy performance classes, the MEPS assumptions used in the Modelled Cases have been aligned with class boundaries. Where there are no performance classes currently in existence the distribution of product efficiencies for the type of product was examined and then the range subdivided into equal increments of performance and the modelling cases were based on these subdivisions. An alternative approach would have been to set the MEPS level to capture a given proportion of products; however, as the energy performance classes for existing labelling are subdivided into equal increments it was deemed more appropriate to use the aforementioned approach.

The values for the Modelled Cases are used because the existing data relates to EER, which is subsequently converted to SEER which is a more appropriate metric for modelling purposes.

Life-cycle cost optimal values have not been calculated for this study, but figures from other sources were identified and related to the Modelled Cases.

B3.5 Deriving Energy Performance Levels for Products and System Components

In order to determine the potential effect of MEPS, labelling and financial incentives it was necessary to first determine the range of current performance levels that exist in the marketplace for the particular product or component. For moveable units, RAC units, and chillers, these were estimated from the distribution of performance for products included in the Eurovent database[lxxx]. In the absence of information on the sales for each product it was assumed that the distribution by number of products would be the same as that for product sales (effectively assuming similar sales levels for each product).

The typical performance values were determined for both current installations and existing installations. The typical performance values for new installations were based on a recent

[76] They may have attributes other than price that make them attractive to purchasers: size, quietness, comfort.

(2011) version of the Eurovent database. The typical performance values for current installations were determined based on products listed in earlier versions of the Eurovent database, as this will be more representative of the performance of the current installed stock. These typical values were used to calculate the energy consumption for cooling systems for the base case.

The next step was to determine how labelling, MEPS and financial incentives would impact on the typical product/component values identified above.

For MEPS a new distribution of performance values was calculated by replacing all products with a performance value below the MEPS threshold with those at the threshold and recalculating the market average based on the new distribution of product performance.

It was assumed that labelling will result in a 5% increase in sales for the highest performing group with a proportional reduction in sales across the remainder of the distribution. The addition of financial incentives was assumed to increase this percentage by a further 5%.

For other (non-cooling) products and components, other available data sources were drawn upon to determine the typical and improved energy performance values for the Modelled Cases. The data sources and assumptions used to derive the energy performance values used in the modelling are described in more detail in the following sections of this chapter.

The following sections detail how MEPS values were selected for Modelled Cases for products and components. System and building level performance levels are discussed below in Sections B3.7 and B3.8 respectively, and system switching is discussed in Section B3.9.

The analysis in this section describes the derivation of the modelling input assumptions and the percentage performance improvement. Figures reported in this section for indicative overall performance improvement do not take account of the full range of issues covered by the detailed modelling and were only used to assess suitable Modelled Cases.

It should be noted that for cooling products and system components, energy performance levels can be measured in two ways – the Energy Efficiency Ratio (EER) and the Seasonal Energy Efficiency Ratio (SEER). The EER refers to the performance under standard rated conditions (i.e. at the nominal level of output for the equipment). The SEER refers to the seasonal efficiency value and, as such, gives a better indication of how a system might perform in practice over the whole cooling season and is therefore used in the modelling. Many of the data, however, are available only as EER and are shown as such in figure B3.2 which give an indication of the scale of reduction potentially achievable. These data were then converted to SEER for the purposes of the modelling. The conversion was estimated using SEER/EER multiplier values from German standard DIN 18599-7.

It should also be noted that indicative percentage savings in the section represent the (percentage) improvement of the overall efficiency of sales after implementation of a measure relative to the equivalent figure for the current (installed) stock of air conditioners of the same type. In a number of instances where data are unavailable the distribution of certified products has been used as a proxy for the latter figure.

B3.6 Determining the Effect of Labelling, MEPS and Financial Incentives on the Energy Performance of Cooling Products and System Components

In order to define cases for the modelling, it was necessary to estimate the aggregate seasonal efficiency with which cooling demands are converted to energy consumption for each sub-sector of the market that is modelled: for example for all room units < 12kW capacity.

The overall performance figures were derived from frequency distributions for products (or systems) of different performance levels where the overall efficiency is the weighted harmonic mean value. This was calculated from the distribution of EERs for models that are currently on the market, the implicit assumption being that there will be similar levels of sales rates for the models within each performance class. Although there is no evidence to justify this assumption, equally there is no prima facia reason to believe that the performance distribution for sales will be different to that for models on the market.

In order to estimate the impact of different levels of MEPS, energy performance labels and financial incentives for cooling products and components, it was necessary to use seasonal efficiency (SEER) rather than rated efficiency (EER). The way in which this was done varied according to the information available and is described for each case separately.

The process of estimating the (indicative) impact of a measure is summarised below:

- for a particular type of product, analyse the frequency distribution of models of different efficiency currently in the stock
- where necessary, estimate seasonal performance from rated performance (that is SEER from EER)
- calculate the aggregate seasonal efficiency (which is actually the weighted harmonic mean SEER)
- repeat this for the distribution of products currently sold
- estimate the impact of introducing MEPS (or other policy instruments) on the frequency distribution
- recalculate the aggregate SEER
- assess the savings and the proportion of products removed from the market

The assumptions made when information is incomplete are described in each section.

In the modelling described in section B4 and reported in B5 the aggregate SEER values were applied to each country individually as default assumptions. Where there is information to show that a country has a different distribution of product efficiencies, these over-rode the default values.

B3.6.1 MEPS

For MEPS it was assumed that sales of products removed from the market will be replaced by those of the lowest efficiency that are still permitted. The aggregate performance was then calculated based on a revised distribution of performance.

B3.6.2 Labelling and Financial Incentives

Whilst Southern European countries have significant markets for room air conditioners for use in dwellings, most room air conditioners (and nearly all central air conditioning system) are sold to organisations via business-to-business supply chains with different procurement drivers. The Modelled Cases illustrate the situations where the introduction of energy labels increases the market share of the best products. In particular, purchasers can introduce procurement rules that increase the market share of products in the highest labelling classes (or equivalent) products. The effect was modelled as an increase of this market share by a step change of 5 percentage points, with a proportionate reduction of products with lower energy ratings.

In addition, the Modelled Cases also illustrate the situation where financial incentives are introduced. Where labelling is already mandatory, or when financial incentives are introduced as well, the effect was modelled as a 5 percentage point increase in the market share[77, 78] and where these are introduced with labelling a 10 percentage point increase was used[79].

There appears to be little quantitative information about the effect of the introduction of energy labels or of financial incentives on sales distributions. Comparisons exist of changes to market distributions with time (for example of small split systems)[lxxxi] but it is difficult to identify causality, or to confidently transfer the impact to the business-to-business market sectors that dominate air conditioning[80]. Because of these difficulties, the limited impacts for the labels explained above were modelled. This is discussed in more detail in section B6.1 below

These assumptions were applied to all MEPS whether they are applied at product or system level.

B3.6.3 Determining Energy Performance Levels for Moveable Room Air Conditioners

It was not possible to locate figures for the distribution of models of moveable room air conditioners of different energy performance, apart from a limited number of test results from consumer organisations[lxxxii]. It was therefore assumed that the distribution by energy label class is broadly similar to that for fixed room units (though the values of EERs for each class are different) with the exception that it was assumed that there are no products with performances better than an A-rating[81]. This reflects the comments made by TopTen[lxxxiii], which suggests that high performance products are unusual. Products with additional evaporative cooling were not considered. The modelling also concentrated on single-duct units, which represent the majority of the market and for which more data are available. The data source for frequencies for current sales was the sales market distributions (for small split systems) shown by Attali and Bush[lxxxiv], weighted by country. Of the countries covered by this source, Italy has a markedly different distribution from the remainder. Because Italy appears to be atypical, the analysis in this section (to select MEPS cases for modelling) was based on the average distribution of the non-Italian Attali and Bush countries (France, Germany, UK, and Portugal). The national distributions were, of course, retained in the modelling baseline itself. The figures for EER were taken as mid-points of the current labelling system. The aggregate EER used for the existing stock was the Lot 10 Base Case. The distinction between double-duct and single-duct products was not possible, since data are lacking. Market analysis reported in the Lot 10 Preparatory Study[lxxxv] shows that the majority of moveable units sold are single-duct. The Commission draft Regulation[lxxxvi] reports BAT figures of 3.00 for double duct and 3.15 for single duct (in both cases with evaporative

[77] In the modelling itself, the baseline aggregate efficiencies reflect national distributions where these are available – with the European average being used as a default in the absence of national information.

[78] In principle there may be differences reflecting national or regional energy prices and "cultural" issues such as building use patterns. In the absence of quantifiable information, our modelling only includes climatic effects and – where we are aware of them – regulatory requirements.

[79] Incentives seem most likely to be restricted to top-rated products. Anecdotal evidence suggests that the implied guarantee of performance is as important as the monetary value.

[80] The closest analogy is probably the use of voluntary independent building sustainability ratings such as the BREEAM procedure. The main impact of these appears to be that a part of the market sets up formal or informal procurement procedures that aim at achieving the highest level of rating.

[81] This is consistent with the BAT figures quoted in the draft Commission Regulation.

cooling) which may be taken as an indicator of the probable scale of differences. TopTen reports speak of the imminent arrival of variable-speed double-duct units, but none appear to be on the market at present.

Figure 21:B3.2 below shows that in order to improve the aggregate efficiency[82] of new sales of moveable air conditioners by more than 10%, compared to the aggregate value for the current stock, then minimum performance requirements that eliminate all but the best-performing products would be required. It should be noted that for the last four performance requirements on this chart there is no additional percentage improvement for MEP + incentive over just MEP. This is due to the fact that as the requirement gets closer to the BAT then the additional impact of financial incentives is not expected to deliver any further improvements. The planned requirements would improve aggregate performance by between 2% and 6%. There appears to be significant technical scope to improve product performance. Incentives are unlikely to have a significant impact unless they have a substantially greater effect than that assumed.

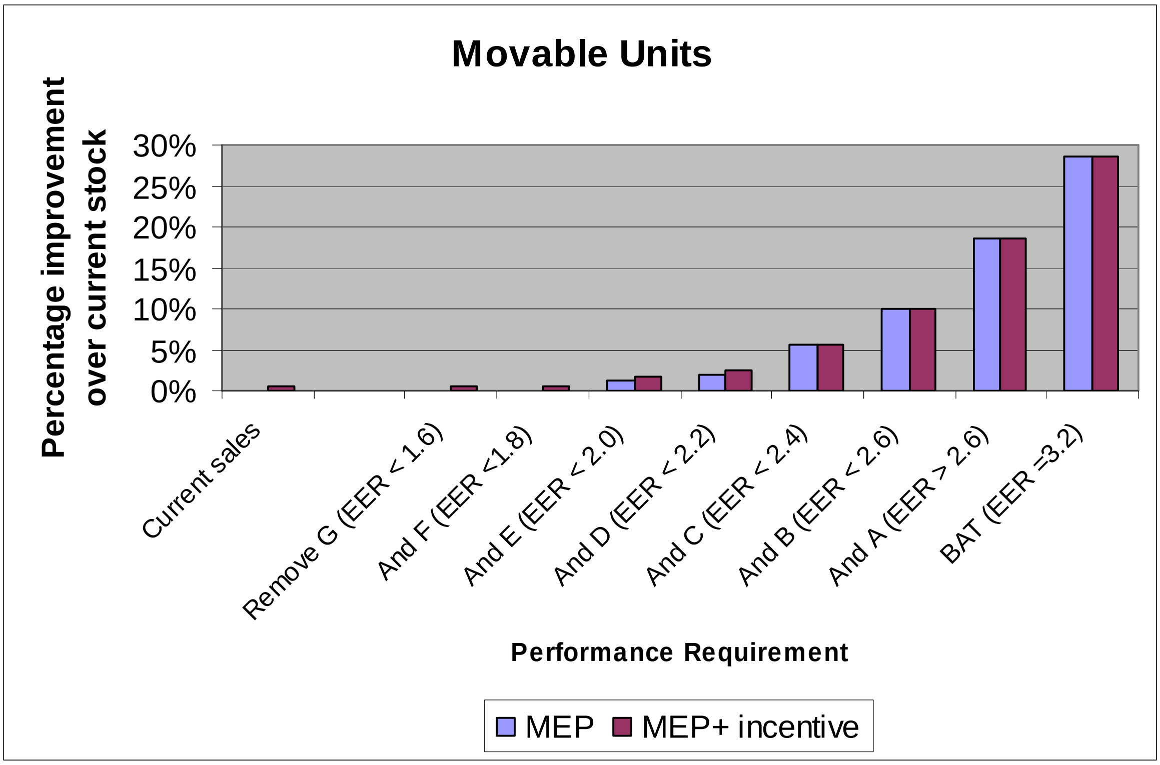


Figure 21:B3.2: Potential performance improvement compared to current aggregate performance value that would be achieved by progressive removal of poorer performing products from the market (Based on Attali and Bush (2009) modified from EuP Lot 10 (2008) base case for existing stock.)

The following performance levels options for MEPS and MEPS plus incentives were modelled:

[82] Aggregate efficiency refers to the harmonic mean of efficiencies weighted by product type. Whilst the aggregate efficiency is directly related to the indicative overall performance improvement, it is a simplified calculation in order to identify what MEPS levels to model. The modelling then takes this analysis further.

- Proposed MEPS (eliminate C and below 2 years after approval and B and below 4 years after approval) ***(Corresponding to Modelled Cases M1 and M4 (with financial incentives))***
- Eliminate C and below (Proposed MEPS 2 years after approval [lxxxvii]) Removes approximately 42% of products from the market. Indicative overall performance improvement 6% ***(Corresponding to Modelled Cases M2 and M5 (with financial incentives))***
- Eliminate B and below (Proposed MEPS 4 years after approval) Removes approximately 60% of products from the market. Indicative overall performance improvement 10% ***(Corresponding to Modelled Cases M3 and M6 (with financial incentives))***
- BAT. Indicative overall performance improvement 29% ***(Corresponding to modelled case M8)***

B3.6.4 Determining Energy Performance Levels for Room Air Conditioners < 12 kW Cooling

The distribution of for Room AC < 12 kWh by energy labelling class [lxxxviii] shows that there is now a large proportion of class A and better products (criteria for classes A+, A++, and A+++ have been extrapolated from the current system). The median product is class A and has an EER of 3.2. The highest EER listed is 5.7.[lxxxix] Attali and Bush show similar distributions for product numbers and sales of products in five European countries that represent major markets (Italy, France, Germany, UK, and Portugal). The figures reported by TopTen[xc] suggest that the relationship between number of models available and numbers sold varies widely between countries, but on average the number of models seems to be a fair proxy for number sold, slightly underestimating sales of the most efficient products and also underestimating sales of the less efficient ones. Figure B3.3 shows the combined (weighted) distribution for France, Germany, UK and Portugal. The reasons for excluding Italy from this part of the report are described in Section1.5.1.

This is very different from the analysis that was done for Lot 10, when there were significantly more lower-performance products and fewer high-performance ones. The reasons for the change can only be speculated on. Lot 10 showed that high-performance products were readily available outside Europe, so technical constraints were not an issue. It would seem that once these were made available, a significant number of purchasers were motivated to choose them. The introduction of energy labelling may have well been a factor but it is noticeable that the change is greatest in Italy which also provided incentives for the purchase of efficient equipment. Being a major market, Italy has an impact on the EU-wide distribution. Other factors relating to Italy include high electricity prices, a substantial market for room air conditioners for dwellings. A generally hot climate, and active promotion of energy-efficient products (including rebates for many products – but it is understood that this does not include air conditioners). As noted above, similar data for moveables would appear to be unavailable. The Lot 10 distribution was retained to represent the existing stock[83].

Based on detailed technical modelling of possible room air conditioner designs and a range of potential energy-efficiency design features, Lot 10 identified technical potential for an EER of up to 5.8, corresponding to a SEER of 6.5.[84] [xci](The proposed threshold for an A+++ rating is a SEER of 5.1). Topten reports a Chinese BAT SEER of 7.3 (Lot 10 task 7 suggests that a

[83] As a result the modelled base case includes improvements in overall efficiency. This is described in more detail in Section B3.

[84] This modelling included calibration against laboratory measurements for existing products. Details are given in the Preparatory Study report and the modelling approach is reported in academic papers see for example http://www.labothap.ulg.ac.be/cmsms/index.php?page=lt-news-n54

value of 7.0 is possible for a different metric "SEERon" which excludes energy consumption when the unit is not actively cooling[85].

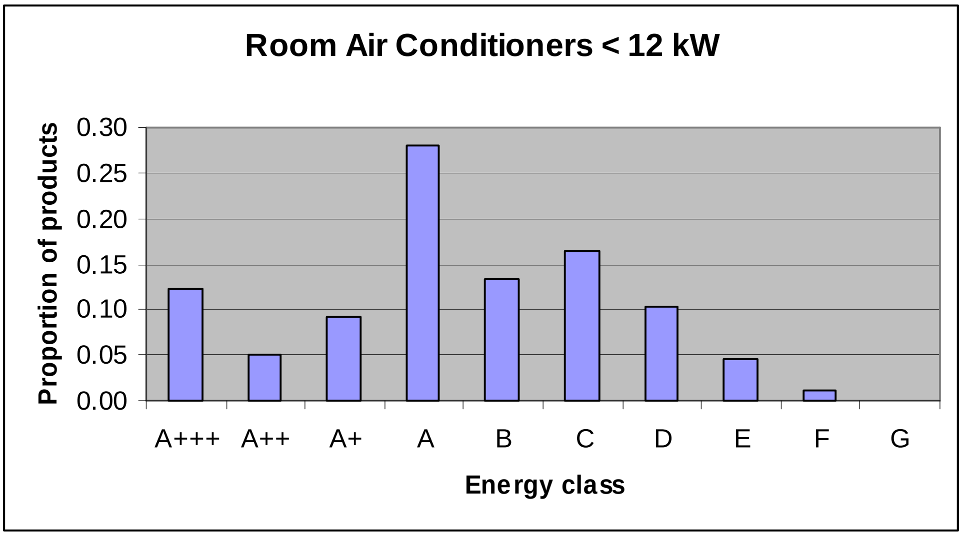


Figure 22: B3.3: Distribution of models by energy rating (From Attali and Bush (2009), excluding Italy[86]

Products with low efficiencies – and therefore impacted by MEPS - occur at all sizes. The products with the highest EERS tend to be at the smaller sizes, although this is not universal. The figures shown are for reversible products, which account for over 70% of the market.

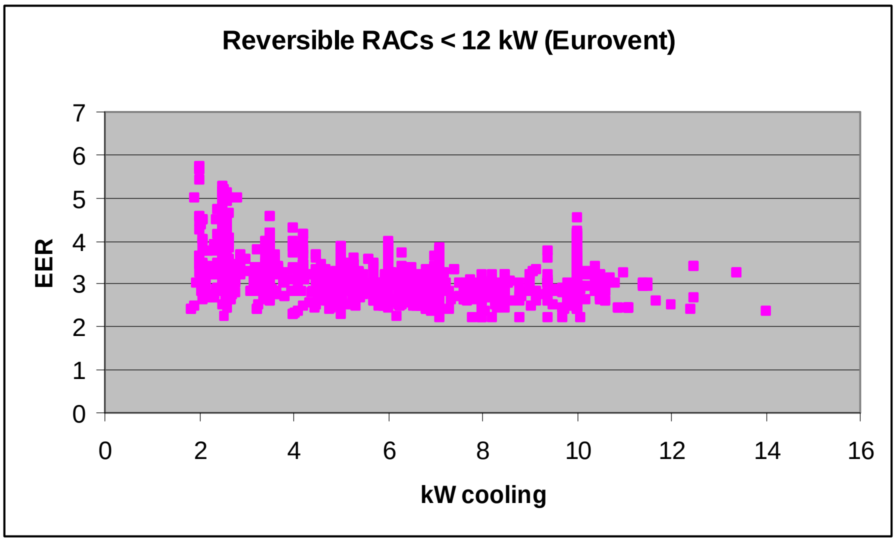


Figure 23: B3.4: Distribution of EER by cooling capacity in the current stock (From Eurovent database accessed February 2011 covering products on the market on the access date)

[85] Quoted EER and SEER figures are under standard test conditions unless otherwise stated. The difference between SEER and SEERon is important: the former includes energy use for displays and controls; the latter does not and is therefore inherently higher.

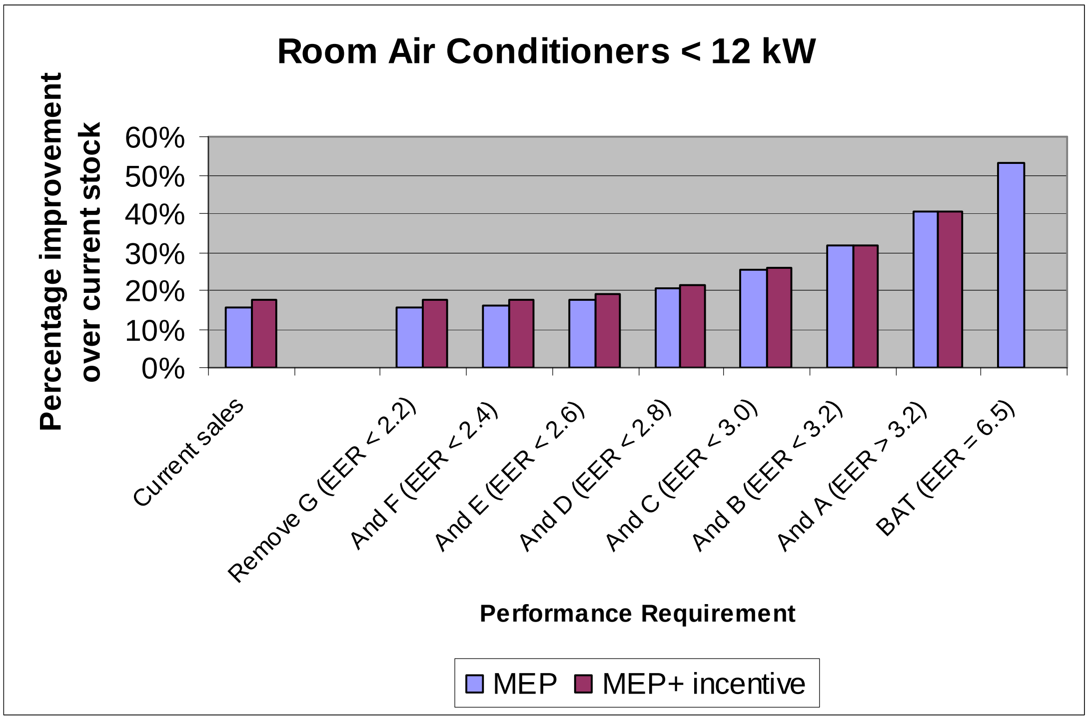
[86] see text in 1.5.1 for discussion of this)

There is no prima facia reason why a larger unit cannot be produced which is as efficient as a smaller unit. Alternatively it would be possible to install a number of more efficient smaller units rather a less efficient larger unit.

For the energy modelling SEER values were required, but the existing label classes and the reported market frequencies are in terms of EER. The proposed new label classes are in terms of SEER and the ratios of SEER to EER at the class boundaries suggest that the boundaries are consistent (as far as this is possible - there are likely to be some products that change classes). On this basis, for sales, the frequency distribution of EER can still be used to inform the performance improvement percentage points in the Modelled Cases. Furthermore, the SEER values for the equivalent new classes provide an estimate of the proportionate potential aggregate savings for different cases[87]. For the existing stock, the distribution of products that was found in the EuP Lot 10 study was used, and estimated SEER from EER assuming that all products have on/off control.

The change in the market mix since the Lot 10 analysis represents a significant improvement of aggregate energy efficiency for new sales of 16% beyond the current stock. Figure 24: B3.5 shows that the proposed EU MEPS[xcii] hardly increase this for the initial level proposed and only by a further 4% for the second stage. Products with performance well in excess of those required for A-class labels are readily available for the most commonly sold sizes and will be identifiable under the changes to labelling which will come into force in 2013. More demanding MEPS which would increase potential savings to more than 30% compared to the existing stock are therefore technically feasible – and indeed applied in other countries (as EER limits). Incentives are unlikely to have a significant additional impact, especially when MEPS are in place, unless they have a substantially greater effect than that assumed[88].

Figure B3.5 shows that progressively removing the worst performing units from the market will not have a significant effect until units with a performance level of D and below are removed.



87 This ignores differences in national markets that are included in the full modelling.

88 With relatively demanding MEPs, the market becomes “bunched” and the scope for incentives to encourage purchasers to move from low efficiency to high efficiency models is therefore limited.

Figure 24: B3.5: The Effect of removing units of different performance levels from the market on the aggregated performance of the current stock, (excluding Italy) for current sales; from EuP Lot 10 for current stock and BAT (consistent with overseas markets). (Attali and Bush 2009)

The following options were modelled for MEPS and MEPS plus incentives:

- Proposed MEPS (eliminate C and below 2 years after approval and B and below 4 years after approval) *(Corresponding to Modelled Cases RAC1 and RAC5 (with financial incentives)*
- Eliminate C and below (Approximately the proposed MEPS 4 years after approval the actual value falls part way into class C) Removes approximately 37% of products from the market. Indicative overall performance improvement 25% *(Corresponding to Modelled Cases RAC2 and RAC6 (with financial incentives)*
- Eliminate B and below Removes approximately 52% of products from the market Indicative overall performance improvement 32%. *(Corresponding to Modelled Cases RAC3 and RAC7 (with financial incentives)*
- Eliminate A and below Removes approximately 84% of products from the market. Indicative overall performance improvement 41% *(Corresponding to Modelled Cases RAC4 and RAC8 (with financial incentives)*
- BAT. Indicative overall performance improvement 53% *(Corresponding to modelled case RAC9)*

Accurate price information for Europe for products of different efficiency is not available in the public domain (discounting from "price lists" is common) but information does exist for Japan. Figure 25: B3.6 below shows the relationship between price and EER in Japan in 2002[xciii. 89]. This relates to products at the upper end of the efficiency range of the European market. At this level of performance, an increase in EER of 1% is associated with a cost increase of about 5%. However, private communication with manufacturers suggests that perhaps 25% of the extra cost is associated with other features provided with "premium" products. Koizumi[xciv] shows similar results. Data from the Chinese market illustrates that at lower EER values there is a significant, but somewhat lower price premium for higher efficiency[90] [91].

[89] APF is a Japanese energy efficiency metric for reversible air conditioners.

[90] Superimposed on this there are variations of price with time. US studies http://www1.eere.energy.gov/buildings/appliance_standards/residential/pdfs/aham2_dfr_app-08j_learning_2011-04-13.pdf show a steady decline in real prices.

[91] A consequence of this is that the optimal life-cycle cost depends – amongst other factors – on the "Equivalent Full Load Hours". This varies with climate (but not simply with severity) and type of space served.

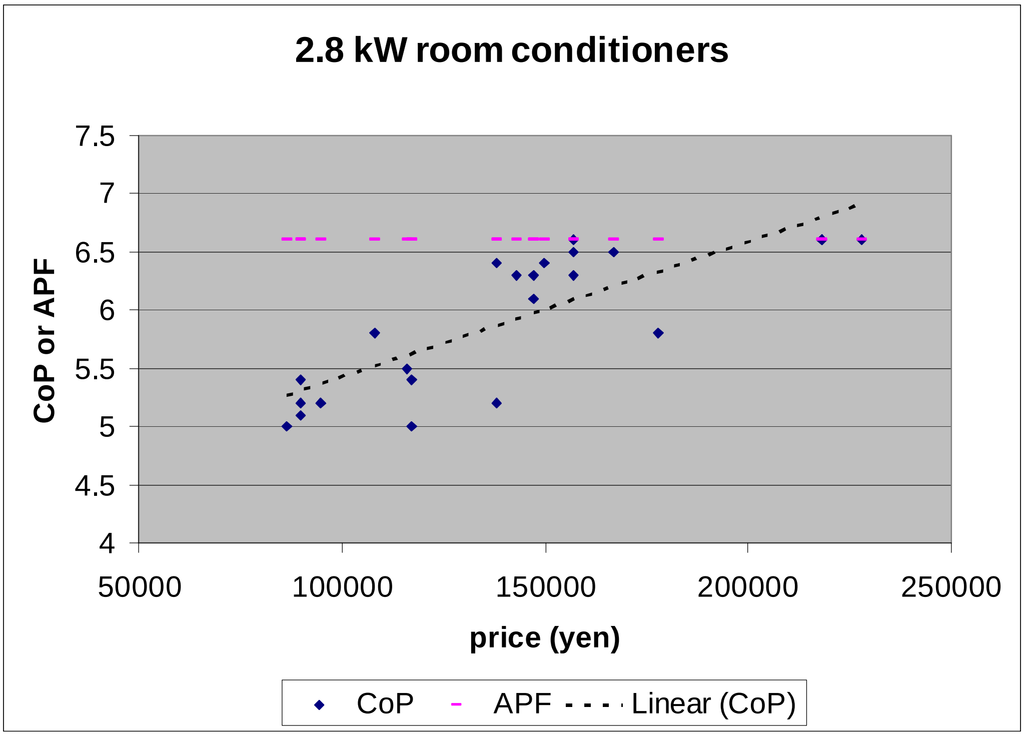


Figure 25: B3.6: The relationship between prices and efficiency for room conditioners on the Japanese Market In-country research (2002). see also Koizumi (2006)

There is therefore evidence that price is related to efficiency. A similar conclusion (and a suggestion that the performance levels are not cost-effective) was reached by Kimura [xcv]

B3.6.5 Determining Energy Performance Levels for Split Systems, Multi-Split Systems and Variable Refrigerant Flow > 12 kW

Split systems, multi-split systems and variable refrigerant flow > 12kW make up something of a portmanteau category that covers larger DX systems (except rooftops). For large single and multi-split products, Eurovent data[92] (see Figure 26: B3.7) shows that the most efficient products tend to be at the smaller ratings, but the less efficient ones are spread across the size range.

[92] Analysis of data from Eurovent database Feb 2010 (Reversible single and multi-split products 12 kW to 45 kW)

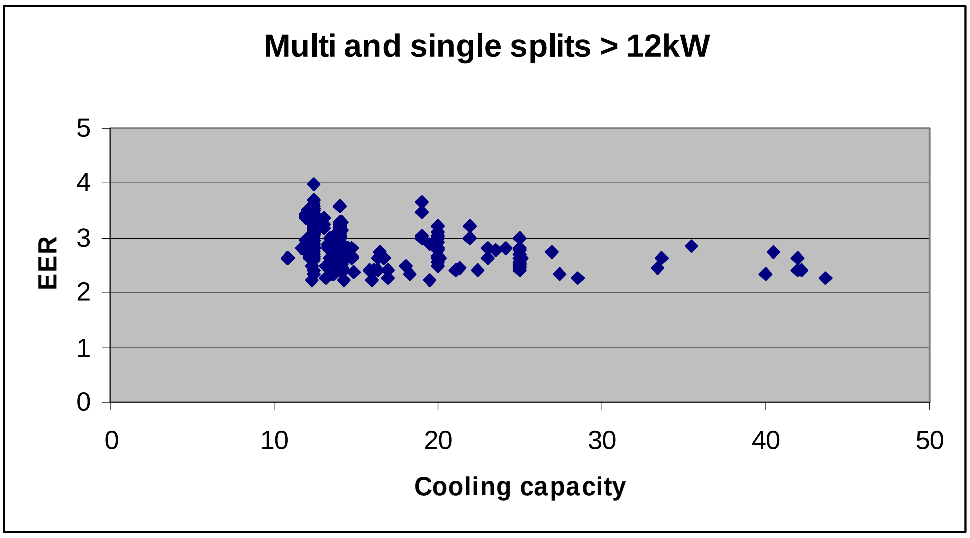


Figure 26: B3.7: Distribution of EER by cooling capacity in the current stock. Source: Eurovent database accessed February 2011 covering products on the market on the access date

There are no voluntary or mandatory European energy classification schemes for these products. In order to illustrate the impact of possible MEPS and related policies, products were divided into groups of different EER using the distribution of products in the Eurovent directory. EER was used as this is the certified efficiency metric. For current sales, each group has been associated with a SEER value, estimated using SEER/EER multiplier values from German standard DIN 18599-7 and assuming that the proportion of products with variable-speed compressors varies with label class – being universal in the highest performance group , absent in the worst and proportionately present in the remainder. On this basis, VRF[93] systems fall into the second-highest group[94]. Their importance has been estimated from BRE estimates of the sales levels of the different products. As can be seen, VRF systems then form the largest single component of the combined class. The resulting distribution for current sales is shown in Figure 27:B3.8.

In the absence of data on the frequency distribution by sales, the distribution of products was used as a proxy.

The aggregate efficiency of the existing stock was estimated assuming that all products have on/off control (rather than the mixture of variable-speed and on/off control described above for current sales).

[93] Variable refrigerant flow systems – described in Section B1

[94] There is very little information available on the variations of efficiency between VRF systems. In addition to inter-model differences, there are differences between individual systems as each system is built up from a combination of outdoor and indoor units that best suits the application. Therefore the relationship between nominal efficiencies and those achieved in practice for this type of product is particularly uncertain.

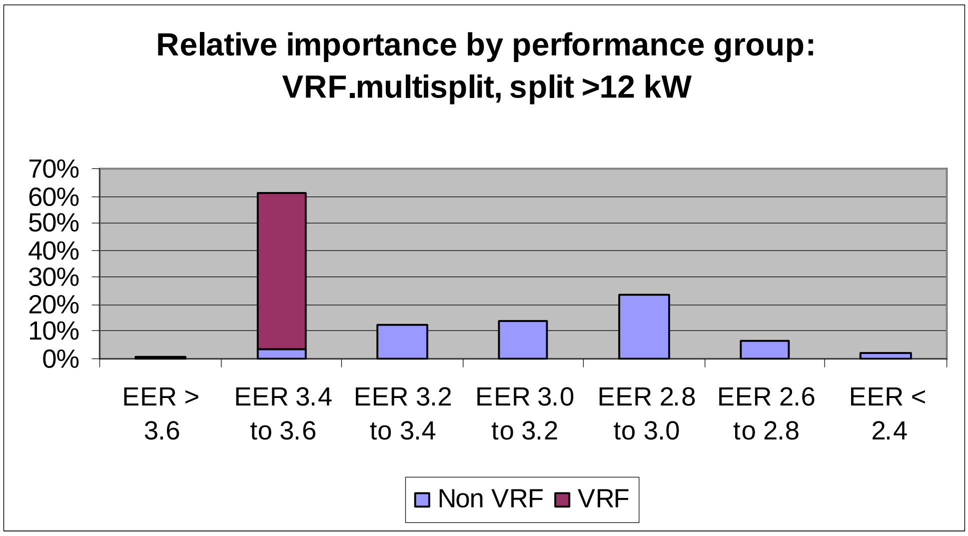


Figure 27:B3.8: Distribution of models by energy rating in the current sales. Source: Eurovent database February 2011 covering products on the market on the access date and processed as described in the text

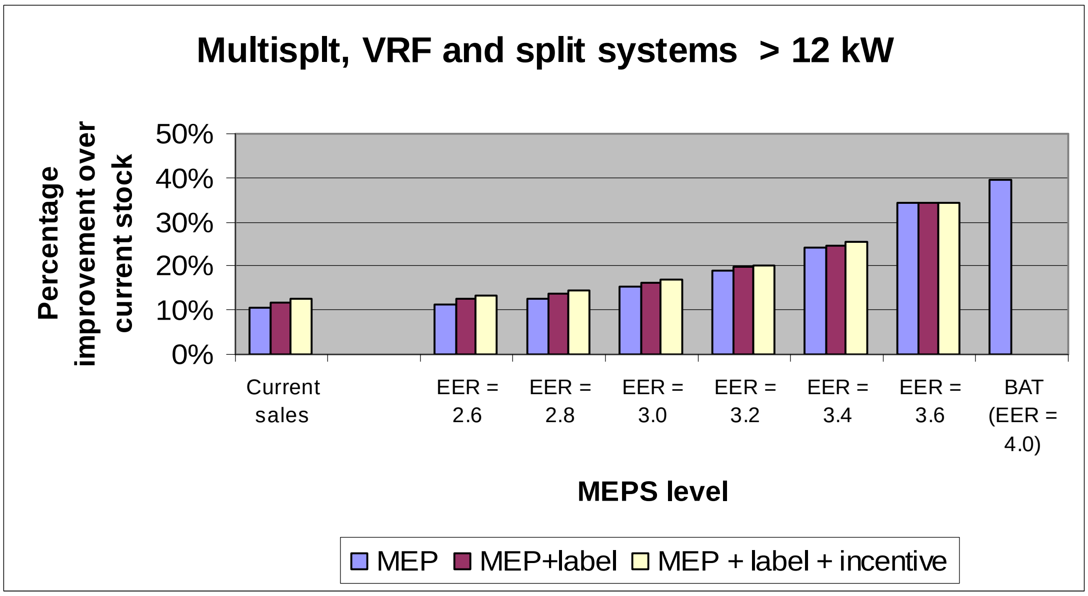


Figure 28: B3.9: The effect of removing units of different performance levels from the market. Source: Eurovent database February 2011 covering products on the market on the access date and processed as described in the text

Because of the large influence of VRF systems of reportedly high performance, there appears to be significant scope for improving aggregate efficiency in this class. However, this disguises the fact that large single split systems and multisplit and VRF systems are not necessarily interchangeable options. In the modelling VRF system were handled separately.

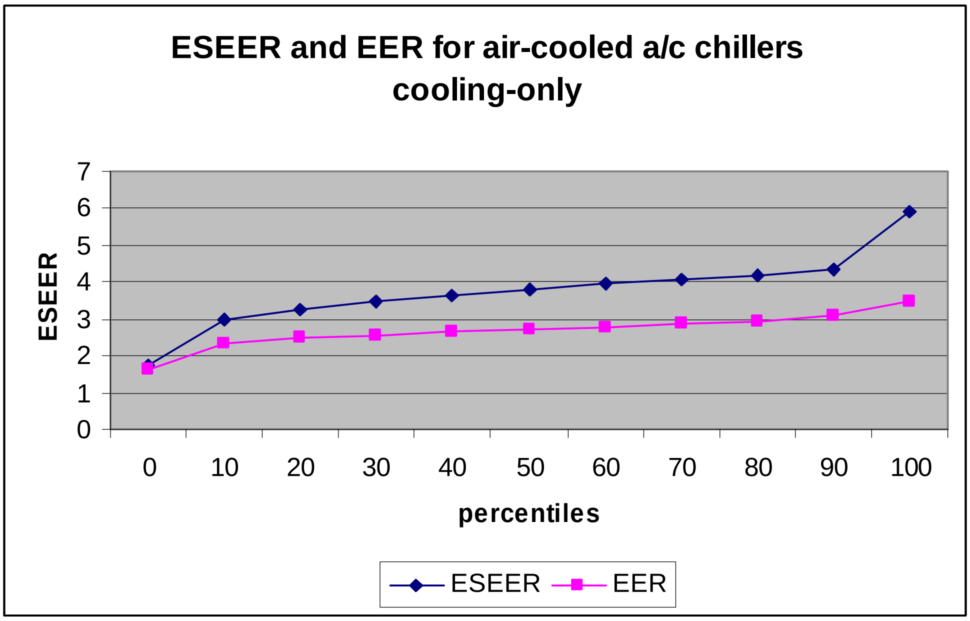
The following options were modelled for labels *(Corresponding to modelling case C1)*, labels plus financial incentives *(Corresponding to modelling case C1)*, MEPS plus labels, and MEPS plus labels and incentives where MEPS were set at the following levels:

- Eliminate the three groups of lowest performance and below. Removes approximately 32% of products from the market. Indicative overall performance improvement 15% *(Corresponding to modelling cases C2 and C6 (with financial incentives))*
- Eliminate all except the highest performance group. Removes approximately 40% of products from the market. Indicative overall saving/performance improvement 26% *(Corresponding to modelling cases C3 and C7 (with financial incentives))*
- Eliminate all except the highest performance group. Removes approximately 60% of products from the market. Indicative overall performance improvement 39% *(Corresponding to modelling cases C4 and C8 (with financial incentives))*
- BAT. Indicative overall performance improvement 40% *(Corresponding to modelling case C9)*

B3.6.6 Determining Energy Performance Levels for Packaged Chillers

Most (77%[95]) packaged chillers sold in Europe are air-cooled, and the analysis below (and the modelling) is based on this case. Water-cooled chillers (and those with a remote condenser) have nominally higher efficiencies but these figures exclude the energy used for heat rejection[96].

The Eurovent database[97] provides both EER and ESEER[98] values. Eurovent Certification operates a voluntary (but mandatory for participants) energy classification. Analysis of the frequency of EER and ESEER values (by number of models certified by Eurovent) shows relatively modest variations – see Figure 29: B3.10. Between the 10 and 90 percentiles, EER varies by 31%, ESEER shows a greater variation of 41% and are considerably higher than the market average value of 3.9. The use of ESEER therefore offers more discrimination as well as being more logically satisfactory. Most products are in the central classes B, C and D where the performance range is fairly limited. The highest values of ESEER (5.9) relate to a small number of products sharing the same basic technology[99].



[95] BRE analysis of market research data 2010

[96] The labelling and MEPs data in section B2 illustrate relative figures. Regulations clearly have to cover all situations.

[97] Analysis of data from Eurovent database Feb 2010 (packaged chillers, air-cooled, not reversible)

[98] ESEER is a European standardised measure of SEER for chillers.

[99] Notably oil-free compressors using magnetic bearings

Figure 29: B3.10: Distribution of frequencies by EER and ESEER in the current stock. Source: Eurovent database February 2011 covering products on the market on the access date

Figure 30: B3.11 shows that there is no evident systematic variation of ESEER with cooling capacity, although the least efficient products are more common at the smaller sizes (which may lead to some overestimation of the impact of the less demanding MEP levels).

Detailed information on price variation with SEER is not available: typically price per kW cooling is lower for larger equipment. From information provided by private industry sources, it is estimated that the (undiscounted) payback time for the BAT products compared to the median product is in the range 4 to 11 years[100, 101]. At a discount rate of 5% per annum these become 5 and 16 years respectively. From analysis of sales and replacement figures, the average life of existing chillers is typically around 20 years. The BAT products have a sufficiently long presence in the market to have overcome any initial reliability issues, but long-term reliability is, of course, unproven.

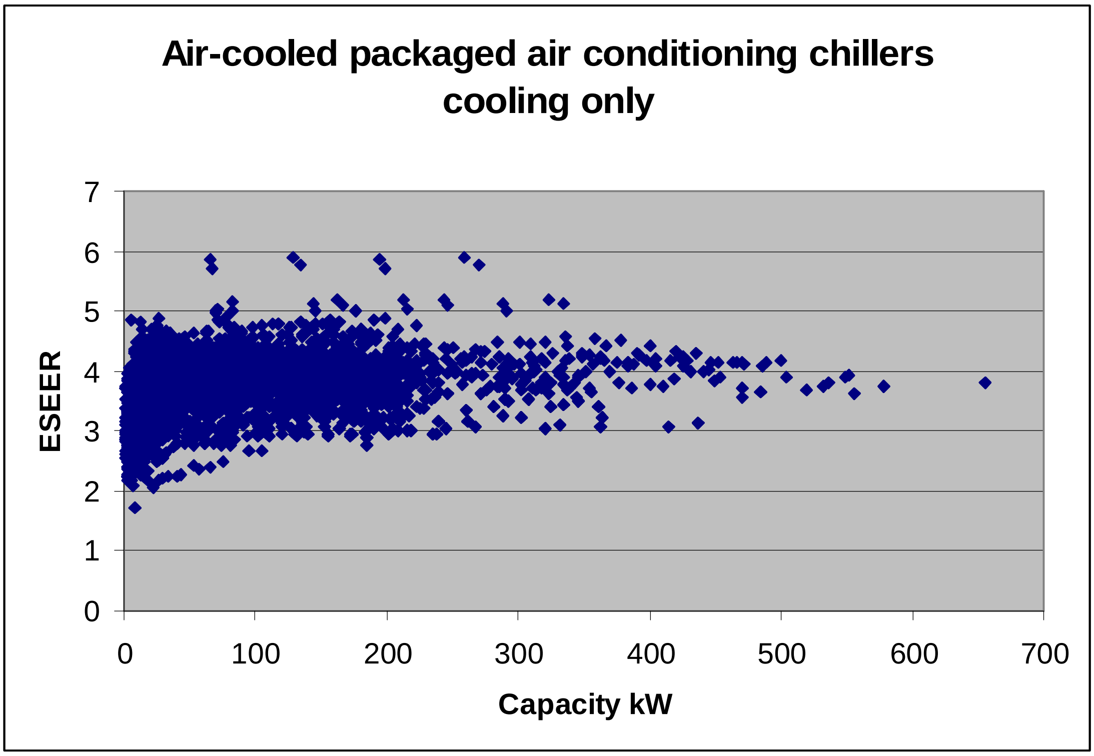


Figure 30: B3.11: The variation in performance for chillers of different sizes currently certified. Source: Eurovent database, February 2011 covering products on the market on the access date

Comparing the EER distribution with that for products certified in 2002 shows that the average efficiency has improved. The aggregate performance of the existing stock is based on the earlier figures.

[100] Payback depends on the annual load factor, expressed here as Equivalent Full load Hours. This depends on the relative values of design outdoor temperature duration and severity of the cooling season. It is not simply a matter of hot climates generating shorter paybacks.

[101] This comparison with reported "typical" price and median performance does not mean that these products will always be more cost-effective than less expensive products of lesser – but still good – performance.

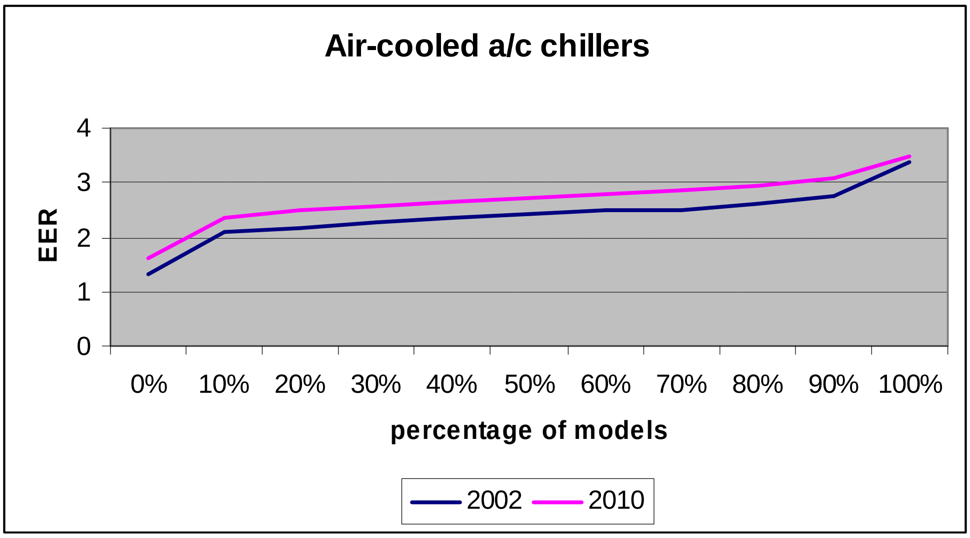


Figure 31: B3.12: Comparison of the distribution of chiller performance in 2002 and 2011. Source: Eurovent database, February 2011 covering products on the market on the access date (and historical data for 1996)

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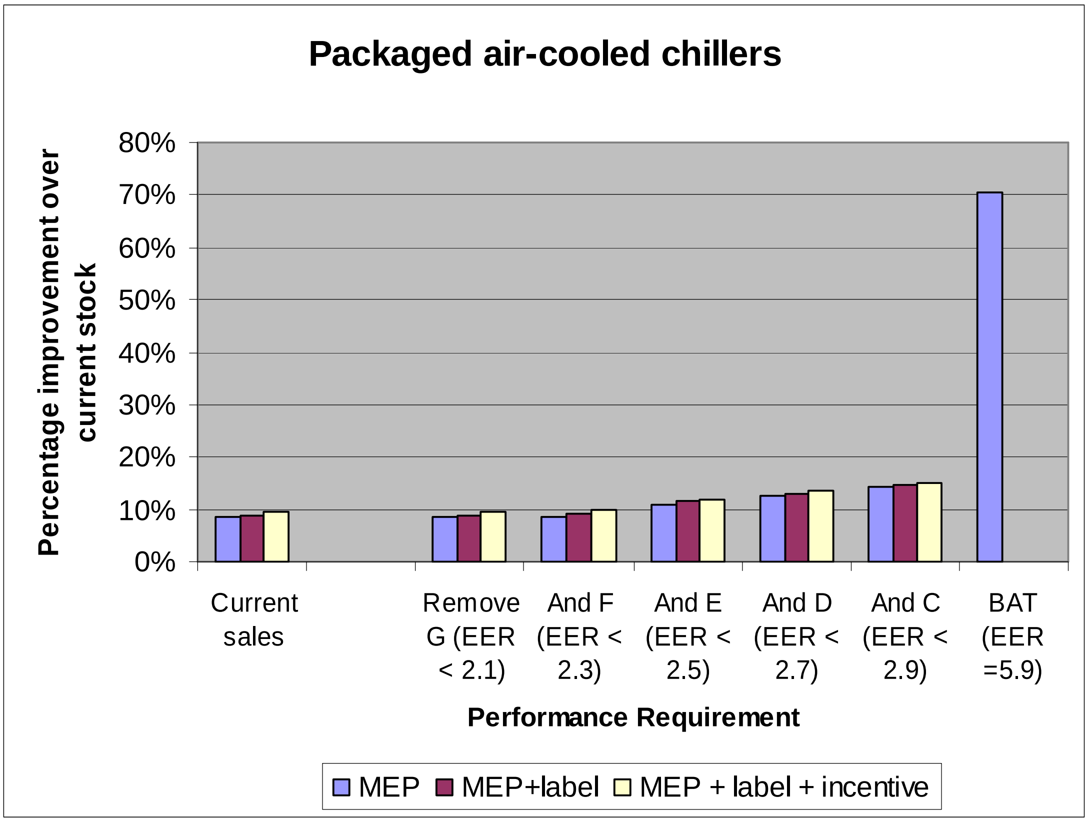

Figure 32: B3.13: The effect of removing units of different performance levels from the market

The distribution of chillers of different performance was based on the Eurovent Certification voluntary labelling. This was not intended to imply recommendation (or otherwise) of this particular scheme.

As can be seen in Figure 32: B3.13, MEPS have relatively little impact, improving aggregate efficiency of sales by no more than 10% of that of the existing stock, unless the requirement level is set to eliminate all but A-rated products. This would remove about 80% of products from the market and is slightly more demanding than the recommendations of the latest (2010) version of American standard ASHRAE 90.1. This relatively weak impact is a reflection of the concentration of models in the B, C and D classes, within an EER range of 2.5 to 3.1. As already noted, there is a small number of products on the market of considerably higher seasonal performance indicating that there is technical potential to substantially improve performance. Those countries in Europe that have set requirements have done so at the lower end of the range of product performance, reflecting their status as minimum "backstop" requirements [xcvi, xcvii]..

The following options were modelled for labels *(Corresponding to modelling case C1)*, labels plus financial incentives *(Corresponding to modelling case C1)*, MEPS plus labels, and MEPS plus labels and incentives where MEPS were set at the following levels:

- Eliminate E and below (roughly equivalent to existing "back-stop" values where these exist). Removes approximately 17% of products from the market. Indicative overall performance improvement 11% *(Corresponding to modelling cases C2 and C6 (with financial incentives))*
- Eliminate C and below removes approximately 90% of products from the market. Indicative overall performance improvement 20% *(Corresponding to modelling cases C3 and C7 (with financial incentives))*
- Eliminate all except the highest performance group removes approximately 95% of products from the market. Indicative overall performance improvement 40% *(Corresponding to modelling cases C4 and C8 (with financial incentives))*
- BAT. Indicative overall performance improvement 71% *(Corresponding to modelling case C9)*

B3.6.7 Determining Energy Performance Levels for Rooftop Units

In Europe rooftop units are predominantly used in the retail sector and to a lesser extent (and largely in Italy) in industry. In the US they are more widely used and have been described as the "workhorses of commercial air conditioning"[xcviii, xcix]. Performance is reported as net EER – i.e., including the energy used by the fans, etc. (which are an integral part of the unit). Fan energy consumption was therefore included within the EER value. Published European values for SEER could not be identified but a US study[c] compared the EER and IPLV (the US equivalent of ESEER) values for several products. Generally they were similar, though some models have slightly higher IPLVs[102] than EERs and others have slightly lower values. EER was, therefore, used as a proxy for SEER. The most efficient product currently available in Europe has an EER of 3.4 – slightly better than the 2010 US MEP. The American study referred to above, included a design study for an efficient rooftop unit, suggesting that a seasonal value of 4.2 was possible with current technology. (This design had an EER of 3.2 but included features that improved part-load performance.) In 2010 the US DOE announced a challenge to manufacturers to put such products into production with an ambitious seasonal performance target of 5.13. This is the BAT case modelled, although it is not yet available on the market in Europe or elsewhere[ci].

Most models in the Eurovent database[103] are in (voluntary) energy classes B and C covering a range of EERs from 2.6 to 3.0. The following analysis groups products according to their Eurovent Certification energy rating. This does not imply a recommendation (or otherwise) for the use of this labelling scheme).

[102] IPLV is a US standardised seasonal efficiency metric.
[103] Analysis of data from Eurovent database Feb 2010 (rooftop units).

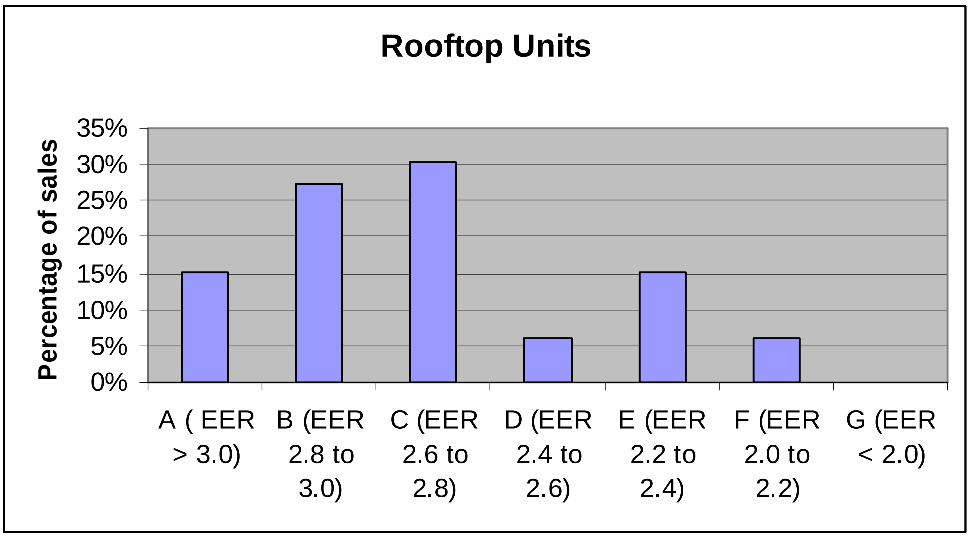

Figure 33: B3.14: Distribution of energy performance classes for roof tops. Source: Eurovent database, February 2011 covering products on the market on the access date

Figure 34: B3.15 shows that there does not appear to be a systematic variation of EER with product size.

In the absence of sales figures, the distribution of products was used as a proxy for the distribution of sales. The aggregate efficiency of the existing stock was taken to be the same as that for sales. SEER values were estimated from EER values using factors from DIN 18599-7 with the assumption that control is on/off.

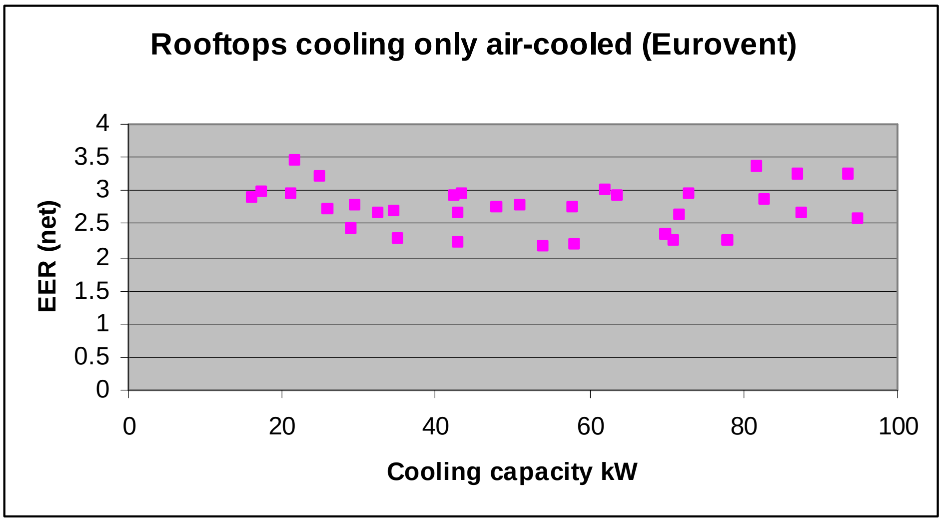

Figure 34: B3.15: Cooling capacity of rooftops vs energy performance. Source: Eurovent database, February 2011 covering products on the market on the access date

Figure 35: B3.16 shows that MEPS have a rather small impact until they reach levels roughly equivalent to current US requirements, eliminating (voluntary) labels C to F[104]. At this point potential aggregate savings are 6%. Because of the apparent importance of class C products, measures to move purchasers to more efficient products than this have a more marked effect. More demanding MEPS have the potential to increase the savings to 10%. The American design study and challenge suggests that there is significant technical potential to develop

[104] Previous MEPS was less demanding.

products of better performance than are currently seen in Europe perhaps halving consumption.

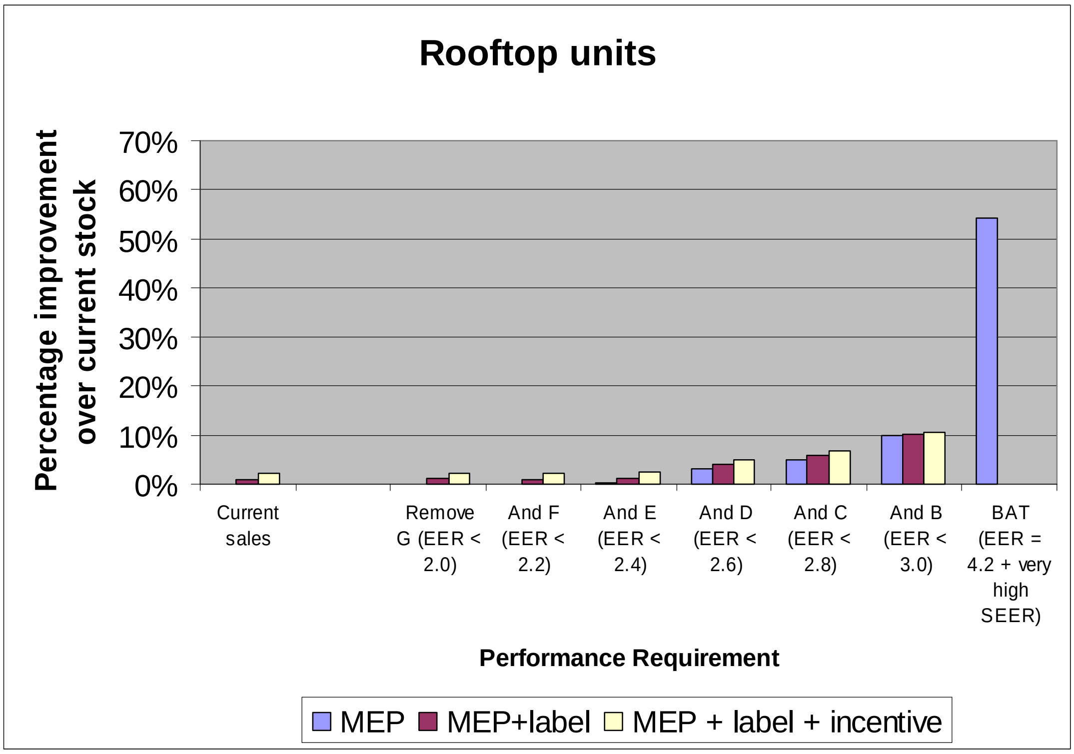

Figure 35: B3.16. Effect of removing units of different performance levels from the market

MEPs that are less demanding than removing class B have only a limited impact as shown in Figure 35: B3.16.

The following options were modelled for labels *(Corresponding to modelling case C1)*, labels plus financial incentives *(Corresponding to modelling case C1)*, MEPS plus labels, and MEPS plus labels and incentives where MEPS were set at the following levels:

- Eliminate E and below removes approximately 21% of products from the market. Indicative overall performance improvement < 1% *(Corresponding to modelling cases C2 and C6 (with financial incentives))*
- Eliminate C and below removes approximately 85% of products from the market. Indicative overall performance improvement 10% *(Corresponding to modelling cases C3 and C7 (with financial incentives))*
- Eliminate all except the highest performance group removes approximately 95% of products from the market. Indicative overall performance improvement 40% *(Corresponding to modelling cases C4 and C8 (with financial incentives))*
- BAT (US challenge) Indicative overall performance improvement 54% *(Corresponding to modelling case C9)*

B3.6.8 Energy Performance Levels for Distribution Components of System

***Determining Energy Performance* Levels: Fan Coil Units**

The metric used for these products was fan kW/cooling kW. Analysis of the Eurovent data shows that this parameter takes a wide range of values, though most products fall into a relatively narrow band. There is more variation in smaller sizes. Some of the variation may well result from products designed for different mounting and applications, so the analysis below should not be considered definitive.

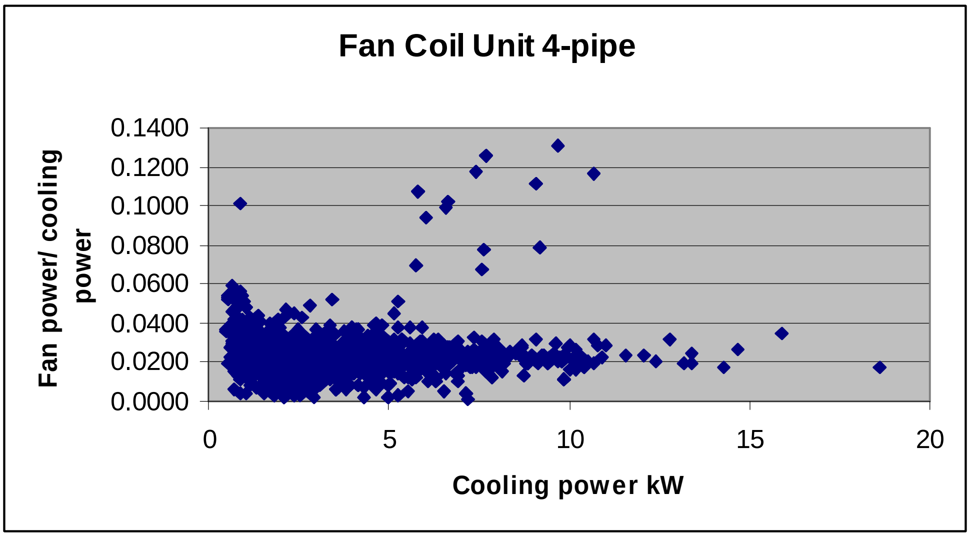

Figure 36: B3.17: Energy performance of terminal units vs cooling power. Source: Eurovent database, February 2011 covering products on the market on the access date

There are no voluntary or mandatory European energy labelling schemes for these products. In order to illustrate the impact of possible MEPS and related policies, the performance range of this metric in the Eurovent database was divided into groups of similar performance. Figure 37**:B3.18** shows that, while there are a few products of low efficiency (by this metric) most fall into a fairly narrow subset of the range.

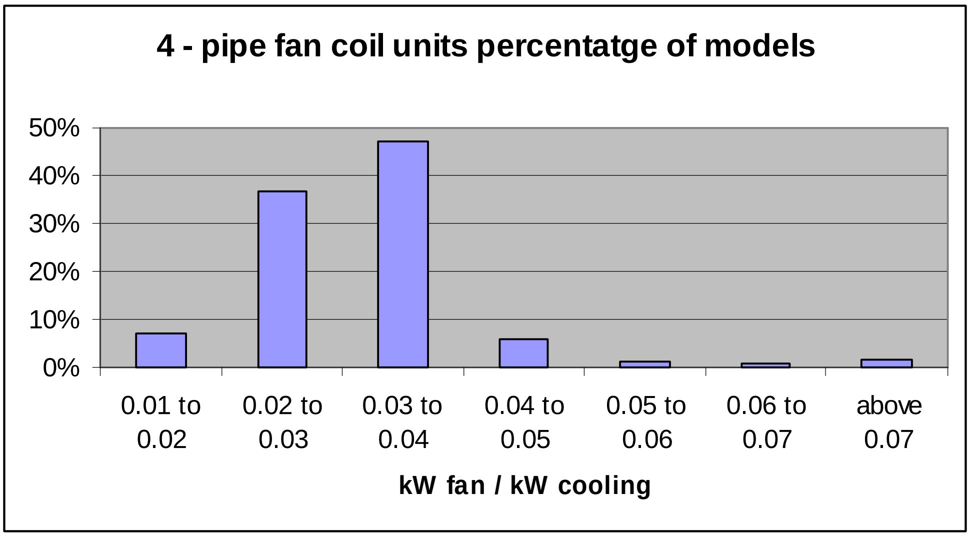

Figure 37:B3.18: Notional distribution of energy performance classes for terminals. Source: Eurovent database, February 2011 covering products on the market on the access date

Because of this distribution, MEPS have little impact until they start to cut into the most populated part of the distribution.

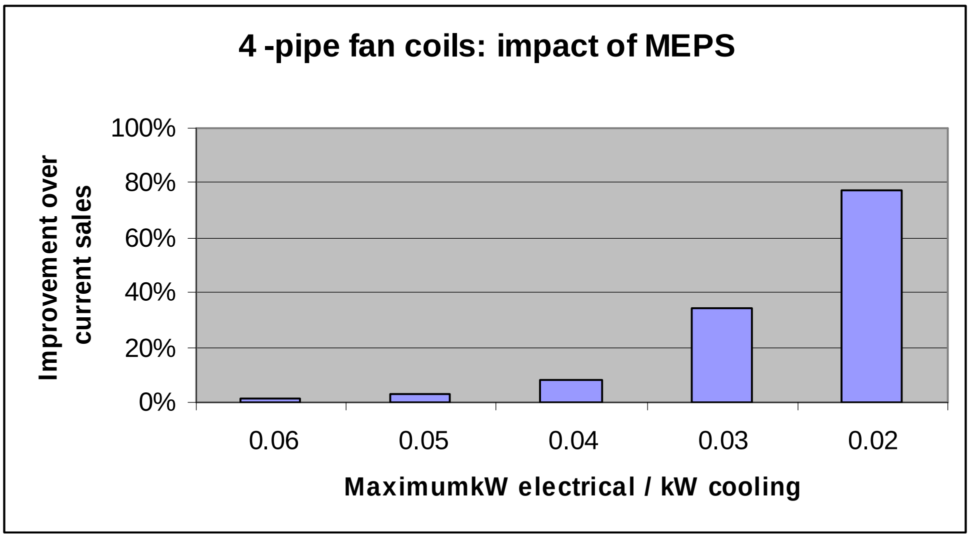

Figure 38: B3.19: Effect of removing units of different performance levels from the market. Source: Eurovent database, February 2011 covering products on the market on the access date

The following options were modelled for MEPS plus labels, and MEPS plus labels and incentives, where MEPS were set at the following levels:

- Eliminate the lowest efficiency groups *(Corresponding to modelling case C15 and C16 (with financial incentives)*
- Eliminate all but the highest efficiency group (BAT) *(Corresponding to modelling case C17)*

Determining Energy Performance Levels: Specific Fan Power
Specific fan power is an attribute of a fan or air handling unit, but is actually a system performance metric, since it is determined both by the fan and air handling unit (and filters and heat exchanger coils etc.) and by the sizing and design of the ductwork system to which it is attached.

European standard EN 13141-6:2004[cii] defines classes of specific fan power. Railio and Makinen[ciii] suggest that common regulatory values are between 2 and 2.5 kW/m^{3}s, which represents current state of the art. They note that figures as high as 5 to 10 were normal practice until relatively recently. They suggest that levels in the range 1 to 1.5 are “technically possible but not economically feasible”. Please see summary in Table B3.5.

	Market Aggregate SFP	**Comments**
Current sales	3.00	In countries without SFP regulation. May be higher
Universal introduction of SFP requirements	2.25	Typical of countries that regulate SFP
BAT	1.25	Has implications for building design and planning which will impose practical constraints to widespread use.

Table 39: B3.5: Specific Fan Power in central systems. Source: From Railio and Makinen. Current sales BRE estimate

Options were modelled for labelling *(Corresponding to modelling case C10)*, labelling plus financial incentives *(Corresponding to modelling case C11)* and MEPS plus labelling and MEPS plus labelling and financial incentives for the following MEPS:

- all countries have regulations equivalent to those that are typical of existing regulations, where these exist *(Corresponding to modelling cases C12 and C13 (with financial incentives))*
- BAT *(Corresponding to modelling case C14)*

Pump Energy Use

The British Pump Manufacturers Association 30% to 50% energy savings[105] from the use of variable-speed pumps without specifying the application.

Options were modelled for MEPS and MEPS plus Labelling for the following MEPS:

- With an energy savings of 20% compared to current performance *(Corresponding to modelling cases C18 and C19 (with financial incentives))*
- With an energy savings of 40% compared to current performance (BAT) *(Corresponding to modelling case C20)*

B3.7 System Level Labelling and MEPS

The previous section considered energy performance levels for product/component level for MEPS, labelling and incentives. This section considers how these performance improvements have been determined at the system level.

B3.7.1 Energy Performance at the Overall System Level

Quantified information on system energy efficiency is limited to calculated values, and the distribution of system types and qualities is almost unknown. The Modelled Cases have therefore been constructed as different mixtures of component performance requirements plus changes to the assumed distribution of system types. These illustrate the range of impacts which are possible, but further data collection and analysis would be needed to analyse specific policy options. The detailed definitions of the scope for system switching depend on initial modelling to estimate which systems have the lowest energy consumptions in different climates and applications, and therefore cannot be fully defined a priori.

In order to assess the energy savings potential from system level MEPS plus labelling the following cases were modelled for each sub-system:

- System level labelling: This was modelled using the energy performance determined for mandatory labelling of chillers and AHUs, plus light/moderate MEPS for pumps and terminals**.** *(Corresponding to Modelled case C25)*

- System BAT, which would relate to a system that comprises BAT components for each system type. *(Corresponding to Modelled case C26)*

The typical and BAT savings for switching between system sub-types and the major system categories were quantified separately.

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[105] See for example British Pump Manufacturers Association http://www.bpma.org.uk/page.asp?node=123&sec=Carry_out_an_energy_audit

Other system performance options modelled were reduced fresh air flow rates and MEPS for AHU and duct leakage.
If system flow rates were to reflect a switch within a building from “some smoking” to “no smoking”” in the spaces served, the fresh air requirement would be halved. This results in a halving of fan energy. (In theory there should be bigger potential savings in existing systems, provided that air distribution and system balancing can be maintained. This is because, for a given ductwork system, the fan energy falls very quickly with lower velocities. For new systems it was assumed that duct sizes would be reduced to maintain the same SFP).

In addition to this saving of fan power, there is a reduction in cooling demand at times when the supply air is cooled. It is common practice to reduce the fresh air supply temperature to 10°C below room temperature. Within the model the cooling energy was reduced by reducing the equivalent full-load hours by 40 hours, noting that this may be an overestimate where outside air can be used to provide “free cooling”.

The case modelled was for all countries to reduce fresh air rates by 50%. *(Corresponding to Modelled case C23)*

B3.7.3 Energy Performance Levels for Duct and AHU Leakage

European standards define leakage classes for ductwork and air handling units[civ, cv] and some, mainly Scandinavian, countries have a history of regulating leakage rates. Several studies have examined the issues recently[cvi, cvii, cviii, cix, cx] and these were used as a basis for setting a base case value and two MEPS levels. The market aggregate percent leakage rates used in the model for the base case, one MEPS level, and BAT are presented in Table B3.26. In addition to energy savings attributable to the cooling function, the detailed modelling also reports the associated reductions of energy consumption by air handling units.

Case	Market Aggregate leakage in %	Comments
Current sales and stock	20%	In countries without duct leakage regulation. May be higher
Typical of countries that have established leakage regulation	5%	Typical of countries with regulation
BAT	3%	

Table 40: B3.6: Leakage Rates for AHU and ductwork Leakage rates from EN1886 and EN 12237

The cases modelled were:

- All countries have regulations equivalent to those that are typical of existing regulations, where these exist. *(Corresponding to Modelled case C21)*
- All countries have BAT levels. *(Corresponding to Modelled case C22)*

B3.8 Building Level Energy Performance Improvements

This section considers building level options for instruments. These relate to reducing the cooling load through building envelope measures and demand reduction.

B3.8.1 Reduced Load from Building Envelope Measures/Demand Reduction

The information sources used to inform the savings potential used in the modelling are outlined below and in the References.

The KeepCool project [cxi] assessed the potential for reducing cooling demand in existing offices across Europe from the following measures:

- Reduced solar gain
- Enhanced ventilation
- Improved equipment and lighting efficiency
- Reflective surfaces and added insulation
- Windows

The KeepCool study assessed the potential by simulating example buildings in five climate zones and attributing each country to one of the zones. A more detailed explanation of the results from this and related projects is provided in Appendix B2, but Figure 39: B3. provides a summary of the results which form the basis of the estimates of the potential aggregate load reductions in this current study.

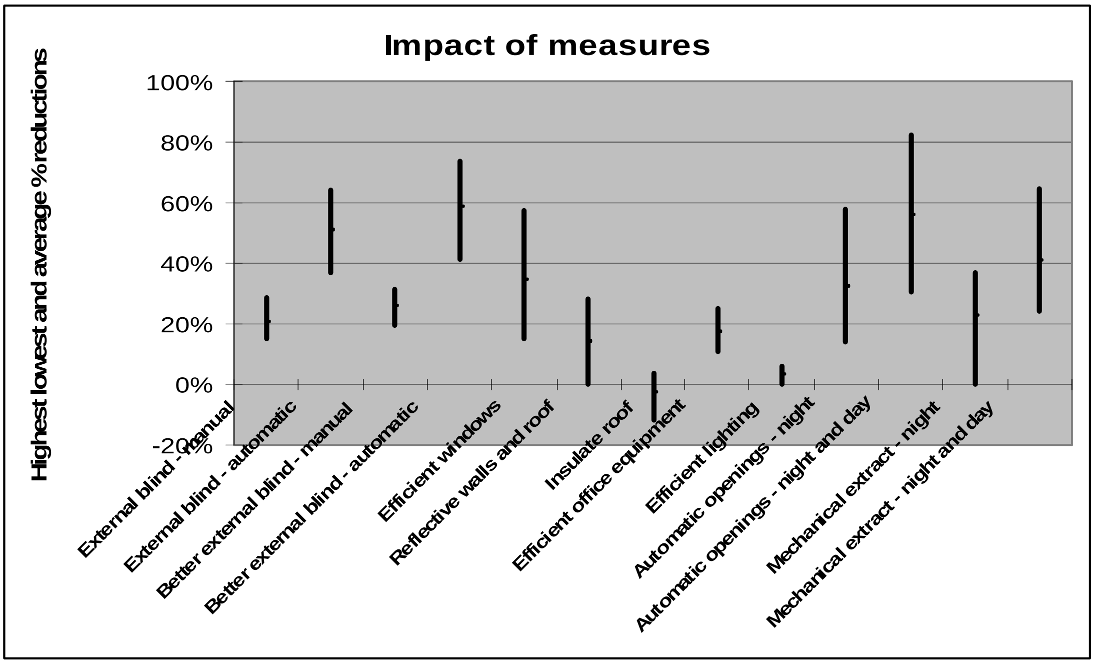

Figure 39: B3.20: Impact of measures, range of potential reductions [106]

[106] Please note that the impacts of the measures are not necessarily additive due to overlaps between alternate measures or due to interactions between different measures used together in the same building

Summary of KeepCool results
% reduction in annual cooling demand (average for two office buildings): simulation results

	Palermo	Lisbon	Milan	Paris	Stockholm
Shading systems					
External blind - manual	16%	19%	20%	21%	26%
External blind - automatic	42%	49%	47%	54%	62%
Better external blind - manual	21%	26%	26%	28%	29%
Better external blind - automatic	51%	58%	55%	62%	68%
Windows and fabric					
Efficient windows	21%	27%	36%	33%	55%
Reflective walls and roof	20%	17%	17%	10%	6%
Insulate roof	1%	-1%	0%	-5%	-9%
Equipment and Lighting					
Efficient office equipment	12%	14%	18%	23%	19%
Efficient lighting	3%	3%	4%	2%	3%
Additional ventilation (natural and mechanical)					
Automatic openings - night	20%	25%	37%	51%	28%
Automatic openings - night and day	38%	43%	55%	77%	66%
Mechanical extract - night	17%	17%	28%	36%	15%
Mechanical extract - night and day	27%	33%	40%	51%	54%

Other cities in the same climate zone

Athens	Madrid	Bratislava	Amsterdan	Helsinki
Larnaca	Marseille	Budapest	Berlin	Riga
Luga	Rome	Ljubljana	Brussels	Gdansk
Seville	Lisbon	Vienna	Copenhage	Tovarene
			Dublin	
			London	
			Macon	
			Nancy	
			Paris	
			Prague	
			Warsaw	

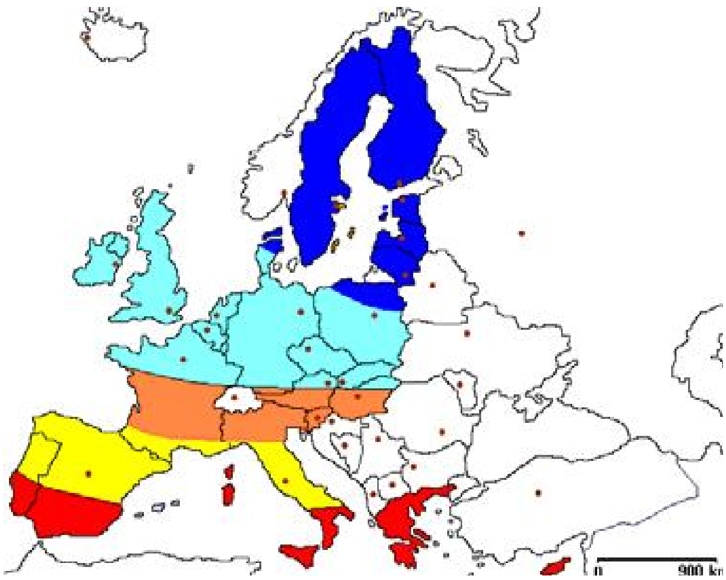

Figure 40: B3.21: Summary of KeepCool results on individual measures (no overlap or interactions between measures)

- A BAT case was then defined for the purposes of the current study that combines the most effective shading strategy (high quality automatic external blinds), the most effective ventilation strategy (automatic window opening during both night and day) and reflective surfaces for each climate zone, but which also takes account of the technical applicability. The resulting theoretical demand reductions are considerable: between 45% and 55% depending on climate. The smallest percentage savings are in the hottest climates, but apply to the largest absolute demands. *(Corresponding to Modelled case C27)*

- As a comparison figure, the exercise was repeated using a lower level of savings that represents the implementation of measures that were found to be commonly identified and recommended by inspection. This represents the situation where every building is treated, but with (presumably) less costly measures and results in a reducing in cooling demand in the region of 7%. *(Corresponding to Modelled case C27)*

For the modelling, these percentage reductions in cooling demand in the specific country studies were converted to an average absolute reduction in FTELH. This absolute reduction was then applied across all building types in all countries.

The BAT case is unlikely to be cost effective even at the societal level as the capital costs for achieving such low levels of cooling demand are likely to be very high. However, the more modest level of savings is based on measures recommended by inspection where it is reasonable to assume that the recommendations will be potentially cost effective in at least some instances, therefore it is reasonable to assume that this lower level of savings would be cost effective at the societal level.

The data sources and assumptions used to estimate the potential savings for both the BAT and the more moderate levels identified above are described in more detail below:

Neither of these sets of figures takes account of the practicality of installing the measures universally, their application to buildings other than offices, nor of the process of identifying where they may be applied. An estimate of these figures can be obtained by comparing the KeepCool results with those from the Harmonac project. In the Harmonac project 42 air-conditioned buildings (denoted Case Studies) were analysed in detail to identify possible energy saving opportunities. On average, the potential savings from fabric measures (using a similar menu of possibilities to KeepCool) were about 60% of those from KeepCool. This represents the result of extensive monitoring and analysis of the air conditioning on these buildings and we assume that the difference from KeepCool is predominantly due to barriers to application rather than to identification. It was therefore possible to estimate a “practical BAT” case which has cooling demand reductions of between 45% and 55% depending on climate.

Further issues are the extent to which the opportunities can be identified. Some light can be thrown on this from Harmonac[cxii] project results. The project carried out several hundred “enhanced” inspections of air-conditioned buildings in order to determine what energy saving opportunities were identified and the time required to identify them. These were much less detailed than for the Case Study buildings. The inspections were mainly carried out by air-conditioning technical staff (who were briefed to look for demand reduction opportunities) and might serve as a proxy for identification by a non-specialist building manager. The potential cooling demand savings identified were 8% of those found in the Case Studies. Combining the two figures suggests that demand reductions identified in this way would account for 6% to 7% of the inferences from KeepCool. If inspection was by building design specialists such as energy performance of buildings assessors, higher figures may be found. Table 41:B3. summarises the results of the above analyses.

Derived figures from KeepCool simulations and Harmonac studies

	Palermo	Lisbon	Milan	Paris	Stockholm
	Combined savings - fabric measures only				
BAT					
(Best shading, best ventilation, reflective surfaces)	76%	80%	83%	92%	90%
"Technical" minimum					
(Worst shading, worst ventilation, no reflective surfaces)	31%	33%	42%	49%	37%
Adjusted to reflect Harmonac results					
Scaled to reflect identification in detailed Case Studies (assumed to reflect practical applicability)	45%	48%	50%	55%	54%
Scaled to reflect identification from inspection	6%	6%	7%	7%	7%

Table 41:B3.22: Derived figures for combined saving. Source: KeepCool and Harmonac projects [cxiii] [cxiv]

The BAT modelling case uses the "practical BAT" figures summarised above, which account for an estimate of technical applicability. Contributions to load reduction from fabric measures that are within "building plus system" and "building-level labelling" were based on the lower figures that only include measures identified during inspections.

Further information on this is contained in Appendix B2.

B3.8.2 Better Operation and management

None of the modelling cases considered better operation and management. The potential savings associated with better operation and management were gleaned from other studies and are described in Section A4 of this report.

B3.9 System Switching

Overall system efficiency varies with the EFTLH[107] parameter which was applied to the cooling generation equipment. This is more climate and application dependent than the energy used by air handling units, resulting in the overall system efficiency also varying.

As a result, it was not possible to define the modelling cases a priori, but only after initial modelling to determine which systems are most energy efficient in which climates and buildings. This is described in section B4.

Two types of system switching were analysed for this study:

- Switching between system subtypes within each of the three major system categories
- Switching across all system subtypes

In both instances the modelling studies estimated the energy savings that would be achieved if the current mix of system types for all future installations were replaced by the most system types for each application[108] for the following two cases:

- Firstly, where the system efficiencies remain at current levels. This represents the impact of simply changing the mixture of system types being installed

[107] This is not simply a measure of climate severity – for example, a climate with a low seasonal cooling demand, but the possibility of occasional periods of high demand, will have a high value.
[108] Represented in the modelling by the FTELH cooling demand for each building type in each country.

- Secondly, by also assuming that the new systems are at BAT levels of efficiency. This represents the maximum savings achievable through system performance improvements (but excluding load reduction and operational savings)

Although there may be significant variations in the capital and running costs between system types, there are significant overlaps in the NPV between the system types (See Section B1). This indicates that switching to a more efficient system type at current efficiency levels is likely to be cost effective to the end user in some instances. Therefore it is not unreasonable to assume that a significant proportion of system switching at current efficiency levels with be cost effective at the societal level. Although in practice user requirements other than energy efficiency e.g., mechanical ventilation requirements, noise levels etc, are likely to play a more important role in determining choice of system type.

B3.10 SEER and other component values Used in the modelling of the specific Cases

This section summarises the modelling input values used for the Modelled Cases at the individual system level. The derivation and sources for these values are detailed in previous sections of this Chapter.

The next three tables show the market average SEER values that were used as modelling inputs for Moveable units, Wall/Window units and Split Systems <12kW. In all instances the average SEER for the existing cooling installations remains unchanged as product and component level policy components are only applied to new installations[109].

For moveable units the same values were used for both single and double duct units as there was insufficient data available to differentiate between the performances of the two subtypes.

case no.	Market Average SEER values - Single and Double Duct Moveables				
	Base case		Modelled Case		
	existing	current new	new year 1 on	new year 2 on	new year 4 on
M0	2.3	2.49	2.49	2.49	2.49
M1	2.3	2.49	2.49	2.63	2.74
M2	2.3	2.49	2.49	2.49	2.49
M3	2.3	2.74	2.74	2.74	2.74
M4	2.3	2.49	2.49	2.63	2.74
M5	2.3	2.49	2.49	2.49	2.49
M6	2.3	2.74	2.74	2.74	2.74
M7	2.3	3.20	3.20	3.20	3.20
M8	2.3	2.49	2.49	2.49	2.49
M9	2.3	2.49	2.49	2.49	2.49

Table 42: B3.22 Input values for Modelled Cases for moveable units

For moveable units revised values for new installations were implemented from year 1 with the exception of M1 and M4 which relate to the MEPS proposed in 2010[110] which would have

[109] New installations include replacement system and new installations in both new and existing buildings.

[110] These proposals were subsequently replaced by more rapid implementation which has not been modelled.

been implemented in two stages in year 2 and in year 4. Slightly revised proposals will now be implemented.

Values for M2 and M5 are identical as financial incentives are not expected to lead to any additional increase in the market average performance. The same applies for M3 and M6.

M8 and M9 relate to building envelope improvements so the SEER values were unchanged from the base case (MO).

case no.	Market Average SEER values - RACs - single splits <12kW				
	Base case		Modelled Case		
	existing	new	new year 1 on	new year 2 on	new year 4 on
RAC0	3.22	3.22	3.22	3.22	3.22
RAC1	3.22	3.22	3.22	3.73	3.89
RAC2	3.22	3.22	3.73	3.73	3.73
RAC3	3.22	3.22	3.89	3.89	3.89
RAC4	3.22	3.22	3.99	3.99	3.99
RAC5	3.22	3.22	4.43	4.43	4.43
RAC6	3.22	3.22	3.22	3.74	3.90
RAC7	3.22	3.22	3.74	3.74	3.74
RAC8	3.22	3.22	3.90	3.90	3.90
RAC9	3.22	3.22	3.89	3.90	3.90
RAC10	3.22	3.22	3.99	4.43	4.43
RAC11	3.22	3.22	4.43	4.43	4.43
RAC12	3.22	3.22	3.22	3.22	3.22
RAC13	3.22	3.22	3.22	3.22	3.22

Table 43: B3.23: Input values for Modelled Cases for room air conditioning units – single splits <12kW

case no.	Market Average SEER values - RACs - Window/Wall units				
	Base case		Modelled Case		
	existing	current new	new year 1 on	new year 2 on	new year 4 on
RAC0	4.25	4.7	4.7	4.7	4.7
RAC1	4.25	4.7	4.7	5.12	5.32
RAC2	4.25	4.7	5.12	5.12	5.12
RAC3	4.25	4.7	5.32	5.32	5.32
RAC4	4.25	4.7	5.59	5.59	5.59
RAC5	4.25	4.7	5.98	5.98	5.98
RAC6	4.25	4.7	4.7	5.16	5.35
RAC7	4.25	4.7	5.16	5.16	5.16
RAC8	4.25	4.7	5.35	5.35	5.35
RAC9	4.25	4.7	5.59	5.59	5.59
RAC10	4.25	4.7	5.98	5.98	5.98
RAC11	4.25	4.7	6.5	6.5	6.5
RAC12	4.25	4.7	4.7	4.7	4.7
RAC13	4.25	4.7	4.7	4.7	4.7

Table 44: B3.24: Input values for Modelled Cases for room air conditioning units – window/wall units

For RAC units revised values for new installations were implemented from year 1 with the exception of RAC1 and RAC6 which relate to the MEPS which were proposed on 2010 MEPS[111] to be implemented in two stages in year 2 and in year 4. Slightly revised proposals will now be implemented).Values for RAC4 and RAC9 are identical as financial incentives and are not expected to lead to any additional increase in the market average performance. The same applies for RAC5 and RAC10.

RAC12 and RAC13 relate to building envelope improvements so the SEER values were unchanged from the base case (MO).

Case no.	New/ Existing Installations	Central Systems SEER (Chillers and Packaged Units)					
		Split systems	VRF	Roof top	Heat pump loop	Chillers	Passive chilled beam
C0-C9	Existing	3.88	4.66	3.33	4.03	3.46	3.46
C0	New	4.29	4.66	3.33	4.03	3.75	3.75
C1	New	4.33	4.66	3.36	4.05	3.77	3.77
C2	New	4.37	4.66	3.40	4.99	3.79	3.79
C3	New	4.50	4.66	3.53	4.35	3.86	3.86
C4	New	4.84	4.84	4.03	4.39	3.97	3.97
C5	New	5.42	5.42	5.13	4.59	5.90	5.90
C6	New	4.54	4.66	3.56	5.05	3.87	3.87
C7	New	4.86	4.86	4.03	5.35	3.98	3.98
C8	New	5.42	5.42	5.13	5.59	5.90	5.90
C9	New	5.42	5.42	5.13	5.59	5.90	5.90

Table 45: B3.25: Input values for Modelled Cases for central and larger systems – cases relating to chillers and packaged units

Modelled Cases C1-C9 are the only ones where the average market SEER value for chillers was changed.

As for Moveables and RAC units, the market average chiller SEER for existing units remained the same for all Modelled Cases.

Tables B3.26 to B3.29 summarise the parameter values used as inputs to the Cases (defined earlier) representing energy efficiency improvements to components of central air conditioning systems.

Case no.	New/ Existing Installations	AHU
		SFP (W/l/s)
C10	New	2.95
C11	New	2.25
C12	New	2.20
C13	New	2.20
C14	New	1.25

Table 46: B3.26: Input values for Modelled Cases for central and larger systems – cases relating to AHU/SFP

[111] These proposals were subsequently replaced by slightly more demanding ones to be introduced on a more rapid timetable (see section B2). These have not been explicitly modelled.

Case no.	New/ Existing Installations	Pumps
		% improvement
C18	New	20%
C19	New	25%
C20	New	40%

Table 47: B3.27: Input values for Modelled Cases for central and larger systems – cases relating to pumps

Case no.	New/ Existing Installations	Terminal
		% improvement
C15	New	28%
C16	New	33%
C17	New	82%

Table 48: B3.28: Input values for Modelled Cases for central and larger systems – cases relating to terminals

Case no.	New/ Existing Installations	Central Systems SEER (Chillers and Packaged Units)						AHU	Duct Loss	Pump	Terminal	Reduction in FTELH	
		Split systems	VRF	Roof top	Heat pump loop	Chillers	Passive chilled beam	SFP (W/l/s)	AHU	Pump (% improvement)	Terminal (% improvement)	FTEH	Reduction in fan operating hours
C21	All								5%				
C22	All								3%				
C23	All							1.25				40	
C24	All	+5%	+5%	+5%	+5%	+5%	+5%					20	10%
C25	New	4.50	4.66	3.53	4.35	3.86	3.86	2.20		20%	28%		
C26	New	5.42	5.42	5.13	5.59	5.90	5.90	1.25		40%	82%		
C27	All											25	
C28	All											191	

Table 49: B3.29: Input values for Modelled Cases for central and larger systems – other cross-system cases

B4 MODELLING PROCESS AND ADDITIONAL INPUT VALUES

B4.1: Overview of Modelling Approach

The main objective of the model is to evaluate the impact on energy use by air conditioners in the EU by introducing changes to the efficiency of AC equipment, AC system components and to the characteristics of the building shell or central AC system. In order to produce this type of estimate, it is necessary to first determine the amount of energy currently being used by ACs in the EU and in each MS, the annual sale of ACs by type, the average efficiency of currently installed products and systems, the average AC energy use per household or per commercial establishment, the distribution of efficiency in equipment currently in the market, and other data.

Next in the process, it is necessary to model air conditioner energy use for each type of AC (according to its unique set of operating characteristics) to permit the evaluation of the potential impact on energy use of implementing a variety of initiatives aimed at reducing the amount of energy required for AC. In order to evaluate the impact on the entire EU, one must start with a model of energy use by the typical operation of the average installed air conditioner to represent the *status quo;* then it is necessary to apply the changes in parameters to the AC equipment or system that represent the energy saving initiatives, and finally, it is necessary to calculate the difference in annual consumption between the *Base Case* (*status quo*) and the *Case* in question. This process is repeated for each type of AC, since the operating and energy consuming characteristics for each type are quite different. The estimated differences in (annual) energy consumption are then projected upwards to the savings at the MS level and at the EU level.

This process required the collection or estimation of information on several aspects of product efficiency :

- the aggregate average efficiency level of different types of air conditioner (moveables, room-type and central)
- the distribution of efficiency levels for units currently on the market
- The efficiency of the best available technologies available in the market.

This information is used as the starting data for modelling how energy is used by the three types of ACs, and to estimate how much energy could be saved by improving the efficiency of new equipment under each of the initiatives called *Cases.* A family of *Cases* was defined around each type of products to represent initiatives that could be tested using the model in order to estimate their impact on energy requirements for air conditioning over a ten year period (technical potential). In actuality, the savings that can be achieved depend on the degree and speed at which the initiatives are implemented.

As product and system policies are a key focus of this study, the above product-driven approach was adopted to model both the energy savings, and the associated reductions in carbon emissions that could be achieved through implementing improvements in cooling performance at different levels. As well as assessing the potential savings associated with improving the performance of the products and systems, the model also quantifies the potential impact of policy measures that aim to reduce cooling loads, either by reducing internal gains or by altering the building fabric, or encourage more energy-efficient operation and maintenance practices.

The aim of the model is to generate estimates of the energy savings that could be achieved by implementing the modelling cases described in Section B3 of this report, disaggregated by country. Carrying out detailed dynamic modelling studies that cover all possible types of systems, building construction, pattern of internal gains and external climate would require vast amounts of detailed input data and analysis time and are far beyond the scope of this study. Therefore, a parametric approach was used to model the energy performance and calculate the energy consumption for a limited range of system and building types to represent those most commonly found in Europe using available data sources.

The three main market strands for cooling systems that were used in the modelling are:

i. Moveable units, which are self contained systems,
ii. RAC units (room air conditioners), which are small self contained systems, and
Central systems, which include all other centralised and larger cooling systems[112].

These and the system types that were used in the model are described in more detail in Section B1.

[113]The three strands or types of air conditioners were separately modelled; the energy impacts that could be achieved by switching between sub-systems and between the three main system categories have also been assessed by comparing the typical (modelled) energy efficiency for the current mix of system types compared to a more efficient system type (or mix of system types). The models used for each type of air conditioner or system are described in more detail in the sections following.

B4.2 Modelling Energy Use in Moveables and RACs

Moveables and RACs are modelled in a similar manner and the primary inputs to the model are:

- The amount of cooling plant installed in the existing building stock as kW cooling capacity.
- Current sales of cooling systems and self contained cooling products[114] quantified according to their kW cooling capacity, which is a known parameter and is disaggregated by sub-system, building type and country in the model
- Sales growth rate by product/system type and country
- Cooling demands for different building types in different countries (which takes account of both climate and typical constructions and internal gains)

Other inputs to the moveable and RAC modelling are: an oversizing factor, an assumed standby energy consumption, off mode energy consumption, and a notional control factor[115].

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[112] A definition of the system types that have been explicitly used in the model are described in section B1.
[113] In order to reflect the way in which cooling systems are being dealt with in the Ecodesign preparatory studies[113], the division between room air conditioners and centralised plant has been drawn to be consistent with the Ecodesign studies so that room air conditioners include wall/window units and split systems <12kW cooling capacity, whilst larger split systems were included with centralised systems.

[114] See sections A2 and B1 for more detail about the products and components that comprise cooling systems.
[115] This is to represent unavoidable mismatching cooling demand and system supply.

For moveables and room air conditioners the modelling work already carried out in support of the Ecodesign Preparatory Study for Room Air Conditioners (Lot 10) provides information on the stock and sales of moveable and room air conditioning units and also the cooling loads associated with the six different building types that were used to represent the building stock. These are:

- new offices
- new retail
- new residential
- existing offices
- existing retail, and
- existing residential

The annual cooling demands for different building types were determined by the occupancy/operational hours, typical internal gains, the thermal performance of the building envelope and the climate. The modelling studies carried out in support of the Lot 10 study[116] took all these factors into account and calculated the typical full load equivalent cooling hours for three main building types; residential buildings, offices and retail buildings in each of the 27 EU Member States. They reflect the typical construction types and thermal regulations of each Member State. As the thermal performance of new buildings is likely to be significantly different to that of the existing building stock, separate cooling demands were defined for new and existing versions of each building type. The impact of climate and building type on cooling demand is best expressed in terms of full load equivalent cooling hours, which is a key parameter within the modelling process.

For this study the modelling was extrapolated to cover the additional EU and EEA countries based on proximity to other countries and prorated on the basis of population[117].

Energy consumption at the national level was calculated based on the energy use for:

- the mix of products and system types that are used in each country,
- the typical energy performance of the products and system components in each country,
- the mix of building types in each country.

This gives base case energy consumption for cooling broken down by market sector, system type and country.

The associated carbon emissions were then calculated by applying the system average emission factor for each country.

To get from installed cooling capacity to the energy use, and hence the carbon impact of cooling systems, it is necessary to consider both the annual cooling demand that systems are required to meet and the cooling efficiency of the product.

The energy savings that arise from making improvements to products and system components are determined by replacing the typical performance values in the base case model with improved values. Comparing the energy consumption for the typical performance values with the improved values then gives the energy savings. The way the dynamics are taken into account is explained below.

[117], Iceland, Lichtenstein and Norway which have been estimated from data for Spain, Finland, France and Sweden, respectively based on population

The effect of changes to the building fabric and measures to reduce internal gains are modelled as a reduction FTELH cooling.

Moveable units and room air conditioners are not usually carefully matched to calculated room cooling demands. It was assumed for the purposes of the modelling that they are, on average, oversized, as specifiers and installers will always tend to err on side of caution. In particular, an oversizing factor[118] was applied to the kW cooling capacity installed in order to provide a realistic estimate of the peak cooling demand that is actually placed on the product. The cooling demand was then calculated from this peak cooling demand and the full load equivalent hours for the space it is servicing. The cooling energy consumption of self contained units was then calculated by dividing the cooling demand by the Seasonal Energy Efficiency Ratio (SEER)[119],. However, the extent to which the cooling output of the cooling unit is matched to the cooling demand of the space also needs to be considered, (e.g. times when the cooling unit is either providing more cooling than is required or providing cooling at times when the building is unoccupied and therefore not required). To account for this a loss factor, which accounts for the extent to which the cooling system is imperfectly controlled, was included in the modelling.

As well as energy use for cooling, there may also be energy use associated with the unit when it is in standby mode, i.e. it is switched on and ready to provide cooling when it is required. This was included in the model and is defined in terms of kW standby per kW cooling capacity, and the annual energy consumption calculated from this and the time the unit is switched on ready to provide, but not actively providing, cooling (the net standby hours).

This process for calculating energy consumption for moveable units and RAC units (self contained cooling products) is summarised in the following schematic.

[118] This oversizing factor only includes oversizing that is over and above that which is required due to system inefficiencies and net losses that occur between the chiller and the room cooling demand. The value chosen is based on BRE experience.

[119] Section B3.5 explains how EER values have been converted to SEER for cooling products and system components.

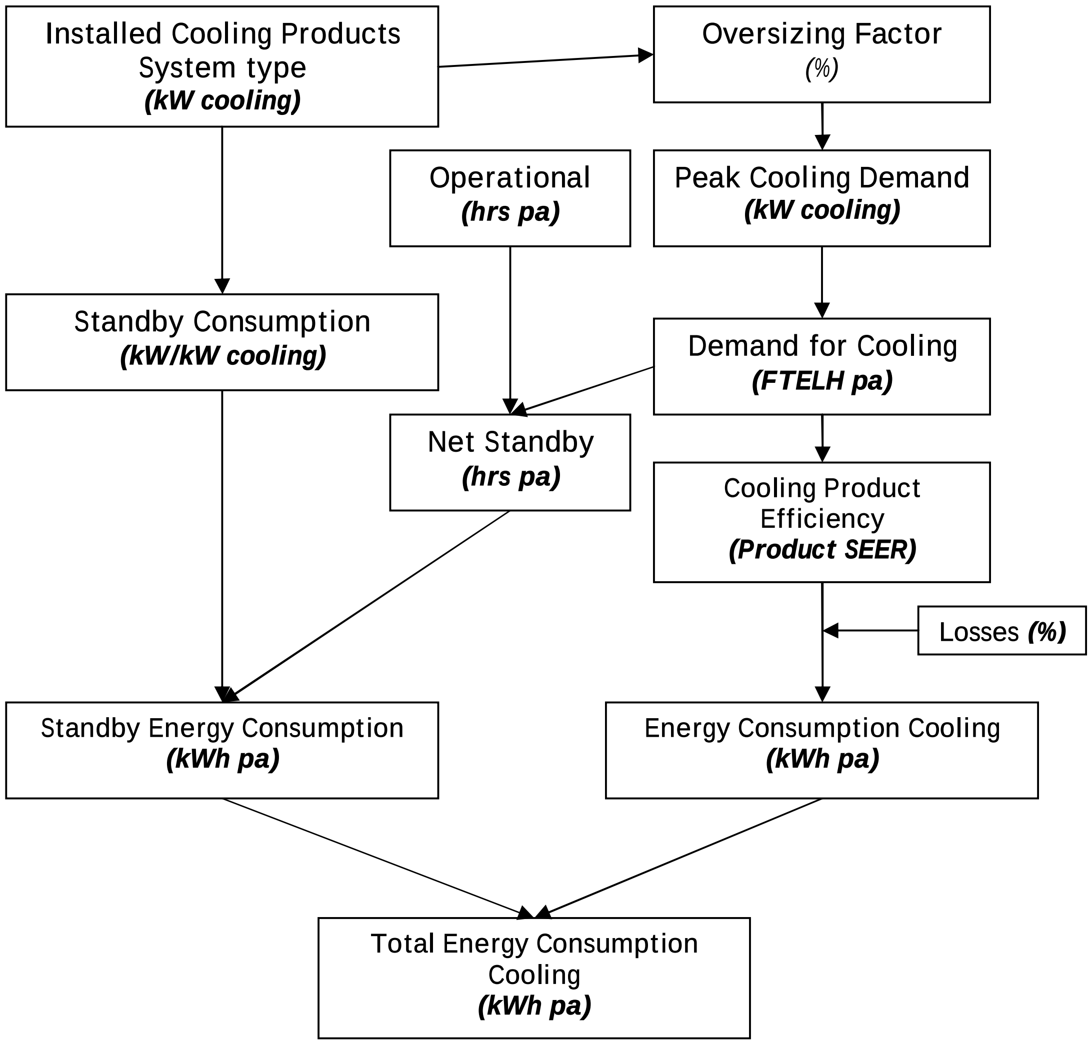

Figure 41: B4. 1: Calculating Energy Consumption for Moveable units and Room Air Conditioners (Self Contained Cooling products)

For RAC units, in addition to standby energy use, “off mode” energy use was also included, where it accounts for energy use for displays and other electronic functions that are active whenever the unit is connected to the electricity supply.

In order to calculate the energy consumption of self contained cooling products in both existing buildings, and from future installations, the energy calculation procedure outlined above was embedded in a wider spreadsheet model. This model calculates the energy consumption for the installed cooling load according to the mix of system types, building types and typical energy performance characteristics found in each country, for both the existing stock of systems and for projected new installations expected over the next 10 years. This was then used to calculate the reference, or base case, energy consumption. The effect of varying certain modelling inputs was then explored by replacing the base case values for each country with an alternative value that leads to lower energy consumption. In order to avoid modelling instances where better performing products, components or systems might be replaced by ones with lower performance levels, the model was set up to retain existing values where this leads to a better overall energy performance compared to the other available/modelled options.

The primary information used to drive this model is the cooling capacity of each type of system. This was derived from information on the stocks and projected sales of air conditioning products from the Lot 10 study [cxv], expressed in terms of kW of cooling capacity. The mix of representative building types that cooling products are installed in for each country was also derived from the lot 10 study.

For moveable units the Lot 10 study concentrated on single duct units, which are by far the most common type of moveable unit sold in the EU, estimated to account for 98% of all moveable units, so most of the detailed information relating to the energy performance concerns single duct units. In the absence of reliable data, therefore, it was assumed that the performance characteristics of the double duct product are the same as for single duct.

B4.3 Modelling Energy Use in Central Systems

For larger and centralised systems the energy consumption will depend on both the efficiency of the products and components that comprise the system and their configuration. The modelling procedure is similar to that for moveables and RAC units in many respects, but required more detailed system level energy modelling to be carried out.

At the outset of this study it had been anticipated that the Lot 6 system modelling would have generated modelling results that could be drawn on directly. However, this project has experienced delays and this work is still in progress, therefore it was necessary to use an alternative approach for this study. As an alternative, the algorithm which is used to calculate the HVAC system performance within SBEM, which forms part of the UK's National Calculation Methodology [cxvi] was selected as it is simple enough to be adapted for use in this study and is capable of modelling the energy performance of a range of different system types and of taking account of the efficiency of various system components and different cooling demands.

The information on stocks and sales of products that comprise centralised cooling systems was taken from the Lot 6 Ecodesign preparatory study and the information from the Lot 10 Ecodesign preparatory study on cooling loads associated with the different building types is equally applicable to centralised cooling systems.

The overall process of calculating energy consumption for centralised systems is summarised in the following schematic.

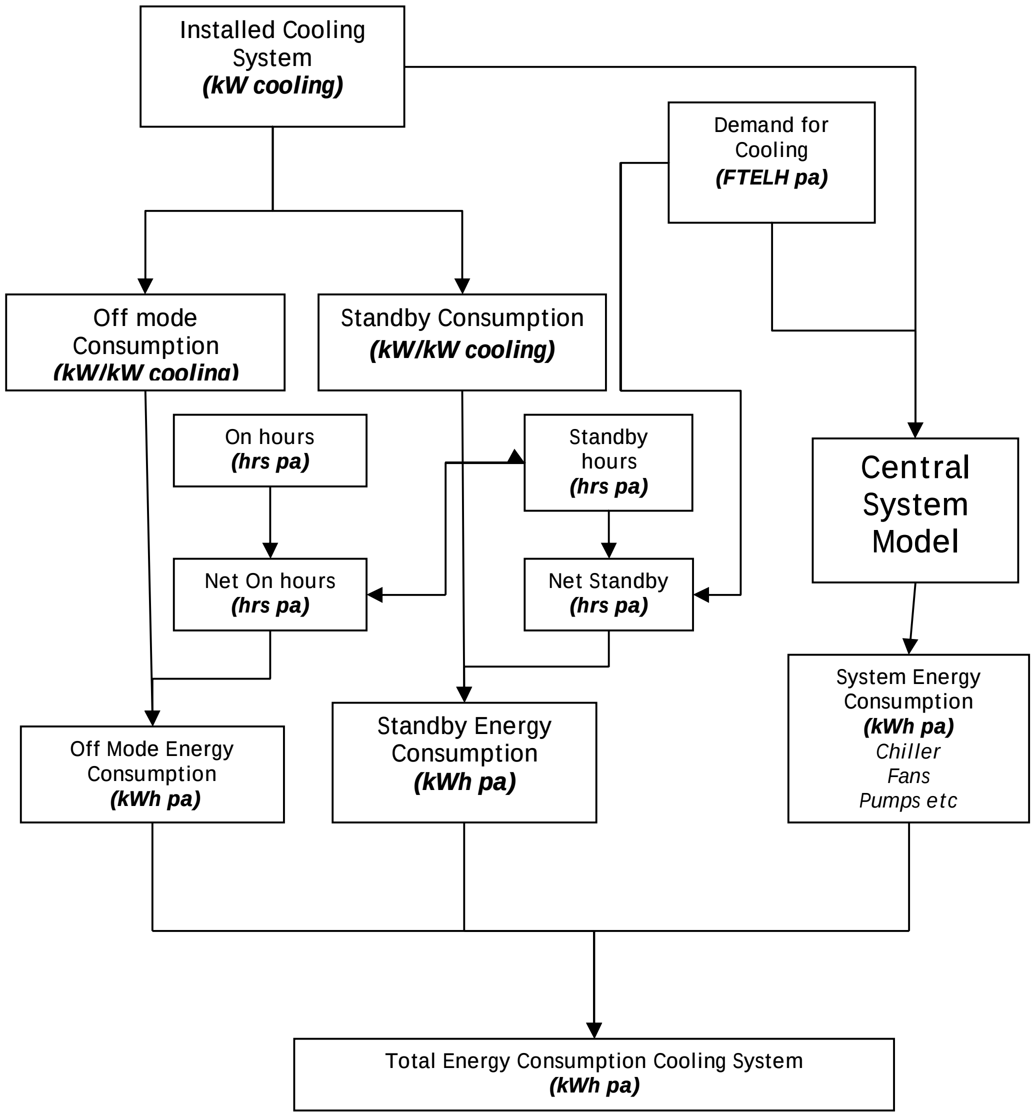

Figure 42: B4.2: Calculating Energy Consumption for Centralised Systems

The "central system model" box in the schematic above is expanded further in the following diagrams which show how the energy use for chillers, fans in AHUs (for systems with air distribution), pumps (for systems with chilled water distribution), terminal units (for systems with terminal units) and heat rejection. In the model, air heat rejection is assumed for all system types as this is the most common method of heat rejection used in central systems across Europe. Cooling towers are now rarely used for building cooling applications because of fears of Legionella disease. See section B1 for further discussion of the pros and cons of evaporative heat rejection such as cooling towers.

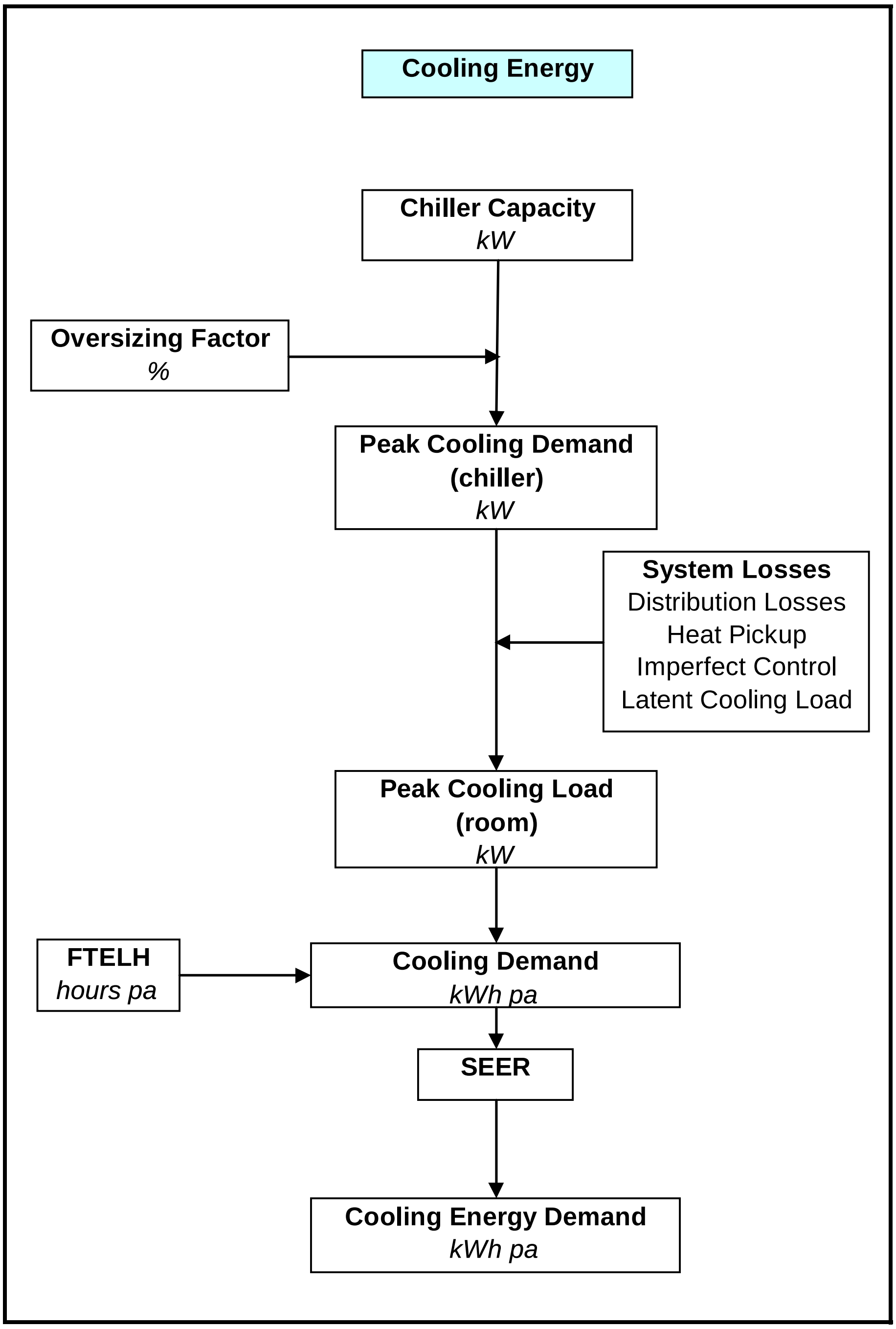

Figure 43: B4.3: Calculating Cooling (Chiller) Energy Consumption for Centralised Systems

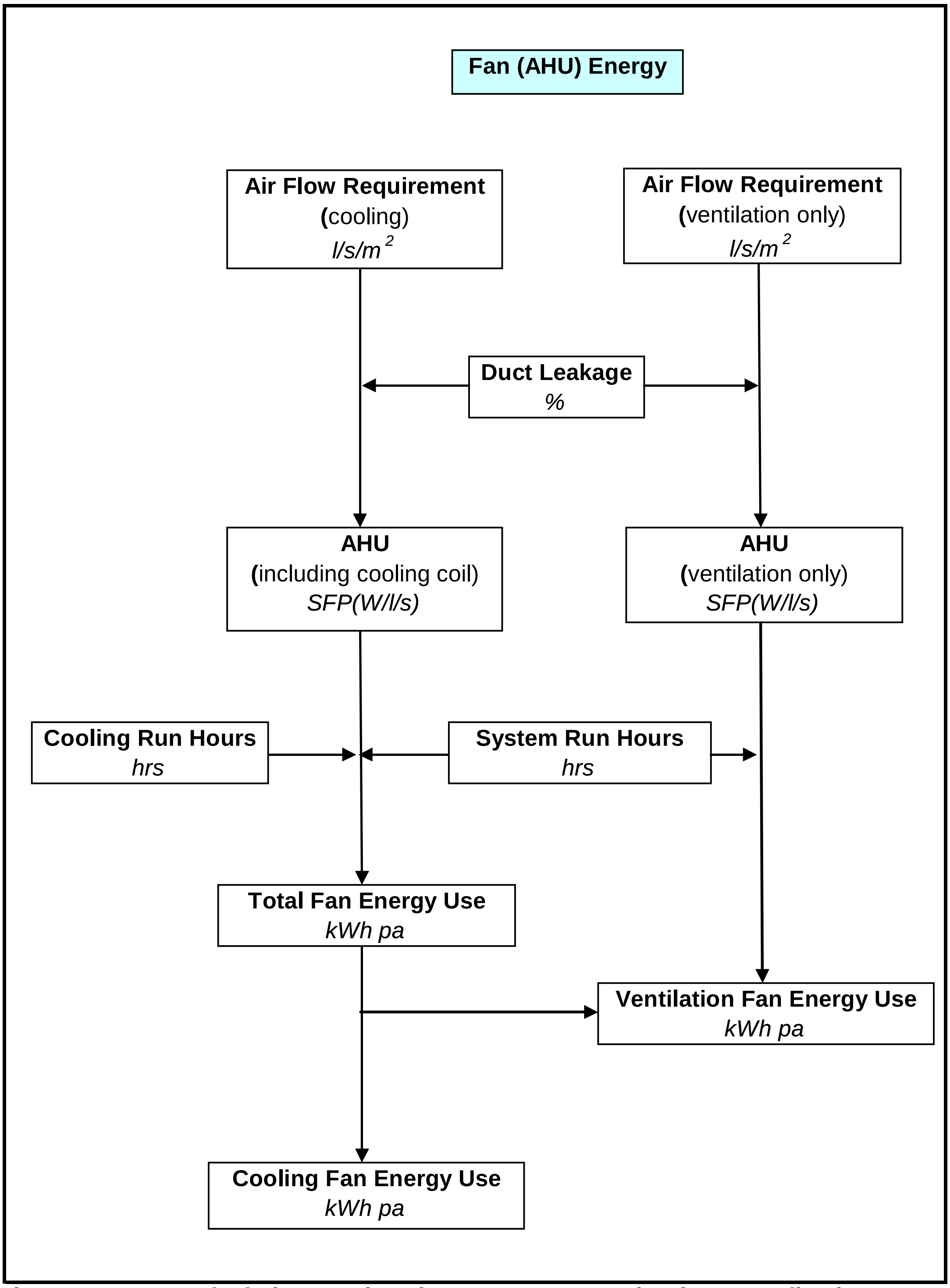

Figure 44: B4.4: Calculating Fan (AHU) Energy Consumption for Centralised Systems

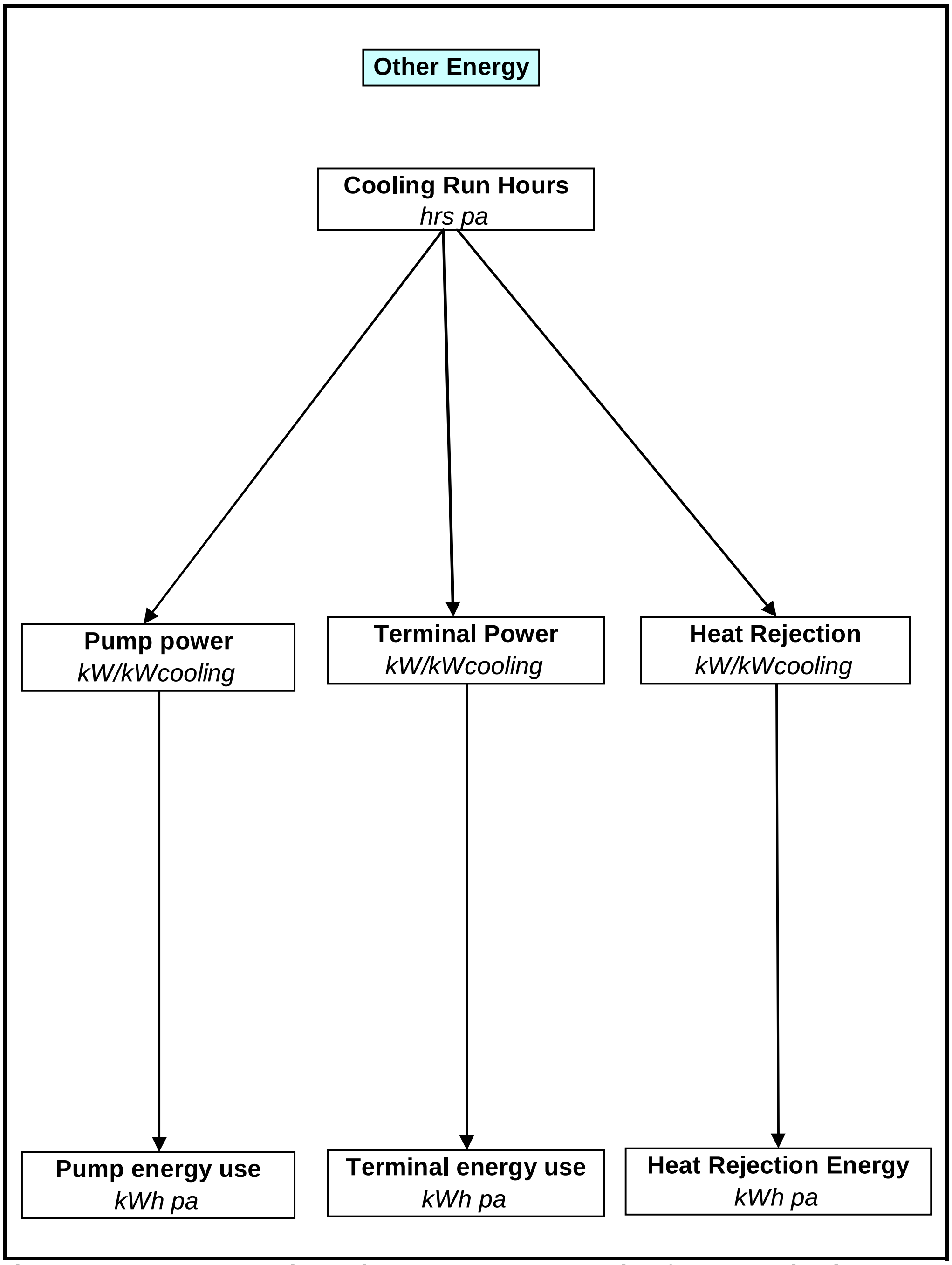

Figure 45: B4.5: Calculating Other Energy Consumption for Centralised Systems

The wide range of centralised plant system types and configurations is represented in the modelling by the ten system types described in more detail in Section B1, these are: split systems, VRF, roof top, all air constant volume, all air VAV, water based fan coil, water based induction, heat pump loop, active chilled beam, passive chilled beam. These 10 systems were assessed across all countries considered in this study.

The first element for centralised systems was to determine the current energy consumption in the existing stock of buildings.

Since data are available for the current kW installed by system and by country, this was taken to be the starting point in determining the total consumption. The total consumption was determined by considering a range of factors which impact on the energy used by the installed systems. These factors are summarised in the following table:

Separation of air and water sub systems		
Air	% of load handled by air sub system	Allows separation of load handled by air and water sub systems
Water	% of load handled by water/liquid sub-system	Allows separation of load handled by air and water sub-systems
Air and water cooling space demand (energy required to meet demand for coolth for a given space)		
Air and water	Peak cooling demand	% of total installed kW assumed to be used at peak cooling demand - this accounts for oversizing of plant resulting in it not being used to full capacity
	Equivalent full load cooling hours	Hours in use based on occupancy/operational hours, typical internal gains, thermal performance of the building envelope and climate
	Terminal auxiliary power parameter	kW/kW cooling* peak cooling demand
	Terminal auxiliary pickup factor	Takes account of additional heat generated by distribution fan which also needs to be cooled
	Local latent load	Takes account of loss due to some of the cooling condensing on the cooling coils in the room
	Allowance for imperfect local control	Estimate of losses due to imperfect control
	Extra cooling load from mixing reheat	Estimate of losses due to mixing of reheated air requiring additional cooling
	Extra load from imperfect zoning	Estimate of losses due to provision of more cooling than required
Air cooling demand on chiller (demand for coolth for a given space plus additional energy demands placed on chiller)		
Air	Air cooling space demand	Calculated as described above
	Duct leakage	Takes account of duct leakage resulting in proportion of cold air not reaching desired location
	Duct heat pickup	Losses occurring in the transportation of coolth through the duct work for air based parts of systems
	Central latent load	Takes account of loss due to some of the cooling condensing in the AHU
	Fan energy use allocated to cooling	This determines the amount of energy consumption for cooling only by removing the ventilation part of the system so that only the cooling part remains and ensures like is compared with like across the systems
	Fan energy pickup factor	Takes account of that fact that some heat from the running of the fan ends up in the ducts
Water heating demand on chiller (demand for coolth for a given space plus additional energy demands placed on chiller)		
Water	Water cooling space demand	Calculated as described above
	Pipe heat pickup	Losses occurring in the transportation of coolth through the pipe work for water/liquid-based parts of systems
	Cooling pump energy	Energy consumed by cooling pumps
	Cooling pump pickup factor	Takes account of losses due to heat generated by the pumps in water/liquid-based systems
Other elements included in the model		
All systems	SEER	Takes account of the Seasonal Energy Efficiency Ratio of the chiller applied to total cooling (chiller) consumption, standby and off chiller energy use
Fans	Fan energy use allocated to cooling	This determines the amount of energy consumption for cooling only by removing the ventilation part of the system so that only the cooling part remains and ensures like is compared with like across the systems
Pumps	Cooling pump energy	Energy consumed by cooling pumps
Chiller standby	Current stock standby energy	% of current stock (kW installed) which is associated with standby
	Standby hours	Hours in standby mode
	Current stock	kW installed - current stock
Chiller off mode	Current stock off mode energy	% of current stock (kW installed) which is associated with off mode
	Off hours	Hours in off mode
	Current stock	kW installed - current stock
Terminal	Terminal auxiliary energy use	Energy use at terminal auxiliary
	Cooling only run hours	Hours system is in active cooling mode

Table 50: B4.1: Table of inputs to the modelling of total energy consumption for centralised systems (N.B. heat rejection is included within the chiller SEER where appropriate)

As shown in Table B4: 1 the total load was split into the percentage handled by the air sub-system and the percentage handled by the water sub-system. This separation is important as different factors affect the energy consumption associated with each of these sub-systems. In addition, for fan consumption of air sub-systems it was necessary to remove the proportion of fan consumption dedicated to ventilation from the model so that only the cooling proportion remained and thus ensured like for like comparison across the 10 system types.

The cooling space demand was then determined separately for air and water sub-systems. The cooling space demand is a reflection of the amount of energy required to meet the demand for coolth in a given space. As shown in the table the model takes account of potential system oversizing, equivalent full load cooling hours and ratio of energy used by the terminal, by the pumps and for the heat rejection. The model also includes an estimation of losses occurring in the system – for example due to imperfect control or due to mixing of reheated air requiring additional cooling.

The cooling space demand was then used as the basis for determining the cooling demand on the chiller – again separated into air and water sub-systems. This gives an estimate of the demand for cooling placed on the chiller based on the demand for coolth in a given space plus various additional cooling demands placed on the chiller. As the table shows, many of these additional demands are indeed further losses to the system; for example for air sub-systems losses occurring in the transportation of coolth through the duct work are included, as is the additional energy required to cool heat generated by the fans.

For air sub-systems, fan energy use is included in the model as the method of distributing the coolth; for water sub-systems pump energy use is included instead. Terminal energy use is included in the model for both sub-systems. For direct expansion systems like split systems and VRFs the energy use for delivery of coolth to the room and the rejection of heat are included in the performance of the self contained packages.

The result of the above is an estimate of the total energy consumption in active cooling mode. The model then goes a step further and was used to assess consumption of the chiller in standby mode and off mode. This assessment was based on determining the number of hours each system is in each of these modes, the kW installed in the current stock and an estimate made of the percentage of this which is associated with each of these modes.

For all 10 system types, a (system specific) SEER is applied to the total cooling (chiller) consumption, the standby consumption and the off mode consumption (the calculation of systems specific SEER is explained in B3.4).

A spreadsheet implementation of a modified version of the SBEM algorithm was constructed for each of the ten centralised system types. Because centralised systems often provide both cooling and ventilation via the same distribution system, in order to make a fair comparison between the energy performances of different system types, the energy use for distribution must be apportioned between the cooling and ventilation demands. This was achieved within the model by calculating the energy use that would be required to meet the ventilation requirements by a similar system with no cooling capability[120]. Then, for instances when cooling and ventilation are provided simultaneously, calculating where the ventilation requirement for a system (with no cooling) would be larger than the overall calculated energy use. This additional energy use for ventilation was then subtracted to give the energy use for distributing the cooling.

[120] The presence of a cooling coil in an Air Handling Unit leads to increased air resistance which requires greater energy use to distribute the same volume of air around the building.

The sources of data inputs to the central model are summarised below in Table B4. 2, and further tables showing the input values used in the base case model are provided in Section B4.7. In instances where no data sources could be identified, indicative values were assumed based on BRE technical expertise and experience.

Parameter	Units	country specific values	system specific values	source	comments
Installed cooling capacity	kW installed	X	X	lot 6	EU mix of system types is applied across all countries
current stock standby energy	kW/kW cooling			BRE assumption	
current stock gross standby hours	gross annual hours			BRE assumption	
current stock off mode energy	kW/kW cooling			BRE assumption	
current stock gross off mode hours	gross annual hours			BRE assumption	
% unecessary oversizing	%			BRE assumption	
peak cooling demand	kW			SBEM algorithm	See below
peak cooling demand per m2	kW/m2	X		BRE assumption	Base value is UK typical figure. Modified for other countries using analysis of (unpublished) lot 10 modelling results. These take account of the mix of building types in each country
Implied floorarea -	m2			calculated	from peak cooling demand and peak cooling demand per m2
controls factor	% control			SBEM algorithm	Allows for presence or absence of time controls, metering and monitoring. Value taken from UK Building Regulations advisory document ADL2A
Equivalent full load cooling hours	hours pa	X		BRE assumption	Base value is UK typical figure. Modified for other countries using analysis of (unpublished) lot 10 modelling results. These take account of the mix of building types in each country
net Standby hours (standby - cooling)	hours pa			calculated	gross standby less FTELH
net off hours (off -standby)	hours pa			calculated	gross off hours less standby hours
Room cooling demand	kWh pa			calculated	peak cooling demand * FTELH
kW terminal/kW cooling	kW/kW cooling		X	SBEM algorithm	CIBSE Technical Manual TM 32
Terminal auxiliary power parameter	kW		X	calculated	terminal energy demand * kW installed
Local latent load	kW cooling		X	SBEM algorithm	Based on manufacturers' catalogue values
Terminal Auxiliary pickup factor	% pickup			SBEM algorithm	Cautious assumption that it is zero
Allowance for imperfect local control	% loss			SBEM algorithm	Based on figures of control effectiveness in EN15232
Extra cooling load from mixing reheat etc	% loss		X	SBEM algorithm	Mainly from simulation results but some figures from Dutch standard NEN 2916
Extra load from imperfect zoning	% loss		X	SBEM algorithm	BRE assumption
Proportion of load handled by air sub-system	% air distribution		X	BRE assumption	Assumption based on "engineering approximations"
Duct leakage	% loss	X		BRE assumption	Default values with country specific exceptions where regulations exist.
Reclaimed leakage losses	% reclaim			SBEM algorithm	Cautious assumption that it is zero
Duct heat pickup	% increase			SBEM algorithm	Based on NEN 2916 and other sources
Reclaimed cold losses	% reclaim			SBEM algorithm	Cautious assumption that it is zero
Central latent load	% loss		X	SBEM algorithm	Worked examples in textbooks (assumes no intentional mopisture control)
SFP	W/l/s	X		BRE assumption	default values with country specific exceptions where regulations exist
Difference in sfp (this accounts for the extra resistence of cooling coils	W/l/s			BRE assumption	Based on figures in EN15242
equivalent SFP for ventilation only system	W/l/s			calculated	SFP - effect of cooling coil
VAV factor (ratio of efth with VAV:efth withou VAV)	% saving		X	BRE assumption	Only relevant for VAV
SFP actual ventilation	W/l/s			calculated	SFP * VAV factor
Fan energy pickup factor	%			SBEM algorithm	Assumes that motor losses do not contribute to cooling demand but all fan energy does
System run hours	hours pa			BRE assumption	
ventilation flow required	W/l/s			BRE assumption	
kW fan required to meet ventilation requirement	kW			calculated	from ventilation flow required, implied floorare and system run hours
cooling only run hours	hours pa			BRE assumption	
notional flow factor	l/s/m2			SBEM alogorithm	Assumed air supply rate for all air systems based on engineering calculations
minimum ventilation energy no cooling coils	kWh pa			calculated	kW to meet ventilation requirement*system run hours plus duct leakage
ventilation requirement incl cooling coils	kWh pa			calculated	minimum ventilation energy no coiling coils* ratio SFP with and without cooling coils
fan energy use for required ventilation	kWh pa			calculated	kW to meet ventilation requirement* sytem run hours plus duct leakage
total energy use allocated to cooling	kWh pa			calculated	total system fan energy use - fan energy use
total system fan energy use	kWh pa			calculated	cooling flow rate plus duct leakage*SFP*VAV factor*system run hours
Pipe heat pickup	%		X	SBEM algorithm	CIBSE Technical Manual TM 32
Reclaimed cold losses	% reclaim		X	SBEM algorithm	Cautious assumption that it is zero
Cooling pump pickup factor	%		X	SBEM algorithm	Cautious assumption that it is zero
Cooling pump power	kW/kW cooling		X	SBEM algorithm	Assumption based on "engineering approximations"
Cooling pump power	kW			calculated	terminal energy demand * kW installed
Cooling pump energy	kWh pa			calculated	kW to meet ventilation requirement*system run hours
Cooling Flow Rate	W/l/s		X	BRE assumption	Only relevant for systems with air distribution
Chiller performance (SEER)	ratio		X	BRE assumption	Based on analysis of Eurovent data
Chiller Ancillaries	kW/kW cooling		X	SBEM algorithm	Relevant for systems with non integral heat rejection
Cooling proportion	%		X	SBEM algorithm	Only relevant for VAV
Emission factor	kg CO2/kWh	X		Defra company reporting guidelines 2010	

Table 51: B4.2: Summary of Data inputs to the central system modelling

The data inputs for the moveables and RAC models are included in the more detailed modelling assumptions in Section B4.7.

B4.4: System Efficiencies (Base Case)

The seasonal energy performance of moveable units and RACs is determined by the product seasonal energy efficiency ratio (SEER) (see Section B3.4 for details of how product EER was converted to SEER, plus any standby or off mode energy consumption.)

The base case, SEER values for both existing and new self-contained cooling units and for chillers used in the central system modelling are shown in the following table:

SEER	existing installations	new installations
Roof top	3.33	3.33
Single split <12kW	4.25	4.7
Wall/window	3.22	3.22
Single duct	2.30	2.49
Double duct	2.30	2.49
Split systems >12kW	3.88	4.29
VRF	4.66	4.66
All air constant volume	3.46	3.75
All air VAV	3.46	3.75
Water based fan coil	3.46	3.75
Water based induction	3.46	3.75
Heat pump loop	4.03	4.03
Active chilled beam	3.46	3.75
Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation	3.46	3.75

Table 52: B4.3: Table of base case SEER values for air conditioning products (for self-contained and packaged units) and chillers (for central plant systems)

However, the overall efficiency for a particular system type will depend not only on the SEER of the self-contained unit or chiller, but also the efficiency of the other energy using components and the various factors that affect their performance, again, plus any standby or off mode energy consumption. This overall system SEER is calculated from the kW cooling installed divided by the total system energy use calculated using the models. These overall system values will therefore be lower than their respective product or chiller SEER and will vary significantly with cooling demand. The system SEER for new installations of the ten different central system types over a range of cooling hours is shown in the following graph.

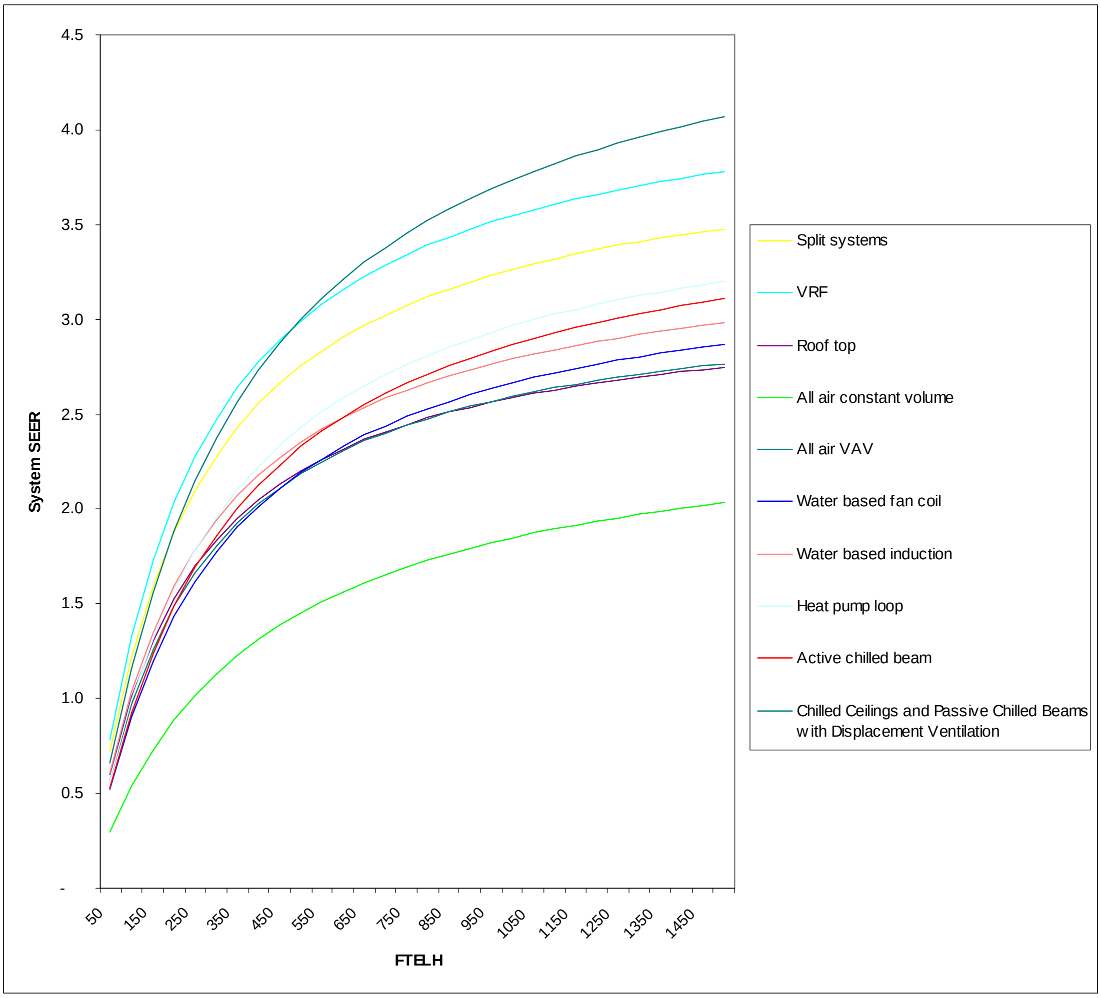

Figure 46: B4.6: Showing how the system efficiency for central systems varies with FTELH cooling

These results indicate that central air system are typically the least efficient system type, which arises because the fans in the AHU will be running at full load for the cooling system run hours. It is clear that amongst the other system types, in particular chilled ceilings and passive chilled beams with displacement ventilation, VRF and split system would appear to be the more efficient choices in most instances. However, there will be considerable variation in the actual performance in a particular application so the appropriate choice of system is far from obvious. Furthermore, technical constraints, such as having the necessary space to install a system will be important, as will economic considerations. Section B1 discusses these constraints in more detail.

Whilst some types are clearly more efficient than others it needs to be remembered that not all systems are appropriate for specific applications, and although two systems may provide a similar level of cooling they may not provide equivalent levels of comfort. For example direct expansion system (e.g. split systems, VRF) and chilled ceilings do not provide humidity control. Similarly there may be other advantages associated with certain systems which cannot be directly accounted for in the modelling e.g., the ability of heat pump loops and VRF systems to move heat around between different spaces to minimise heating energy use.

Therefore, identification of the best performing system is not as straightforward as it might appear at first sight.

As well as modelling the effect of improvements to the efficiency of products and components and reducing cooling demand on energy consumption at the individual system level the model can also be used to explore the potential savings that system switching might realise.

B4.5 Modelling the potential savings from system switching for central systems

Section B1 identifies the percentage of instances where a particular system type could potentially be installed. This reflects both technical constraints and comfort and other user requirements, but does not take into account economic considerations.

To apply this switching potential within the model, the specific building applications, e.g., low rise office, etc., were mapped onto the three main building types based on the estimated[121] breakdown of cooled floor area across Europe based on the occupancy and cooling demand pattern they were most similar to.

Offices	Offices	Shallow plan
	Offices	Deep plan
	Hotels	Public areas
	Hospitals	Treatment/diagnostic rooms
Retail	Retail	Small shop
	Retail	Large store/dept store
	Retail	Supermarkets
	Retail	Malls
	Hospitals	Operating theatres
	Theatres/cinemas	
	Exhibition halls	
	Night clubs/large venues	
	Airport/transport terminals	
Residential	Residential	
	Hotels	Bedrooms
	Hospitals	Core zones

Table 53: B4.4: Mapping Detailed Building Applications onto representative building types modelled

To model the energy savings potential associated with switching between each system type the overall system efficiency was calculated for a range of different cooling hours for new systems of typical efficiency (shown in Figure B4. 6). This was then used to rank the system types in order of efficiency for different FTELHs (See Figure B4. 7 below).

[121] In the absence of more detailed data, the distribution of cooled space amongst the building types was based on expert knowledge of the UK situation, which applied across all EU countries.

FTELhrs	Split systems	VRF	Roof top	All air constant volume	All air VAV	Water based fan coil	Water based induction	Heat pump loop	Active chilled beam	Ceilings and Passive Chilled Beams with
50.0	2	1	5	10	7	9	4	6	8	3
100.0	2	1	5	10	7	9	4	6	8	3
150.0	2	1	6	10	7	9	4	5	8	3
200.0	3	1	6	10	8	9	4	5	7	2
250.0	3	1	6	10	8	9	4	5	7	2
300.0	3	1	7	10	8	9	5	4	6	2
350.0	3	1	7	10	8	9	5	4	6	2
400.0	3	1	7	10	8	9	5	4	6	2
450.0	3	1	7	10	8	9	5	4	6	2
500.0	3	2	7	10	9	8	5	4	6	1
550.0	3	2	8	10	9	7	5	4	6	1
600.0	3	2	8	10	9	7	6	4	5	1
650.0	3	2	8	10	9	7	6	4	5	1
700.0	3	2	8	10	9	7	6	4	5	1
750.0	3	2	8	10	9	7	6	4	5	1
800.0	3	2	8	10	9	7	6	4	5	1
850.0	3	2	9	10	8	7	6	4	5	1
900.0	3	2	9	10	8	7	6	4	5	1
950.0	3	2	9	10	8	7	6	4	5	1
1,000.0	3	2	9	10	8	7	6	4	5	1
1,050.0	3	2	9	10	8	7	6	4	5	1
1,100.0	3	2	9	10	8	7	6	4	5	1
1,150.0	3	2	9	10	8	7	6	4	5	1
1,200.0	3	2	9	10	8	7	6	4	5	1
1,250.0	3	2	9	10	8	7	6	4	5	1
1,300.0	3	2	9	10	8	7	6	4	5	1
1,350.0	3	2	9	10	8	7	6	4	5	1
1,400.0	3	2	9	10	8	7	6	4	5	1
1,450.0	3	2	9	10	8	7	6	4	5	1
1,500.0	3	2	9	10	8	7	6	4	5	1

Figure 47: B4.7: Ranking of typical system efficiency for new installations (1= most efficient)

The appropriate energy efficiency ranking was then applied to each of the six modelled building types (new and existing offices, retail and residential) based on their FTELHs. The most efficient mix of system types was then determined by applying the appropriate percentage of possible system mix for each building type to the efficiency ranking until 100% is reached. This was done using the percentage of technical possible system sub types identified in Table B1.6.

For example, for new offices in Cyprus the FTELHs for cooling is 517 which, by consulting the first column in Figure B4. 7 and then reading across the system types, corresponds to an efficiency ranking order as follows:

- Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation,
- VRF,
- Split Systems,
- Heat Pump Loop,
- Water Based Induction,
- Active Chilled Beam
- Water Based Fan Coil
- Rooftop,
- All air VAV and,
- All Air Constant Volume

Applying the percentage of possible system types for offices to this hierarchy gives the most efficient mix of system types that could be installed in new offices in Cyprus. In this example Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation systems are identified as being appropriate in 60% of office applications, and VRF appropriate in 100%. Therefore the most efficient mix of system types for new offices in Cyprus would be 60% Chilled Ceilings and 40% VRF systems. The resultant energy savings from switching to the most efficient system mix are calculated from the energy consumption for the current system mix of system types and that for the most efficient system mix.

The additional potential energy savings that would be achieved from switching to the most efficient mix of the most efficient versions of each system type (i.e. one made up of BAT components)[122] was calculated in a similar way. The efficiency ranking of BAT systems is different to that for systems of typical efficiency and is shown in Figure B4.8

FTELhrs	Split systems	VRF	Roof top	All air constant volume	All air VAV	Water based fan coil	Water based induction	Heat pump loop	Active chilled beam	Ceilings and Passive Chilled Beams with
50	4	4	9	10	3	7	2	8	6	1
100	4	4	9	10	3	7	2	8	6	1
150	4	4	9	10	3	7	2	8	6	1
200	4	4	9	10	3	7	2	8	6	1
250	4	4	9	10	3	7	2	8	6	1
300	5	5	9	10	3	7	2	8	4	1
350	5	5	9	10	3	7	2	8	4	1
400	5	5	9	10	3	7	2	8	4	1
450	6	6	9	10	3	5	2	8	4	1
500	6	6	9	10	3	5	2	8	4	1
550	6	6	9	10	3	5	2	8	4	1
600	6	6	9	10	3	5	2	8	4	1
650	6	6	9	10	4	5	2	8	3	1
700	6	6	9	10	4	5	2	8	3	1
750	6	6	9	10	4	5	3	8	2	1
800	6	6	9	10	4	5	3	8	2	1
850	6	6	9	10	4	5	3	8	2	1
900	6	6	9	10	4	5	3	8	2	1
950	6	6	10	9	4	5	3	8	2	1
1,000	6	6	10	9	4	5	3	8	2	1
1,050	6	6	10	9	4	5	3	8	2	1
1,100	7	7	10	9	4	5	3	6	2	1
1,150	7	7	10	9	4	5	3	6	2	1
1,200	7	7	10	9	4	5	3	6	2	1
1,250	7	7	10	9	4	5	3	6	2	1
1,300	7	7	10	9	4	5	3	6	2	1
1,350	7	7	10	9	4	5	3	6	2	1
1,400	7	7	10	9	4	5	3	6	2	1
1,450	7	7	10	9	4	5	3	6	2	1
1,500	7	7	10	9	4	5	3	6	2	1

Figure 48: B4.8: Ranking of BAT system efficiency for new installations (1= most efficient)

The within system type analysis for moveable units and RAC units is much more straightforward as here the calculated energy performance can be calculated by altering running the model with the product SEER set to the level of the most efficient sub type for all installations.

[122] The system ranking for best performing systems

B4.6 Using the model to determine potential energy and carbon savings

The effect of applying a wide variety of energy saving options to cooling systems across the EU is explored by substituting alternative values into the energy use calculation described above. The parameters in the model that are varied in order to model the energy saving cases are summarised below:

For moveables and RACs

- ***Product seasonal energy efficiency ratio (SEER),*** which is the average energy efficiency and takes into account the seasonal load pattern
- ***Full Time Equivalent Load Hours Cooling (FTELH).*** Reduction in cooling demand compared to the base case.

For central systems

- ***Chiller seasonal energy efficiency ratio (SEER),*** which is the average energy efficiency and takes into account the seasonal load pattern
- ***Full Time Equivalent Load Hours Cooling (FTELH).*** Reduction in cooling demand compared to the base case.

And where relevant

- ***Terminal Efficiency.*** Determined as a percentage change in efficiency compared to the base case which is defined in terms of kW/KWcooling
- ***Pump Efficiency.*** Determined as a percentage change in efficiency compared to the base case which is defined in terms of kW/KWcooling
- ***AHU Efficiency*** measured in terms of the Specific Fan Power (SFP)[123]
- ***Duct Leakage*** measured as a percentage air leakage from AHU/ductwork

In order to provide policy makers with an indication of the scale of savings that the policy measures might be able to address the potential for savings that could be achieved in both existing and future cooling system installations was explored. In some instance e.g., those that require product or component replacement, they are likely to be applicable to new installations, whilst measures that impact on controls or reduced FTELH for cooling can potentially be applied to both current and future installations.

The expected growth in air conditioning across Europe is taken into account and the annual potential energy savings for new installations are calculated for the next 12 years. The growth in air conditioning systems in Europe is taken from the market analyses carried out for the Lot 6 study for central systems and the Lot 10 study for moveables and RACs. The process used - a modified form of the Bass market diffusion model calibrated to market research sales data is described in the Preparatory Study reports.

B4.7 Input Data: Base Case Assumptions and Country Specific Data used in the Model

This section summarises key inputs to the modelling, identifying data sources, assumptions and uncertainties and limitations associated with the data. The rationale for the cases that have been used to model specific cases are described in detail in Section B3 of this report.

[123] This takes account of the effect of filters and other aspects of AHU efficiency. Despite its name, SFP is actually a system characteristic.

B4.7.1 Installed Cooling Load: Moveables and Room Air Conditioners

The installed load of cooling systems and future sales of cooling systems in each EU/EEA country was taken directly from the market analyses carried out for the Lot 6 and Lot 10 Ecodesign preparatory studies[124]. For countries not covered by these studies, specifically, , Iceland, Lichtenstein and Norway, the installed stock was estimated from data for Spain, Finland, France and Sweden, respectively, on a prorate basis from population statistics. For moveables no distinction was made between single duct and double duct units in the Lot 10 study. For this study the split between single and double duct moveable systems was estimated for all countries based on available market statistics [cxvii], which indicated that double duct units make up 2% of the market.

	MW installed					
	Moveables		RACs			
Country	**Single Duct**	**Double Duct**	**Window/Wall**	**Single Split**	**Total**	***% of total***
Austria	110	2	34	2,682	2,827	***1%***
Belgium	139	3	42	3,393	3,577	***1%***
Bulgaria	359	7	67	5,345	5,778	***2%***
Cyprus	0.3	0.006	15	1,229	1,245	***0%***
Czech Republic	812	17	248	19,838	20,915	***8%***
Denmark	71	1	22	1,745	1,839	***1%***
Estonia	19	0.4	6	452	477	***0%***
Finland	86	2	14	1,152	1,254	***0%***
France	812	17	248	19,838	20,915	***8%***
Germany	1,324	27	49	3,889	5,288	***2%***
Greece	4	0.1	213	17,052	17,269	***7%***
Hungary	41	0.8	37	2,931	3,009	***1%***
Iceland	5	0.1	0.9	68	74	***0%***
Ireland	68	1	11	913	994	***0%***
Italy	3,803	78	709	56,692	61,281	***23%***
Latvia	30	0.6	9	743	783	***0%***
Liechtenstein	0.5	0.0	0.1	11	12	***0%***
Lithuania	9	0.2	1	90	100	***0%***
Luxembourg	7	0.1	2	162	170	***0%***
Malta	38	0.8	7	571	617	***0%***
Netherlands	217	4	66	5,299	5,586	***2%***
Norway	77	2	13	1,025	1,116	***0%***
Poland	812	17	248	19,838	20,915	***8%***
Portugal	0.8	0.0	38	3,024	3,063	***1%***
Romania	768	16	143	11,454	12,381	***5%***
Slovakia	143	3	27	2,135	2,307	***1%***
Slovenia	60	1	11	887	959	***0%***
Spain	14	0.3	650	52,015	52,679	***20%***
Sweden	148	3	25	1,977	2,153	***1%***
United Kingdom	988	20	165	13,190	14,363	***5%***
Total	10,967	224	3,120	249,638	263,950	***100%***
% of total	***4%***	***0%***	***1%***	***95%***	***100%***	

[124] Lot 10 Final Report Task 2: Appendix B: Installed stock of air conditioners in 2010. EU 27 in kW cooling.

Table 54: B4.5: Breakdown of the installed stock of small self-contained air conditioners used by country used in the modelling (kW of cooling capacity)

The above table indicates that moveable units account for around an eighth of the total market for small self-contained air conditioning systems and that split systems dominate accounting for nearly 90% of the installed load. Seventy percent of the total cooling load is installed in Spain, Italy, France Greece and the United Kingdom.

	Annual Sales of Systems (2010) - MW installed					
	Moveables		**RACs**			
Country	**Single Duct**	**Double Duct**	**Window/Wall**	**Single Split**	**Total**	***% of total***
Austria	12	0.2	3	269	285	***1%***
Belgium	15	0.3	4	340	360	***2%***
Bulgaria	64	1	5	391	461	***2%***
Cyprus	0.003	0.000	1	94	95	***0%***
Czech Republic	90	2	25	1,991	2,108	***9%***
Denmark	8	0.2	2	175	185	***1%***
Estonia	2	0.0	0.6	45	48	***0%***
Finland	14	0.3	1	105	121	***1%***
France	90	2	25	2,033	2,150	***9%***
Germany	144	3	4	313	464	***2%***
Greece	0.0	0.001	16	1,299	1,315	***5%***
Hungary	2	0.0	4	284	290	***1%***
Iceland	0.8	0.0	0.1	6	7	***0%***
Ireland	11	0.2	1	83	96	***0%***
Italy	675	14	52	4,320	5,061	***21%***
Latvia	3	0.1	1	75	79	***0%***
Liechtenstein	0.1	0.001	0.0	1	1	***0%***
Lithuania	1	0.0	0.1	9	10	***0%***
Luxembourg	0.7	0.0	0.2	16	17	***0%***
Malta	7	0.1	0.5	42	49	***0%***
Netherlands	24	0.5	7	532	563	***2%***
Norway	13	0.3	1	94	108	***0%***
Poland	90	2	25	1,991	2,108	***9%***
Portugal	0.002	0.000	3	269	272	***1%***
Romania	136	3	11	837	987	***4%***
Slovakia	25	0.5	2	156	184	***1%***
Slovenia	11	0.2	0.8	65	76	***0%***
Spain	1	0.0	59	4,834	4,895	***20%***
Sweden	24	0.5	2	181	208	***1%***
United Kingdom	162	3	15	1,230	1,410	***6%***
Total	1,627	33	273	22,081	24,014	***100%***
% of total	***7%***	***0%***	***1%***	***92%***	***100%***	

Table 55: B4.6: Breakdown of the current sales (2010) of small self-contained air conditioners by country used in the modelling (kW of cooling)

In terms of current (2010) sales, the breakdown between system types is similar to that for the existing stock of units, with a slight shift away from mobile units. Spain, Italy, France Greece and the United Kingdom account for two thirds of total sales.

The market modelling undertaken for the Lot 10 study indicates that sales of self-contained air conditioning units in Europe will continue to grow. For the modelling carried out for this study these market projections were adopted and are shown in Figure B4.9. This indicates that annual European sales are projected to increase by around 60% between 2010 and 2020.

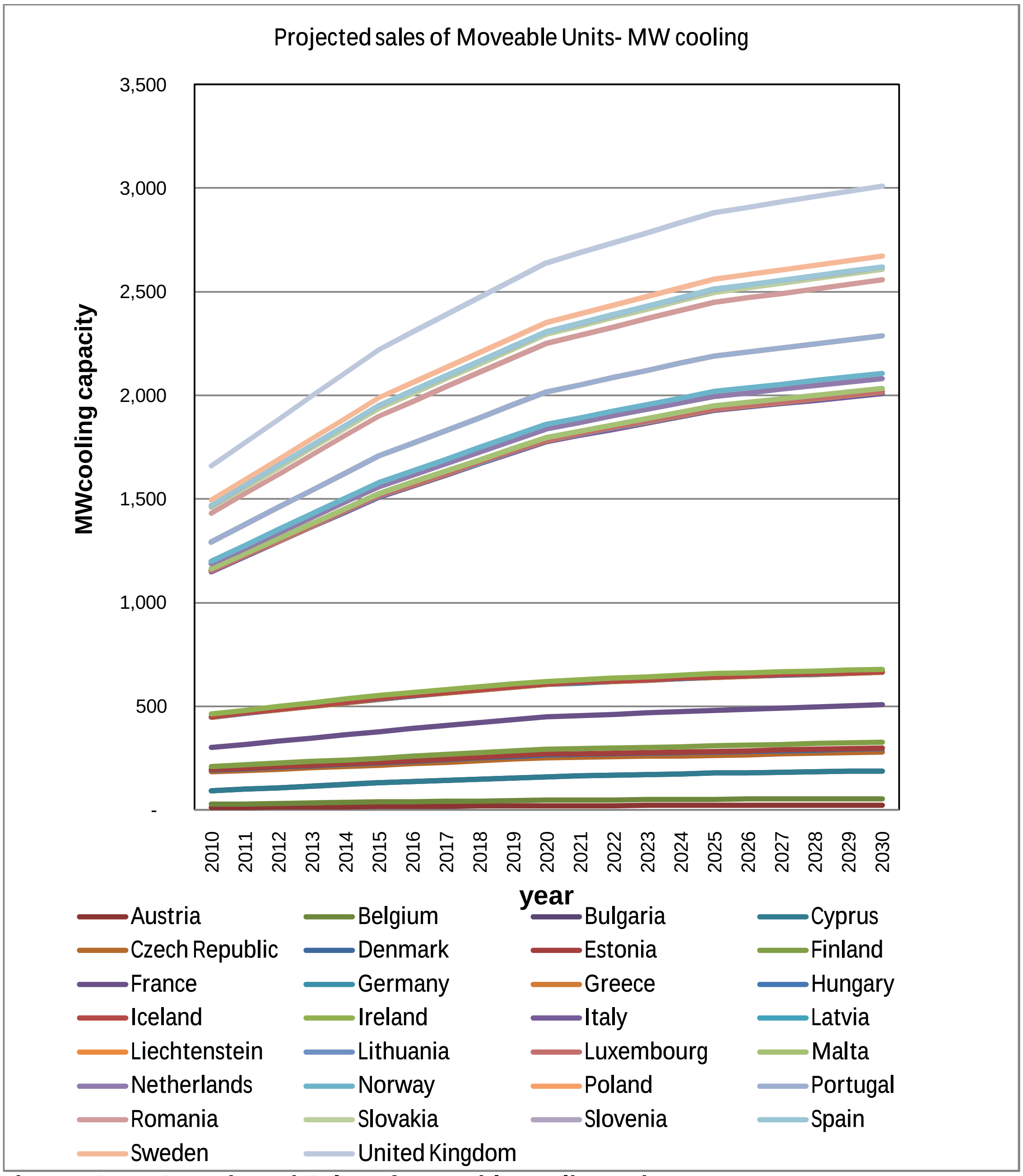

Figure 49: B4.9: Projected Sales of Moveable cooling units.

Growth in RACs over a similar period shows a more modest growth of around 25% as shown in Figure B4.10.

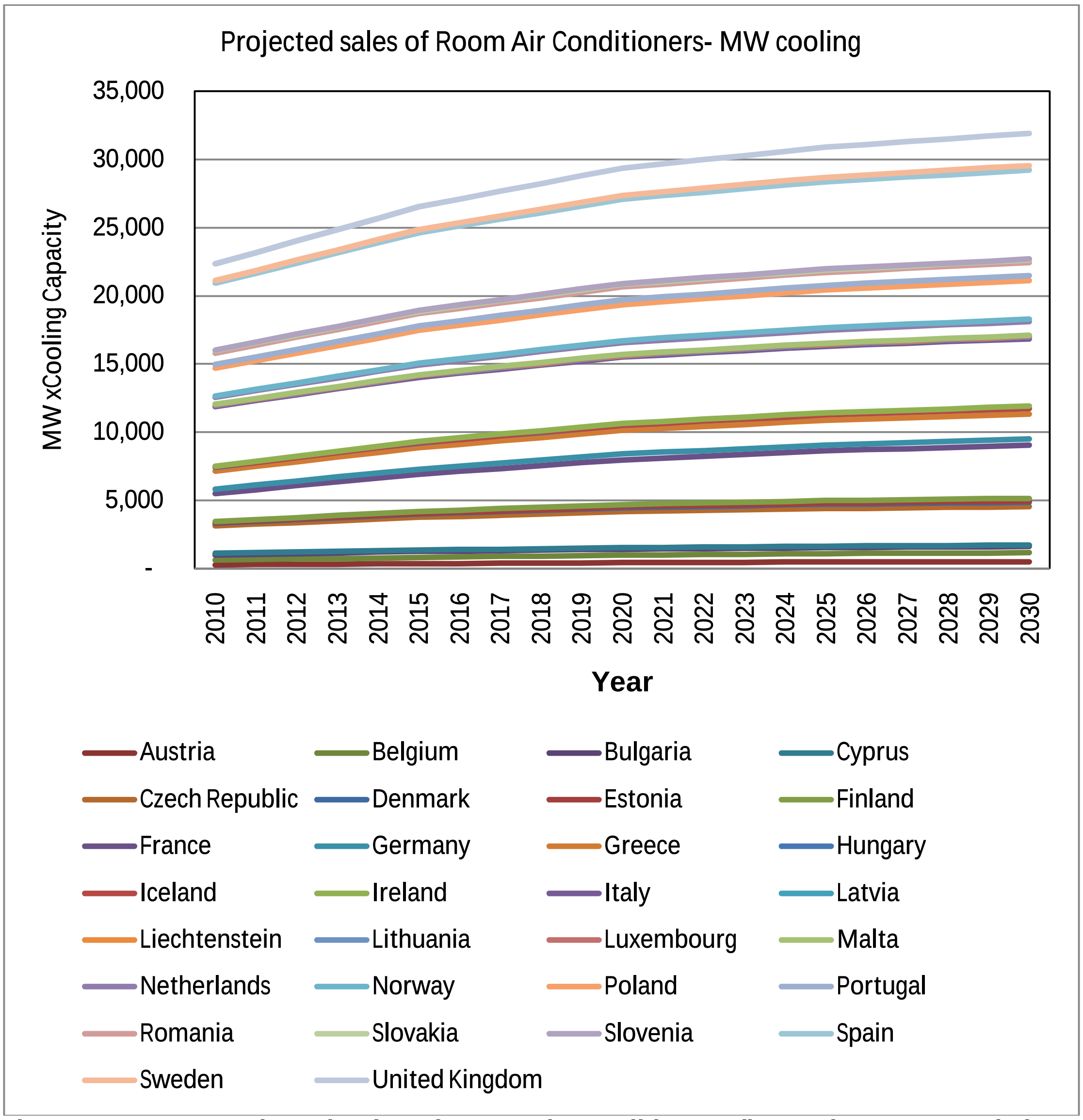

Figure 50: B4.10: Projected Sales of Room Air Conditioners (by equipment capacity) broken down by country.

B4.7.2 Installed Cooling Load: Central systems

For central systems three countries, Spain, Italy, and the UK account for over half of central systems in both existing buildings and for new installations. In both cases fan coil unit systems are the most common system type followed by larger splits (See Tables B4.7 and B4.8).

	MW installed											
MW Cooling Capacity of Central Systems in Existing Buildings	**Split systems**	**VRF**	**Roof top**	**All air constant volume**	**All air VAV**	**Water based fan coil**	**Water based induction**	**Heat pump loop**	**Active chilled beam**	**Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation**	All Central Systems	**% of total**
Austria	315	263	77	630	776	2,467	306	59	110	110	5,111	2%
Belgium	2,145	448	523	690	851	2,705	335	64	120	120	8,002	3%
Bulgaria	469	263	114	221	273	867	107	21	38	38	2,413	1%
Cyprus	138	216	34	72	89	282	35	7	12	12	896	0%
Czech Republic	517	191	126	497	612	1,946	241	46	86	86	4,348	2%
Denmark	1,152	16	281	96	119	377	47	9	17	17	2,129	1%
Estonia	169	30	41	25	30	97	12	2	4	4	415	0%
Finland	1,195	20	291	222	274	870	108	21	39	39	3,078	1%
France	4,393	3,273	1,071	1,863	2,297	7,303	904	173	324	324	21,926	8%
Germany	2,597	1,895	633	2,443	3,012	9,575	1,186	227	425	425	22,418	8%
Greece	1,561	1,180	381	610	752	2,392	296	57	106	106	7,441	3%
Hungary	209	122	51	676	833	2,648	328	63	118	118	5,166	2%
Iceland	68	1	16	20	24	77	10	2	3	3	224	0%
Ireland	386	126	94	410	506	1,608	199	38	71	71	3,510	1%
Italy	8,447	3,590	2,059	5,869	7,236	23,001	2,849	546	1,021	1,021	55,639	20%
Latvia	169	39	41	42	51	163	20	4	7	7	544	0%
Liechtenstein	2	2	0.6	1	1	4	0.5	0.1	0.2	0.2	12	0%
Lithuania	169	15	41	62	76	241	30	6	11	11	661	0%
Luxembourg	34	25	8	11	14	45	6	1	2	2	148	0%
Malta	93	65	23	15	18	57	7	1	3	3	284	0%
Netherlands	24	552	6	970	1,196	3,801	471	90	169	169	7,447	3%
Norway	1,017	20	248	294	363	1,154	143	27	51	51	3,368	1%
Poland	1,001	248	244	317	390	1,241	154	29	55	55	3,734	1%
Portugal	1,653	738	403	288	355	1,130	140	27	50	50	4,834	2%
Romania	984	173	240	545	672	2,136	265	51	95	95	5,255	2%
Slovakia	388	95	94	223	275	873	108	21	39	39	2,154	1%
Slovenia	515	126	126	63	77	246	30	6	11	11	1,210	0%
Spain	24,280	2,774	5,917	3,513	4,330	13,766	1,705	327	611	611	57,834	20%
Sweden	1,961	38	478	568	700	2,226	276	53	99	99	6,496	2%
UK	9,835	2,698	2,397	4,699	5,793	18,416	2,281	437	818	818	48,191	17%
Total	65,885	19,241	16,057	25,954	31,996	101,713	12,597	2,414	4,515	4,515	284,887	**100%**
% of total	**23%**	**7%**	**6%**	**9%**	**11%**	**36%**	**4%**	**1%**	**2%**	**2%**	**100%**	

Table 56: B4.7: Showing the breakdown of the current sales (2010) of central systems used in the modelling

	Annual Sales of Systems (2010) - MW installed											
Country	**Split systems**	**VRF**	**Roof top**	**All air constant volume**	**All air VAV**	**Water based fan coil**	**Water based induction**	**Heat pump loop**	**Active chilled beam**	**Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation**	All Central Systems	**% of total**
Austria	20	36	5	38	47	151	19	4	7	7	333	2%
Belgium	134	61	35	29	35	112	14	3	5	5	431	2%
Bulgaria	29	36	8	6	7	22	3	0.5	1	1	112	1%
Cyprus	9	30	2	2	2	7	0.9	0.2	0.3	0.3	53	0%
Czech Republic	32	26	8	13	15	49	6	1	2	2	155	1%
Denmark	72	2	19	4	5	16	2	0.4	0.7	0.7	121	1%
Estonia	11	4	3	2	2	6	0.7	0.1	0.3	0.3	28	0%
Finland	74	3	19	11	14	44	6	1	2	2	177	1%
France	274	448	71	125	154	491	61	12	22	22	1,678	9%
Germany	162	259	42	98	120	383	47	9	17	17	1,154	6%
Greece	97	161	25	49	61	194	24	5	9	9	634	4%
Hungary	13	17	3	17	21	67	8	2	3	3	154	1%
Iceland	4	0	1	1	2	5	0.7	0.1	0.2	0.2	15	0%
Ireland	24	17	6	13	17	53	7	1	2	2	142	1%
Italy	526	491	136	381	470	1,495	185	35	66	66	3,854	22%
Latvia	11	5	3	3	3	10	1	0.2	0.4	0.4	37	0%
Liechtenstein	0	0	0	0.1	0.1	0.3	0.0	0.006	0.0	0.0	1	0%
Lithuania	11	2	3	4	5	15	2	0.3	0.7	0.7	42	0%
Luxembourg	2	3	1	0.5	0.6	2	0.2	0.0	0.1	0.1	9	0%
Malta	6	9	1	0.4	0.5	1	0.2	0.0	0.1	0.1	19	0%
Netherlands	1	76	0	56	69	218	27	5	10	10	472	3%
Norway	63	3	16	20	25	79	10	2	4	4	225	1%
Poland	62	34	16	16	20	62	8	1	3	3	225	1%
Portugal	103	101	27	16	19	62	8	1	3	3	342	2%
Romania	61	24	16	14	17	54	7	1	2	2	198	1%
Slovakia	24	13	6	6	7	22	3	0.5	1	1	83	0%
Slovenia	32	17	8	4	5	15	2	0.4	0.7	0.7	85	0%
Spain	1,513	380	391	295	364	1,157	143	27	51	51	4,373	25%
Sweden	122	5	32	39	48	153	19	4	7	7	435	2%
UK	613	369	158	153	189	601	74	14	27	27	2,227	12%
Total	4,106	2,634	1,061	1,415	1,744	5,545	687	132	246	246	17,815	**100%**
% of total	**23%**	**15%**	**6%**	**8%**	**10%**	**31%**	**4%**	**1%**	**1%**	**1%**	**100%**	

Table 57: B4.8: Showing the breakdown of the current sales (2010) of central systems used in the modelling

There are considerable levels of uncertainty associated with this market data. The primary sources for the information used in the Lot 10 and Lot 6 studies are country specific market studies carried out by the Building Services Research and Information Association (BSRIA)125. [cxviii] These inevitably involve a degree of uncertainty and rely on extrapolation. Furthermore, this information was further extrapolated to cover additional countries and sales projections, which will further increase the level of uncertainty associated with this market data. Nevertheless this information is thought to provide a reasonably good picture of the market.

B4.7.3 Other Base Case Modelling Assumptions

The full load equivalent hours shown in Table B4.9 were used across all market sectors.

	new			existing		
FTELH	residential	office	retail	residential	office	retail
Austria	180	327	419	157	303	357
Belgium	95	293	294	94	218	216
Bulgaria	320	359	613	268	321	458
Cyprus	602	517	803	554	473	733
Czech Republic	145	331	425	88	213	284
Denmark	80	273	287	66	200	230
Estonia	450	446	453	124	261	323
Finland	362	491	511	301	400	473
France	216	350	462	208	291	367
Germany	89	231	280	76	151	243
Greece	525	488	779	405	434	652
Hungary	400	472	600	220	419	524
Iceland	293	435	587	242	405	345
Ireland	31	158	226	27	79	140
Italy	320	359	613	268	321	458
Latvia	464	425	478	167	267	204
Liechtenstein	180	327	419	157	303	357
Lithuania	489	285	398	24	144	210
Luxembourg	129	290	400	108	247	280
Malta	503	456	732	457	408	642
Netherlands	100	249	278	77	191	210
Norway	293	435	587	242	405	345
Poland	465	459	482	252	369	359
Portugal	270	301	578	211	234	423
Romania	400	472	600	220	419	524
Slovakia	321	406	596	255	322	445
Slovenia	295	390	486	192	301	385
Spain	413	381	626	341	336	504
Sweden	293	435	587	242	405	345
United Kingdom	79	285	300	63	200	256

Table 58: B4.9: Full load equivalent cooling hours by country and building type

The same FTELH were assumed for future years in the Modelled Cases as the growth in demand for cooling is already incorporated in the projected sales data. However, if the average temperature in the cooling season were to increase this would result in an increase in the annual average full load equivalent hours. Although this is not expected to happen on the timescales of a decade or so, which is the focus of this study, it would be possible to use the model to explore the effect of increasing external temperatures on cooling energy consumption and emissions across Europe. This could also be used to explore the extent to which this would impact on the most efficient system mix as the efficiency ranking of system types varies with FTELH.

Table B4.10 shows the country-specific inputs used in the base case model for peak cooling demand, duct leakage, specific fan power and carbon emission factors. The differences between countries in duct leakage rates and SFP arise from differences in regulations across the Member States.

	Peak Cooling Demand	Duct Leakage		SFP		Emission Factor
	kW/m2	% existing	% new	W/l/s existing	W/l/s new	kgCO2/kWh
Austria	0.093	20%	20%	3.0	3.0	0.44
Belgium	0.076	20%	20%	3.0	2.0	0.37
Bulgaria	0.091	20%	20%	3.0	2.5	0.79
Cyprus	0.121	20%	20%	3.0	3.0	1.14
Czech Republic	0.072	20%	20%	3.0	3.0	0.92
Denmark	0.067	7%	5%	3.0	3.0	0.61
Estonia	0.067	20%	20%	3.0	2.5	2.21
Finland	0.075	7%	5%	3.0	3.0	0.34
France	0.089	20%	20%	3.0	2.5	0.11
Germany	0.086	20%	20%	3.0	2.0	0.72
Greece	0.123	20%	20%	3.0	2.0	1.14
Hungary	0.091	20%	20%	3.0	3.0	0.74
Iceland	0.072	20%	20%	3.0	3.0	-
Ireland	0.061	20%	20%	3.0	3.0	0.88
Italy	0.098	20%	20%	3.0	2.5	0.64
Latvia	0.074	20%	20%	3.0	3.0	2.21
Liechtenstein	0.089	20%	20%	3.0	3.0	0.44
Lithuania	0.067	20%	20%	3.0	3.0	0.12
Luxembourg	0.085	20%	20%	3.0	3.0	0.64
Malta	0.121	20%	20%	3.0	3.0	0.59
Netherlands	0.078	20%	20%	3.0	3.0	0.72
Norway	0.075	7%	5%	3.0	3.0	0.05
Poland	0.067	20%	20%	3.0	2.5	1.18
Portugal	0.118	20%	20%	3.0	2.0	0.69
Romania	0.091	20%	20%	3.0	3.0	0.80
Slovakia	0.091	20%	20%	3.0	3.0	0.50
Slovenia	0.081	20%	20%	3.0	3.0	0.48
Spain	0.114	20%	20%	3.0	3.0	0.59
Sweden	0.072	7%	5%	3.0	3.0	0.10
United Kingdom	0.069	20%	7%	3.0	2.5	0.68

Table 59: B4.10: Country specific input used to define the base case in the central system model (N.B. emission factors apply to all market sectors)

Table B4.11 shows the system specific input parameters and values used for the base case of the central system model.

Parameter	*unit*	Split systems	VRF	Roof top	All air constant volume	All air VAV	Water based fan coil	Water based induction	Heat pump loop	Active chilled beam	Chilled Ceilings and Passive Chilled Beams with Displacement Ventilation
kW terminal/kW cooling	*kW/kW cooling*	0.00	0.00	0.00	0.00	0.00	0.02	0.00	0.02	0.02	0.00
Local latent load	*kW cooling*	0.25	0.25	0.25	0.00	0.00	0.10	0.10	0.25	0.00	0.00
Extra cooling load from mixing reheat etc	*% loss*	0%	0%	0%	0%	4%	4%	4%	0%	4%	4%
Extra load from imperfect zoning	*% loss*	0%	0%	0%	15%	0%	0%	0%	0%	0%	0%
Proportion of load handled by air sub-system	*% air distribution*	0%	0%	35%	100%	100%	35%	35%	0%	35%	0%
Central latent load	*% loss*	10%	10%	10%	25%	10%	10%	10%	10%	10%	10%
VAV factor (ratio of efth with VAV:efth withou VAV)	*% saving*	100%	100%	100%	100%	30%	100%	100%	100%	100%	100%
Pipe heat pickup	*%*	5%	5%	5%	5%	5%	5%	5%	3%	5%	5%
Reclaimed cold losses	*% reclaim*	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Cooling pump pickup factor	*%*	50%	50%	50%	50%	50%	50%	50%	50%	50%	50%
Cooling pump power	*kW/kW cooling*	0.00000	0.00000	0.00000	0.00000	0.00000	0.00065	0.00075	0.00065	0.00090	0.00090
Cooling Flow Rate	*W/l/s*	2.08	2.08	2.08	8.33	8.33	2.08	2.08	2.08	2.08	1.56
Chiller Ancillaries	*kW/kW cooling*	0.00	0.00	0.00	0.10	0.10	0.10	0.10	0.10	0.10	0.10
Cooling proportion	*%*	0%	0%	0%	33%	0%	0%	0%	0%	0%	0%

Table 60: B4.11: System specific input used to define the base case in the central system model

Table B4.12 summarises other base case central system inputs that are neither country specific nor system specific.

Parameter	Units	Value
current stock standby energy	kW/kW cooling	0.05
current stock gross standby hours	gross annual hours	4380
current stock off mode energy	kW/kW cooling	0.01
current stock gross off mode hours	gross annual hours	8760
% unecessary oversizing	%	0.25
peak cooling demand	kW	0.8
Implied floorarea -	m2	8
controls factor	% control	0.95
Terminal Auxiliary pickup factor	% pickup	1
Allowance for imperfect local control	% loss	0.02
Reclaimed leakage losses	% reclaim	0
Duct heat pickup	% increase	0.05
Reclaimed cold losses	% reclaim	0
Difference in sfp (this accounts for the extra resistenc	W/l/s	0
Fan energy pickup factor	%	0.8
System run hours	hours pa	3325
ventilation flow required	W/l/s	2.083
cooling only run hours	hours pa	1000
notional flow factor	l/s/m2	10

Table 61: B4.12: Other (non system and non-country specific) inputs used to define the base case in the central system model

The above input parameters form the base case of the modelling, which is then used as the reference point against which the other cases are modelled and compared. For example, for a modelled case that takes into account labelling programmes or MEPS implementation, the EER of products might be expected to change as a result and such changes form the basis of the Modelled Cases. The above input parameters are those used as inputs to the spreadsheet model included with this report.

B5 MODELLING RESULTS

This section presents the potential energy and carbon savings for the Modelled Cases and described in Section B3, using the modelling process outlined in B4. These form the quantitative basis of the analysis in section A4, which in turn leads to the recommendations in section A3 (discussed in more detail in B6). While this section contains some commentary, the principal analysis is in A3.

The results cover a large number of cases, each of which can be examined from several perspectives. This section therefore contains many tables. The following paragraphs explain the structure if the section

Section B5.1 presents an overview of the results for the *Base Case* defined in section B3, The Base Case represents the annual energy consumption of all cooling installations currently in use combined with the expected annual sales of air conditioners over the next 10 years in order to calculate the cumulative expected energy consumption over the coming 10 years. All other *Cases* are compared against this case in order to estimate the potential savings associated with the initiatives in the particular *Case*.

Section 5.2 reports the results of the other cases separately for each of the three broad categories of air-conditioning systems: moveable units, fixed packaged systems; central systems. In each category one case represents the maximum potential savings that could be achieved by the universal implementation of BAT, whilst the remainder are less extreme options. These cases represent the potential impact of possible measures, and different levels of requirement within each type of measure.

Within each subsection modelling results are presented for potential reductions in energy consumption and the consequent carbon emissions for each country and in total. These are presented both as:

- absolute values that show which countries have the largest potential for reductions, generally reflecting the size of the market in each country
- percentage savings (relative to the base case) that more clearly identify the impact of other modelled national differences such as climate, market maturity, existing policy, mixture of system types etc

Some cases impact only on newly installed systems or products (whether as replacements or first-time installations in new or existing buildings), while others also impact on existing systems. Within each subsection absolute and percentage potential savings are presented separately for “existing stock” and “new installations”

Different types of air conditioning systems have inherently different efficiencies and the model was also used to examine what energy and carbon savings that could, in principle, be achieved by switching to an idealised mix of system types. This was done both within each of the three main system categories and across all system types. These results are reported in Section 5.3

Some of the cases considered are unlikely to be implemented except as part of a major building refurbishment or change of air conditioning system. Section B5.4 explains how the modelling results have been modified to take account of these additional constraints before being used as the basis for the recommendations that are presented in Section A3 An overview at the start of each section provides a summary of the results in that section, focusing on the cumulative potential energy savings over a ten year period following the introduction of a measure.

The results relate to energy used to support a “comfort cooling” service and a mechanical ventilation service if this is provided by the air conditioning system. They do not include energy used for a heating service (which can be provided by the majority of air conditioning systems) nor additional energy that may be required for specialist applications (for example to meet special filtration needs or close control of humidity).The modelling studies carried out for this study are necessarily based on typically performing products, systems and buildings whereas in reality there will be a wide range of performance characteristics and an associated variation in the energy and carbon savings that can be achieved. In addition there is a degree of uncertainty associated with some of the input values and assumptions used in the modelling (Section B3 provides r details of the base case data sources and assumptions). Furthermore, they presume that a particular change can be implemented universally across all systems. In most cases the effect of implementing multiple measures will not be additive because of interactions and overlaps. These are taken into account when considering the realisable savings from policy components and the procedure used to avoid double counting of savings described in Section B5.4.

B5.1: Current Energy Consumption

This section provides an overview of the annual energy use for existing installations of cooling systems and predicted energy use for all new installations over the next ten years. This constitutes the base case energy use against which the Modelled Cases are compared to calculate the energy savings potential.

The base case represents the current situation and includes energy savings measures that are already in effect. It includes existing policies such as mandatory labelling of units smaller than 12 kW, voluntary labelling of chillers and air handling units and national regulations on duct leakage (where these are known to exist). The base case also takes account of typical building construction and prevalent building codes via the typical annual cooling demand (FTELH cooling as kW/m^2) for six representative building types in each country in each country (See Section B4 for further details).

The codes used for the modelled base cases are M0, RAC0 and C0, where these are related to moveable units, fixed room air conditioners < 12kW and central systems (and packaged system > 12 kW) respectively. These specific modelling inputs for these are provided in Section B3.

The modelled total energy consumption for cooling from all air conditioning systems (moveables, RAC and central systems) is 112.2 TWh pa with an additional 49 TWh pa consumed by air conditioning systems to support the ventilation function. (The majority of fan energy consumption is assumed to support the provision of fresh air: the component that is used to support the cooling function is accounted under the cooling heading. The modelling procedure that was used to determine the cooling related proportion of fan energy consumption is provided in section B4.3). This is slightly lower that the figure presented in the EECCAC study [cxix] in 2003, which estimated likely consumption in 2010 to be about 94.7 TWh pa. The Harmonac study estimated the total consumption for cooling and ventilation functions of air conditioning systems to be about 198 TWh pa. This compares to this study’s estimate of 140.50 TWh pa for both the cooling and ventilation function of these systems. The modelled figure may be an under-estimate as it assumes reasonably well-controlled systems, but research [cxx] shows that many systems operate for unnecessarily long hours.

These figures are all appreciably higher than the figures reported by JRC[cxxi]. It seems likely that the JRC report omits central systems, and only includes fixed and moveable room units.

The only reference source appears to be the Energy-using Product Preparatory Study for air conditioners of less than 12kW cooling capacity. The estimated energy consumption of such products in the present study is similar to the JRC figure.

Name of Study	Total estimated Annual cooling consumption in EU countries TWh pa	Comments
This study	112.2 (moveables+ Room ACs + central systems) plus 49 for ventilation-related energy consumption (161.7 cooling and ventilation)	Model results from the present study
EcoDesign Preparatory Studies [cxxii]	Cooling: 38.6 (Lot 10 but for earlier year) + 74 (Lot 6) = 112.6 Ventilation (not only associated with air conditioning) 100 TWh [126]	
EECCAC study [cxxiii] in 2003	94.7	
Harmonac study	198	
Electricity Consumption and Efficiency Trends in European Union - Status Report 2009, European Commission Joint Research Centre Institute for Energy [cxxiv]	38.6	Likely omits energy consumed by central systems

Table 62: B5.1 Comparison of air conditioning annual consumption estimates for EU by various studies

The estimated consumption for the cooling function alone represents about 11% of tertiary sector electricity consumption.[cxxv] When the ventilation function is added, the percentage increases to 18%

To put the relative magnitude of energy use by product type, the following pie chart illustrates that the large systems account for nearly two thirds of the total energy consumption of AC systems.

[126] This figure is not explicitly stated in the report but has been inferred from data in the report)

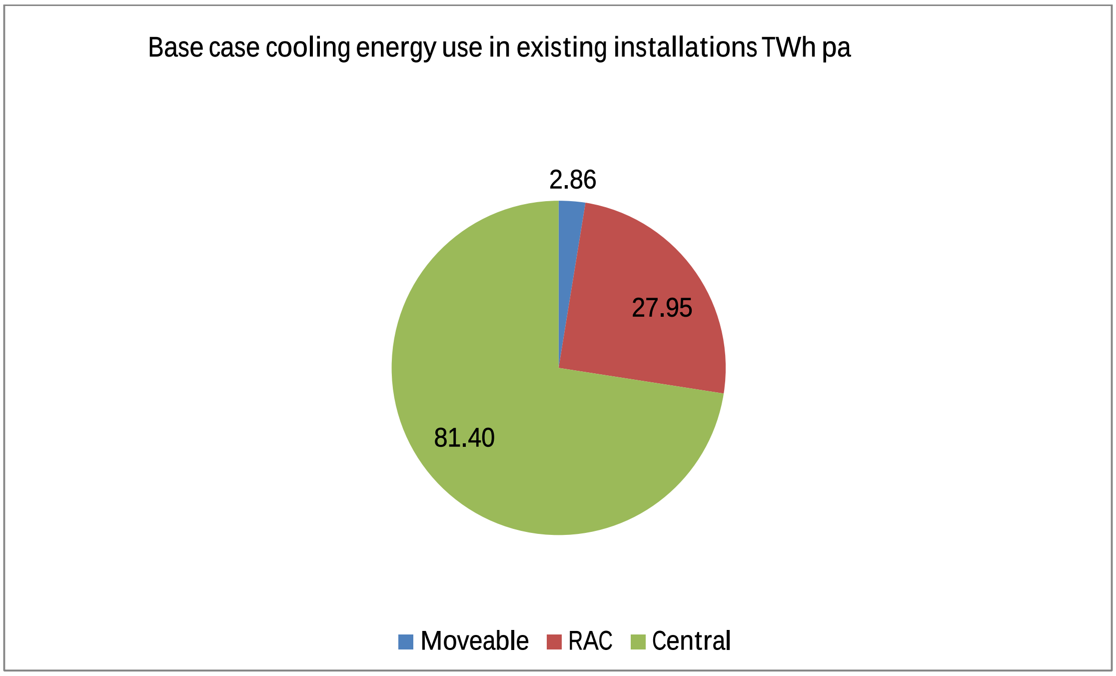

Figure 51: B5.1 Base Case Consumption by System Type

Figure B5.1 shows that fixed and moveable room units of less than 12 kW cooling capacity account for just over a quarter of cooling-related consumption. Moveable units only account for 4%. In addition, essentially all ventilation energy associated with air conditioning systems is from central systems. Energy used by mechanical ventilation systems without mechanical cooling has not been considered in the modelling studies. When energy consumption for both cooling and ventilation is considered, central systems account for around 85% of consumption.

The annual energy consumption for both the existing stock of cooling systems and installations in future years (sales) of cooling systems were calculated based on projected sales of products and the estimated installed stock for different building types in each European country where it is available and has been interpolated to cover countries where it is not. The typical performance of the products and system components were based on an analysis of the market mix of products at the European level, or more specific national level information where this was available. The cooling energy consumption in each country determined using typical FTELH (equivalent full-load hours of cooling per year) for six building types within each country[127]. Further details of the calculation procedures adopted for each of the three main system types are provided in Section B4 of this report.

The resultant annual electricity consumption attributed to the use of air conditioning of buildings in Europe is substantial and is expanding. The economic downturn notwithstanding, it is likely that annual product sales (measured by kW cooling) will be about 35% higher in ten years' time, and the installed stock will be at least 30% higher. Air conditioning energy use accounts for over 110 TWH per annum of electricity use in the EU, with an additional 49 TWh per annum consumed by air conditioning systems to support the ventilation and air distribution functions. The breakdown of AC use in TWh per annum by country and by type of equipment used is presented on Table B5.2.

[127] The FTELH cooling takes account of both the climate and the typical building constructions within each country

Estimated Energy Use by Existing Installations (2010)						
Energy Consumption TWh pa	**Cooling**				**Ventilation**	**All Cooling and Ventilation**
	Moveable	**RAC**	**Central**	**All Systems**	**Central**	**All systems**
Austria	0.03	0.35	1.59	**1.97**	0.79	**2.76**
Belgium	0.02	0.27	1.90	**2.20**	1.64	**3.84**
Bulgaria	0.11	0.60	0.72	**1.43**	0.41	**1.84**
Cyprus	0.00	0.23	0.31	**0.54**	0.12	**0.66**
Czech Republic	0.15	1.69	1.22	**3.06**	0.89	**3.95**
Denmark	0.01	0.13	0.40	**0.55**	0.48	**1.03**
Estonia	0.00	0.04	0.10	**0.14**	0.10	**0.25**
Finland	0.03	0.16	0.86	**1.05**	0.59	**1.63**
France	0.20	2.17	5.91	**8.28**	3.88	**12.16**
Germany	0.22	0.27	5.82	**6.31**	3.86	**10.17**
Greece	0.00	2.57	2.46	**5.03**	0.96	**5.99**
Hungary	0.01	0.43	1.90	**2.34**	0.80	**3.14**
Iceland	0.00	0.01	0.06	**0.07**	0.05	**0.12**
Ireland	0.01	0.04	0.85	**0.90**	0.85	**1.76**
Italy	1.21	6.12	18.35	**25.68**	8.50	**34.18**
Latvia	0.01	0.07	0.13	**0.20**	0.12	**0.32**
Liechtenstein	0.00	0.00	0.00	**0.00**	0.00	**0.01**
Lithuania	0.00	0.01	0.16	**0.16**	0.15	**0.32**
Luxembourg	0.00	0.01	0.03	**0.05**	0.03	**0.08**
Malta	0.02	0.09	0.08	**0.18**	0.04	**0.22**
Netherlands	0.04	0.39	2.09	**2.52**	1.36	**3.88**
Norway	0.02	0.13	0.91	**1.07**	0.62	**1.69**
Poland	0.22	2.45	1.05	**3.72**	0.87	**4.59**
Portugal	0.00	0.30	1.16	**1.46**	0.68	**2.14**
Romania	0.28	1.45	1.76	**3.48**	0.87	**4.35**
Slovakia	0.04	0.24	0.67	**0.95**	0.36	**1.31**
Slovenia	0.02	0.09	0.28	**0.39**	0.25	**0.64**
Spain	0.00	6.35	16.25	**22.60**	8.34	**30.95**
Sweden	0.04	0.25	1.77	**2.06**	1.24	**3.31**
United Kingdom	0.17	1.05	12.59	**13.80**	10.64	**24.45**
All Countries	**2.86**	**27.95**	**81.40**	**112.21**	**49.51**	**161.72**

Table 63: B5.2. Estimated annual energy consumption by system type attributed to existing cooling installations plus the additional energy used by these systems to provide a ventilation function in each EU/EEA member country.

The European air conditioning market is still expanding and, since air conditioning systems have relatively long lives, decisions taken today will affect consumption for decades to come. Furthermore, there is a greater potential for policy to act on future installations than the existing stock so the energy use of future installations is likely to be more important. Table B5.2 estimates the cumulative energy use for all new installations for a 10-year “business as usual” case. Roughly two-thirds of this is market growth; the remaining one-third is replacement sales, though the proportion of replacements is increasing.

Estimated Cumulative Cooling Energy Consumption for all new installations between 2010 and 2019 (including replacements)						
Energy Consumption TWh pa	**Cooling**				**Ventilation**	**All Cooling and Ventilation**
	Moveable	**RAC**	**Central**	**All Systems**	**Central**	**All systems**
Austria	0.16	2.81	7.29	**10.26**	3.77	**14.04**
Belgium	0.17	2.65	5.92	**8.74**	5.99	**14.73**
Bulgaria	1.43	3.36	1.97	**6.76**	1.53	**8.29**
Cyprus	0.00	1.25	1.04	**2.28**	0.57	**2.86**
Czech Republic	0.90	17.29	2.73	**20.92**	2.44	**23.36**
Denmark	0.08	1.30	1.35	**2.74**	1.80	**4.54**
Estonia	0.04	0.53	0.50	**1.07**	0.53	**1.60**
Finland	0.29	1.30	3.97	**5.55**	2.84	**8.39**
France	1.31	19.41	27.43	**48.14**	20.12	**68.26**
Germany	1.36	2.04	17.59	**20.99**	14.36	**35.35**
Greece	0.00	16.98	12.55	**29.53**	5.07	**34.60**
Hungary	0.03	3.33	3.69	**7.06**	1.74	**8.80**
Iceland	0.01	0.07	0.27	**0.35**	0.19	**0.53**
Ireland	0.10	0.45	1.72	**2.27**	1.99	**4.26**
Italy	15.00	33.73	61.13	**109.86**	30.18	**140.04**
Latvia	0.07	0.86	0.67	**1.60**	0.60	**2.20**
Liechtenstein	0.00	0.01	0.01	**0.03**	0.01	**0.04**
Lithuania	0.02	0.08	0.80	**0.90**	0.71	**1.61**
Luxembourg	0.01	0.14	0.13	**0.27**	0.13	**0.41**
Malta	0.18	0.46	0.32	**0.96**	0.21	**1.17**
Netherlands	0.26	3.78	7.12	**11.17**	4.97	**16.14**
Norway	0.24	1.13	3.72	**5.09**	2.35	**7.44**
Poland	1.90	22.30	3.90	**28.10**	3.48	**31.58**
Portugal	0.00	2.24	4.73	**6.97**	3.10	**10.07**
Romania	3.19	8.67	4.10	**15.96**	2.52	**18.48**
Slovakia	0.57	1.42	1.61	**3.60**	1.06	**4.66**
Slovenia	0.20	0.56	1.45	**2.20**	1.35	**3.55**
Spain	0.02	46.63	65.68	**112.33**	33.23	**145.57**
Sweden	0.47	2.17	7.19	**9.84**	4.70	**14.53**
United Kingdom	1.98	9.10	25.16	**36.25**	26.00	**62.25**
All Countries	**30.02**	**206.05**	**275.74**	**511.81**	**177.52**	**689.33**

Table 64: B5.3 The estimated cumulative energy consumption attributed to cooling plus the additional energy used by these systems to provide a ventilation function for all new installations 2010-2019 for each EU/EEA member country.

Please note that the numbers on Table B5.3 represent estimated cumulative energy consumption in TWh over ten years for each country. The previous Table B5.2 represents the annual consumption for current air conditioning units in operation. The size of both existing cooling energy consumption and of that which can be targeted by efficiency measures varies considerably among the EU and EEA Member States. This is because of the differences in population size, climatic conditions, type of building construction, differences in building codes, shading practices and differences in simple things such as the installation of (secure) openable windows to allow natural ventilation. Many new office buildings, for example, are not provided with openable windows, and all ventilation air and cooling must be provided mechanically.

The following section reports the potential energy savings that have been addressed for a range of Modelled Cases. These have been calculated by comparing the calculated energy consumption that would be achieved if the stated change were universally implemented across all European countries, to the energy consumption calculated for the base case above.

B5.1.1 Overview of Modelled Cases

The energy savings calculated by the model implicitly assume that the cooling system is operated and maintained appropriately. Most operational and maintenance savings are really related to waste avoidance and are the product of human/system interactions (e.g., appropriate setting of time and temperature controls and routine maintenance schedules) and are not amenable to the engineering based modelling approach used here. Instead, potential savings from operation and maintenance measures are taken directly from other field studies. The model does however consider some automated aspects of control that affect energy performance, e.g., the impact of VAV drives and other unavoidable system losses. Existing data from actual building studies rather than modelling are used to inform the potential savings associated with behavioural measures and controls. These are discussed in section B5.4 which explains how the realisable savings potential for policy components were derived.

Whilst the results of the Modelled Cases presented here provide a reasonable basis for assessing the scale of energy and carbon savings that could potentially be accessed by different sorts of policy interventions, more detailed studies would be required to explore the likely savings that might arise from more specific policy options.

The modelling is based on an assessment of energy use and savings on an annual basis and for existing systems the model represents an idealised view of the potential savings assuming that all systems are changed immediately. The summarised results, therefore, show just a single potential savings figure for each case for existing buildings.

The Modelled Cases explore the energy saving opportunities for cooling systems at three different levels;

- Product and component energy performance
- System energy performance, which incorporates component energy performance
- Building energy performance, which relates to building design

The cases that have been modelled for this study explored the potential savings that can be achieved for each of the following system types:

Moveable Systems:

Single Duct

Double Duct

Room Air Conditioners:

Window Wall

Single Split <12kW

Central systems:

Larger Split Systems

VRF

Rooftops

All Air Constant Volume (CAV)

All Air Variable Volume (VAV)

Water based fan coil unit

Water based induction unit

Heat pump Loop

Active Chilled Beam

Chilled Ceiling/Passive chilled beam/other construction embedded cooling

A detailed description of these system types is provided in Section B1 of this report.

The Modelled Cases assess the realisable annual savings over a ten year period from a series of possible components of policy, such as different levels of MEPS. These savings are the difference between projected consumption in the base case and that of the modelled case. They capture both the savings resulting from the replacement of existing systems and products by more efficient ones (and, for load reduction, the upgrading of existing buildings) and also the reduction in the growth in consumption from the use of more efficient products and systems (or reduced loads).

The Modelled Cases consider the effect of a range of different performance standards from BAT level downwards that are applied at either the product/component, system or building level.

For building and system level cases, the potential annual energy savings for the existing installations were calculated as well as those for new installations.

System Type	Policy Intervention Point		Base Case	Labelling and information	Labelling information and financial incentives	MEPs and labelling		MEPs, labelling and financial incentives		BAT
						Light	Moderate	Light	Moderate	
Moveables	***Product/System***		MO			M1/M2	M3	M4/M5	M6	M7
	Building						M8			M9
RAC	***Product/System***		RAC0			RAC1/RAC2/RAC3	RAC4/RAC5	RAC6/RAC7/RAC8	RAC9/RAC10	RAC11
	Building						RAC12			RAC13
Central and Larger Systems	***Product***	Chiller	C0	C1	C2	C3/C4	C5	C6/C7	C8	C9
		AHU (incorporating fans)		C10	C11		C12		C13	C14
		Pumps					C18		C19	C20
		Terminal efficiency					C15		C16	C17
	System	Ductwork air leakage					C21			C22
		Overall performance					C25/C24/C23			C26
	Building						C27			C28

Table 65: B5.4 Summary of Modelled Cases (details of the cases can be found in Section B3

Table B5.4 presents an overall picture of the cases that were modelled. The rows indicate the system types and system components and the columns indicate the particular initiative, starting with the base case (no initiative) going through various MEPS, levels and financial incentives, and ending with the Best Available Technology case. The letters and numbers in the boxes represent the various case numbers that were run through the modelling process, where the products are identified as follows:

- M0 to M9 represent mobile AC cases,
- RAC1 to RAC13 represent mobile air conditioning cases, and
- C1 to C28 represent central AC systems and components cases.

These Modelled Cases are described in more detail in Section B3.

In addition, the potential savings that could be achieved by system switching *within* each of the main system categories, and from system switching *between* the main system categories, were also explored.

B5.1.2 Modelled Savings for New Installations

The uptake rate for new installations that is used in the model is based on projected sales of products quantified in terms of kW cooling. For moveable and RAC, sales of units can be directly related to the volume of new installations. However, for central systems sales of chiller units do not necessarily relate to system installations. This is because most central systems comprise a variety of standard and bespoke components and these components have different lifetimes and are often replaced independently. Where central systems are installed in new buildings and retrofit applications in existing buildings, the one to one relationships between chiller sales and system installation is retained. However, where these sales relate to the replacement of failed units in existing buildings, this relationship does not hold and it is appropriate to make adjustments to the savings generated directly from the modelling in instances when they relate to components other than chillers.

For the Modelled Cases that relate to product or component standards, the modelled savings for new installations provide a good indication of the level of savings that standard related policies are likely to achieve. In practice failures in measurement standards and metric and compliance may lead to the savings not being fully realised.

For Modelled Cases that relate to system and building measures, the levels of uncertainty associated with the results are likely to be higher than those for product standards. Here there will be an even greater variation in performance across the stock (compared to product and component measures) arising from the additional variation of system and building related variables.

The modelling is based on an assessment of energy use and savings on an annual basis and for simplicity the model assumes that all installations take place on January 1. In reality systems are likely to be installed more evenly over the course of 12 months, so the actual savings that accrue in the first year will be around half of the reported savings. The results presented in this section for new installations are summarised to show the cumulative savings over 10 years, from 2010 (the baseline year) to 2019.

B5.1.3 Modelled Savings for Existing Buildings

The results from Modelled Cases for the existing building stock indicate the potential savings that exist across the currently installed stock of cooling systems. The extent to which these savings could be realised in practice will be dependent on the policy implementation route, in particular the roll out rate, the extent to which the policy accesses the savings assumed in the modelled case and the compliance rate. For example, if the modelled case presented here for A/C system inspection were to be required for all existing buildings on sale or rent (e.g., where an EPC is required under the EPBD), then the savings achievable would relate to the proportion of the existing stock that is sold or rented each year, how effective the policy is expected to be in realising the savings identified and the extent to which the policy is complied with. The modelled savings presented in this section indicate the annual savings potential for the estimated current installed stock.

These considerations are taken into account when generating the realisable savings potential identified in Section B5.4

B5.2 Results for Modelled Cases

This section summarises the modelling results obtained for the Modelled Cases using the input values detailed in section B3.9. The Modelled Cases are presented in detail in section B3. The first part summarises the maximum savings that would be achieved by implementing the current best available technology (BAT) in all feasible instances regardless of cost considerations. This then establishes a limiting yardstick. Whilst current BAT technology is unlikely to be cost effective, even at the societal level, it is not unreasonable to assume that current BAT might be nearly cost effective in a few instances; it would be unlikely to be on the market in the first place if this was not the case. Furthermore, for cooling products the cost of current BAT technology is liable to decrease rather than increase so it may become cost effective in more instances in the future. Therefore it is reasonable to assume that current BAT technology has the potential to become cost effective (at least at the societal level) in the future.

B5.2.1 Maximum Technical Potential Savings (BAT)

One set of Modelled Cases deals with the maximum technical potential for savings that would arise if “Best Available Technology” (BAT) was applied universally to all types of air conditioners. This sets limits on possible savings using current – but not generally common - technology.

The combined effect of implementing BAT for each system type produces aggregate potential savings of around 48% for new installations, where the BAT system savings are comprised of BAT moveable units (M7), BAT RACs (RAC11), VAT chillers and larger packaged units (C9), BAT AHUs (C14), BAT fan coil units (C17) and BAT pumps (C20). The modelling results show that the cumulative energy savings would be 213 TWh over the next 10 years if all future installations were of BAT energy efficiency. Figure B5.2 shows how these savings are distributed over the three main system types.

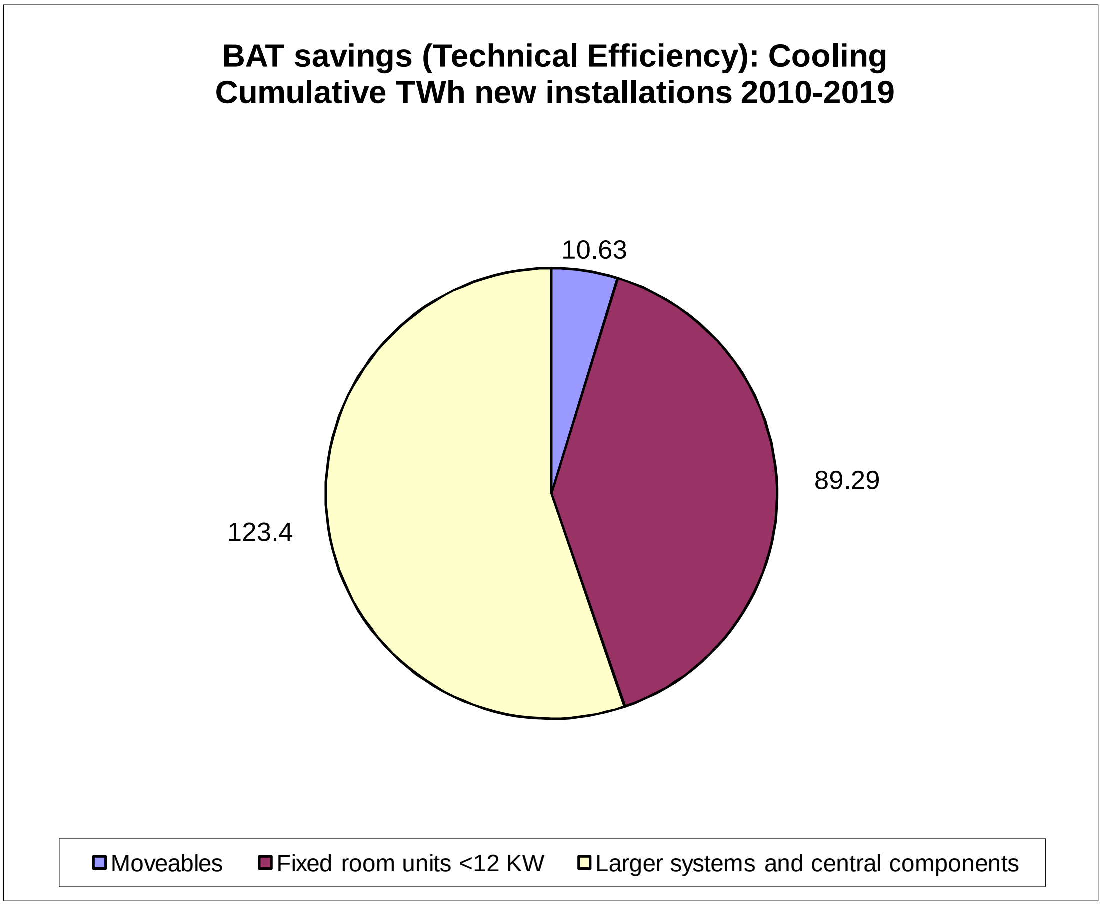

Figure 52: B5.2 Potential Savings (technical efficiency) when BAT is applied to air conditioning equipment (excluding energy to move air or chilled water distribution equipment)

Load reduction measures relating to the building envelope have the potential for similar saving: 273 TWh per annum or 53% of base case consumption if it were applied to all new cooling installations. In addition, there is the technical potential for a similar proportion of savings to be made in existing buildings.

The combined potential savings from BAT products and components and BAT envelope measures amount to 75% of base case consumption. Although the potential savings are very high, in practice, it is impractical to retrofit every installation with the best available technology for air conditioning, but the figure indicates the magnitude of the opportunity. In practice, equipment is replaced after it fails, becomes too expensive to repair and operate, or because of building refurbishment. Figure B5.2 shows the distribution of potential energy savings for the cooling function. It broadly reflects that of existing consumption, but that the importance of central systems is greater compared to other system types.

More detailed results are shown graphically on the charts in Figures B5.3 and B5.4 below.

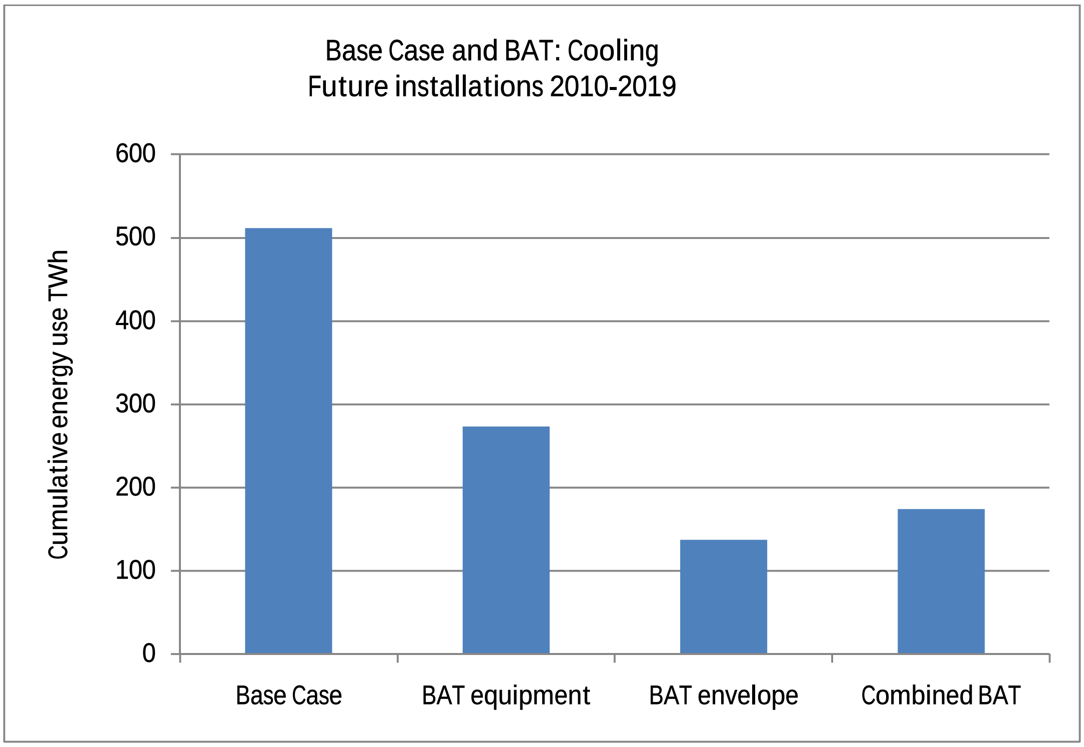

Figure 53: B5.3 Summary of BAT cases: cooling

Due to the impracticality of replacing all systems with BAT and reducing building envelope heat gains, these calculated energy savings are indicative of the technical potential that exists, but it will require considerable time, effort and money to realize.

The potential savings that are theoretically available are considerable. The contributions of load reduction by building envelope measures (basically shading and ventilation, to a lesser extent from insulation) and by improvements to system efficiency are of very similar magnitude.

In addition to cooling related energy use, the amount of energy consumed by air distribution systems (central systems) for moving air for ventilation purposes can be very significant. (Outside air is added to provide the required rate of air change for health reasons, adding to the air distribution load both in volume and in operating time of the equipment.) Considering only the energy component of the air handling system associated with the ventilation function only, the model was used to calculate the amount of energy used per annum by these systems under the following four conditions:

First column: Base case, representing the cumulative energy consumption of air handling systems for ventilation only of all future installations from 2010-2019, of about 266TWh

Second column: Cumulative energy consumption if BAT systems are applied to air handling and distribution systems, of about 210 TWh.

Third column: Cumulative energy consumption with reduced air flow requirement (for non-smoking buildings), of 111 TWh.

Fourth column: Cumulative consumption of all air handling and distribution systems with BAT applied and reduced air flow requirement to all future installations 2010-2019, of about 87 TWh.

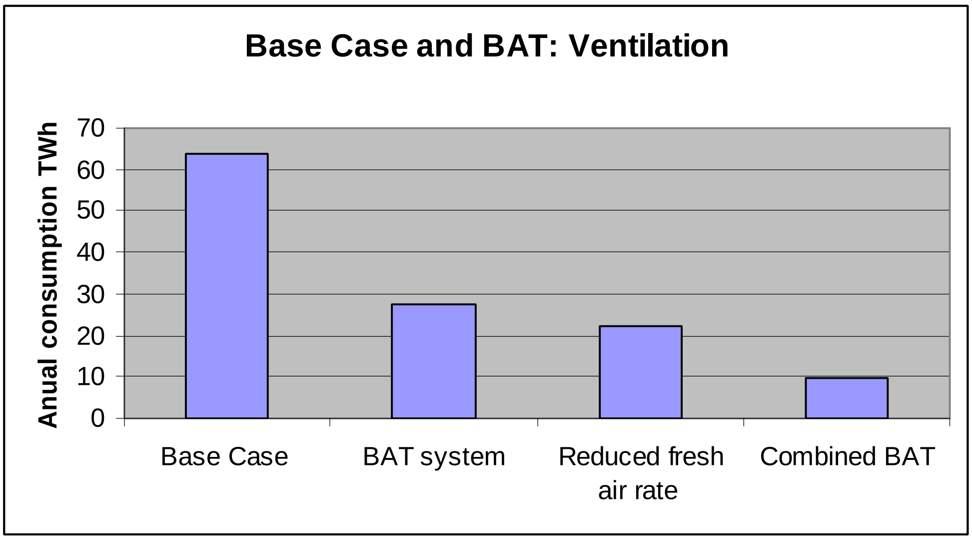

Figure 54: **B5.4 Summary of BAT cases: ventilation**

Analysis of potential energy savings in actual buildings [cxxvi] suggests that there are also additional comparable levels of savings to be made from improvements to system operation. (The base case assumes well-managed systems).

Simulation studies[cxxvii] show that additional, but smaller savings are available from the use of more efficient lighting systems and office equipment.

There is therefore an a priori case for considering policy components that address system efficiency, load reduction and system operation.

A more detailed breakdown of the results for all the Modelled Cases for each of the three main system types is provided in the following sub-sections.

B5.2.2 Modelling Results Moveable Units

B5.2.2.1 Overview for Moveable Units

The key points from the results for movable units are itemised below. In absolute terms the aggregate consumption and the potential savings are small compared to other types of air conditioning system. Only the most extreme cases exceed 10 TWh savings. The cases modelled are detailed in section B3.

- Impact of MEPS (cases M1, M2, M3)
    - The modelling quantifies the impact of imposing progressively tighter MEPS. We must keep in mind that there are physical limits to how far and how fast MEPS levels can be changed, due to the potentially large fraction of the units in the market that would not be able to meet the levels, as well as the difficulties that manufacturers would have in making engineered product changes to a lot of their models in a short time. Nevertheless, manufacturers do welcome challenges that can give them a marketing edge or new rules (such as MEPS) that can knock some of their competitors off the market.
    - Even at the most demanding levels, the absolute savings for moveable units are small compared to those available with other products.
    - The European MEPS levels initially proposed (case M1) have a very small impact. (The revised levels agreed were not modelled but will not materially alter this conclusion)
- BAT (case M7)
    - BAT levels of performance are well above those of most products on the market. As a result the savings associated with the universal use of BAT are substantially greater than increase in the savings if all products were at BAT levels of performance
- Financial Incentives (Cases M4, M5 and M6)
    - The addition of financial incentives to MEPS generates no significant increase in energy saving (this is a reflection of the assumptions made about the effect of incentives on purchaser behaviour. See section B3.3.2[128])
- Load reduction (Cases M8 and M9)
    - The application of all feasible load reduction measures to the building envelope (case M9) has a similar impact to that for the universal use of BAT products
    - More realistic assumptions about likely implementation reduce this to a much smaller figure (case M8)

National differences

- As might be expected, the level of savings reflects the market size, being largest for Italy, followed by the UK, France, and Germany.

The Modelled Cases for Moveable Units are summarised in Table 64 below. They are defined in Section B3

[128] This is because the 5% shift towards more efficient products (which is the impact financial incentives are assumed to have) will not lead a significant increase in the aggregate product efficiency in this instance. See Section B3 for further details.

Case no.	Description	Installations
M0	Base case (labelling + existing building regulations)	All
M1	(Product) proposed MEPs	New
M2	(Product) MEP 1	New
M3	(Product) MEP 2	New
M4	(Product) proposed MEPs + financial incentives	New
M5	(Product) MEP 1 + financial incentives	New
M6	(Product) MEP 2 + financial incentives	New
M7	(Product) BAT	New
M8	(Building) acheivable envelope savings	All
M9	(Building) BAT envelope savings	All

Table 66: B5.5: List of modelled cases for Moveable units

B5.2.2.2 Movable Units Summary Results: Combined EU plus EEAC countries

The modelling results for the Modelled Cases are summarised in the table below: Key results are summarised in the overview above. The leftmost column identifies the cases. Each panel (containing three columns) summarises a different aspect of the results.

The *Energy Consumption Panel* shows, from left to right: energy *consumption* by the installed stock in the base year; the consumption by newly-purchased units in the following year (year 1); the ***aggregate*** consumption by all units purchased in the ten years following the base year. In other words, the units installed in year one will continue saving the same amount of energy every year for ten years, those installed in year 2 will save energy for 9 years, etc.

The *Energy Savings Panel* shows the energy *savings* for each case, relative to the "business as usual" case (case M0) for the same categories.

The next two panels convert these energy consumptions and savings to carbon dioxide abatement using the appropriate national carbon intensity figures for electricity for each country. They therefore show the carbon emissions and carbon emission reductions corresponding to the energy figures.

case no.	Moveable Units											
	Energy Consumption TWh			Energy Savings TWh			Million Tonnes CO2			Carbon Savings Million Tonnes CO2		
	exisiting installations	new installations		exisiting installations	new installations		exisiting installations	new installations		exisiting installations	new installations	
		in year 1	to year 10		in year 1	to year 10		in year 1	to year 10		in year 1	to year 10
M0	2.9	0.45	30				1.9	0.31	20			
M1	2.9	0.45	28	-	-	1.6	1.9	0.31	19	-	-	1.1
M2	2.9	0.41	27	-	0.041	2.8	1.9	0.28	18	-	0.028	1.9
M3	2.9	0.38	25	-	0.070	4.6	1.9	0.26	17	-	0.047	3.1
M4	2.9	0.45	28	-	-	1.6	1.9	0.31	19	-	-	1.1
M5	2.9	0.41	27	-	0.041	2.8	1.9	0.28	18	-	0.028	1.9
M6	2.9	0.38	25	-	0.070	4.6	1.9	0.26	17	-	0.047	3.1
M7	2.9	0.29	19	-	0.16	11	1.9	0.20	13	-	0.11	7.2
M8	2.7	0.44	29	0.13	0.017	1.1	1.8	0.29	19	0.09	0.011	0.73
M9	1.9	0.33	22	1.0	0.12	8.1	1.3	0.22	15	0.65	0.082	5.4

Table 67: B5.6: Summary results for moveable units Modelled Cases – All EU and EEAC countries

The following table presents these results as percentage changes relative to the base case.

Table 68: B5.7: % energy and carbon savings for moveable units Modelled Cases – All EU and EEAC countries

For new installations the summary of results above shows the potential savings in year 1 and the cumulative savings to year 10. M0 represents the base case so there are no savings associated with this case.[129]

The biggest savings are associated with product BAT (M7) and building load reduction BAT (M9), with the latter impacting on both new and existing "installations" (which for movable units is simply ownership and use). The results indicate that the level of MEPS currently proposed (M1) would lead to energy savings of 5% for new installations of moveable units in year 10. However, setting MEPS to the highest (BAT) level (M7) could lead to energy savings of up to 34%. The modelling also shows that carrying out improvements to the building envelope to reduce the cooling load to the best possible level (M9) could potentially lead to a similar level of energy savings (36% in existing and 30% in new installations[130]). In reality, however, this level of savings is unlikely to be cost effective, particularly for existing buildings. A more realistic level of cooling load reduction (M8) is likely to lead to savings of around 4%-5%.

The energy and carbon savings for each year for each modelled case for new installations and the total potential for the existing stock is shown inTables B5.10 and B5.11:

[129] For existing installations, the results represent an idealised approach whereby all systems are impacted immediately. Section B5.4 explains how the modelling results have been modified to take account of these additional constraints before being used as the basis for the recommendations that are presented in Section A3

[130] The savings are higher for existing installation because the cooling demand that existing systems are required to meet are higher than for new installations, which are more likely to be in new building which tend to have higher occupancy levels with higher internal gains.

TWh energy saved	Existing stock	New Installations											
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
M0	-	-	-	-	-	-	-	-	-	-	-	-	-
M1	-	-	-	0.027	0.029	0.053	0.055	0.058	0.060	0.062	0.064	0.066	0.068
M2	-	0.041	0.044	0.047	0.050	0.053	0.056	0.059	0.061	0.063	0.065	0.067	0.069
M3	-	0.070	0.075	0.080	0.085	0.090	0.09	0.10	0.10	0.11	0.11	0.11	0.12
M4	-	-	-	0.027	0.029	0.053	0.055	0.058	0.060	0.062	0.064	0.066	0.068
M5	-	0.041	0.044	0.047	0.050	0.053	0.056	0.059	0.061	0.063	0.065	0.067	0.069
M6	-	0.070	0.075	0.080	0.085	0.090	0.09	0.10	0.10	0.11	0.11	0.11	0.12
M7	-	0.16	0.17	0.18	0.19	0.21	0.22	0.23	0.23	0.24	0.25	0.26	0.27
M8	0.13	0.017	0.018	0.019	0.020	0.021	0.022	0.023	0.024	0.025	0.026	0.026	0.027
M9	1.0	0.12	0.13	0.14	0.15	0.16	0.16	0.17	0.18	0.18	0.19	0.20	0.20

Table 69: B5.8: Energy savings in existing stock and annual savings from new installations for Modelled Cases for moveable units - All EU and EEAC countries.

Million Tonnes CO2 saved	Existin g stock	New Installations											
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
M0	-	-	-	-	-	-	-	-	-	-	-	-	-
M1	-	-	-	0.019	0.020	0.035	0.037	0.039	0.040	0.042	0.043	0.045	0.045
M2	-	0.028	0.030	0.032	0.034	0.036	0.038	0.039	0.041	0.042	0.044	0.045	0.046
M3		0.047	0.051	0.054	0.057	0.061	0.064	0.066	0.069	0.071	0.074	0.076	0.078
M4	-	-	-	0.019	0.020	0.035	0.037	0.039	0.040	0.042	0.043	0.045	0.045
M5	-	0.028	0.030	0.032	0.034	0.036	0.038	0.039	0.041	0.042	0.044	0.045	0.046
M6	-	0.047	0.051	0.054	0.057	0.061	0.064	0.066	0.069	0.071	0.074	0.076	0.078
M7	-	0.11	0.12	0.12	0.13	0.14	0.15	0.15	0.16	0.16	0.17	0.17	0.18
M8	0.09	0.011	0.012	0.013	0.013	0.014	0.015	0.015	0.016	0.016	0.017	0.017	0.018
M9	0.65	0.082	0.088	0.09	0.10	0.10	0.11	0.11	0.12	0.12	0.13	0.13	0.13

Table 70: B5.9: Carbon savings in existing stock and annual savings from new installations for Modelled Cases for moveable units - All EU and EEA countries.

B5.2.2.3 Movable Unit Results: Energy Savings in Existing Stock

Tables B5.10 and 5.11 below show the absolute and percentage energy savings for the existing stock of systems achieved by each modelled case per country. For movable units the only Modelled Cases that impact on existing products are those that result in load reductions (M8 and M9)

Energy savings existing installations (TWh)	M0-M7	M8	M9
Austria	-	0.0013	0.010
Belgium	-	0.0017	0.011
Bulgaria	-	0.0044	0.034
Cyprus	-	0.00000	0.00003
Czech Republic	-	0.010	0.061
Denmark	-	0.00087	0.0049
Estonia	-	0.00023	0.0016
Finland	-	0.0011	0.0081
France	-	0.010	0.077
Germany	-	0.016	0.11
Greece	-	0.00005	0.00041
Hungary	-	0.00050	0.0038
Iceland	-	0.00006	0.00048
Ireland	-	0.00084	0.0027
Italy	-	0.046	0.36
Latvia	-	0.00037	0.0029
Liechtenstein	-	0.00001	0.00004
Lithuania	-	0.00011	0.00050
Luxembourg	-	0.00008	0.00054
Malta	-	0.00047	0.0036
Netherlands	-	0.0027	0.016
Norway	-	0.0009	0.0073
Poland	-	0.010	0.077
Portugal	-	0.00001	0.00008
Romania	-	0.009	0.073
Slovakia	-	0.0017	0.014
Slovenia	-	0.00073	0.0056
Spain	-	0.00017	0.0013
Sweden	-	0.0018	0.014
United Kingdom	-	0.012	0.066
Total	**-**	0.13	1.0

Table 71: B5.10: Energy savings in existing installations for moveable units Modelled Cases per country.

By far the largest potential savings are in Italy, reflecting its dominance in terms of current ownership. There are also substantial savings in France, the UK and Germany.

Energy savings existing installations (%)	M0	M1-M7	M8	M9
Austria	0%	0%	5%	41%
Belgium	0%	0%	7%	43%
Bulgaria	0%	0%	4%	30%
Cyprus	0%	0%	2%	18%
Czech Republic	0%	0%	7%	41%
Denmark	0%	0%	7%	41%
Estonia	0%	0%	6%	41%
Finland	0%	0%	4%	31%
France	0%	0%	5%	39%
Germany	0%	0%	8%	49%
Greece	0%	0%	3%	20%
Hungary	0%	0%	4%	28%
Iceland	0%	0%	4%	34%
Ireland	0%	0%	10%	33%
Italy	0%	0%	4%	30%
Latvia	0%	0%	6%	45%
Liechtenstein	0%	0%	5%	41%
Lithuania	0%	0%	9%	38%
Luxembourg	0%	0%	6%	41%
Malta	0%	0%	3%	23%
Netherlands	0%	0%	7%	43%
Norway	0%	0%	4%	34%
Poland	0%	0%	4%	34%
Portugal	0%	0%	3%	27%
Romania	0%	0%	3%	26%
Slovakia	0%	0%	4%	30%
Slovenia	0%	0%	4%	33%
Spain	0%	0%	4%	32%
Sweden	0%	0%	4%	34%
United Kingdom	0%	0%	7%	40%
Total	0%	0%	5%	34%

Table 72:B5.11: % Energy savings in existing installations for moveable units Modelled Cases per country.

In percentage terms, the savings reflect the differing scope for load reduction in each country which may arise because of differences in the quality of the building stock or for climatic reasons. Although there may be scope for larger absolute savings in climates that impose large annual cooling demands – for example, shading will have a bigger impact in sunny climates – this does not necessarily translate into a larger proportion of the annual cooling consumption. Thus the application of realistic levels of cooling load reduction (M8) suggests energy savings of between 3% (Cyprus and Portugal) to 11% (Lithuania) and 12% (Ireland)for existing installations. Generally, the higher percentage savings are in countries with milder climates and relatively small air conditioning markets).

B5.2.2.3 Movable Unit Results: Energy Savings for New “Installations”

Tables B5.12 and B5.13 below show the absolute and percentage energy savings for new “installations” (that is new replacement products and new acquisitions in new and existing buildings) for each modelled case for each country.

TWh saved new installations year 2010-2019	**M0**	**M1**	**M2**	**M2**	**M3**	**M4**	**M6**	**M5**	**M6**	**M7**	**M8**	**M9**
Austria	-	0.0089	0.13	0.014	0.024	0.0089	0.055	0.014	0.024	0.055	0.0084	0.065
Belgium	-	0.009	0.13	0.014	0.024	0.009	0.055	0.014	0.024	0.055	0.011	0.064
Bulgaria	-	0.078	1.2	0.13	0.23	0.078	0.52	0.13	0.23	0.52	0.044	0.34
Cyprus	-	0.00000	0.00006	0.00001	0.00001	0.00000	0.00003	0.00001	0.00001	0.00003	0.00000	0.00001
Czech Republic	-	0.044	0.69	0.077	0.13	0.044	0.30	0.077	0.13	0.30	0.049	0.37
Denmark	-	0.0046	0.063	0.0068	0.012	0.0046	0.027	0.0068	0.012	0.027	0.0055	0.031
Estonia	-	0.0023	0.034	0.0040	0.0067	0.0023	0.015	0.0040	0.0067	0.015	0.0014	0.011
Finland	-	0.015	0.23	0.027	0.045	0.015	0.10	0.027	0.045	0.10	0.010	0.075
France	-	0.071	1.0	0.11	0.19	0.071	0.44	0.11	0.19	0.44	0.062	0.48
Germany	-	0.068	1.0	0.11	0.19	0.068	0.44	0.11	0.19	0.44	0.083	0.56
Greece	-	0.00004	0.00071	0.00008	0.00014	0.00004	0.00032	0.00008	0.00014	0.00032	0.00002	0.00019
Hungary	-	0.0017	0.028	0.0033	0.0056	0.0017	0.013	0.0033	0.0056	0.013	0.0012	0.009
Iceland	-	0.00068	0.011	0.0013	0.0021	0.00068	0.0048	0.0013	0.0021	0.0048	0.00049	0.0038
Ireland	-	0.0053	0.073	0.0076	0.013	0.0053	0.030	0.0076	0.013	0.030	0.0073	0.036
Italy	-	0.81	12	1.4	2.4	0.81	5.4	1.4	2.4	5.4	0.46	3.6
Latvia	-	0.0038	0.056	0.0065	0.011	0.0038	0.025	0.0065	0.011	0.025	0.0023	0.018
Liechtenstein	-	0.00004	0.00054	0.00006	0.00010	0.00004	0.00023	0.00006	0.00010	0.00023	0.00004	0.00028
Lithuania	-	0.0011	0.016	0.0019	0.0032	0.0011	0.0072	0.0019	0.0032	0.0072	0.00072	0.0056
Luxembourg	-	0.00047	0.0066	0.00073	0.0012	0.00047	0.0028	0.00073	0.0012	0.0028	0.00051	0.0036
Malta	-	0.010	0.14	0.017	0.029	0.010	0.065	0.017	0.029	0.065	0.0047	0.036
Netherlands	-	0.014	0.19	0.021	0.035	0.014	0.082	0.021	0.035	0.082	0.017	0.10
Norway	-	0.013	0.19	0.022	0.038	0.013	0.086	0.022	0.038	0.086	0.0087	0.067
Poland	-	0.10	1.5	0.18	0.30	0.10	0.69	0.18	0.30	0.69	0.062	0.48
Portugal	-	0.00000	0.00002	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00001	0.00000	0.00001
Romania	-	0.17	2.6	0.30	0.51	0.17	1.2	0.30	0.51	1.2	0.09	0.73
Slovakia	-	0.031	0.46	0.053	0.090	0.031	0.21	0.053	0.090	0.21	0.017	0.14
Slovenia	-	0.010	0.16	0.018	0.031	0.010	0.071	0.018	0.031	0.071	0.0069	0.053
Spain	-	0.0012	0.019	0.0022	0.0037	0.0012	0.0085	0.0022	0.0037	0.0085	0.00082	0.0063
Sweden	-	0.026	0.38	0.044	0.073	0.026	0.17	0.044	0.073	0.17	0.017	0.13
United Kingdom	-	0.11	1.5	0.16	0.28	0.11	0.64	0.16	0.28	0.64	0.11	0.69
Total	**-**	1.6	24	2.8	4.6	1.6	11	2.8	4.6	11	1.1	8.1

Table 73: B5.12: Cumulative energy savings for new installations (2010-2019) for moveable units Modelled Cases by country.

As for existing systems, by far the largest potential savings are in Italy, again because of the projected continuation of high levels of sales over the next 10 years. Significant potential savings exist in France, the United Kingdom and, to a lesser degree, Germany

% energy saved new installations year 2010-2019	M0	M1	M2	M2	M3	M4	M6	M5	M6	M7	M8	M9
Austria	0%	5%	77%	9%	15%	5%	34%	9%	15%	34%	5%	40%
Belgium	0%	5%	75%	8%	14%	5%	32%	8%	14%	32%	6%	37%
Bulgaria	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	24%
Cyprus	0%	5%	82%	10%	16%	5%	37%	10%	16%	37%	3%	20%
Czech Republic	0%	5%	77%	9%	14%	5%	33%	9%	14%	33%	5%	41%
Denmark	0%	5%	75%	8%	14%	5%	32%	8%	14%	32%	6%	36%
Estonia	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	26%
Finland	0%	5%	80%	9%	16%	5%	36%	9%	16%	36%	3%	26%
France	0%	5%	78%	9%	15%	5%	34%	9%	15%	34%	5%	37%
Germany	0%	5%	76%	8%	14%	5%	32%	8%	14%	32%	6%	41%
Greece	0%	5%	82%	10%	16%	5%	37%	10%	16%	37%	3%	22%
Hungary	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	26%
Iceland	0%	5%	80%	9%	16%	5%	36%	9%	16%	36%	4%	28%
Ireland	0%	5%	72%	8%	13%	5%	30%	8%	13%	30%	7%	36%
Italy	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	24%
Latvia	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	26%
Liechtenstein	0%	5%	77%	9%	15%	5%	34%	9%	15%	34%	5%	40%
Lithuania	0%	5%	80%	9%	16%	5%	36%	9%	16%	36%	4%	28%
Luxembourg	0%	5%	76%	8%	14%	5%	33%	8%	14%	33%	6%	41%
Malta	0%	5%	82%	10%	16%	5%	37%	10%	16%	37%	3%	20%
Netherlands	0%	5%	75%	8%	14%	5%	32%	8%	14%	32%	6%	40%
Norway	0%	5%	80%	9%	16%	5%	36%	9%	16%	36%	4%	28%
Poland	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	25%
Portugal	0%	5%	78%	9%	15%	5%	34%	9%	15%	34%	5%	35%
Romania	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	23%
Slovakia	0%	5%	81%	9%	16%	5%	36%	9%	16%	36%	3%	24%
Slovenia	0%	5%	80%	9%	16%	5%	36%	9%	16%	36%	3%	27%
Spain	0%	5%	80%	9%	16%	5%	36%	9%	16%	36%	3%	27%
Sweden	0%	5%	80%	9%	16%	5%	36%	9%	16%	36%	4%	28%
United Kingdom	0%	5%	76%	8%	14%	5%	32%	8%	14%	32%	6%	35%
Total	**0%**	5%	80%	9%	15%	5%	35%	9%	15%	35%	4%	27%

Table 74: B5.13: % Cumulative energy savings for new installations (2010-2019) for moveable units Modelled Cases by country.

Cases reflecting load reductions (M8 and M9) show a similar climatic pattern of percentage reductions to those seen for existing systems, albeit that the differences between countries are less marked. New installations include use in new buildings which comply with better building energy codes. As a result of this, differences of thermal performance between similar buildings in different countries may be less than for the existing stock.

For cases that reflect changes in the average efficiency of products, the differences between countries in percentage savings are small, with a tendency for smaller figures in milder climates. The application of BAT to new installations (M7) suggests savings ranging from 27% (Ireland) to 37% (Cyprus, Greece, Malta). This tendency may reflect the greater relative importance of “standby-mode” energy consumption in countries where products are on standby for longer periods.

B5.2.2.4 Movable Unit Results: Carbon Savings

Tables B5.14 and B 5.15 show the carbon savings associated with the energy savings discussed above. The results reflect a combination of the air conditioning energy demand and the carbon intensity of the electricity supply in each country. This is not quite the same as the carbon intensity of the installed generation plant, since many countries import and export electricity.

There are several countries whose electricity supply has a low carbon content, either because of high proportions of nuclear or of renewable generation: These are Iceland, Norway, Lithuania, Sweden, France. Countries with high proportions of fossil-fuel and especially coal-fired generation have high carbon intensities[131].

[131] These figures are annual averages: carbon intensity varies according to demand level time of day and year and the relative prices of fuels.

Carbon savings existing installations (M tonnes CO2)	M0	M1-M7	M8	M9
Austria	-	-	0.00059	0.0046
Belgium	-	-	0.00062	0.0039
Bulgaria	-	-	0.0034	0.027
Cyprus	-	-	0.00000	0.00003
Czech Republic	-	-	0.009	0.056
Denmark	-	-	0.00054	0.0030
Estonia	-	-	0.00050	0.0035
Finland	-	-	0.00036	0.0027
France	-	-	0.0011	0.0082
Germany	-	-	0.012	0.076
Greece	-	-	0.00006	0.00047
Hungary	-	-	0.00037	0.0029
Iceland	-	-	0.00000	0.00000
Ireland	-	-	0.00074	0.0024
Italy	-	-	0.030	0.23
Latvia	-	-	0.00082	0.0063
Liechtenstein	-	-	0.00000	0.00002
Lithuania	-	-	0.00001	0.00006
Luxembourg	-	-	0.00005	0.00034
Malta	-	-	0.00020	0.0016
Netherlands	-	-	0.0019	0.011
Norway	-	-	0.00004	0.00033
Poland	-	-	0.012	0.09
Portugal	-	-	0.00001	0.00005
Romania	-	-	0.0076	0.058
Slovakia	-	-	0.00088	0.0068
Slovenia	-	-	0.00035	0.0027
Spain	-	-	0.00010	0.00079
Sweden	-	-	0.00019	0.0015
United Kingdom	-	-	0.0082	0.045
Total	-	-	0.09	0.65

Table 75: B5.14: Carbon savings in existing installations for Modelled Cases for moveable units broken down by country.

Carbon savings new installations 2010-2019 (M tonnes CO2)	M0	M1	M2	M2	M3	M4	M6	M5	M6	M7	M8	M9
Austria	-	0.0039	0.056	0.0062	0.010	0.0039	0.024	0.0062	0.010	0.024	0.0037	0.029
Belgium	-	0.0034	0.048	0.0052	0.0088	0.0034	0.020	0.0052	0.0088	0.020	0.0039	0.024
Bulgaria	-	0.061	0.9	0.11	0.18	0.061	0.41	0.11	0.18	0.41	0.035	0.27
Cyprus	-	0.00000	0.00007	0.00001	0.00001	0.00000	0.00003	0.00001	0.00001	0.00003	0.00000	0.00002
Czech Republic	-	0.040	0.64	0.071	0.12	0.040	0.28	0.40	0.43	0.53	0.045	0.34
Denmark	-	0.0028	0.039	0.0042	0.0071	0.0028	0.016	0.0042	0.0071	0.016	0.0034	0.019
Estonia	-	0.0051	0.075	0.0088	0.015	0.0051	0.034	0.0088	0.015	0.034	0.0031	0.024
Finland	-	0.0052	0.077	0.0089	0.015	0.0052	0.034	0.0089	0.015	0.034	0.0033	0.025
France	-	0.0076	0.11	0.012	0.021	0.0076	0.048	0.012	0.021	0.048	0.0067	0.052
Germany	-	0.049	0.74	0.081	0.14	0.049	0.31	0.081	0.14	0.31	0.060	0.40
Greece	-	0.00005	0.00081	0.00010	0.00016	0.00005	0.00037	0.00010	0.00016	0.00037	0.00003	0.00022
Hungary	-	0.0013	0.021	0.0025	0.0041	0.0013	0.009	0.0025	0.0041	0.009	0.00089	0.0068
Iceland	-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	-
Ireland	-	0.0046	0.064	0.0067	0.011	0.0046	0.027	0.0067	0.011	0.027	0.0064	0.032
Italy	-	0.52	7.7	0.9	1.5	0.52	3.5	0.9	1.5	3.5	0.30	2.3
Latvia	-	0.0083	0.12	0.014	0.024	0.0083	0.055	0.014	0.024	0.055	0.0051	0.040
Liechtenstein	-	0.00002	0.00024	0.00003	0.00004	0.00002	0.00010	0.00003	0.00004	0.00010	0.00002	0.00012
Lithuania	-	0.00013	0.0019	0.00022	0.00037	0.00013	0.00084	0.00022	0.00037	0.00084	0.00008	0.00065
Luxembourg	-	0.00030	0.0042	0.00046	0.00078	0.00030	0.0018	0.00046	0.00078	0.0018	0.00032	0.0023
Malta	-	0.0041	0.062	0.0073	0.012	0.0041	0.028	0.0073	0.012	0.028	0.0020	0.016
Netherlands	-	0.010	0.14	0.015	0.026	0.010	0.059	0.015	0.026	0.059	0.012	0.074
Norway	-	0.00060	0.0088	0.0010	0.0017	0.00060	0.0039	0.0010	0.0017	0.0039	0.00040	0.0031
Poland	-	0.12	1.8	0.21	0.36	0.12	0.81	0.21	0.36	0.81	0.074	0.57
Portugal	-	0.00000	0.00002	0.00000	0.00000	0.00000	0.00001	0.00000	0.00000	0.00001	0.00000	0.00001
Romania	-	0.14	2.1	0.24	0.41	0.14	0.9	0.24	0.41	0.9	0.076	0.58
Slovakia	-	0.015	0.23	0.027	0.045	0.015	0.10	0.027	0.045	0.10	0.0087	0.068
Slovenia	-	0.0051	0.078	0.0089	0.015	0.0051	0.034	0.0089	0.015	0.034	0.0033	0.026
Spain	-	0.00068	0.011	0.0013	0.0022	0.00068	0.0050	0.0013	0.0022	0.0050	0.00048	0.0037
Sweden	-	0.0027	0.040	0.0046	0.0077	0.0027	0.018	0.0046	0.0077	0.018	0.0018	0.014
United Kingdom	-	0.073	1.0	0.11	0.19	0.073	0.44	0.11	0.19	0.44	0.077	0.47
Total	**-**	1.1	16	1.9	3.1	1.1	7.2	2.2	3.4	7.4	0.73	5.4

Table 69: B5.16: Cumulative carbon savings in new installations (2010-2019) for Modelled Cases for moveable units broken down by country

For both the existing stock and new installations of movable units, Italy is easily the largest emitter of carbon dioxide, followed by the United Kingdom and Germany.

There are no carbon savings for Iceland shown as electricity generation is from renewable sources.

B5.2.3 Modelling Results RAC Units

The key points from the results for fixed room air conditioning units are itemised below. Numerically these are the dominant type of air conditioning system but because they are individually much smaller than chillers, this translates into an important but not dominant share of consumption. The cases modelled are detailed in section B3. The existing European energy labelling system is included in the base case.

B5.2.3.1 Overview for Fixed Room Units < 12 kW

- This section summarises the modelled impact of MEPS applied to fixed room air conditioners (cases RAC1, RAC2, RAC3, RAC4, RAC5)
  - The modelling quantifies the impact of imposing progressively tighter MEPS. The absolute savings are much larger than for moveable units, but smaller than for chillers. At the more demanding levels that were modelled (cases RAC4 and RAC5), the ten-year savings are between 40 and 60 TWh. (These would imply the removal of a substantial number of products from the market, as is explained in section B3)
  - The European MEPS levels initially proposed (case RAC1) and those subsequently adopted have a much smaller impact. (The revised levels agreed were not modelled but will not materially alter this conclusion).
- BAT (case RAC11)
  - There is a further substantial increase in the savings if all products were at BAT levels of performance.
- Financial Incentives (Cases RAC6, RAC7, RAC8, RAC9, RAC10)
- The addition of financial incentives when labelling and MEPS are in place generates no significant increase in energy saving (To some extent, MEPS and financial incentives are alternative policy instruments since incentives can only apply to products that have performances above the MEPS requirement).
- Load reduction (Cases RAC12 and RAC13)
  - The application of all feasible load reduction measures to the building envelope (case RAC11) has a similar potential impact to that for the universal use of BAT products
  - More realistic assumptions about likely implementation reduce this to a significantly smaller 10 TWh figure (case RAC10)

National differences

- As might be expected, the level of savings reflects the market size, being largest for Italy, and Spain, followed by, France, Greece, and the UK. (Greece has a particularly high ownership of room air conditioners and Germany a low ownership).

The Modelled Cases for RAC Units are:

Case no.	Description	Installations
RAC0	RAC (Base case) labelling + existing building regulations	All
RAC1	RAC (Product) proposed MEPs	New
RAC2	RAC (Product) MEP 1	New
RAC3	RAC (Product) MEP 2	New
RAC4	RAC (Product) MEP 3	New
RAC5	RAC (Product) MEP 4	New
RAC6	RAC (Product) proposed MEPs + financial incentives	New
RAC7	RAC (Product) MEP 1 + financial incentives	New
RAC8	RAC (Product) MEP 2 + financial incentives	New
RAC9	RAC (Product) MEP 3 + financial incentives	New
RAC10	RAC (Product) MEP 4 + financial incentives	New
RAC11	RAC (Product) BAT	New
RAC12	RAC (Building Envelope) acheivable envelope savings	All
RAC13	RAC (Building Envelope) BAT envelope savings	All

Table 76: B5.18: List of Modelled Cases for RAC units

B5.2.3.2 RAC Units Summary Results: Combined EU plus EEAC countries

The modelling results for the Modelled Cases are shown in Table [insert #] below : Key results are summarised in the overview above.

The leftmost column identifies the cases. Each panel (containing three columns) summarises a different aspect of the results.

The *Energy Consumption Panel* shows, from left to right: energy *consumption* by the installed stock in the base year; the consumption by newly-purchased units in the following year (year 1); the ***aggregate*** consumption by all units purchased in the ten years following the base year. In other words, the units installed in year one will continue saving the same amount of energy every year for ten years, those installed in year 2 will save energy for 9 years, etc.

The *Energy Savings Panel* shows the energy *savings* for each case, relative to the “business as usual” case (case M0) for the same categories.

The next two panels convert these energy consumptions and savings to carbon dioxide abatement using the appropriate national carbon intensity figures for electricity for each country. They therefore show the carbon emissions and carbon emission reductions corresponding to the energy figures.

case no.	RAC Units											
	Energy Consumption TWh			Energy Savings TWh			Million Tonnes CO2			Carbon Savings Million Tonnes CO2		
	exisiting installations	new installations		exisiting installations	new installations		exisiting installations	new installations		exisiting installations	new installations	
		in year 1	to year 10		in year 1	to year 10		in year 1	to year 10		in year 1	to year 10
RAC0	17	2.1	124				11	1.4	81			
RAC1	17	2.1	119	-	-	5.6	11	1.4	77	-	-	3.8
RAC2	17	1.8	110	-	0.24	15	11	1.2	71	-	0.17	10
RAC3	17	1.7	102	-	0.37	22	11	1.1	66	-	0.25	15
RAC4	17	1.6	93	-	0.51	31	11	1.0	61	-	0.34	21
RAC5	17	1.4	82	-	0.70	42	11	0.90	54	-	0.46	28
RAC6	17	2.1	118	-	-	6.2	11	1.4	77	-	-	4.1
RAC7	17	1.8	108	-	0.27	16	11	1.2	70	-	0.18	11
RAC8	17	1.7	101	-	0.39	23	11	1.1	66	-	0.26	15
RAC9	17	1.6	93	-	0.51	31	11	1.0	61	-	0.34	21
RAC10	17	1.4	82	-	0.70	42	11	0.90	54	-	0.46	28
RAC11	17	1.2	71	-	0.89	53	11	0.77	46	-	0.59	35
RAC12	16	2.0	118	1.1	0.11	6.5	11	1.3	77	0.70	0.069	4.1
RAC13	8.7	1.2	75	8.2	0.83	50	5.9	0.83	50	5.3	0.53	32

Table 77: B5.19: Summary results for RAC units Modelled Cases - All EU/EEA countries

The following table presents these results as percentage energy and carbon savings relative to the base case (RAC0):

case no.	RAC Units					
	% Energy saving			% Carbon Savings		
	exisiting installations	new installations		exisiting installations	new installations	
		in year 1	to year 10		in year 1	to year 10
RAC0						
RAC1	0%	0%	4%	0%	0%	5%
RAC2	0%	12%	12%	0%	12%	12%
RAC3	0%	18%	18%	0%	18%	18%
RAC4	0%	25%	25%	0%	25%	25%
RAC5	0%	34%	34%	0%	34%	34%
RAC6	0%	0%	5%	0%	0%	5%
RAC7	0%	13%	13%	0%	13%	13%
RAC8	0%	19%	19%	0%	19%	19%
RAC9	0%	25%	25%	0%	25%	25%
RAC10	0%	34%	34%	0%	34%	34%
RAC11	0%	43%	43%	0%	43%	43%
RAC12	6%	5%	5%	6%	5%	5%
RAC13	49%	40%	40%	47%	39%	39%

Table 78: B5.20: % energy and carbon savings for RAC units Modelled Cases – All EU and EEAC countries

For new installations the summary of results above shows the potential savings in year 1 and the cumulative savings to year 10. M0 represents the base case so there are no savings associated with this case.[132] RAC0 represents the base case so there are no savings associated with this case.

The results indicate that the level of MEPS originally proposed (RAC1) would lead to 4% energy savings for new installations of room air conditioning units. However, setting MEPS to the highest (BAT) level (RAC 11) could lead to savings of up to 43%. The modelling also shows that carrying out improvements to the building envelope to reduce the cooling load to the best possible level (RAC13) could potentially lead to a similar level of savings (energy savings of 49% in existing and 40% in new installations[133]), although in reality it is unlikely to be cost effective particularly for existing buildings and a more realistic level of cooling load reduction (RAC12) is likely to lead to savings of around 5%-6%.

Tables B5.21 and B5.22 below show the energy and carbon savings, for each year for new installations and the total potential for the existing stock for each of the Modelled Cases:

[132] For existing installations, the results represent an idealised approach whereby all systems are impacted immediately**.** Section B5.4 explains how the modelling results have been modified to take account of these additional constraints before being used as the basis for the recommendations that are presented in Section A3

[133] The savings are higher for existing installation because the cooling demand that existing systems are required to meet are higher than for new installations, which are more likely to be in new building which tend to have higher occupancy levels with higher internal gains.

TWh energy saved	Existing stock	New Installations											
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
RAC0	-	-	-	-	-	-	-	-	-	-	-	-	-
RAC1	-	-	-	0.25	0.26	0.27	0.28	0	0	0	0	0	0
RAC2	-	0.42	0.44	0.45	0.47	0.49	0.50	1	1	1	1	1	1
RAC3	-	0.62	0.65	0.67	0.69	0.72	0.74	1	1	1	1	1	1
RAC4	-	0.86	0.89	0.9	1.0	1.0	1.0	1	1	1	1	1	1
RAC5	-	1.2	1.2	1.2	1.3	1.3	1.4	1	1	1	1	2	2
RAC6	-	-	-	0.28	0.29	0.30	0.31	0	0	0	0	0	0
RAC7	-	0.46	0.48	0.50	0.52	0.53	0.55	1	1	1	1	1	1
RAC8	-	0.65	0.68	0.70	0.73	0.75	0.77	1	1	1	1	1	1
RAC9	-	0.86	0.89	0.9	1.0	1.0	1.0	1	1	1	1	1	1
RAC10	-	1.2	1.2	1.2	1.3	1.3	1.4	1	1	1	1	2	2
RAC11	-	1.5	1.5	1.6	1.6	1.7	1.7	2	2	2	2	2	2
RAC12	1.8	0.18	0.18	0.19	0.20	0.20	0.21	0	0	0	0	0	0
RAC13	14	1.3	1.4	1.5	1.5	1.6	1.6	2	2	2	2	2	2

Table 79: B5.21: Energy savings in existing stock, and annual savings from new installations for RAC units Modelled Cases - All EU and EEAC countries.

Million Tonnes CO2 saved	Existing stock	New Installations											
		Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10	Year 11	Year 12
RAC0	-	-	-	-	-	-	-	-	-	-	-	-	-
RAC1	-	-	-	0.19	0.19	0.20	0.21	0.21	0.22	0.22	0.23	0.23	0.23
RAC2	-	0.32	0.33	0.34	0.35	0.36	0.37	0.38	0.39	0.39	0.40	0.41	0.41
RAC3	-	0.46	0.48	0.49	0.51	0.53	0.54	0.55	0.56	0.57	0.58	0.59	0.60
RAC4	-	0.63	0.65	0.67	0.70	0.72	0.74	0.76	0.77	0.78	0.80	0.81	0.82
RAC5	-	0.84	0.87	0.90	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
RAC6	-	-	-	0.21	0.21	0.22	0.23	0.23	0.24	0.24	0.25	0.25	0.25
RAC7	-	0.34	0.36	0.37	0.38	0.39	0.41	0.41	0.42	0.43	0.44	0.45	0.45
RAC8	-	0.48	0.50	0.51	0.53	0.55	0.57	0.58	0.59	0.60	0.61	0.62	0.63
RAC9	-	0.63	0.65	0.67	0.70	0.72	0.74	0.76	0.77	0.78	0.80	0.81	0.82
RAC10	-	0.84	0.87	0.90	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1
RAC11	-	1.1	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.3	1.4	1.4
RAC12	1.3	0.12	0.13	0.13	0.14	0.14	0.14	0.15	0.15	0.15	0.16	0.16	0.16
RAC13	10	0.9	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2

Table 80: B5.22: Carbon savings in existing stock and annual savings from new installations for RAC units Modelled Cases - All EU and EEAC countries.

RAC0 represents the base case so there are no savings associated with this

B5.2.3.3 RAC Unit Results: Energy Savings in the Existing Stock

Tables B5.23 and B5.24 below show the absolute and percentage energy savings for the existing stock of systems for each Modelled Cases for each country: The only Modelled Cases that impact on the existing stock are those that result in load reductions (RAC12 and RAC13).

Energy savings existing installations (TWh)	**RAC 0-11**	**RAC12**	**RAC13**
Austria	-	0.019	0.15
Belgium	-	0.024	0.18
Bulgaria	-	0.039	0.30
Cyprus	-	0.0089	0.068
Czech Republic	-	0.14	1.1
Denmark	-	0.013	0.09
Estonia	-	0.0033	0.024
Finland	-	0.0083	0.064
France	-	0.14	1.1
Germany	-	0.028	0.18
Greece	-	0.12	1.0
Hungary	-	0.021	0.16
Iceland	-	0.00049	0.0038
Ireland	-	0.0066	0.025
Italy	-	0.41	3.2
Latvia	-	0.0054	0.041
Liechtenstein	-	0.00008	0.00063
Lithuania	-	0.00064	0.0038
Luxembourg	-	0.0012	0.0086
Malta	-	0.0041	0.032
Netherlands	-	0.038	0.28
Norway	-	0.0074	0.057
Poland	-	0.14	1.1
Portugal	-	0.022	0.17
Romania	-	0.083	0.64
Slovakia	-	0.015	0.12
Slovenia	-	0.0064	0.049
Spain	-	0.38	2.9
Sweden	-	0.014	0.11
United Kingdom	-	0.10	0.69
Total	**-**	1.8	14

Table 81: B5.23: Energy savings in existing installations for RAC units Modelled Cases by country

By far the largest potential savings are in Italy and Spain, with substantial additional potential in France and Greece. Together these countries contain about half of the potential savings. This is largely a reflection of the size of the installed stock in each country. Application of realistic levels of cooling load reduction for RAC units (RAC12) suggests energy savings of between 4% (Cyprus) and 15% (Ireland) for existing installations.

% Energy savings existing installations	RAC0	RAC1 - RAC 11	RAC12	RAC13
Austria	0%	0%	5%	42%
Belgium	0%	0%	9%	66%
Bulgaria	0%	0%	6%	50%
Cyprus	0%	0%	4%	30%
Czech Republic	0%	0%	8%	64%
Denmark	0%	0%	9%	67%
Estonia	0%	0%	7%	55%
Finland	0%	0%	5%	40%
France	0%	0%	7%	51%
Germany	0%	0%	10%	67%
Greece	0%	0%	5%	37%
Hungary	0%	0%	5%	38%
Iceland	0%	0%	6%	44%
Ireland	0%	0%	15%	58%
Italy	0%	0%	7%	52%
Latvia	0%	0%	8%	62%
Liechtenstein	0%	0%	7%	50%
Lithuania	0%	0%	11%	66%
Luxembourg	0%	0%	8%	58%
Malta	0%	0%	5%	37%
Netherlands	0%	0%	10%	71%
Norway	0%	0%	6%	44%
Poland	0%	0%	6%	45%
Portugal	0%	0%	7%	57%
Romania	0%	0%	6%	44%
Slovakia	0%	0%	7%	50%
Slovenia	0%	0%	7%	56%
Spain	0%	0%	6%	46%
Sweden	0%	0%	6%	44%
United Kingdom	0%	0%	9%	65%
Total	0%	0%	6%	49%

Table 82: B5.24: % Energy savings in existing installations for RAC units Modelled Cases by country

B5.2.3.4 RAC Unit Results: Energy Savings for New Installations

Tables B5.25 and B5.26] below show the energy for new installations between 2010 and 2019 for by each Modelled Cases for each country:

Energy savings new installations 2010-2019 (TWh)	**RAC 0**	**RAC 1**	**RAC 2**	**RAC 3**	**RAC 4**	**RAC 5**	**RAC 6**	**RAC 7**	**RAC 8**	**RAC 9**	**RAC 10**	**RAC 11**	**RAC 12**	**RAC 13**
Austria	-	0.16	0.42	0.58	0.77	1.0	0.18	0.45	0.60	0.77	1.0	1.3	0.15	1.1
Belgium	-	0.15	0.38	0.53	0.71	0.9	0.17	0.41	0.55	0.71	0.9	1.2	0.18	1.3
Bulgaria	-	0.19	0.50	0.69	0.9	1.2	0.20	0.54	0.72	0.9	1.2	1.5	0.18	1.4
Cyprus	-	0.069	0.19	0.26	0.35	0.46	0.075	0.21	0.27	0.35	0.46	0.57	0.044	0.34
Czech Republic	-	1.0	2.5	3.5	4.7	6.2	1.1	2.7	3.7	4.7	6.2	7.7	1.0	7.7
Denmark	-	0.076	0.19	0.26	0.35	0.45	0.083	0.20	0.27	0.35	0.45	0.57	0.09	0.69
Estonia	-	0.031	0.079	0.11	0.15	0.19	0.033	0.085	0.11	0.15	0.19	0.24	0.024	0.19
Finland	-	0.076	0.20	0.27	0.36	0.48	0.083	0.21	0.28	0.36	0.48	0.59	0.057	0.44
France	-	0.87	2.2	3.4	4.8	6.5	1.0	2.5	3.6	4.8	6.5	8.3	1.1	8.1
Germany	-	0.12	0.29	0.40	0.54	0.70	0.13	0.31	0.42	0.54	0.70	0.88	0.16	1.2
Greece	-	1.0	2.6	3.6	4.8	6.2	1.0	2.8	3.7	4.8	6.2	7.8	0.65	5.0
Hungary	-	0.19	0.50	0.70	0.9	1.2	0.21	0.54	0.73	0.9	1.2	1.5	0.14	1.1
Iceland	-	0.0040	0.010	0.015	0.019	0.025	0.0043	0.011	0.015	0.019	0.025	0.032	0.0031	0.024
Ireland	-	0.027	0.062	0.086	0.11	0.15	0.029	0.067	0.089	0.11	0.15	0.19	0.045	0.28
Italy	-	1.0	2.7	4.8	7.3	10	1.2	3.1	5.1	7.3	10	14	1.9	14
Latvia	-	0.050	0.13	0.18	0.24	0.31	0.055	0.14	0.19	0.24	0.31	0.39	0.040	0.31
Liechtenstein	-	0.00062	0.0016	0.0022	0.0029	0.0038	0.00068	0.0017	0.0023	0.0029	0.0038	0.0047	0.00062	0.0048
Lithuania	-	0.0049	0.012	0.017	0.023	0.030	0.0053	0.013	0.018	0.023	0.030	0.037	0.0049	0.038
Luxembourg	-	0.0081	0.020	0.028	0.037	0.049	0.0088	0.022	0.029	0.037	0.049	0.061	0.0087	0.065
Malta	-	0.025	0.069	0.10	0.13	0.17	0.028	0.075	0.10	0.13	0.17	0.21	0.020	0.15
Netherlands	-	0.22	0.54	0.75	1.0	1.3	0.24	0.58	0.78	1.0	1.3	1.6	0.29	2.1
Norway	-	0.066	0.17	0.24	0.31	0.41	0.071	0.18	0.24	0.31	0.41	0.51	0.051	0.39
Poland	-	1.3	3.3	4.7	6.2	8.1	1.4	3.6	4.8	6.2	8.1	10	1.0	7.7
Portugal	-	0.10	0.26	0.39	0.55	0.74	0.11	0.28	0.41	0.55	0.74	0.9	0.13	1.0
Romania	-	0.48	1.3	1.8	2.4	3.2	0.52	1.4	1.9	2.4	3.2	3.9	0.40	3.1
Slovakia	-	0.079	0.21	0.29	0.39	0.51	0.086	0.23	0.31	0.39	0.51	0.64	0.074	0.57
Slovenia	-	0.031	0.082	0.11	0.15	0.20	0.034	0.089	0.12	0.15	0.20	0.25	0.031	0.24
Spain	-	2.0	5.4	8.2	12	16	2.3	6.0	8.6	12	16	20	2.3	18
Sweden	-	0.13	0.33	0.45	0.60	0.79	0.14	0.35	0.47	0.60	0.79	1.0	0.10	0.75
United Kingdom	-	0.41	1.0	1.5	2.2	3.0	0.46	1.1	1.6	2.2	3.0	3.8	0.64	4.6
Total	**-**	10	26	38	53	70	11	28	40	53	70	89	11	82

Table 83: B5.25: Energy savings in new installations (2010-2019) for RAC units Modelled Cases by country

About half the potential savings are in Spain and Italy with significant potential in France and Greece. This mainly reflects the large numbers of projected sales in these countries. Climate has two impacts: in addition to its impact on the need for cooling and therefore the market size, climate also affects annual consumptions and thus the size of savings from system efficiency improvements. RAC0 represents the base case and thus there are no savings associated with this case.

% Energy savings new installations 2010-2019	RAC 0	RAC 1	RAC 2	RAC 3	RAC 4	RAC 5	RAC 6	RAC 7	RAC 8	RAC 9	RAC 10	RAC 11	RAC 12	RAC 13
Austria	0%	6%	15%	21%	28%	36%	6%	16%	21%	28%	36%	45%	5%	40%
Belgium	0%	6%	14%	20%	27%	35%	6%	16%	21%	27%	35%	44%	7%	51%
Bulgaria	0%	6%	15%	21%	27%	36%	6%	16%	21%	27%	36%	45%	5%	42%
Cyprus	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	27%
Czech Republic	0%	6%	15%	20%	27%	36%	6%	16%	21%	27%	36%	45%	6%	44%
Denmark	0%	6%	14%	20%	27%	35%	6%	15%	21%	27%	35%	43%	7%	53%
Estonia	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	36%
Finland	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	34%
France	0%	4%	11%	17%	25%	33%	5%	13%	18%	25%	33%	43%	5%	42%
Germany	0%	6%	14%	20%	26%	35%	6%	15%	21%	26%	35%	43%	8%	59%
Greece	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	30%
Hungary	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	33%
Iceland	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	35%
Ireland	0%	6%	14%	19%	25%	33%	6%	15%	20%	25%	33%	42%	10%	62%
Italy	0%	3%	8%	14%	22%	31%	3%	9%	15%	22%	31%	40%	6%	43%
Latvia	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	36%
Liechtenstein	0%	6%	15%	20%	27%	36%	6%	16%	21%	27%	36%	44%	6%	45%
Lithuania	0%	6%	15%	20%	27%	36%	6%	16%	21%	27%	36%	44%	6%	45%
Luxembourg	0%	6%	15%	20%	27%	35%	6%	16%	21%	27%	35%	44%	6%	47%
Malta	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	33%
Netherlands	0%	6%	14%	20%	26%	35%	6%	15%	21%	26%	35%	43%	8%	56%
Norway	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	35%
Poland	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	35%
Portugal	0%	4%	11%	17%	24%	33%	5%	13%	18%	24%	33%	42%	6%	44%
Romania	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	35%
Slovakia	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	40%
Slovenia	0%	6%	15%	21%	27%	36%	6%	16%	21%	27%	36%	45%	5%	42%
Spain	0%	4%	12%	18%	25%	34%	5%	13%	18%	25%	34%	43%	5%	38%
Sweden	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	35%
United Kingdom	0%	4%	11%	17%	24%	32%	5%	12%	18%	24%	32%	41%	7%	51%
Total	0%	5%	12%	18%	25%	34%	5%	14%	19%	25%	34%	43%	5%	40%

Table 84: B5.26: %Energy savings in new installations (2010-2019) for RAC units Modelled Cases by country

For new installations of RAC units, most of the Modelled Cases show minor differences in percentage savings across the different countries. The application of BAT levels of cooling load reduction for RAC units (RAC13) suggests theoretical energy savings of between 27% (Cyprus) and 62% (Ireland) for new installations.

B5.2.3.5 RAC Unit Results: Carbon Savings

Tables B5.27 and B5.28 show the carbon savings associated with the energy savings discussed above. The results reflect a combination of the air conditioning energy demand and the carbon intensity of the electricity supply in each country. This is not quite the same as the carbon intensity of the installed generation plant, since many countries import and export electricity.

There are several low carbon countries with high proportions of nuclear or renewable generation: Iceland, Norway, Lithuania, Sweden, France. Countries with high proportions of fossil-fuel and especially coal-fired generation have high carbon intensities.[134]

Carbon savings existing installations (M Tonnes CO_2)	**RAC0-11**	**RAC12**	**RAC13**
Austria	-	0.0085	0.066
Belgium	-	0.0089	0.066
Bulgaria	-	0.030	0.23
Cyprus	-	0.010	0.078
Czech Republic	-	0.13	1.0
Denmark	-	0.0077	0.056
Estonia	-	0.0072	0.054
Finland	-	0.0028	0.022
France	-	0.015	0.12
Germany	-	0.020	0.13
Greece	-	0.14	1.1
Hungary	-	0.016	0.12
Iceland	-	0.00000	0.00000
Ireland	-	0.0058	0.022
Italy	-	0.26	2.0
Latvia	-	0.012	0.09
Liechtenstein	-	0.00004	0.00028
Lithuania	-	0.00007	0.00044
Luxembourg	-	0.00074	0.0055
Malta	-	0.0018	0.014
Netherlands	-	0.028	0.20
Norway	-	0.00034	0.0026
Poland	-	0.17	1.3
Portugal	-	0.015	0.12
Romania	-	0.066	0.51
Slovakia	-	0.0077	0.060
Slovenia	-	0.0031	0.024
Spain	-	0.22	1.7
Sweden	-	0.0015	0.012
United Kingdom	-	0.065	0.47
Total	**-**	1.3	10

[134] These figures are annual averages: carbon intensity varies according to demand level time of day and year and the relative prices of fuels.

Table 85**: B5.27: Carbon savings in existing installations for Modelled Cases for room air conditioning units broken down by country.**

% Carbon savings existing installations	RAC0	RAC1 - RAC11	RAC12	RAC 13
Austria	0%	0%	5%	42%
Belgium	0%	0%	9%	66%
Bulgaria	0%	0%	6%	50%
Cyprus	0%	0%	4%	30%
Czech Republic	0%	0%	8%	64%
Denmark	0%	0%	9%	67%
Estonia	0%	0%	7%	55%
Finland	0%	0%	5%	40%
France	0%	0%	7%	51%
Germany	0%	0%	10%	67%
Greece	0%	0%	5%	37%
Hungary	0%	0%	5%	38%
Iceland	-	0%	-	-
Ireland	0%	0%	15%	58%
Italy	0%	0%	7%	52%
Latvia	0%	0%	8%	62%
Liechtenstein	0%	0%	7%	50%
Lithuania	0%	0%	11%	66%
Luxembourg	0%	0%	8%	58%
Malta	0%	0%	5%	37%
Netherlands	0%	0%	10%	71%
Norway	0%	0%	6%	44%
Poland	0%	0%	6%	45%
Portugal	0%	0%	7%	57%
Romania	0%	0%	6%	44%
Slovakia	0%	0%	7%	50%
Slovenia	0%	0%	7%	56%
Spain	0%	0%	6%	46%
Sweden	0%	0%	6%	44%
United Kingdom	0%	0%	9%	65%
Total	0%	0%	6%	48%

Table 79: B5.28: Carbon savings in existing installations for Modelled Cases for room air conditioning units broken down by country.

Carbon savings new installations 2010-2019 (M Tonnes CO2)	**RAC 0**	**RAC 1**	**RAC 2**	**RAC 3**	**RAC 4**	**RAC 5**	**RAC 6**	**RAC 7**	**RAC 8**	**RAC 9**	**RAC 10**	**RAC 11**	**RAC 12**	**RAC13**
Austria	-	0.072	0.18	0.26	0.34	0.45	0.078	0.20	0.27	0.34	0.45	0.56	0.064	0.49
Belgium	-	0.056	0.14	0.19	0.26	0.34	0.061	0.15	0.20	0.26	0.34	0.42	0.067	0.49
Bulgaria	-	0.15	0.39	0.54	0.72	0.9	0.16	0.42	0.57	0.72	0.9	1.2	0.14	1.1
Cyprus	-	0.079	0.22	0.30	0.40	0.53	0.085	0.23	0.31	0.40	0.53	0.65	0.050	0.39
Czech Republic	-	0.9	2.3	3.3	4.3	5.7	1.0	2.5	3.4	4.3	5.7	7.1	0.9	7.1
Denmark	-	0.047	0.11	0.16	0.21	0.28	0.051	0.12	0.17	0.21	0.28	0.35	0.058	0.42
Estonia	-	0.068	0.17	0.24	0.32	0.42	0.074	0.19	0.25	0.32	0.42	0.53	0.054	0.42
Finland	-	0.026	0.066	0.09	0.12	0.16	0.028	0.071	0.10	0.12	0.16	0.20	0.019	0.15
France	-	0.09	0.24	0.36	0.51	0.70	0.10	0.26	0.38	0.51	0.70	0.89	0.11	0.87
Germany	-	0.083	0.21	0.29	0.38	0.50	0.09	0.22	0.30	0.38	0.50	0.63	0.11	0.86
Greece	-	1.1	2.9	4.1	5.5	7.1	1.2	3.2	4.3	5.5	7.1	8.9	0.75	5.8
Hungary	-	0.14	0.37	0.52	0.69	0.9	0.15	0.40	0.54	0.69	0.9	1.1	0.11	0.82
Iceland	-	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000	0.00000
Ireland	-	0.023	0.054	0.076	0.10	0.13	0.025	0.059	0.079	0.10	0.13	0.17	0.040	0.25
Italy	-	0.65	1.7	3.1	4.7	6.6	0.75	2.0	3.3	4.7	6.6	8.7	1.2	9
Latvia	-	0.11	0.28	0.40	0.53	0.69	0.12	0.31	0.41	0.53	0.69	0.86	0.089	0.69
Liechtenstein	-	0.00027	0.00069	0.0010	0.0013	0.0017	0.00030	0.00074	0.0010	0.0013	0.0017	0.0021	0.00027	0.0021
Lithuania	-	0.00056	0.0014	0.0020	0.0026	0.0034	0.00061	0.0015	0.0021	0.0026	0.0034	0.0043	0.00056	0.0044
Luxembourg	-	0.0051	0.013	0.018	0.024	0.031	0.0056	0.014	0.019	0.024	0.031	0.039	0.0056	0.042
Malta	-	0.011	0.030	0.041	0.055	0.072	0.012	0.032	0.043	0.055	0.072	0.090	0.0085	0.065
Netherlands	-	0.16	0.39	0.54	0.72	0.9	0.17	0.42	0.56	0.72	0.9	1.2	0.21	1.5
Norway	-	0.0030	0.0077	0.011	0.014	0.019	0.0033	0.0083	0.011	0.014	0.019	0.023	0.0023	0.018
Poland	-	1.5	4.0	5.5	7.3	10	1.6	4.3	5.7	7.3	10	12	1.2	9
Portugal	-	0.068	0.18	0.27	0.38	0.51	0.075	0.20	0.28	0.38	0.51	0.66	0.088	0.68
Romania	-	0.39	1.0	1.5	1.9	2.5	0.42	1.1	1.5	1.9	2.5	3.2	0.32	2.5
Slovakia	-	0.040	0.11	0.15	0.20	0.26	0.043	0.11	0.15	0.20	0.26	0.32	0.037	0.28
Slovenia	-	0.015	0.040	0.056	0.074	0.10	0.016	0.043	0.058	0.074	0.10	0.12	0.015	0.11
Spain	-	1.2	3.2	4.8	6.8	9	1.3	3.5	5.1	6.8	9	12	1.4	10
Sweden	-	0.013	0.034	0.048	0.063	0.083	0.014	0.037	0.050	0.063	0.083	0.10	0.010	0.079
United Kingdom	-	0.28	0.69	1.0	1.5	2.0	0.31	0.76	1.1	1.5	2.0	2.6	0.43	3.1
Total	**-**	7.3	19	28	38	51	8.0	21	29	38	51	64	7.4	57

Table80: B5.29: Carbon savings in new installations (2010-2019) for Modelled Cases for room air conditioning units broken down by country

For both the existing stock and new installations, Italy and Spain have the greatest potential for carbon savings, with substantial potential also in Greece. The high energy savings potential in France is not translated into carbon saving potential because of its reliance on nuclear electricity.

% Carbon savings new installations 2010-2019	RAC 0	RAC 1	RAC 2	RAC C3	RAC C4	RAC 5	RAC 6	RAC 7	RAC 8	RAC 9	RAC 10	RAC 11	RAC 12	RAC 13
Austria	0%	6%	15%	21%	28%	36%	6%	16%	21%	28%	36%	45%	5%	40%
Belgium	0%	6%	14%	20%	27%	35%	6%	16%	21%	27%	35%	44%	7%	51%
Bulgaria	0%	6%	15%	21%	27%	36%	6%	16%	21%	27%	36%	45%	5%	42%
Cyprus	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	27%
Czech Republic	0%	6%	15%	20%	27%	36%	6%	16%	21%	27%	36%	45%	6%	44%
Denmark	0%	6%	14%	20%	27%	35%	6%	15%	21%	27%	35%	43%	7%	53%
Estonia	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	36%
Finland	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	34%
France	0%	4%	11%	17%	25%	33%	5%	13%	18%	25%	33%	43%	5%	42%
Germany	0%	6%	14%	20%	26%	35%	6%	15%	21%	26%	35%	43%	8%	59%
Greece	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	30%
Hungary	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	33%
Iceland	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ireland	0%	6%	14%	19%	25%	33%	6%	15%	20%	25%	33%	42%	10%	62%
Italy	0%	3%	8%	14%	22%	31%	3%	9%	15%	22%	31%	40%	6%	43%
Latvia	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	36%
Liechtenstein	0%	6%	15%	20%	27%	36%	6%	16%	21%	27%	36%	44%	6%	45%
Lithuania	0%	6%	15%	20%	27%	36%	6%	16%	21%	27%	36%	44%	6%	45%
Luxembourg	0%	6%	15%	20%	27%	35%	6%	16%	21%	27%	35%	44%	6%	47%
Malta	0%	6%	15%	21%	28%	37%	6%	16%	22%	28%	37%	46%	4%	33%
Netherlands	0%	6%	14%	20%	26%	35%	6%	15%	21%	26%	35%	43%	8%	56%
Norway	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	35%
Poland	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	35%
Portugal	0%	4%	11%	17%	24%	33%	5%	13%	18%	24%	33%	42%	6%	44%
Romania	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	35%
Slovakia	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	5%	40%
Slovenia	0%	6%	15%	21%	27%	36%	6%	16%	21%	27%	36%	45%	5%	42%
Spain	0%	4%	12%	18%	25%	34%	5%	13%	18%	25%	34%	43%	5%	38%
Sweden	0%	6%	15%	21%	28%	36%	6%	16%	22%	28%	36%	45%	4%	35%
United Kingdom	0%	4%	11%	17%	24%	32%	5%	12%	18%	24%	32%	41%	7%	51%
Total	0%	5%	13%	19%	26%	35%	5%	14%	20%	26%	35%	44%	5%	39%

Table 81: B5.30: % Carbon savings in new installations (2010-2019) for Modelled Cases for room air conditioning units broken down by country.

B5.2.4 Modelling Results Central and Larger Systems

This section reports the results of Modelled Cases that apply to central air conditioning systems or to the component parts of such systems. Although this section contains some commentary on the results,, the principal analysis is in section A3.

Most central systems provide two principal air conditioning services: cooling and ventilation. Both of these are significant in terms of energy consumption. [135] Almost all the energy used in central systems is consumed by the "cold-generating" component (usually a chiller) and the air handling unit. Changes to either the cooling or ventilation demand can have an impact on either the energy demand either of these energy-using components. Thus policy instruments that primarily address cooling demand can have an effect on air handling energy use and vice versa.

Following an overview subsection B5.2.4.1, the next subsections B5.2.4.2 to B5.2.4.5 reports changes to the cooling energy consumption of both chillers and air handling units. [136]. Subsection B5.2.4.6 deals with energy used to support the ventilation function. The overviews summarises key results for both cooling and ventilation energy. The savings are combined for the analysis in Section A3: and the subsequent recommendations.

Results from cases that relate to potential switching between system types – whether between different types of central system or between central systems and self-contained systems are addressed in section B5.3

B5.2.4.1 Overview for Central systems (including packaged systems over 12 kW)

- The range and complexity of the systems considered causes a large number of Modelled Cases and reported results. This overview is therefore also relatively long and subdivided into results for chillers, air handling, other components, combined impact, inspections and audits, and load reduction. Within section B5.2.3 there are tables that break down savings by different types of central system. The key points are itemised below. The cases modelled are detailed in section B3. Chillers: Impact of MEPS (cases C3, C4, C5)
  - The modelling quantifies the impact of imposing progressively tighter MEPS
  - The absolute aggregate savings are comparable to those for room air conditioners, except for the most demanding levels, where they are substantially higher. At the most demanding levels that were modelled (case C5) the ten-year cumulative savings were over 90 TWh. (This implies the removal of most existing products from the market, as is explained in section B3). As section B3 shows, there is a significant performance increase between the (relatively few) most efficient products on the market and even the "best of the rest".
- BAT (case C9)
  - The BAT efficiency is only slightly higher than the most demanding MEPS level modelled, and so the potential savings are only slightly greater than that case. This small difference arises because there is a small proportion of high-performance chillers in the market, and in use in small numbers in applications where their higher costs can be justified.

[135] They usually also provide a heating service, which is not considered in this report.

[136] In the modelling, the energy consumed by air handling units is partitioned into that required to provide satisfactory levels of mechanical ventilation (assigned to the ventilation function); and – for all-air systems – the additional energy required to deliver cooling (assigned to the cooling function)

- Chillers: Financial Incentives (Cases C6, C7, C8)
    - Incentives do not show a marked effect when added to any of the MEPS plus labelling Modelled Cases for chillers and packaged units (C3, C4, C5).
- Air handling subsystem: MEPS for specific fan power (cases C12 and C14)
    - Specific fan power is an attribute of the air handling unit, but its value depends strongly on the design of the ductwork connected to the unit and it therefore reflects the efficiency of the air handling subsystem as a whole.
    - MEPS set at levels that are already in force in some countries show significant modelled savings potential of 56 TWh over ten years, almost all attributable to the ventilation function.
    - BAT levels increase this to 130 TWh (Case C14)
- Air handling subsystem: MEPS on air leakage (Case C21, C22):
    - MEPS set at levels that are already in force in some countries show smaller but still significant modelled savings potential of nearly 30 TWh over ten years, almost all attributable to the ventilation function. BAT levels only increase this slightly.
    - Labelling and financial incentives alone or in combination with MEPS show only small additional savings (cases C10, C11, C13).
- Air handling subsystem: reduced fresh air supply (case C23)
    - Many systems have been (and possibly still are) designed for spaces in which smoking was permitted, but where this is no longer the case. Reducing fresh air rates to lower values has the potential to reduce consumption by a large amount: 180 TWh over ten years. However, this figure is uncertain and may be an over-estimate since the extent of existing over-supply is not known.
    - MEPS and other measures for other system components – specifically pumps and terminal units – lead to only small energy savings (cases C16, C17, C18, C19, C20). (However, they may still be cost-effective.)
- Whole system: system-level MEPS (cases C25 and C26)
    - The savings from component MEPS are not simply additive and this case examines their combined impact. The potential savings are around 30 TWh over ten years. However, this ignores the considerable additional potential savings due to the system described in the following section. As is discussed in section A4 there are several barriers to implementation in the short run. Applying BAT to all components increases the figure by a further 90 TWh (case C26)
- Whole system: inspection and audits (case C24)
    - The impact of air conditioning system inspections as required by the EPBD was not modelled, but was estimated from other research, as is described is section A4.
    - The potential impact from measures that the same research found to be identifiable by thorough detailed auditing, including measurement and, in many cases detailed system modelling, was modelled. The potential savings are high –approaching 60 TWh over ten years (but the process is very expensive).
- Load reduction (Cases C27 and C28)

- The application of all feasible load reduction measures to the building envelope (case C28) has a large impact: savings of over 120 TWh over ten years.

- More realistic assumptions about likely implementation reduce this to the very much smaller figure of 20 TWh figure (case C27)

National differences:

- The absolute savings are, unsurprisingly, in countries with the largest stock or sales of central air conditioning systems: Italy and Spain followed by France, Germany, Greece and the UK.

B5.2.4.2 Modelling Results Central and Larger Systems: Cooling Energy

The cooling energy for Modelled Cases for Central and Larger Systems are:

Case no.	Description	Installations
C0	Central (Base case) voluntary labelling and existing building regulations	New and Existing
C1	Central (Product (Chillers and Packaged Units)) labelling	New
C2	Central (Product (Chillers and Packaged Units)) labelling + financial incentives	New
C3	Central (Product (Chillers and Packaged Units)) MEP1 + labelling	New
C4	Central (Product (Chillers and Packaged Units)) MEP2 + labelling	New
C5	Central (Product (Chillers and Packaged Units)) MEP3 + labelling	New
C6	Central (Product (Chillers and Packaged Units)) MEP1 + labelling + financial incentives	New
C7	Central (Product (Chillers and Packaged Units)) MEP2 + labelling + financial incentives	New
C8	Central (Product (Chillers and Packaged Units)) MEP3 + labelling + finacial incentives	New
C9	Central (Product (Chillers and Packaged Units)) BAT	New
C10	Central (Product (AHU)) labelling	New
C11	Central (Product (AHU)) labelling + financial incentives	New
C12	Central (Product (AHU)) MEP1 + labelling	New
C13	Central (Product (AHU)) MEP1 + labelling + financial incentives	New
C14	Central (Product (AHU)) BAT	New
C15	Central (Product (Fan coil terminal units)) MEP1 + labelling	New
C16	Central (Product (Fan coil terminal units)) MEP1 + labelling + financial incentives	New
C17	Central (Product (Fan coil terminal units)) BAT	New
C18	Central (Product (Pump)) MEP1 + labelling	New
C19	Central (Product (Pump)) MEP1 + labelling + financial incentives	New
C20	Central (Product (Pump)) BAT	New
C21	Central (System (air leakage)) MEPS	New and Existing
C22	Central (System (air leakage)) BAT	New and Existing
C23	Central (System (AHU)) reduce fresh air flow rate	New and Existing
C24	Central (System (rigourous A/C inpection)	New and Existing
C25	Central (System (All components)) MEPS	New
C26	Central (System (All components)) BAT	New
C27	Central (Building Envelope) achievable envelope savings	New and Existing
C28	Central (Building Envelope) BAT envelope savings	New and Existing

Table 82: B5.31: list of Modelled Cases for Central and Larger Systems

B5.2.4.2.1 Modelling Results Cooling Energy in Central and Larger Systems: Combined EU plus EEAC countries

The modelling results for the Modelled Cases are shown in Tables B5.32 and below:

case no.	Central Systems Units											
	Energy Consumption TWh			Energy Savings TWh			Thousand Tonnes CO2			Carbon Savings		
	exisiting installations	new installations		exisiting installations	new installations		exisiting installations	new installations		exisiting installations	new installations	
		in year 1	to year 10		in year 1	to year 10		in year 1	to year 10		in year 1	to year 10
C0	81	4.6	276				50	2.8	164			
C1	81	4.6	274	-	0.033	1.9	50	2.7	162	-	0.020	1.2
C2	81	4.5	271	-	0.073	4.4	50	2.7	161	-	0.045	2.7
C3	81	4.4	265	-	0.18	10	50	2.6	157	-	0.11	6.5
C4	81	4.2	249	-	0.45	27	50	2.5	147	-	0.28	16
C5	81	2.6	153	-	2.1	123	50	1.5	90	-	1.2	73
C6	81	4.4	264	-	0.20	12	50	2.6	156	-	0.13	7.5
C7	81	4.1	247	-	0.48	29	50	2.5	146	-	0.29	17
C8	81	2.5	152	-	2.1	123	50	1.5	90	-	1.2	73
C9	81	2.5	152	-	2.1	123	50	1.5	90	-	1.2	73
C10	81	4.6	274	-	0.022	1.3	50	2.7	163	-	0.013	0.78
C11	81	4.6	273	-	0.044	2.6	50	2.7	162	-	0.026	1.6
C12	81	4.3	256	-	0.33	20	50	2.6	152	-	0.20	12
C13	81	4.3	255	-	0.35	21	50	2.5	151	-	0.21	12
C14	81	3.8	230	-	0.77	46	50	2.3	136	-	0.46	27
C15	81	4.6	274	-	0.022	1.3	50	2.7	163	-	0.013	0.78
C16	81	4.6	274	-	0.027	1.6	50	2.7	163	-	0.016	0.9
C17	81	4.5	272	-	0.065	3.9	50	2.7	161	-	0.039	2.3
C18	81	4.6	276	-	0.00047	0.028	50	2.8	164	-	0.00028	0.017
C19	81	4.6	276	-	0.00057	0.034	50	2.8	164	-	0.00034	0.020
C20	81	4.6	276	-	0.00081	0.048	50	2.8	164	-	0.00048	0.029
C21	76	4.4	261	5.0	0.25	15	47	2.6	155	3.2	0.15	9
C22	76	4.3	259	5.7	0.29	17	46	2.6	153	3.6	0.18	10
C23	55	3.6	218	26	1.0	58	34	2.2	129	16	0.58	34
C24	57	3.8	224	24	0.86	51	35	2.2	133	15	0.51	30
C25	81	4.0	242	-	0.57	34	50	2.4	143	-	0.34	20
C26	81	1.9	114	-	2.7	162	50	1.1	68	-	1.6	96
C27	72	4.5	268	8.9	0.12	7.4	44	2.7	159	5.5	0.073	4.3
C28	26	3.7	220	55	0.9	55	16	2.2	131	34	0.55	33

Table 83: B5.32:Summary results for Modelled Cases for central and larger systems - All EU and EEAC countries.

For new installations the summary of results above shows the potential savings in year 1 and the cumulative savings to year 10. C0 represents the base case so there are no savings associated with this case.[137]

These results identify the following percentage energy and carbon savings for each modelled case in relation to the base case (C0):

case no.	Central Systems Units					
	% Energy saving			% Carbon Savings		
	exisiting installations	new installations		exisiting installations	new installations	
		in year 1	to year 10		in year 1	to year 10
C0						
C1	0%	1%	1%	0%	1%	1%
C2	0%	2%	2%	0%	2%	2%
C3	0%	4%	4%	0%	4%	4%
C4	0%	10%	10%	0%	10%	10%
C5	0%	45%	45%	0%	45%	45%
C6	0%	4%	4%	0%	5%	5%
C7	0%	10%	10%	0%	11%	11%
C8	0%	45%	45%	0%	45%	45%
C9	0%	45%	45%	0%	45%	45%
C10	0%	0.48%	0.48%	0.00%	0.47%	0.48%
C11	0%	0.95%	0.96%	0.00%	0.95%	0.95%
C12	0%	7%	7%	0%	7%	7%
C13	0%	8%	8%	0%	8%	8%
C14	0%	17%	17%	0%	17%	17%
C15	0%	0%	0%	0%	0%	0%
C16	0%	1%	1%	0%	1%	1%
C17	0%	1%	1%	0%	1%	1%
C18	0%	0%	0%	0%	0%	0%
C19	0%	0%	0%	0%	0%	0%
C20	0%	0%	0%	0%	0%	0%
C21	6%	5%	5%	6%	6%	6%
C22	7%	6%	6%	7%	6%	6%
C23	32%	21%	21%	33%	21%	21%
C24	30%	19%	19%	30%	19%	19%
C25	0%	12%	12%	0%	12%	12%
C26	0%	59%	59%	0%	59%	59%
C27	11%	3%	3%	11%	3%	3%
C28	68%	20%	20%	68%	20%	20%

Table 84: B5.27: Percentage energy and carbon savings for Central Systems units Modelled Cases – All EU/EEA countries

[137] For existing installations, the results represent an idealised approach whereby all systems are impacted immediately**.** Section B5.4 explains how the modelling results have been modified to take account of these additional constraints before being used as the basis for the recommendations that are presented in Section A3

The setting of demanding MEPS requirements (Case C5) produces potential savings of 48

The modelling shows that carrying out improvements to the building envelope to reduce the cooling load to the best possible level (C28) achieves the highest level of potential savings, 70% for existing stock and 63% for new installations energy savings. In reality this level of reduction is unlikely to be cost effective, particularly for existing buildings, and a more realistic level of cooling load reduction (C27) is likely to lead to savings of around 10%-12%.

Cases C1 to C20 relate to potential improvements in efficiency associated with component replacement. They therefore do not generate immediate savings in existing systems.

The results indicate that incentives do not appear to have a marked effect when added to any of the MEPS plus labelling Modelled Cases for chillers and packaged units (C3, C4, C5). For AHU, labelling and incentives do not show any significant savings (C10 and C11), which was also the case for the 3 cases modelled for pumps (C18, C19, C20).

B5.2.4.2.2 Modelling Results Cooling Energy in Central and Larger Systems: Breakdown by System Type.

The potential savings can also be examined by system type. The aggregate savings reflect the prevalence of different system types (in terms of total cooling power) and variations of impact of particular cases on different system types.

Tables 87 to 92 below [insert #s] show the energy and carbon savings, respectively for each of the Modelled Cases by system type, expressed in absolute terms or as a percentage of the base case is indicated.

Energy Savings: Existing Stock

TWh energy saving existing stock	C0	C1 - C20, C25 and C26	C21	C22	C23	C24	C27	C28
Split systems	-	-	0.0	0.0	1.9	3.4	1.2	7.2
VRF	-	-	0.0	0.0	0.5	0.8	0.3	1.8
Roof top	-	-	0.3	0.4	1.6	1.3	0.5	3.1
All air constant volume	-	-	1.5	1.7	6.3	3.8	1.4	9.3
All air VAV	-	-	0.8	0.9	3.0	2.7	1.0	6.3
Water based fan coil	-	-	2.1	2.4	11.0	9.9	3.7	22.7
Water based induction	-	-	0.2	0.3	1.3	1.1	0.4	2.5
Heat pump loop	-	-	0.0	0.0	0.4	0.7	0.2	1.4
Active chilled beam	-	-	0.1	0.1	0.5	0.4	0.1	0.9
Passive chilled beam	-	-	0.0	0.0	0.0	0.1	0.0	0.2
Total	**-**	**-**	**5.0**	**5.7**	**26.4**	**24.2**	**8.9**	**55.3**

Table 85: B5.28: Energy savings in existing stock for Modelled Cases for central and larger systems broken down by system type - All EU and EEAC countries

There are only a few cases that apply to existing systems: principally load reduction and effective inspection and related activities. The largest potential energy savings are associated with the most common systems (by total cooling capacity) that are currently in use: fan coil systems and all-air (especially variable volume) systems.

TWh energy saving existing stock	C0	C1 - C20, C25 and C26	C21	C22	C23	C24	C27	C28
Split systems	0%	0%	0%	0%	18%	32%	11%	68%
VRF	0%	0%	0%	0%	19%	33%	12%	70%
Roof top	0%	0%	7%	7%	33%	28%	10%	64%
All air constant volume	0%	0%	10%	12%	45%	27%	10%	67%
All air VAV	0%	0%	9%	10%	33%	30%	11%	69%
Water based fan coil	0%	0%	6%	7%	34%	30%	11%	69%
Water based induction	0%	0%	7%	8%	35%	29%	11%	68%
Heat pump loop	0%	0%	0%	0%	19%	33%	12%	71%
Active chilled beam	0%	0%	6%	7%	34%	29%	11%	68%
Passive chilled beam	0%	0%	0%	0%	6%	15%	4%	28%
Total	**0%**	**0%**	**6%**	**7%**	**32%**	**30%**	**11%**	**68%**

Table 86: B5.29: % Energy savings in existing stock for Modelled Cases for central and larger systems broken down by system type - All EU and EEAC countries

Differences between system types in terms of percentage savings largely result from differences in potential savings related to air movement, with systems relying most heavily on air to provide cooling generally having the greatest potential for savings. Passive chilled beams are assumed to be used with relatively low-flow displacement ventilation and show the lowest savings potential (but are amongst the most efficienct systems in the first place).

Rigorous inspection shows the next set of best results in terms of systems across building types, except for split systems, roof top, and all air VAV systems, which achieve slightly higher savings via application of system (All components) MEPS

Energy Savings: New Installation .

For new installations, the results obtained by system type are shown in Tables B3.50 to B3.53 below:

TWh energy saving cumulative sales 2010-2019	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
Split systems	-	0.7	1.4	3.5	8.2	14.2	4.1	8.4	14.2	14.2	-	-	-	-	-
VRF	-	-	-	-	1.6	5.9	-	1.8	5.9	5.9	-	-	-	-	-
Roof top	-	0.3	0.6	1.7	5.1	9.6	2.0	5.1	9.6	9.6	0.1	0.2	1.6	1.7	3.6
All air constant volume	-	0.2	0.4	1.1	2.6	20.5	1.2	2.7	20.5	20.5	0.4	0.9	6.4	6.8	14.9
All air VAV	-	0.2	0.3	0.8	1.9	14.8	0.9	2.0	14.8	14.8	0.1	0.3	2.2	2.4	5.1
Water based fan coil	-	0.5	1.0	2.7	6.3	49.2	2.9	6.7	49.2	49.2	0.5	1.1	8.2	8.8	19.2
Water based	-	0.1	0.1	0.3	0.8	5.9	0.4	0.8	5.9	5.9	0.1	0.1	1.0	1.1	2.4

induction															
Heat pump loop	-	0.0	0.5	0.2	0.2	0.3	0.5	0.6	0.6	0.6	-	-	-	-	-
Active chilled beam	-	0.0	0.0	0.1	0.3	2.1	0.1	0.3	2.1	2.1	0.0	0.0	0.4	0.4	0.9
Passive chilled beam	-	0.0	0.0	0.0	0.1	0.7	0.0	0.1	0.7	0.7	-	-	-	-	-
Total	**-**	**1.9**	**4.4**	**10.5**	**27.0**	**123.1**	**12.1**	**28.5**	**123.4**	**123.4**	**1.3**	**2.6**	**19.8**	**21.1**	**46.1**

TWh energy saving cumulative sales 2010-2019	**C15**	**C16**	**C17**	**C18**	**C19**	**C20**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C28**
Split systems	-	-	-	-	-	-	0.0	0.0	2.5	8.6	0.0	14.2	1.5	11.4
VRF	-	-	-	-	-	-	0.0	0.0	1.5	5.1	0.0	5.9	0.9	6.9
Roof top	-	-	-	-	-	-	1.1	1.3	4.4	3.6	2.5	12.4	0.5	3.7
All air constant volume	-	-	-	-	-	-	4.3	5.0	16.2	7.0	10.0	31.5	0.8	6.0
All air VAV	-	-	-	-	-	-	2.5	2.9	6.4	5.5	4.5	19.2	0.8	5.9
Water based fan coil	1.2	1.5	3.7	0.0	0.0	0.0	5.9	6.8	23.0	17.9	14.5	66.3	2.4	17.7
Water based induction	-	-	-	0.0	0.0	0.0	0.7	0.8	2.8	2.2	1.6	7.7	0.3	2.2
Heat pump loop	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.7	0.1	0.4
Active chilled beam	0.1	0.1	0.2	0.0	0.0	0.0	0.3	0.3	1.0	0.8	0.6	2.8	0.1	0.7
Passive chilled beam	-	-	-	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.0	0.7	0.1	0.5
Total	**1.3**	**1.6**	**3.9**	**0.0**	**0.0**	**0.0**	**14.8**	**17.1**	**58.0**	**51.3**	**33.8**	**161.5**	**7.4**	**55.3**

Table 87: B5.30: Energy savings in new installations for Modelled Cases for central and larger systems broken down by system type - All EU and EEAC countries

In almost all cases, the biggest aggregate potential savings are for fan coil systems, reflecting their widespread use for new installation (and in the case of component replacements their prevalence in the existing stock). The exceptions are measures that reduce air leakage from ductwork and AHUs. (Cases C21 and C22) For these measures the biggest potential savings are in all-air systems for which air leakage leads to more energy wastage.

The above translate into the following percentage energy savings by system type shown in Tables [insert #s] below:

TWh energy saving cumulative sales 2010-2019	**C0**	**C1**	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**	**C10**	**C11**	**C12**	**C13**	**C14**
Split systems	0%	2%	4%	9%	21%	37%	11%	22%	37%	37%	0%	0%	0%	0%	0%
VRF	0%	0%	0%	0%	7%	26%	0%	8%	26%	26%	0%	0%	0%	0%	0%
Roof top	0%	1%	3%	9%	26%	49%	10%	26%	49%	49%	1%	1%	8%	9%	19%
All air constant volume	0%	0%	1%	2%	6%	45%	3%	6%	45%	45%	1%	2%	14%	15%	33%
All air VAV	0	1	1%	3%	6%	50	3%	7%	50	50	0%	1%	7%	8%	17

	%	%				%			%	%					%
Water based fan coil	0%	1%	1%	3%	6%	49%	3%	7%	49%	49%	1%	1%	8%	9%	19%
Water based induction	0%	1%	1%	3%	6%	49%	3%	7%	49%	49%	1%	1%	9%	9%	20%
Heat pump loop	0%	1%	34%	14%	15%	22%	35%	42%	46%	46%	0%	0%	0%	0%	0%
Active chilled beam	0%	0%	1%	3%	6%	48%	3%	7%	48%	48%	1%	1%	8%	9%	20%
Passive chilled beam	0%	0%	1%	2%	4%	35%	2%	4%	35%	35%	0%	0%	0%	0%	0%
Total	0%	1%	2%	4%	10%	45%	4%	10%	45%	45%	0%	1%	7%	8%	17%

TWh energy saving cumulative sales 2010-2019	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28
Split systems	0%	0%	0%	0%	0%	0%	0%	0%	6%	23%	0%	37%	4%	30%
VRF	0%	0%	0%	0%	0%	0%	0%	0%	7%	23%	0%	26%	4%	31%
Roof top	0%	0%	0%	0%	0%	0%	6%	6%	23%	18%	13%	64%	3%	19%
All air constant volume	0%	0%	0%	0%	0%	0%	10%	11%	36%	16%	22%	70%	2%	13%
All air VAV	0%	0%	0%	0%	0%	0%	9%	10%	22%	19%	15%	65%	3%	20%
Water based fan coil	1%	1%	4%	0%	0%	0%	6%	7%	23%	18%	14%	65%	2%	17%
Water based induction	0%	0%	0%	0%	0%	0%	6%	7%	24%	18%	14%	64%	2%	18%
Heat pump loop	2%	3%	6%	0%	0%	0%	0%	0%	6%	22%	2%	51%	4%	28%
Active chilled beam	1%	2%	4%	0%	0%	0%	6%	7%	23%	17%	15%	66%	2%	16%
Passive chilled beam	0%	0%	0%	0%	0%	0%	0%	0%	6%	14%	0%	35%	3%	26%
Total	0%	1%	1%	0%	0%	0%	5%	6%	21%	19%	12%	59%	3%	20%

Table 88: B5.31: % Energy savings in new installations for Modelled Cases for central and larger systems broken down by system type - All EU/EEA countries

For all system types, the greatest percentage savings are associated with BAT for chillers and packaged units (case C9), and demanding MEPS for chillers and packaged systems (C5 and, with incentives, C8). Potential savings are up to 50% (for some system types). Differences of percentage savings between system types are largely related to differences in their reliance on air to transport cooling, and therefore thimpact of measures that improve the fficency of air handling.

Carbon Savings

The energy savings lead to CO_2 emission reductions suggested as in tables 91 and 92 below. In terms of differences between system types, there are no significant differences from the distribution of energy savings.

Thousand Tonnes CO2 emissions existing stock	**C0**	**C1 - C20, C25 and C26**	**C21**	**C22**	**C23**	**C24**	**C27**	**C28**
Split systems	-	-	0.0	0.0	1.1	2.0	0.7	4.2
VRF	-	-	0.0	0.0	0.3	0.5	0.2	1.1
Roof top	-	-	0.2	0.2	0.9	0.8	0.3	1.8
All air constant volume	-	-	0.9	1.0	3.9	2.4	0.9	5.8
All air VAV	-	-	0.5	0.6	1.8	1.7	0.6	3.9
Water based fan coil	-	-	1.3	1.5	6.8	6.2	2.3	14.1

Water based induction	-	-	0.2	0.2	0.8	0.7	0.2	1.6
Heat pump loop	-	-	0.0	0.0	0.2	0.4	0.2	0.9
Active chilled beam	-	-	0.1	0.1	0.3	0.2	0.1	0.6
Passive chilled beam	-	-	0.0	0.0	0.0	0.1	0.0	0.1
Total	**-**	**-**	**3.2**	**3.6**	**16.3**	**14.9**	**5.5**	**33.9**

Table 89: B5.32: Carbon savings in existing stock for Modelled Cases for central and larger systems broken down by system type - All EU and EEAC countries.

Thousand Tonnes CO2 emissions existing stock	**C0**	**C1 - C20, C25 and C26**	**C21**	**C22**	**C23**	**C24**	**C27**	**C28**
Split systems	0%	0%	0%	0%	18%	32%	11%	68%
VRF	0%	0%	0%	0%	18%	33%	12%	69%
Roof top	0%	0%	7%	8%	33%	28%	10%	64%
All air constant volume	0%	0%	11%	12%	45%	28%	10%	67%
All air VAV	0%	0%	9%	11%	33%	30%	11%	69%
Water based fan coil	0%	0%	6%	7%	34%	30%	11%	69%
Water based induction	0%	0%	7%	8%	35%	30%	11%	68%
Heat pump loop	0%	0%	0%	0%	19%	33%	12%	71%
Active chilled beam	0%	0%	7%	7%	34%	29%	11%	68%
Passive chilled beam	0%	0%	0%	0%	6%	15%	4%	28%
Total	0%	0%	6%	7%	33%	30%	11%	68%

Table 90: B5.33: Carbon savings in new installations for Modelled Cases for central and larger systems broken down by system type - All EU/EEA countries

B5.2.4.2.3 Modelling Results Cooling Energy in Central and Larger Systems: Energy Savings in Existing Stock

Tables[insert #s] 93 below shows the potential energy savings for the existing stock of systems for each of the relevant Modelled Cases for each country The only Modelled Cases that impact on the existing stock are C21 and C22 relating to duct and AHU leakage, C23 (reduced outdoor air supply), C24 (rigorous inspections or similar processes) and C27 and C28 relating to load reduction measures. Note that the results are quoted here in TWh (the tables for movables and room air conditioners are in GWh)

TWh energy saving existing stock	**C0-C20, C25 and C26**	**C21**	**C22**	**C23**	**C24**	**C27**	**C28**
Austria	-	0.1	0.1	0.5	0.5	0.2	1.1
Belgium	-	0.1	0.1	0.8	0.7	0.3	1.7
Bulgaria	-	0.0	0.1	0.2	0.2	0.1	0.4
Cyprus	-	0.0	0.0	0.1	0.1	0.0	0.1
Czech Republic	-	0.1	0.1	0.5	0.4	0.2	1.0
Denmark	-	0.0	0.0	0.1	0.1	0.1	0.4
Estonia	-	0.0	0.0	0.0	0.0	0.0	0.1

Finland	-	0.0	0.0	0.2	0.2	0.1	0.5
France	-	0.4	0.4	1.9	1.7	0.6	4.0
Germany	-	0.4	0.5	2.5	2.1	0.9	5.1
Greece	-	0.1	0.2	0.6	0.6	0.2	1.1
Hungary	-	0.1	0.2	0.6	0.5	0.1	1.0
Iceland	-	0.0	0.0	0.0	0.0	0.0	0.0
Ireland	-	0.1	0.1	0.5	0.4	0.2	0.8
Italy	-	1.2	1.4	5.5	5.0	1.7	11.0
Latvia	-	0.0	0.0	0.0	0.0	0.0	0.1
Liechtenstein	-	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	-	0.0	0.0	0.1	0.1	0.0	0.1
Luxembourg	-	0.0	0.0	0.0	0.0	0.0	0.0
Malta	-	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	-	0.2	0.2	0.9	0.7	0.3	2.0
Norway	-	0.0	0.0	0.3	0.3	0.1	0.6
Poland	-	0.1	0.1	0.3	0.3	0.1	0.7
Portugal	-	0.1	0.1	0.3	0.3	0.1	0.8
Romania	-	0.1	0.1	0.5	0.4	0.1	0.9
Slovakia	-	0.0	0.1	0.2	0.2	0.1	0.4
Slovenia	-	0.0	0.0	0.1	0.1	0.0	0.2
Spain	-	0.8	1.0	4.1	4.4	1.4	9.2
Sweden	-	0.0	0.0	0.5	0.5	0.2	1.1
United Kingdom	-	0.9	1.0	5.0	4.4	1.9	10.7
Total	**-**	**5.0**	**5.7**	**26.4**	**24.2**	**8.9**	**55.3**

Table 86: B5.34: Energy savings in existing installations for Modelled Cases for central and larger systems broken down by country.

The largest potential savings are in Italy, Spain and the United Kingdom, with smaller but significant potential savings in France and Germany. The first three countries collectively account for over 50% of the potential savings: including the other two covers more than 70%

Table 94 below shows the percentage energy savings (relative to the base case) for each country.

TWh energy saving existing stock	C0-C20, C25 and C26	C21	C22	C23	C24	C27	C28
Austria	0%	7%	8%	34%	29%	10%	67%
Belgium	0%	6%	7%	40%	35%	15%	91%
Bulgaria	0%	6%	7%	29%	27%	9%	59%
Cyprus	0%	6%	7%	21%	24%	6%	42%
Czech Republic	0%	7%	8%	39%	32%	13%	80%
Denmark	0%	1%	1%	37%	37%	16%	90%
Estonia	0%	6%	6%	32%	31%	12%	74%
Finland	0%	1%	2%	26%	27%	8%	56%
France	0%	6%	7%	32%	29%	10%	68%
Germany	0%	7%	8%	43%	36%	16%	87%
Greece	0%	6%	7%	23%	24%	7%	46%

Hungary	0%	7%	8%	29%	25%	8%	53%
Iceland	0%	6%	7%	31%	28%	10%	64%
Ireland	0%	7%	8%	54%	47%	26%	99%
Italy	0%	7%	8%	30%	27%	9%	60%
Latvia	0%	6%	7%	38%	34%	14%	90%
Liechtenstein	0%	6%	7%	32%	29%	11%	68%
Lithuania	0%	7%	8%	43%	37%	18%	94%
Luxembourg	0%	6%	7%	36%	32%	13%	79%
Malta	0%	5%	5%	21%	25%	7%	47%
Netherlands	0%	8%	9%	44%	36%	16%	95%
Norway	0%	1%	2%	30%	28%	10%	65%
Poland	0%	6%	7%	30%	28%	10%	65%
Portugal	0%	5%	6%	29%	29%	10%	67%
Romania	0%	7%	8%	28%	26%	8%	53%
Slovakia	0%	7%	8%	30%	27%	9%	60%
Slovenia	0%	5%	6%	29%	29%	10%	68%
Spain	0%	5%	6%	26%	27%	8%	56%
Sweden	0%	1%	2%	30%	28%	10%	65%
United Kingdom	0%	7%	8%	40%	35%	15%	85%
Total	0%	6%	7%	32%	30%	11%	68%

Table 87: B5.35: %Energy savings in existing installations for Modelled Cases for central and larger systems broken down by country.

The pattern of differences between countries is similar to that for room air conditioners, with larger percentage savings in relatively mild climates. There are some exceptions to this general rule: Nordic countries have intermediate levels of percentage savings. The highest percentage savings can be more than three times the lowest. This for case C23 (reduced outdoor air supply) the figure for Ireland is 43% and for Cyprus 12%. This is a consequence of the difference in annual cooling energy consumptions being much greater than the difference of the (absolute) savings.

B5.2.4.2.4 Modelling Results Cooling Energy in Central and Larger Systems: Energy Savings in New Installations

Tables 95 and 96 below shows the potential energy savings (compared to the base case C0) for a ten year period following implementation for new installations (meaning replacement components or systems and first-time system installations in new and existing buildings) for each country. Table 95 shows the absolute savings in TWh while table 96 shows the percentage savings relative to the base case.

TWh energy saving cumulative sales 2010-2019	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
Austria	-	0.1	0.1	0.3	0.7	3.4	0.4	0.7	3.4	3.4	0	0.1	0.7	0.7	1.5
Belgium	-	0.1	0.1	0.3	0.7	2.6	0.3	0.7	2.6	2.6	0	0.1	0.5	0.5	1.1
Bulgaria	-	0	0	0.1	0.2	0.8	0.1	0.3	0.8	0.8	0	0	0.1	0.1	0.2

Cyprus	-	0	0	0	0.1	0.4	0	0.1	0.4	0.4	0	0	0	0	0.1
Czech Republic	-	0	0.1	0.1	0.3	1.2	0.1	0.3	1.2	1.2	0	0	0.2	0.2	0.5
Denmark	-	0	0	0.1	0.2	0.6	0.1	0.2	0.6	0.6	0	0	0.1	0.1	0.2
Estonia	-	0	0	0	0.1	0.2	0	0.1	0.2	0.2	0	0	0	0	0.1
Finland	-	0	0.1	0.3	0.6	1.8	0.3	0.6	1.8	1.8	0	0	0.2	0.2	0.5
France	-	0.1	0.2	0.4	1.8	11.5	0.5	1.9	11.5	11.5	0.1	0.3	2	2.1	4.6
Germany	-	0.1	0.3	0.8	1.7	7.8	0.8	1.8	7.8	7.8	0.1	0.2	1.6	1.7	3.7
Greece	-	0.1	0.2	0.6	1.4	5.7	0.7	1.4	5.7	5.7	0	0.1	0.7	0.8	1.7
Hungary	-	0	0.1	0.2	0.4	1.8	0.2	0.4	1.8	1.8	0	0	0.3	0.3	0.7
Iceland	-	0	0	0	0	0.1	0	0	0.1	0.1	0	0	0	0	0
Ireland	-	0	0	0.1	0.2	0.8	0.1	0.2	0.8	0.8	0	0	0.2	0.2	0.4
Italy	-	0.5	1.2	2.9	6.2	28.8	3.3	6.6	28.9	28.9	0.3	0.6	4.6	4.9	10.7
Latvia	-	0	0	0	0.1	0.3	0	0.1	0.3	0.3	0	0	0	0.1	0.1
Liechtenstein	-	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	-	0	0	0	0.1	0.4	0	0.1	0.4	0.4	0	0	0.1	0.1	0.2
Luxembourg	-	0	0	0	0	0.1	0	0	0.1	0.1	0	0	0	0	0
Malta	-	0	0	0	0	0.1	0	0	0.1	0.1	0	0	0	0	0
Netherlands	-	0.1	0.1	0.3	0.6	3.2	0.3	0.6	3.3	3.3	0	0.1	0.7	0.8	1.7
Norway	-	0	0.1	0.2	0.5	1.8	0.2	0.5	1.8	1.8	0	0	0.3	0.3	0.6
Poland	-	0	0.1	0.2	0.5	1.8	0.2	0.5	1.8	1.8	0	0	0.3	0.3	0.6
Portugal	-	0	0.1	0.1	0.5	1.9	0.2	0.5	1.9	1.9	0	0	0.3	0.3	0.6
Romania	-	0	0.1	0.2	0.5	1.9	0.3	0.5	1.9	1.9	0	0	0.3	0.3	0.6
Slovakia	-	0	0	0.1	0.2	0.7	0.1	0.2	0.7	0.7	0	0	0.1	0.1	0.2
Slovenia	-	0	0	0.1	0.2	0.6	0.1	0.2	0.6	0.6	0	0	0.1	0.1	0.2
Spain	-	0.4	0.9	2	6.5	28.8	2.4	6.8	28.9	28.9	0.3	0.5	4.1	4.4	9.6
Sweden	-	0.1	0.2	0.4	0.9	3.4	0.5	0.9	3.4	3.4	0	0.1	0.5	0.5	1.2
United Kingdom	-	0.1	0.3	0.6	2	10.5	0.7	2.2	10.6	10.6	0.1	0.3	1.9	2	4.5
Total	**-**	**1.9**	**4.4**	**10.5**	**27**	**123.1**	**12.1**	**28.5**	**123.4**	**123.4**	**1.3**	**2.6**	**19.8**	**21.1**	**46.1**

TWh energy saving cumulative sales 2010-2019	**C15**	**C16**	**C17**	**C18**	**C19**	**C20**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C28**
Austria	0	0.1	0.1	0	0	0	0.5	0.6	1.8	1.3	1.2	4.7	0.2	1.4
Belgium	0	0	0.1	0	0	0	0.4	0.4	1.4	1.1	0.8	3.5	0.2	1.4
Bulgaria	0	0	0	0	0	0	0.1	0.1	0.3	0.4	0.2	1	0.1	0.4
Cyprus	0	0	0	0	0	0	0	0	0.1	0.2	0.1	0.5	0	0.2
Czech Republic	0	0	0	0	0	0	0.2	0.2	0.6	0.5	0.4	1.6	0.1	0.6
Denmark	0	0	0	0	0	0	-	0	0.3	0.3	0.1	0.7	0.1	0.4
Estonia	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.3	0	0.1
Finland	0	0	0	0	0	0	-	0	0.7	0.8	0.2	2.2	0.1	0.8
France	0.1	0.2	0.4	0	0	0	1.7	1.9	5.9	5.1	3.5	15.5	0.8	5.9
Germany	0.1	0.1	0.3	0	0	0	1.2	1.3	4.6	3.3	2.7	10.8	0.6	3.9

Greece	0	0.1	0.1	0	0	0	0.7	0.8	2.1	2.3	1.4	7.2	0.3	2.1
Hungary	0	0	0.1	0	0	0	0.3	0.3	0.8	0.7	0.5	2.3	0.1	0.6
Iceland	0	0	0	0	0	0	0	0	0.1	0	0	0.2	0	0.1
Ireland	0	0	0	0	0	0	0.1	0.1	0.5	0.3	0.3	1.1	0.1	0.3
Italy	0.3	0.4	0.9	0	0	0	4.2	4.7	13.1	11.1	8.5	37.9	1.5	11.3
Latvia	0	0	0	0	0	0	0	0	0.1	0.1	0.1	0.4	0	0.1
Liechtenstein	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Lithuania	0	0	0	0	0	0	0.1	0.1	0.2	0.1	0.1	0.5	0	0.2
Luxembourg	0	0	0	0	0	0	0	0	0	0	0	0.1	0	0
Malta	0	0	0	0	0	0	0	0	0	0.1	0	0.1	0	0.1
Netherlands	0.1	0.1	0.2	0	0	0	0.5	0.6	2	1.3	1.2	4.6	0.2	1.4
Norway	0	0	0.1	0	0	0	-	0	0.7	0.7	0.3	2.2	0.1	0.7
Poland	0	0	0	0	0	0	0.2	0.3	0.8	0.7	0.5	2.3	0.1	0.8
Portugal	0	0	0	0	0	0	0.2	0.2	0.8	0.9	0.5	2.4	0.1	1.1
Romania	0	0	0	0	0	0	0.2	0.3	0.7	0.8	0.5	2.4	0.1	0.8
Slovakia	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.2	0.9	0	0.3
Slovenia	0	0	0	0	0	0	0.1	0.1	0.3	0.3	0.1	0.8	0	0.3
Spain	0.3	0.3	0.8	0	0	0	3.7	4.2	12.2	12.3	7.6	37.2	1.6	12.7
Sweden	0	0	0.1	0	0	0	-	0.1	1.4	1.3	0.5	4.2	0.2	1.4
United Kingdom	0.1	0.2	0.4	0	0	0	0.2	0.4	5.8	4.9	2.2	13.9	0.8	5.8
Total	**1.3**	**1.6**	**3.9**	**0**	**0**	**0**	**14.8**	**17.1**	**58**	**51.3**	**33.8**	**161.5**	**7.4**	**55.3**

Table 88: B5.36a: Annual energy savings in new installations (2010-2019) for Modelled Cases for central and larger systems broken down by country.

As for the existing stock, most if the potential savings are in five countries, although they account for a smaller proportion of the savings for new installations. This reflects the impact of countries with smaller existing stocks of air conditioning systems which are expanding more rapidly than older markets.[138] More than 60% of the potential savings are in Italy, Spain, the United Kingdom, France and Germany with the first two of these jointly accounting for nearly 50%

As for the existing stock, most if the potential savings are in five countries, although they account for a smaller proportion of the savings for new installations. This reflects the impact of several countries with smaller existing stocks of air conditioning systems which have been expanding more rapidly than older markets. More than 60% of the potential savings are in Italy, Spain, the United Kingdom, France and Germany, with the first two of these accounting for nearly 50%

Table]B5.37 shows the results expressed in terms of percentage energy savings per modelled case and by country:

[138] Prominent amongst these is Greece for which a “business as usual” projection now seems particularly optimistic

TWh energy saving cummulative sales 2010-2019	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
Austria	[redacted]	1%	2%	5%	11%	53%	6%	11%	53%	53%	0%	0%	2%	2%	4%
Belgium	[redacted]	1%	3%	6%	14%	48%	7%	15%	48%	48%	0%	0%	1%	1%	3%
Bulgaria	[redacted]	1%	2%	5%	14%	44%	6%	14%	44%	44%	0%	0%	1%	1%	2%
Cyprus	[redacted]	1%	1%	4%	12%	39%	4%	12%	39%	39%	0%	0%	0%	0%	1%
Czech Republic	[redacted]	1%	2%	6%	13%	49%	6%	13%	49%	49%	0%	0%	1%	1%	3%
Denmark	[redacted]	2%	3%	8%	20%	46%	9%	20%	46%	46%	0%	0%	1%	1%	1%
Estonia	[redacted]	1%	3%	7%	16%	46%	7%	16%	47%	47%	0%	0%	1%	1%	2%
Finland	[redacted]	1%	3%	7%	17%	49%	8%	17%	49%	49%	0%	0%	1%	1%	2%
France	[redacted]	0%	1%	2%	8%	45%	2%	9%	45%	45%	0%	0%	1%	1%	3%
Germany	[redacted]	1%	2%	5%	12%	48%	6%	12%	48%	48%	0%	0%	2%	2%	4%
Greece	[redacted]	1%	2%	5%	12%	48%	6%	13%	48%	48%	0%	0%	1%	1%	2%
Hungary	[redacted]	1%	2%	5%	11%	53%	6%	12%	53%	53%	0%	0%	1%	1%	3%
Iceland	[redacted]	1%	3%	7%	14%	52%	7%	15%	52%	52%	0%	0%	1%	1%	3%
Ireland	[redacted]	1%	2%	5%	12%	50%	6%	13%	50%	50%	0%	0%	2%	2%	2%
Italy	[redacted]	1%	2%	5%	12%	51%	6%	13%	52%	52%	0%	0%	1%	1%	3%
Latvia	[redacted]	1%	2%	6%	14%	48%	7%	15%	48%	48%	0%	0%	1%	1%	3%
Liechtenstein	[redacted]	1%	2%	5%	12%	47%	6%	13%	47%	47%	0%	0%	1%	1%	3%
Lithuania	[redacted]	1%	3%	6%	13%	51%	7%	14%	51%	51%	0%	0%	2%	2%	4%
Luxembourg	[redacted]	1%	2%	5%	13%	43%	6%	14%	43%	43%	0%	0%	1%	1%	2%
Malta	[redacted]	1%	2%	5%	14%	38%	5%	15%	38%	38%	0%	0%	0%	0%	1%
Netherlands	[redacted]	1%	2%	5%	10%	52%	5%	10%	52%	52%	0%	0%	2%	2%	5%
Norway	[redacted]	1%	3%	7%	14%	52%	8%	15%	52%	52%	0%	0%	1%	1%	3%
Poland	[redacted]	1%	2%	6%	14%	48%	7%	15%	48%	48%	0%	0%	1%	1%	2%
Portugal	[redacted]	1%	1%	4%	12%	42%	4%	12%	42%	42%	0%	0%	1%	1%	2%
Romania	[redacted]	1%	3%	6%	15%	49%	7%	15%	49%	49%	0%	0%	1%	1%	2%
Slovakia	[redacted]	1%	2%	6%	14%	48%	7%	15%	48%	48%	0%	0%	1%	1%	2%
Slovenia	[redacted]	1%	3%	6%	16%	45%	7%	16%	45%	45%	0%	0%	1%	1%	2%
Spain	[redacted]	1%	2%	4%	12%	47%	5%	12%	47%	47%	0%	0%	1%	1%	2%
Sweden	[redacted]	1%	3%	7%	14%	52%	8%	15%	52%	52%	0%	0%	1%	1%	3%
United Kingdom	[redacted]	1%	1%	3%	10%	45%	4%	11%	46%	46%	0%	0%	1%	1%	3%
Total	[redacted]	1%	2%	5%	12%	48%	5%	12%	48%	48%	0%	0%	1%	1%	3%

TWh energy saving cummulative sales 2010-2019	C15	C16	C17	C18	C19	C20	C21	C22	C23	C24	C25	C26	C27	C28
Austria	1%	1%	3%	0%	0%	0%	5%	5%	21%	31%	17%	59%	11%	69%
Belgium	1%	1%	2%	0%	0%	0%	3%	3%	26%	37%	19%	52%	15%	84%
Bulgaria	0%	0%	1%	0%	0%	0%	3%	3%	16%	29%	17%	47%	9%	58%
Cyprus	0%	0%	1%	0%	0%	0%	2%	2%	11%	26%	14%	41%	6%	44%
Czech Republic	1%	1%	2%	0%	0%	0%	3%	4%	22%	33%	18%	54%	12%	73%
Denmark	0%	0%	1%	0%	0%	0%	0%	0%	26%	37%	21%	47%	16%	85%
Estonia	0%	1%	1%	0%	0%	0%	3%	3%	18%	31%	19%	50%	10%	66%
Finland	1%	1%	2%	0%	0%	0%	0%	0%	15%	28%	18%	52%	9%	57%
France	1%	1%	2%	0%	0%	0%	3%	4%	19%	31%	13%	50%	11%	67%
Germany	1%	1%	3%	0%	0%	0%	3%	4%	28%	37%	17%	54%	16%	85%
Greece	1%	1%	1%	0%	0%	0%	4%	4%	13%	26%	17%	52%	7%	46%
Hungary	1%	1%	2%	0%	0%	0%	5%	5%	16%	27%	17%	58%	8%	53%
Iceland	1%	1%	2%	0%	0%	0%	4%	5%	17%	29%	19%	57%	9%	60%
Ireland	1%	1%	4%	0%	0%	0%	3%	3%	35%	44%	18%	56%	22%	94%
Italy	1%	1%	2%	0%	0%	0%	4%	5%	17%	28%	18%	57%	9%	58%
Latvia	1%	1%	2%	0%	0%	0%	3%	4%	20%	31%	19%	52%	11%	69%
Liechtenstein	1%	1%	2%	0%	0%	0%	3%	4%	20%	31%	17%	52%	11%	69%
Lithuania	1%	1%	3%	0%	0%	0%	4%	4%	23%	33%	19%	57%	13%	74%
Luxembourg	1%	1%	2%	0%	0%	0%	2%	3%	22%	34%	16%	47%	13%	75%
Malta	0%	0%	0%	0%	0%	0%	1%	2%	12%	27%	16%	39%	7%	48%
Netherlands	1%	1%	4%	0%	0%	0%	4%	5%	29%	37%	16%	59%	16%	87%
Norway	1%	1%	2%	0%	0%	0%	0%	1%	17%	29%	16%	55%	9%	59%
Poland	1%	1%	2%	0%	0%	0%	3%	4%	17%	29%	18%	52%	9%	61%
Portugal	0%	1%	1%	0%	0%	0%	2%	3%	17%	30%	15%	46%	10%	63%
Romania	1%	1%	2%	0%	0%	0%	4%	4%	15%	28%	19%	53%	8%	54%
Slovakia	1%	1%	2%	0%	0%	0%	3%	4%	16%	29%	19%	52%	9%	58%
Slovenia	0%	0%	1%	0%	0%	0%	2%	3%	18%	30%	19%	48%	10%	65%
Spain	1%	1%	2%	0%	0%	0%	3%	4%	15%	28%	16%	51%	8%	55%
Sweden	1%	1%	2%	0%	0%	0%	0%	1%	17%	29%	16%	55%	9%	59%
United Kingdom	1%	1%	2%	0%	0%	0%	0%	1%	26%	36%	13%	49%	15%	82%
Total	1%	1%	2%	0%	0%	0%	3%	4%	18%	30%	16%	53%	10%	63%

Table 89: B5.37: % Annual energy savings in new installations (2010-2019) for Modelled Cases for central and larger systems broken down by country.

As for other types of system, cases reflecting load reductions show a similar climatic pattern of percentage reductions to those seen for existing systems, albeit that the differences between countries are less marked. New installations include use in new buildings which comply with better building energy codes. As a result of this, differences of thermal performance between similar buildings in different countries may be less than for the existing stock and the scope for savings smaller and more uniform between countries..

For cases that reflect changes in the average efficiency of products, the differences between countries in percentage savings are small, with a tendency for smaller figures in milder climates. The application of BAT to chillers in new installations (C9) suggests savings ranging from just over 50% in a number of Scandinavian and northern maritime countries to below 40% for Cyprus and Malta).

As in the case of movable units and room air conditioners, measures applied to the building envelope to reduce cooling demand generate the biggest percentage differences between countries.

For the most extreme case (C28) which considers the universal application of the most effective measures, the theoretical savings vary from 44% in Cyprus, to 94% in Ireland (suggesting that building envelope measures could avoid the need for air conditioning in many Irish buildings: the Irish stock of air–conditioning systems is already small) . [139]

B5.2.4.2.5 Modelling Results Cooling Energy in Central and Larger Systems: Carbon Savings

The resulting savings in CO_2 emissions per modelled case by country are provided in Table B5.38 for the existing stock and table 98 for new installations

Thousand Tonnes CO2 emissions existing stock	C0-C20, C25 and C26	C21	C22	C23	C24	C27	C28
Austria	-	0.1	0.1	0.2	0.2	0.1	0.5
Belgium	-	0.0	0.1	0.3	0.2	0.1	0.6
Bulgaria	-	0.0	0.0	0.2	0.2	0.0	0.3
Cyprus	-	0.0	0.0	0.1	0.1	0.0	0.1
Czech Republic	-	0.1	0.1	0.4	0.4	0.1	0.9
Denmark	-	0.0	0.0	0.1	0.1	0.0	0.2
Estonia	-	0.0	0.0	0.1	0.1	0.0	0.2
Finland	-	0.0	0.0	0.1	0.1	0.0	0.2
France	-	0.0	0.0	0.2	0.2	0.1	0.4
Germany	-	0.3	0.3	1.8	1.5	0.7	3.6
Greece	-	0.2	0.2	0.7	0.7	0.2	1.3
Hungary	-	0.1	0.1	0.4	0.4	0.1	0.7
Iceland	-	-	-	-	-	-	-
Ireland	-	0.1	0.1	0.4	0.4	0.2	0.7
Italy	-	0.8	0.9	3.5	3.2	1.1	7.0
Latvia	-	0.0	0.0	0.1	0.1	0.0	0.2
Liechtenstein	-	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	-	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	-	0.0	0.0	0.0	0.0	0.0	0.0
Malta	-	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	-	0.1	0.1	0.7	0.5	0.2	1.4
Norway	-	0.0	0.0	0.0	0.0	0.0	0.0
Poland	-	0.1	0.1	0.4	0.4	0.1	0.8
Portugal	-	0.0	0.0	0.2	0.2	0.1	0.5
Romania	-	0.1	0.1	0.4	0.4	0.1	0.8
Slovakia	-	0.0	0.0	0.1	0.1	0.0	0.2
Slovenia	-	0.0	0.0	0.0	0.0	0.0	0.1
Spain	-	0.5	0.6	2.4	2.6	0.8	5.4
Sweden	-	0.0	0.0	0.1	0.1	0.0	0.1
United Kingdom	-	0.6	0.7	3.4	3.0	1.3	7.3
Total	**-**	**3.2**	**3.6**	**16.3**	**14.9**	**5.5**	**33.9**

Table 90: B5.38: Carbon savings in existing installations for Modelled Cases for central and larger systems broken down by country.

[139] Case C27, which is for a more constrained take-up of measures, shows the same pattern. Case C24 also includes the implementation of some building envelope measures as the result of inspection or energy monitoring

For the existing stock, the biggest carbon emission savings potential is in Italy, the United Kingdom and Spain, followed by Germany and Greece. The energy savings potential in France does not translate into carbon savings potential because of the major role of nuclear electricity generation.

Modelled Cases C0 – C20 are only applied to new installations so there are no savings associated with these Modelled Cases.

Thousand Tonnes CO_2 saving cumulative sales 2010-2019	C0	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12	C13	C14
Austria	-	0.0	0.1	0.1	0.3	1.5	0.2	0.3	1.5	1.5	0.0	0.0	0.3	0.3	0.7
Belgium	-	0.0	0.0	0.1	0.3	1.0	0.1	0.3	1.0	1.0	0.0	0.0	0.2	0.2	0.4
Bulgaria	-	0.0	0.0	0.1	0.2	0.7	0.1	0.2	0.7	0.7	0.0	0.0	0.1	0.1	0.2
Cyprus	-	0.0	0.0	0.0	0.1	0.5	0.0	0.1	0.5	0.5	0.0	0.0	0.0	0.0	0.1
Czech Republic	-	0.0	0.0	0.1	0.3	1.1	0.1	0.3	1.1	1.1	0.0	0.0	0.2	0.2	0.5
Denmark	-	0.0	0.0	0.1	0.1	0.4	0.1	0.1	0.4	0.4	0.0	0.0	0.0	0.1	0.1
Estonia	-	0.0	0.0	0.1	0.1	0.5	0.1	0.2	0.5	0.5	0.0	0.0	0.1	0.1	0.2
Finland	-	0.0	0.0	0.1	0.2	0.6	0.1	0.2	0.6	0.6	0.0	0.0	0.1	0.1	0.2
France	-	0.0	0.0	0.0	0.2	1.2	0.1	0.2	1.2	1.2	0.0	0.0	0.2	0.2	0.5
Germany	-	0.1	0.2	0.5	1.2	5.6	0.6	1.3	5.6	5.6	0.1	0.2	1.1	1.2	2.6
Greece	-	0.1	0.3	0.7	1.5	6.5	0.7	1.6	6.6	6.6	0.1	0.1	0.8	0.9	1.9
Hungary	-	0.0	0.1	0.1	0.3	1.3	0.1	0.3	1.3	1.3	0.0	0.0	0.2	0.2	0.5
Iceland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ireland	-	0.0	0.0	0.1	0.1	0.7	0.1	0.2	0.7	0.7	0.0	0.0	0.2	0.2	0.3
Italy	-	0.3	0.8	1.9	4.0	18.4	2.1	4.2	18.5	18.5	0.2	0.4	2.9	3.1	6.9
Latvia	-	0.0	0.0	0.1	0.2	0.7	0.1	0.2	0.7	0.7	0.0	0.0	0.1	0.1	0.2
Liechtenstein	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Luxembourg	-	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malta	-	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Netherlands	-	0.0	0.1	0.2	0.4	2.4	0.2	0.4	2.4	2.4	0.0	0.1	0.5	0.6	1.2
Norway	-	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0
Poland	-	0.0	0.1	0.2	0.6	2.1	0.3	0.6	2.1	2.1	0.0	0.0	0.3	0.3	0.7
Portugal	-	0.0	0.0	0.1	0.3	1.3	0.1	0.4	1.3	1.3	0.0	0.0	0.2	0.2	0.4
Romania	-	0.0	0.1	0.2	0.4	1.5	0.2	0.4	1.5	1.5	0.0	0.0	0.2	0.2	0.5
Slovakia	-	0.0	0.0	0.0	0.1	0.4	0.0	0.1	0.4	0.4	0.0	0.0	0.1	0.1	0.1

Slovenia	-	0.0	0.0	0.0	0.1	0.3	0.0	0.1	0.3	0.3	0.0	0.0	0.0	0.0	0.1
Spain	-	0.2	0.5	1.2	3.8	17.0	1.4	4.0	17.1	17.1	0.2	0.3	2.4	2.6	5.6
Sweden	-	0.0	0.0	0.0	0.1	0.4	0.0	0.1	0.4	0.4	0.0	0.0	0.1	0.1	0.1
United Kingdom	-	0.1	0.2	0.4	1.4	7.2	0.5	1.5	7.2	7.2	0.1	0.2	1.3	1.4	3.0
Total	**-**	**1.2**	**2.7**	**6.5**	**16.4**	**73.2**	**7.5**	**17.3**	**73.4**	**73.4**	**0.8**	**1.6**	**11.7**	**12.4**	**27.2**

Thousand Tonnes CO2 saving cumulative sales 2010-2019	**C15**	**C16**	**C17**	**C18**	**C19**	**C20**	**C21**	**C22**	**C23**	**C24**	**C25**	**C26**	**C27**	**C28**	**CX**
Austria	0.0	0.0	0.1	0.0	0.0	0.0	0.2	0.3	0.8	0.6	0.5	2.1	0.1	0.6	0.2
Belgium	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.5	0.4	0.3	1.3	0.1	0.5	0.4
Bulgaria	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.2	0.8	0.0	0.3	0.4
Cyprus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.1	0.5	0.0	0.2	0.4
Czech Republic	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.5	0.4	1.5	0.1	0.5	0.4
Denmark	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.2	0.2	0.1	0.4	0.0	0.2	0.3
Estonia	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.2	0.2	0.1	0.6	0.0	0.2	0.3
Finland	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.2	0.3	0.1	0.7	0.0	0.3	0.3
France	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.6	0.4	1.7	0.1	0.6	0.5
Germany	0.1	0.1	0.2	0.0	0.0	0.0	0.8	0.9	3.3	2.4	1.9	7.7	0.4	2.8	1.7
Greece	0.1	0.1	0.2	0.0	0.0	0.0	0.8	0.9	2.4	2.6	1.6	8.2	0.3	2.4	2.6
Hungary	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.5	0.4	1.7	0.1	0.5	0.2
Iceland	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Ireland	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.4	0.3	0.3	0.9	0.1	0.3	0.2
Italy	0.2	0.2	0.6	0.0	0.0	0.0	2.7	3.0	8.4	7.1	5.4	24.2	0.9	7.2	4.6
Latvia	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.3	0.3	0.2	0.9	0.0	0.3	0.3
Liechtenstein	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Lithuania	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Luxembourg	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Malta	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.1
Netherlands	0.0	0.0	0.1	0.0	0.0	0.0	0.4	0.4	1.5	0.9	0.9	3.4	0.1	1.0	0.3
Norway	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Poland	0.0	0.0	0.1	0.0	0.0	0.0	0.3	0.3	0.9	0.9	0.6	2.7	0.1	0.9	1.0
Portugal	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.6	0.3	1.7	0.1	0.8	1.0
Romania	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.6	0.6	0.4	1.9	0.1	0.6	0.7
Slovakia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.2	0.2	0.1	0.5	0.0	0.2	0.2
Slovenia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.1	0.1	0.4	0.0	0.2	0.2
Spain	0.2	0.2	0.4	0.0	0.0	0.0	2.2	2.5	7.2	7.2	4.5	22.0	1.0	7.5	9.1
Sweden	0.0	0.0	0.0	0.0	0.0	0.0	-	0.0	0.2	0.1	0.1	0.4	0.0	0.1	0.1
United Kingdom	0.1	0.1	0.3	0.0	0.0	0.0	0.1	0.3	4.0	3.3	1.5	9.5	0.6	3.9	3.5
Total	**0.8**	**0.9**	**2.3**	**0.0**	**0.0**	**0.0**	**9.1**	**10.4**	**34.2**	**30.4**	**20.2**	**96.0**	**4.3**	**32.5**	**29.1**

Table 91: B5.39: Annual carbon savings in new installations (2010-2019) for Modelled Cases for central and larger systems broken down by country.

For new installations the largest potential for carbon emissions savings is in Italy and Spain, followed by the United Kingdom, Germany and Greece. Again the energy savings potential in France does not translate into carbon savings potential because of the major role of nuclear electricity generation.
[add Table # and title – you cannot apply the same number to 2 separate tables. And as mentioned above you need to discuss or at least describe and point to the most significant findings shown in the tables in the text.]

Modelled case C0 represents the base case and thus there are no savings associated with this case. Similarly, there are no carbon savings for Iceland since all their electricity is supplied from geothermal sources.

B5.2.4.3 Modelling Results Central and Larger Systems: air movement energy

Much of the energy consumed by central air conditioning systems is used by fans, generally in air handling units. This section reports modelling results for this consumption.

Central air conditioning systems almost always provide a ventilation service, but the energy used by fans is partly attributable to the provision of outdoor air to occupied spaces to ensure adequate indoor air quality and partly attributable to the use of air as a means of transporting cooling from cold generators (typically chillers) to cooled spaces. As explained in B1, for all-air systems the energy attributable to cooling can be substantial, though for other types of system the energy consumed by fans is predominantly for the ventilation function.

Several of the Modelled Cases impact directly on fan energy consumption. The relevant Modelled Cases are: reduced air leakage (cases C21 and C22 [BAT]), reduced fresh air supply (case C23) and reduced specific fan power (cases C12 and C14 [BAT]).

For consistency with the model results for cooling energy, the modelled “realisable” ventilation energy results are constrained by replacement rates for chillers. In practice, the constraints for ventilation measures are typically more severe, since the air handling equipment generally has a longer service life. These additional constraints (and similar ones for some other cases) have been taken into account before drawing conclusions for recommendations. Section B5.4 explains how this has been done.

Tables 99 to 104 showing the total fan energy consumption and that attributable to the cooling function (the difference is attributable to the ventilation function).

Fan Energy Base Case

	energy consumption by fans TWh				**energy saving relative to base case TWH**			
Scenario Base	**existing installations (2010 only)**		**new installations 2010-2019**		**existing installations (2010 only)**		**new installations 2010-2019**	
TWh	**total fan energy use**	**cooling only fan energy use**	**total fan energy use**	**cooling only fan energy use**	**total fan energy use**	**cooling only fan energy use**	**total fan energy use**	**cooling only fan energy use**
Austria	1.41	0.62	6.70	2.93	-	-	-	-
Belgium	2.40	0.76	8.17	2.19	-	-	-	-
Bulgaria	0.64	0.23	2.00	0.47	-	-	-	-
Cyprus								

	0.19	0.07	0.72	0.14	-	-	-	-
Czech Republic	1.41	0.52	3.45	1.01	-	-	-	-
Denmark	0.60	0.12	2.17	0.37	-	-	-	-
Estonia	0.13	0.03	0.67	0.14	-	-	-	-
Finland	0.82	0.23	3.89	1.05	-	-	-	-
France	5.84	1.96	29.06	8.94	-	-	-	-
Germany	6.35	2.49	21.51	7.15	-	-	-	-
Greece	1.59	0.62	8.20	3.14	-	-	-	-
Hungary	1.47	0.67	3.00	1.26	-	-	-	-
Iceland	0.07	0.02	0.28	0.09	-	-	-	-
Ireland	1.28	0.43	2.81	0.82	-	-	-	-
Italy	14.45	5.94	50.63	20.45	-	-	-	-
Latvia	0.16	0.05	0.82	0.22	-	-	-	-
Liechtenstein	0.00	0.00	0.02	0.00	-	-	-	-
Lithuania	0.22	0.07	1.04	0.32	-	-	-	-
Luxembourg	0.04	0.01	0.17	0.04	-	-	-	-
Malta	0.06	0.02	0.25	0.04	-	-	-	-
Netherlands	2.33	0.97	8.30	3.33	-	-	-	-
Norway	0.91	0.29	3.54	1.19	-	-	-	-
Poland	1.23	0.35	4.69	1.21	-	-	-	-
Portugal	1.00	0.32	4.24	1.14	-	-	-	-
Romania	1.43	0.56	3.64	1.13	-	-	-	-
Slovakia	0.58	0.23	1.52	0.46	-	-	-	-
Slovenia	0.33	0.08	1.71	0.37	-	-	-	-
Spain	12.38	4.04	51.26	18.03	-	-	-	-
Sweden	1.81	0.57	7.00	2.30	-	-	-	-
United Kingdom	15.73	5.09	35.00	8.99	-	-	-	-
All Countries	**76.87**	**27.37**	**266.43**	**88.91**	**-**	**-**	**-**	**-**

Table 92: B5.40: Fan Energy Base Case

Table 97 below shows the fan energy consumption country by country and in total for existing systems in the base year and the aggregate consumption for newly-installed systems in the ten years following.

The largest consumptions are in countries with the largest installed stock and the largest sales: Italy, Spain, the United Kingdom, and, to a lesser extent, France and Germany. The first three countries collectively account for about 50% of fan energy consumption: the five countries together account for about 70%

Scenario MEPs AHU (air leakage) (Case C21)	Energy Consumption by Fans TWh				Energy Savings relative to the base case TWh			
	existing installations (2010 only)		new installations 2010-2019		existing installations (2010 only)		new installations 2010-2019	
TWh	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use
Austria	1.02	0.07	4.84	0.33	0.15	0.01	0.69	0.05
Belgium	1.90	0.08	6.60	0.22	0.27	0.01	0.94	0.03
Bulgaria	0.49	0.02	1.59	0.05	0.07	0.00	0.23	0.01
Cyprus	0.14	0.01	0.57	0.01	0.02	0.00	0.08	0.00
Czech Republic	1.11	0.06	2.78	0.11	0.16	0.01	0.40	0.02
Denmark	0.57	0.01	2.10	0.03	0.01	0.00	-	-
Estonia	0.11	0.00	0.56	0.01	0.02	0.00	0.08	0.00
Finland	0.74	0.03	3.60	0.12	0.01	0.00	-	-
France	4.47	0.21	22.49	0.96	0.64	0.03	3.21	0.14
Germany	4.76	0.28	16.56	0.78	0.68	0.04	2.37	0.11
Greece	1.12	0.07	5.80	0.34	0.16	0.01	0.83	0.05
Hungary	1.06	0.08	2.20	0.14	0.15	0.01	0.31	0.02
Iceland	0.06	0.00	0.22	0.01	0.01	0.00	0.03	0.00
Ireland	1.05	0.04	2.32	0.07	0.15	0.01	0.33	0.01
Italy	10.47	0.65	36.84	2.25	1.50	0.09	5.26	0.32
Latvia	0.13	0.00	0.66	0.02	0.02	0.00	0.09	0.00
Liechtenstein	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Lithuania	0.18	0.01	0.84	0.03	0.03	0.00	0.12	0.00
Luxembourg	0.03	0.00	0.14	0.00	0.00	0.00	0.02	0.00
Malta	0.04	0.00	0.20	0.00	0.01	0.00	0.03	0.00
Netherlands	1.77	0.11	6.33	0.39	0.25	0.02	0.90	0.06
Norway	0.81	0.03	3.20	0.14	0.02	0.00	-	-
Poland	1.00	0.04	3.86	0.13	0.14	0.01	0.55	0.02
Portugal	0.74	0.03	3.23	0.11	0.11	0.00	0.46	0.02
Romania	1.06	0.06	2.82	0.11	0.15	0.01	0.40	0.02
Slovakia	0.43	0.03	1.18	0.05	0.06	0.00	0.17	0.01
Slovenia	0.27	0.01	1.40	0.03	0.04	0.00	0.20	0.00
Spain	9.18	0.38	37.45	1.77	1.31	0.05	5.35	0.25
Sweden	1.63	0.07	6.38	0.28	0.03	0.00	-	-
United Kingdom	12.65	0.56	32.20	1.05	1.81	0.08	0.61	0.02
All Countries	**58.98**	**2.95**	**208.96**	**9.56**	**7.96**	**0.40**	**23.68**	**1.15**

Air Leakage (Cases C21 and C22)

Table 93: B5.41: Air leakage MEPS

Table 98 shows the fan energy consumption and the savings attributable to the measure (Case 21: the application of air leakage requirements for air handling units and ductwork systems in those countries that do not already have them) country by country: in total for existing systems in the base year, and the aggregate consumption over ten years for newly-installed system. . If a country already has the measure in place at the level modelled there are no savings

Unsurprisingly, for the existing stock, the largest savings are in the countries with the largest consumptions. For new installations, the potential for savings drops to zero in several countries since the measure is already in place.

Scenario BAT AHU (air leakage) (Case C22)	existing installations (2010 only)		new installations 2010-2019		existing installations (2010 only)		new installations 2010-2019	
TWh	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use
Austria	1.00	0.07	4.75	0.32	0.16	0.01	0.78	0.05
Belgium	1.87	0.08	6.47	0.22	0.31	0.01	1.07	0.04
Bulgaria	0.48	0.02	1.56	0.05	0.08	0.00	0.26	0.01
Cyprus	0.13	0.01	0.56	0.01	0.02	0.00	0.09	0.00
Czech Republic	1.09	0.06	2.73	0.11	0.18	0.01	0.45	0.02
Denmark	0.56	0.01	2.06	0.03	0.02	0.00	0.04	0.00
Estonia	0.11	0.00	0.55	0.01	0.02	0.00	0.09	0.00
Finland	0.73	0.03	3.53	0.11	0.03	0.00	0.07	0.00
France	4.38	0.21	22.07	0.95	0.72	0.03	3.64	0.16
Germany	4.67	0.27	16.24	0.77	0.77	0.05	2.68	0.13
Greece	1.09	0.06	5.69	0.33	0.18	0.01	0.94	0.05
Hungary	1.04	0.07	2.16	0.14	0.17	0.01	0.36	0.02
Iceland	0.06	0.00	0.22	0.01	0.01	0.00	0.04	0.00
Ireland	1.03	0.04	2.27	0.07	0.17	0.01	0.38	0.01
Italy	10.28	0.64	36.14	2.21	1.70	0.11	5.97	0.36
Latvia	0.13	0.00	0.65	0.02	0.02	0.00	0.11	0.00
Liechtenstein	0.00	0.00	0.01	0.00	0.00	0.00	0.00	0.00
Lithuania	0.18	0.01	0.83	0.03	0.03	0.00	0.14	0.01
Luxembourg	0.03	0.00	0.13	0.00	0.01	0.00	0.02	0.00
Malta	0.04	0.00	0.20	0.00	0.01	0.00	0.03	0.00
Netherlands	1.73	0.11	6.21	0.38	0.29	0.02	1.03	0.06
Norway	0.80	0.03	3.13	0.14	0.03	0.00	0.06	0.00
Poland	0.98	0.04	3.79	0.12	0.16	0.01	0.63	0.02
Portugal	0.73	0.03	3.17	0.11	0.12	0.01	0.52	0.02
Romania	1.04	0.06	2.76	0.11	0.17	0.01	0.46	0.02
Slovakia	0.43	0.02	1.16	0.05	0.07	0.00	0.19	0.01
Slovenia	0.26	0.01	1.37	0.03	0.04	0.00	0.23	0.01
Spain	9.00	0.38	36.73	1.74	1.49	0.06	6.06	0.29
Sweden	1.59	0.07	6.26	0.27	0.06	0.00	0.12	0.01
United Kingdom	12.41	0.55	31.59	1.03	2.05	0.09	1.23	0.04
All Countries	**57.86**	**2.89**	**204.98**	**9.38**	**9.09**	**0.46**	**27.66**	**1.34**

Table 94: B5.42: Air leakage BAT

Table 99 shows the corresponding figures for Case C22 (BAT air leakage). The distribution between countries is similar to Case 21 and the additional additional savings are small: the introduction of air leakage requirements whre they are currently absent is the key requirement. For Case 21 there are no savings for new installations in countries with existing requirements since the assumed requirements are slightly less demanding than those typically currently implemented.

Specific Fan Power (Cases C12 and C14)

Table 102 shows the fan energy consumption and the savings attributable to the measure (Case 12: the application of specific fan power requirements in those countries that do not already have them) country by country. Since this measure is generally impractical for existing systems, results are only shown for newly-installed systems. If a country already has the measure in place at the level modelled there are no savings .

Scenario MEPS 1 (AHU) (Case C12)	Energy Consumption by Fans TWh				Energy Savings relative to the base case TWh			
	existing installations (2010 only)		new installations 2010-2019		existing installations (2010 only)		new installations 2010-2019	
TWh	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use
Austria	1.16	0.08	4.15	0.30	-	-	1.38	0.08
Belgium	2.18	0.09	5.65	0.20	-	-	1.88	0.05
Bulgaria	0.55	0.03	1.37	0.04	-	-	0.46	0.01
Cyprus	0.16	0.01	0.49	0.01	-	-	0.16	0.00
Czech Republic	1.27	0.07	2.38	0.10	-	-	0.79	0.02
Denmark	0.58	0.01	1.58	0.03	-	-	0.53	0.01
Estonia	0.13	0.00	0.48	0.01	-	-	0.16	0.00
Finland	0.75	0.03	2.70	0.09	-	-	0.90	0.02
France	5.10	0.24	19.28	0.88	-	-	6.43	0.23
Germany	5.44	0.32	14.19	0.71	-	-	4.73	0.18
Greece	1.28	0.08	4.98	0.30	-	-	1.66	0.08
Hungary	1.21	0.09	1.88	0.13	-	-	0.63	0.03
Iceland	0.06	0.00	0.19	0.01	-	-	0.06	0.00
Ireland	1.19	0.04	1.99	0.06	-	-	0.66	0.02
Italy	11.97	0.75	31.58	2.03	-	-	10.53	0.54
Latvia	0.15	0.01	0.57	0.02	-	-	0.19	0.01
Liechtenstein	0.00	0.00	0.01	0.00	-	-	0.00	0.00
Lithuania	0.21	0.01	0.72	0.03	-	-	0.24	0.01
Luxembourg	0.04	0.00	0.12	0.00	-	-	0.04	0.00
Malta	0.05	0.00	0.17	0.00	-	-	0.06	0.00
Netherlands	2.02	0.13	5.43	0.35	-	-	1.81	0.09
Norway	0.83	0.04	2.40	0.11	-	-	0.80	0.03
Poland	1.14	0.04	3.31	0.12	-	-	1.10	0.03
Portugal	0.85	0.04	2.77	0.10	-	-	0.92	0.03
Romania	1.22	0.0[illegible]	2.41	0.10	-	-	0.80	0.03
Slovakia	0.50	0.03	1.01	0.04	-	-	0.34	0.01
Slovenia	0.30	0.01	1.20	0.03	-	-	0.40	0.01
Spain	10.49	0.44	32.10	1.59	-	-	10.70	0.43
Sweden	1.66	0.07	4.78	0.22	-	-	1.59	0.06
United Kingdom	14.46	0.64	24.61	0.86	-	-	8.20	0.21
All Countries	**66.94**	**3.35**	**174.48**	**8.50**	**-**	**-**	**58.16**	**2.21**

Scenario MEPS 1 (AHU) (Case C12)	Energy Consumption by Fans TWh				Energy Savings relative to the base case TWh			
	existing installations (2010 only)		new installations 2010-2019		existing installations (2010 only)		new installations 2010-2019	
TWh	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use
Austria	1.16	0.08	4.15	0.30	-	-	1.38	0.08
Belgium	2.18	0.09	5.65	0.20	-	-	1.88	0.05
Bulgaria	0.55	0.03	1.37	0.04	-	-	0.46	0.01
Cyprus	0.16	0.01	0.49	0.01	-	-	0.16	0.00
Czech Republic	1.27	0.07	2.38	0.10	-	-	0.79	0.02
Denmark	0.58	0.01	1.58	0.03	-	-	0.53	0.01
Estonia	0.13	0.00	0.48	0.01	-	-	0.16	0.00
Finland	0.75	0.03	2.70	0.09	-	-	0.90	0.02
France	5.10	0.24	19.28	0.88	-	-	6.43	0.23
Germany	5.44	0.32	14.19	0.71	-	-	4.73	0.18
Greece	1.28	0.08	4.98	0.30	-	-	1.66	0.08
Hungary	1.21	0.09	1.88	0.13	-	-	0.63	0.03
Iceland	0.06	0.00	0.19	0.01	-	-	0.06	0.00
Ireland	1.19	0.04	1.99	0.06	-	-	0.66	0.02
Italy	11.97	0.75	31.58	2.03	-	-	10.53	0.54
Latvia	0.15	0.01	0.57	0.02	-	-	0.19	0.01
Liechtenstein	0.00	0.00	0.01	0.00	-	-	0.00	0.00
Lithuania	0.21	0.01	0.72	0.03	-	-	0.24	0.01
Luxembourg	0.04	0.00	0.12	0.00	-	-	0.04	0.00
Malta	0.05	0.00	0.17	0.00	-	-	0.06	0.00
Netherlands	2.02	0.13	5.43	0.35	-	-	1.81	0.09
Norway	0.83	0.04	2.40	0.11	-	-	0.80	0.03
Poland	1.14	0.04	3.31	0.12	-	-	1.10	0.03
Portugal	0.85	0.04	2.77	0.10	-	-	0.92	0.03
Romania	1.22	0.07	2.41	0.10	-	-	0.80	0.03
Slovakia	0.50	0.03	1.01	0.04	-	-	0.34	0.01
Slovenia	0.30	0.01	1.20	0.03	-	-	0.40	0.01
Spain	10.49	0.44	32.10	1.59	-	-	10.70	0.43
Sweden	1.66	0.07	4.78	0.22	-	-	1.59	0.06
United Kingdom	14.46	0.64	24.61	0.86	-	-	8.20	0.21
All Countries	**66.94**	**3.35**	**174.48**	**8.50**	**-**	**-**	**58.16**	**2.21**

Table 95:B5.43: Specific fan power MEPS

Three of the five countries with the largest consumption (Spain, the United Kingdom and Germany) already have requirements, so the greatest potential is in Italy and France. Since the savings are not directly dependent on climate, the savings reflect market size and Italy's share of the potential savings is less than for cooling energy savings.

Table 103 shows the corresponding figures for case C14 (BAT levels of requirements).

Table 96: B5.44: Specific fan power BAT

This case results in a larger level of potential savings, including significant levels in those countries that already have (less demanding) requirements. BAT levels of SFP require additional space for air handling equipment in plant rooms and - typically- in ceiling voids. They are therefore rarely feasible in existing buildings. These constraints will also affect application to new buildings: this has not been taken into account in the modelling.

Reduced outdoor air supply rates

Table 104 shows the fan energy consumption and the savings attributable to the measure (reduced outdoor air supply rate) country by country: in total for existing systems in the base year, and the aggregate consumption over ten years for newly-installed system.

Scenario BAT (AHU) (Case C14)	Energy Consumption by Fans TWh				Energy Savings relative to the base case TWh			
	existing installations (2010 only)		new installations 2010-2019		existing installations (2010 only)		new installations 2010-2019	
TWh	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use
Austria	1.16	0.08	2.31	0.20	-	-	3.23	0.18
Belgium	2.18	0.09	3.14	0.14	-	-	4.40	0.12
Bulgaria	0.55	0.03	0.76	0.03	-	-	1.06	0.03
Cyprus	0.16	0.01	0.27	0.01	-	-	0.38	0.01
Czech Republic	1.27	0.07	1.32	0.07	-	-	1.85	0.06
Denmark	0.58	0.01	0.88	0.02	-	-	1.23	0.01
Estonia	0.13	0.00	0.27	0.01	-	-	0.38	0.01
Finland	0.75	0.03	1.50	0.06	-	-	2.10	0.05
France	5.10	0.24	10.71	0.57	-	-	15.00	0.53
Germany	5.44	0.32	7.88	0.47	-	-	11.04	0.43
Greece	1.28	0.08	2.76	0.19	-	-	3.87	0.19
Hungary	1.21	0.09	1.05	0.08	-	-	1.46	0.08
Iceland	0.06	0.00	0.10	0.01	-	-	0.15	0.01
Ireland	1.19	0.04	1.10	0.06	-	-	1.55	0.02
Italy	11.97	0.75	17.54	1.32	-	-	24.56	1.25
Latvia	0.15	0.01	0.32	0.01	-	-	0.44	0.01
Liechtenstein	0.00	0.00	0.01	0.00	-	-	0.01	0.00
Lithuania	0.21	0.01	0.40	0.02	-	-	0.56	0.02
Luxembourg	0.04	0.00	0.06	0.00	-	-	0.09	0.00
Malta	0.05	0.00	0.09	0.00	-	-	0.13	0.00
Netherlands	2.02	0.13	3.02	0.23	-	-	4.22	0.21
Norway	0.83	0.04	1.33	0.08	-	-	1.86	0.07
Poland	1.14	0.04	1.84	0.08	-	-	2.58	0.07
Portugal	0.85	0.04	1.54	0.06	-	-	2.15	0.06
Romania	1.22	0.07	1.34	0.07	-	-	1.88	0.06
Slovakia	0.50	0.03	0.56	0.03	-	-	0.79	0.03
Slovenia	0.30	0.01	0.67	0.02	-	-	0.93	0.02
Spain	10.49	0.44	17.83	1.01	-	-	24.96	1.01
Sweden	1.66	0.07	2.66	0.15	-	-	3.72	0.13
United Kingdom	14.46	0.64	13.67	0.58	-	-	19.14	0.49
All Countries	**66.94**	**3.35**	**96.93**	**5.57**	**-**	**-**	**135.71**	**5.14**

Table 97: B5.45: Reduced fresh air rates

For both existing stock and new installations the major savings are in the countries with the largest stock or sales: Italy, Spain and the United Kingdom, followed by France and Germany. Collectively these countries account for nearly 70% of the potential savings. There are several caveats to these figures:

- The current state of legislation relating to smoking in buildings is complex, and future regulation is uncertain

- Practical constraints on reducing the flow rates of existing systems have not been modelled

Scenario Reduce ventilation Flow rates (case C23)	Energy Consumption by Fans TWh				Energy Savings relative to the base case TWh			
	existing installations (2010 only)		new installations 2010-2019		existing installations (2010 only)		new installations 2010-2019	
TWh	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use	total fan energy use	cooling only fan energy use
Austria	0.42	0.04	2.04	0.17	0.74	0.04	3.50	0.21
Belgium	0.73	0.04	2.60	0.11	1.45	0.05	4.93	0.14
Bulgaria	0.21	0.01	0.69	0.02	0.35	0.02	1.13	0.03
Cyprus	0.06	0.00	0.25	0.01	0.09	0.00	0.39	0.01
Czech Republic	0.44	0.03	1.15	0.06	0.83	0.04	2.03	0.07
Denmark	0.19	0.01	0.72	0.01	0.39	0.01	1.38	0.02
Estonia	0.05	0.00	0.24	0.01	0.08	0.00	0.40	0.01
Finland	0.28	0.01	1.37	0.06	0.47	0.01	2.23	0.06
France	1.87	0.11	9.53	0.51	3.24	0.13	16.18	0.59
Germany	1.80	0.13	6.44	0.38	3.64	0.19	12.48	0.52
Greece	0.49	0.03	2.58	0.18	0.78	0.04	4.05	0.21
Hungary	0.46	0.04	0.96	0.08	0.75	0.05	1.55	0.08
Iceland	0.02	0.00	0.10	0.01	0.04	0.00	0.16	0.01
Ireland	0.32	0.02	0.81	0.04	0.87	0.02	1.84	0.04
Italy	4.49	0.34	15.99	1.20	7.48	0.40	26.11	1.37
Latvia	0.05	0.00	0.28	0.01	0.10	0.00	0.48	0.01
Liechtenstein	0.00	0.00	0.01	0.00	0.00	0.00	0.01	0.00
Lithuania	0.07	0.00	0.34	0.02	0.14	0.00	0.62	0.02
Luxembourg	0.01	0.00	0.06	0.00	0.02	0.00	0.10	0.00
Malta	0.02	0.00	0.09	0.00	0.03	0.00	0.14	0.00
Netherlands	0.66	0.05	2.46	0.19	1.35	0.08	4.77	0.25
Norway	0.31	0.02	1.21	0.07	0.52	0.02	1.99	0.07
Poland	0.42	0.02	1.66	0.07	0.72	0.02	2.75	0.07
Portugal	0.31	0.02	1.38	0.06	0.53	0.02	2.31	0.07
Romania	0.46	0.02	1.23	0.06	0.75	0.04	1.99	0.07
Slovakia	0.19	0.01	0.51	0.03	0.31	0.02	0.84	0.03
Slovenia	0.11	0.00	0.60	0.02	0.19	0.00	1.00	0.02
Spain	3.97	0.20	16.36	0.93	6.52	0.24	26.44	1.10
Sweden	0.61	0.03	2.41	0.14	1.04	0.04	3.97	0.14
United Kingdom	4.90	0.28	11.39	0.48	9.55	0.36	21.42	0.58
All Countries	**23.93**	**1.50**	**85.46**	**4.92**	**43.01**	**1.84**	**147.18**	**5.79**

Table 91: B5.46: Reduced fresh air rates

B5.3 Modelling Results System Switching

Some system types are inherently more efficiency than others but the definition of “the most efficient” depends on the climate and building type as is described in section B3. System switching (using inherently more efficient system configurations in place of the assumed distribution) has the potential for substantial energy savings. The modelling attempts to represent the non-energy constraints on system choice, but these are very uncertain.

This section presents the results of the system switching analysis. There are two elements to this, system switching between systems of the same general type r (sections B5.3.1 and B5.3.2);and switching between system types (SectionB5.3.3). The most straightforward comparison considers the substitution of existing systems by alternative systems of typical efficiency for that type of system. A further comparison is presented where the new systems have BAT levels of performance.

For larger and central systems, there are constraints to substitution set by operational needs or building design, described in Section B3. This is a complicated issue and the constraints are taken into account in the modelling in a simplified way.

B5.3.1 System Switching : Central Systems

The following tables outline the percentage energy performance improvement that would be realised if the (theoretically) most efficient system were installed across each building type and country:

building sector and efficiency assumption	% improvement over current system mix
new office typical efficiency new installation	22.5%
new retail typical efficiency new installation	23.2%
new residential typical efficiency new installation	22.4%
existing office typical efficiency new installation	22.1%
existing retail typical efficiency new installation	22.8%
existing residential typical efficiency new installation	22.1%
overall best system type typical efficiency	**22.7%**
new office BAT	72.8%
new retail BAT	74.8%
new residential BAT	70.5%
existing office BAT	71.4%
existing retail BAT	73.6%
existing residential BAT	69.4%
overall best system type BAT efficiency	**73.0%**

Table 92: B5.47: Summary of the potential % savings from switching from the current mix of central and larger system types to an idealised mix of systems of typical efficiency and BAT efficiency across all EU/EEA countries

Differences across market sectors appear to be small and Table 106 below shows this to also be the case in individual countries

% savings compared to current mix of system types	new installations ideal mix of system types of typical efficiency					
	new office	new retail	new residential	existing office	existing retail	existing residential
Austria	31%	31%	31%	31%	31%	31%
Belgium	19%	19%	19%	19%	19%	19%
Bulgaria	14%	16%	14%	14%	15%	13%
Cyprus	9%	11%	10%	9%	10%	10%
Czech Republic	22%	23%	22%	21%	22%	22%
Denmark	15%	15%	13%	14%	14%	13%
Estonia	18%	18%	18%	17%	17%	16%
Finland	23%	23%	22%	22%	23%	21%
France	19%	20%	18%	19%	19%	18%
Germany	21%	22%	22%	21%	21%	22%
Greece	21%	22%	21%	21%	22%	21%
Hungary	30%	30%	30%	30%	30%	30%
Iceland	27%	28%	27%	27%	27%	26%
Ireland	25%	25%	27%	27%	26%	27%
Italy	27%	28%	27%	27%	27%	26%
Latvia	21%	21%	21%	20%	19%	19%
Liechtenstein	19%	20%	18%	19%	19%	18%
Lithuania	26%	26%	27%	26%	25%	27%
Luxembourg	12%	14%	11%	12%	12%	11%
Malta	8%	9%	8%	7%	9%	8%
Netherlands	30%	30%	32%	31%	30%	33%
Norway	27%	28%	27%	27%	27%	26%
Poland	21%	21%	21%	21%	21%	20%
Portugal	13%	15%	13%	12%	14%	12%
Romania	22%	22%	21%	21%	22%	20%
Slovakia	20%	21%	20%	20%	20%	19%
Slovenia	15%	16%	14%	15%	15%	13%
Spain	21%	23%	22%	21%	22%	21%
Sweden	27%	28%	27%	27%	27%	26%
United Kingdom	19%	19%	19%	19%	19%	19%

Table 3: B5.48: The national potential % savings from switching from the current mix of central and larger system types to an idealised mix of systems of typical efficiency

There are large differences of potential percentage savings between countries: from 8% (Malta) to 33% (Netherlands) with a median of 20% for existing residential buildings, for example. It is difficult to discern any pattern to the figures except for a consistency between market sectors for each country and the smallest percentage changes being in the hottest climates. This is probably a reflection of the fact that the choice of “most efficient system” is itself climate-dependent.

% savings compared to current mix of system types	new installations ideal mix of system types of BAT efficiency					
	new office	new retail	new residential	existing office	existing retail	existing residential
Austria	85%	86%	82%	85%	85%	82%
Belgium	67%	67%	59%	66%	66%	59%
Bulgaria	61%	65%	60%	60%	63%	59%
Cyprus	55%	59%	56%	55%	58%	56%
Czech Republic	72%	74%	66%	70%	71%	64%

Denmark	61%	61%	51%	59%	59%	51%
Estonia	67%	68%	68%	64%	65%	58%
Finland	74%	75%	72%	73%	74%	71%
France	69%	70%	65%	67%	69%	65%
Germany	70%	71%	64%	68%	70%	64%
Greece	72%	75%	72%	71%	74%	71%
Hungary	85%	86%	84%	84%	85%	81%
Iceland	80%	82%	78%	80%	79%	77%
Ireland	74%	75%	70%	70%	72%	70%
Italy	79%	82%	79%	79%	81%	78%
Latvia	71%	72%	72%	68%	67%	65%
Liechtenstein	68%	70%	64%	68%	69%	64%
Lithuania	77%	79%	80%	72%	76%	70%
Luxembourg	58%	61%	52%	56%	58%	52%
Malta	53%	56%	54%	52%	55%	53%
Netherlands	82%	83%	80%	81%	82%	78%
Norway	80%	82%	78%	80%	79%	77%
Poland	72%	72%	72%	71%	71%	68%
Portugal	60%	64%	58%	57%	62%	57%
Romania	73%	74%	72%	72%	73%	67%
Slovakia	71%	72%	69%	69%	71%	67%
Slovenia	63%	64%	60%	62%	63%	57%
Spain	71%	75%	72%	70%	74%	70%
Sweden	80%	82%	78%	80%	79%	77%
United Kingdom	68%	68%	59%	64%	68%	59%

Table 94: B5.49: The national potential % savings from switching from the current mix of central and larger system types to an idealised mix of systems of BAT efficiency

Switching to BAT-level systems rather than typical levels of efficiency increase the percentage savings, but leaves the pattern of savings essentially unchanged.

B5.3.2 System Switching : RACs and Moveable units

Of the two main RAC system types, split systems are more efficient than window/wall units, so this analysis looks at the savings that would arise if all RAC systems were split systems of either typical or BAT efficiency. The energy and carbon savings that would be achieved by switching all window/wall units entirely to split systems for all new installations are shown in the Tables B5.49 below.

TWh saved new installations 2010-2019	**BAT efficiency small split**	**Typical efficiency small split**
Austria	1.28	0.02
Belgium	1.17	0.02
Bulgaria	1.52	-
Cyprus	0.58	-
Czech Republic	7.78	-
Denmark	0.57	-
Estonia	0.24	-

Finland	0.60	-
France	8.35	-
Germany	0.89	0.02
Greece	7.85	-
Hungary	1.53	-
Iceland	0.03	-
Ireland	0.19	-
Italy	13.74	-
Latvia	0.39	0.01
Liechtenstein	0.00	0.00
Lithuania	0.04	-
Luxembourg	0.06	-
Malta	0.21	-
Netherlands	1.65	-
Norway	0.52	-
Poland	10.22	-
Portugal	0.96	-
Romania	3.97	0.08
Slovakia	0.65	0.01
Slovenia	0.25	-
Spain	20.23	-
Sweden	1.00	0.02
United Kingdom	3.81	0.08
Total	90.28	0.26
%	***44%***	***0%***

Table 95: B5.50: National potential percentage energy savings from switching from current mix of RAC system types to split systems of typical efficiency and BAT efficiency for new installations between 2010 and 2019

Million tonnes CO2 emissions saved new installations 2010-2019	**BAT efficiency small split**	**Typical efficiency small split**
Austria	0.56	0.01
Belgium	0.43	0.01
Bulgaria	1.19	-
Cyprus	0.66	-
Czech Republic	7.17	-
Denmark	0.35	-
Estonia	0.53	-
Finland	0.20	-
France	0.90	-
Germany	0.64	0.01
Greece	8.97	-
Hungary	1.14	-
Iceland	-	-
Ireland	0.17	-
Italy	8.79	-
Latvia	0.87	0.02
Liechtenstein	0.00	0.00

Lithuania	0.00	-
Luxembourg	0.04	-
Malta	0.09	-
Netherlands	1.20	-
Norway	0.02	-
Poland	12.08	-
Portugal	0.66	-
Romania	3.20	0.06
Slovakia	0.32	0.01
Slovenia	0.12	-
Spain	11.93	-
Sweden	0.10	0.00
United Kingdom	2.59	0.05
Total	**64.95**	**0.17**
%	*44%*	*0%*

Table 96: B5.51: The national annual potential carbon savings from switching from the current mix of RAC system types to split systems of typical efficiency and BAT efficiency for new installations between 2010 and 2019

The energy and carbon savings for switching from window/wall units of typical efficiency are small, primarily because they only account for a small percentage of the RAC market in the EU (see Section B4 for further market data).

For moveable units there is not sufficient information available to differentiate between the typical energy performance of dual duct systems and single duct units so it was not possible to model the savings for system switching within this market sector.

B5.3.3 System Switching between Central. Movable and RAC Systems

The most efficient system type identified over all the market sectors is small single splits, which have the most efficient chillers at the BAT level. Therefore, this analysis considers replacing all systems with split systems where they are more efficient than the existing system and, for central systems at least, where this is likely to be feasible.

For moveable units it is assumed that all units could be replaced by small split systems at both typical and BAT efficiencies.

For central systems it is assumed that small split systems will only be appropriate in instances where the current system is one of the following types: a larger split system, a VRF system, a rooftop system, or a heat pump loop [140]. These system types account for around 50% of all new installations and roughly coincide with the percentage of possible system types identified in section B1 of this report so should provide a good indication of the potential savings.

As the typical efficiency performance of central chillers is better than the typical efficiency of small single split units, savings will only be achieved by switching to small split systems at the BAT level.

Switching between Movable Units and fixed Room Air Conditioners The potential savings identified for system switching between markets is presented in Tables B5.51 to B5.54 below:

[140] The other systems types require extensive ductwork and also provide mechanical ventilation. These account for around 50% of all new installations and are in agreement with the possible system types identified in section B1 of this report.

Table 98 Shows potential energy savings by country from switching from moveable units of typical efficiency to: split systems of typical efficiency, and to split systems of BAT efficiency for all new installations between 2010 and 2019

TWh saved new installations 2010-2019	BAT efficiency small split	Typical efficiency small split
Austria	0.13	0.10
Belgium	0.13	0.11
Bulgaria	1.16	0.96
Cyprus	0.00	0.00
Czech Republic	0.69	0.57
Denmark	0.06	0.05
Estonia	0.03	0.03
Finland	0.23	0.19
France	1.02	0.84
Germany	1.03	0.84
Greece	0.00	0.00
Hungary	0.03	0.02
Iceland	0.01	0.01
Ireland	0.07	0.06
Italy	12.11	10.06
Latvia	0.06	0.05
Liechtenstein	0.00	0.00
Lithuania	0.02	0.01
Luxembourg	0.01	0.01
Malta	0.14	0.12
Netherlands	0.19	0.16
Norway	0.19	0.16
Poland	1.54	1.28
Portugal	0.00	0.00
Romania	2.59	2.15
Slovakia	0.46	0.38
Slovenia	0.16	0.13
Spain	0.02	0.02
Sweden	0.38	0.31
United Kingdom	1.50	1.22
Total	23.95	19.84
%	***80%***	***66%***

Table 99: B5.52: National potential energy savings from switching from moveable units of typical efficiency to split systems of typical efficiency and BAT efficiency for all new installations between 2010 and 2019

The largest potential savings are in the countries with the largest markets. (Although Spain is a large market for most types of air conditioning, the sale of movable units appears to be low).

Table B5.52shows the carbon savings resulting from the energy savings in Table B5.51

Million tonnes CO2 emissions saved new installations 2010-2019	BAT efficiency small split	Typical efficiency small split
Austria	0.06	0.04

Belgium	0.05	0.04
Bulgaria	0.91	0.69
Cyprus	0.00	0.00
Czech Republic	0.64	0.48
Denmark	0.04	0.03
Estonia	0.08	0.06
Finland	0.08	0.06
France	0.11	0.08
Germany	0.74	0.55
Greece	0.00	0.00
Hungary	0.02	0.02
Iceland	-	-
Ireland	0.06	0.05
Italy	7.74	5.92
Latvia	0.12	0.09
Liechtenstein	0.00	0.00
Lithuania	0.00	0.00
Luxembourg	0.00	0.00
Malta	0.06	0.05
Netherlands	0.14	0.10
Norway	0.01	0.01
Poland	1.82	1.39
Portugal	0.00	0.00
Romania	2.08	1.59
Slovakia	0.23	0.18
Slovenia	0.08	0.06
Spain	0.01	0.01
Sweden	0.04	0.03
United Kingdom	1.02	0.76
Total	16.14	12.28
%	***80%***	***61%***

Table 100**: B5.53: National potential carbon savings from switching from moveable units of typical efficiency to split systems of typical efficiency and BAT efficiency for all new installations between 2010 and 2019**

The largest potential savings are in the countries with the largest markets.

Table 101 shows the potential energy savings by country from switching from some central systems of typical efficiency to split systems of typical efficiency and to split systems of BAT efficiency for all new installations between 2010 and 2019. (Noting that the substitution is only possible for some types of system).

TWh saved new installations 2010-2019	**BAT efficiency small split**	**Typical efficiency small split**
Austria	0.50	-
Belgium	1.23	-
Bulgaria	0.54	-
Cyprus	0.35	-
Czech Republic	0.44	-

Denmark	0.51	-
Estonia	0.13	-
Finland	1.03	-
France	4.83	-
Germany	2.35	-
Greece	2.26	-
Hungary	0.32	-
Iceland	0.04	-
Ireland	0.19	-
Italy	7.17	-
Latvia	0.14	-
Liechtenstein	0.00	-
Lithuania	0.11	-
Luxembourg	0.03	-
Malta	0.14	-
Netherlands	0.36	-
Norway	0.62	-
Poland	0.80	-
Portugal	1.39	-
Romania	0.91	-
Slovakia	0.36	-
Slovenia	0.44	-
Spain	15.47	-
Sweden	1.20	-
United Kingdom	5.12	
Total	**43.85**	**-**
	16%	***0%***

Table 102: B5.54: The national potential energy savings from switching from central systems of typical efficiency to split systems of typical efficiency and BAT efficiency for all new installations between 2010 and 2019

There are no savings if the split systems are of typical current efficiency. By far the largest potential savings for BAT efficiency are in Spain and Italy, with significant potential in the UK and France and – to a lesser extent in Greece and Germany. This reflects the size of each market, the distribution of system types the countries and the climate.

Table 3 shows the carbon savings resulting from the energy savings in Table 112

Million tonnes CO2 emissions saved new installations 2010-2019	BAT efficiency small split	Typical efficiency small split
Austria	0.22	-
Belgium	0.45	-
Bulgaria	0.42	-
Cyprus	0.39	-
Czech Republic	0.40	-

Denmark	0.31	-
Estonia	0.30	-
Finland	0.35	-
France	0.52	-
Germany	1.68	-
Greece	2.58	-
Hungary	0.24	-
Iceland	-	-
Ireland	0.17	-
Italy	4.58	-
Latvia	0.31	-
Liechtenstein	0.00	-
Lithuania	0.01	-
Luxembourg	0.02	-
Malta	0.08	-
Netherlands	0.26	-
Norway	0.03	-
Poland	0.95	-
Portugal	0.96	-
Romania	0.73	-
Slovakia	0.18	-
Slovenia	0.21	-
Spain	9.13	-
Sweden	0.13	-
United Kingdom	3.48	
Total	**29.10**	**-**
%	***18%***	***0%***

Table 100: B5.55: National potential carbon savings from switching from central system of typical efficiency to split systems of typical efficiency and BAT efficiency for all new installations between 2010 and 2019

The distribution of potential reduction by country broadly reflects that for energy , but the importance of France is lower and that of Greece higher.

The system switching savings presented in this section provide an idealistic assessment of the potential savings. The analysis implicitly presumes that it is possible to identify the most appropriate system type based on the cooling demands for each building. Current cooling system models and tools are not good enough to identify the ideal system for each application, and even if they were, building usage patterns tend to change considerably over time, resulting in changes to the cooling demand. Furthermore, the modelling approach used here does not take into account behavioural aspects of building use, nor does it consider other factors that are taken into account when decisions are being made about air conditioning systems. Therefore, in practice it would only be possible to realise a small proportion of the savings identified.

B5.4 Realisable savings for policy components

The previous sections of B5 report potential energy savings that could be achieved for the Modelled Cases. This information feeds into Section A4 Assessment of Potential Policy Measures. Many of the “realisable energy savings” associated with potential policy measures are the direct results of the modelling. In other cases, the modelling results have been modified to take account of additional constraints, or a policy measure includes the combined results of several Modelled Cases which may not be simply additive.

This Section summarises the modelled potential energy savings in section B5.4.1 and explains how the constraints and interactions have been handled in section B5.4.2,

B5.4.1 Overview of Potential Savings over 10 years

Table 114 shows the modelled potential energy savings for the cooling function (for a ten year period assuming immediate implementation) sorted in order of the s potential savings. It can be seen that policy components aimed specifically at pumps and terminals offer relatively small potential savings compared to MEPS for products and systems, and building envelope measures. In the case of MEPS, the Modelled Cases cover a range of possible intervention levels, which illustrate the corresponding range of potential savings
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Case Number	Modelled cases: Hypothetical	Installations	10 year savings future installations TWh	Annual savings potential in existing installations TWh
M0	Base: labelling + building regs	All	-	0
M1	Product proposed MEPS	New	1.62	0
M2	MEP 1	New	23.95	0
M3	MEP 2	New	0.02	0
M4	M1 + Financial Inc.	New	0.01	0
M5	M2 + Financial Inc.	New	0.01	0
M6	M3 + Financial Inc.	New	0.06	0
M7	Product BAT	New	10.63	0
M8	Bldg env. achievable	All	1.09	0.000727
M9	Bldg env.BAT	All	0.06	0.005618

RAC0	Base: labelling + building regs	All	-	-
RAC1	Proposed MEPS	New	9.83	0
RAC2	MEP 1	New	25.70	0
RAC3	MEP 2	New	38.02	0
RAC4	MEP 3	New	52.53	0
RAC5	MEP 4	New	70.50	0
RAC6	Proposed MEPS + Fin. Inc.	New	10.84	0
RAC7	MEP 1 + Fin. Inc.	New	28.25	0
RAC8	MEP 2 + Fin. Inc.	New	39.74	0
RAC9	MEP 3 + Fin. Inc.	New	52.53	0
RAC10	MEP 4 + Fin. Inc.	New	70.50	0
RAC11	BAT	New	89.29	0
RAC12	Achievable envelope savings	All	10.73	1.80
RAC13	BAT envelope savings	All	82.23	13.75
C0	Base case Voluntary labelling+ Bldg Regs	All	-	0
C1	Chillers and Packaged Units labelling	New	1.90	0
C2	Chillers and Packaged Units labelling + Fin Incentives	New	4.40	0
C3	Chillers and Packaged Units labelling +MEP1	New	10.50	0
C4	Chillers and Packaged Units labelling +MEP2	New	27.00	0
C5	Chillers and Packaged Units labelling +MEP3	New	123.10	0
C6	Chillers and Packaged Units labelling +MEP1 + Financial Inc.	New	12.10	0
C7	Chillers and Packaged Units labelling +MEP2 + Financial Inc.	New	28.50	0
C8	Chillers and Packaged Units labelling +MEP3 + Financial Inc.	New	123.40	0
C9	Chillers and Packaged Units BAT	New	123.4	0
C10	AHU labelling	New	1.3	0
C11	AHU labelling + Financial Inc.	New	2.6	0
C12	AHU + MEP1 + Labeling	New	19.8	0
C13	AHU + MEP1 + Labeling + Fin. Inc.	New	21.1	0
C14	AHU BAT	New	46.1	0
C15	Fan-coil Term. Unit MEP1 + Labeling	New	1.3	0
C16	Fan-coil Term. Unit MEP1 + Labeling + Fin Inc.	New	1.6	0
C17	Fan-coil Term. Unit BAT	New	3.9	0
C18	Pump MEP 1 + labeling	New	-	0

C19	Pump MEP 1 + labelling + Fin Inc	New	-	0
C20	Pump BAT	New	-	0
C21	Air Leakage MEPS	All	14.8	4.98
C22	Air Leakage BAT	All	17.1	5.68
C23	AHU Reduce fresh air flow rate	All	58.0	26.36
C24	A/C System inspection rigorous	All	51.3	24.25
C25	Central system all components MEPS	New	33.8	0.00
C26	Central system all components MEPS	New	161.5	0.00
C27	Bldg Envelope Achievable savings	All	7.4	8.91
C28	Bldg Envelope BAT savings	All	55.3	55.34

Table 101: B5.56: Summary table showing the cooling energy savings calculated for all the Modelled Cases ranked according to the cumulative savings potential for new installations between 2010 and 2019

The right-hand column of table 114 shows the results of applying additional constraints to the 10-year potential implementation for cases where measures are unlikely to be adopted except as part of major refurbishment works.

The possible policy instruments that could potentially achieve a significant level of energy savings for cooling based on the Modelled Cases were identified as:

Moderate product MEPs for moveable units, RACs, Chillers, AHUs and Ductwork:

These apply to all new installations and are set at a level that would probably be cost effective from an end-user perspective in most instances across the EU.

Demanding product MEPs for moveable units, RACs, Chillers, AHUs and Ductwork:

These apply to all new installations and are set at a level that is expected to be cost effective from the societal perspective at the EU level.

Reduced fresh air rates:

These apply to all new and existing installations of central systems there is. The policy component would be expected to be cost effective from the societal perspective at the EU level and, in many cases also from and end-user perspective..

Moderate system MEPs:

These apply to all new installations of central systems and are set at a level that would be cost effective from an end-user perspective in most instances at the EU level.

Load Reduction:

This relates to improvements to the building envelope and applies to all new and existing installations. is set at a level that could realistically be achieved cost effectively at the EU level from a societal perspective.

Inspection:

This relates to improvements to the way in which central cooling systems are operated in response to an inspection. These savings relate to controls and behavioural improvements[141] that could realistically be achieved cost effectively at the EU level from a societal perspective. [142]

Detailed Audit:

This relates to improved operation (as outlined in inspection above) plus the implementation of recommendations for component upgrade identified during a more thorough inspection process, possibly linked to operational benchmarking. The level of component upgrade relates to the moderate system MEPS outlined above. The savings identified equate to a level that is potentially cost effective at the EU level from a societal perspective. [143]**Moderate MEPs Building plus system:**

This relates to MEPS being applied at the building level where the level of savings is defined by the combined effect of moderate system level MEPS in addition to load reduction measures applied to the building envelope. The savings identified therefore equate to a level that could realistically be achieved cost effectively at the EU level from a societal perspective.

For some Modelled Cases, there are significant potential energy savings associated with the ventilation function. The combined cooling and ventilation potential energy savings for the policy components with the biggest potential impacts are shown in table 115 and presented graphically in Figure 56. These are discussed further in Section A3

Policy Components	Installations	Relationship to Modelled Cases	Realisable savings cooling	Additional savings ventilation
Moveables: moderate MEPS	New	M2	2.8	-
Moveables: demanding MEPS	New	M3	4.6	-
Room Air Conditioners: moderate MEPS	New	RAC2	25.7	-
Room Air Conditioners: demanding MEPS	New	RAC5	70.5	-
Chillers: moderate MEPS	New	C3	10.5	-
Chillers: demanding MEPS	New	C5	123.1	-
SFP: moderate MEPS	New	C13	12.7	419.2
SFP: demanding MEPS	New	C14 (part)	18.4	281.3
Air leakage MEPS	All	C21(part)	8.9	56.9

[141] Modelling operational savings is complex and beyond the scope of the modelling carried out for this study. Therefore the potential savings used here were taken from other existing studies.

[142] In many instances the measures will be cost-effective for an individual end-user, but the cost of universal inspection including systems which are operated efficiently casts doubt on whether universal inspection is cost-effective for end-users overall.

[143] The question again is whether the cost of auditing reasonably efficient systems is offset by the benefits of improvements to a minority of them. The development of improved methods of automatic energy reporting and analysis may hold the key to this.

Reduced fresh air	All	C23 (part)	50.6	349.4
System Moderate MEPS	New	C25 (part)	39.5	419.2
Load reduction	All	C27 (part)	60.1	-
Inspection (savings from recommendations rather than implementation)	All	from other studies	8.9	-
Detailed audit (includes component upgrades)	All	Inspection + C25(part)	46.5	419.2
Building plus system: moderate MEPS	All	C25 and C27 (part)	64.7	419.2

Table 102: B5.57: Realisable savings for policy components based potential savings from Modelled Cases and other sources

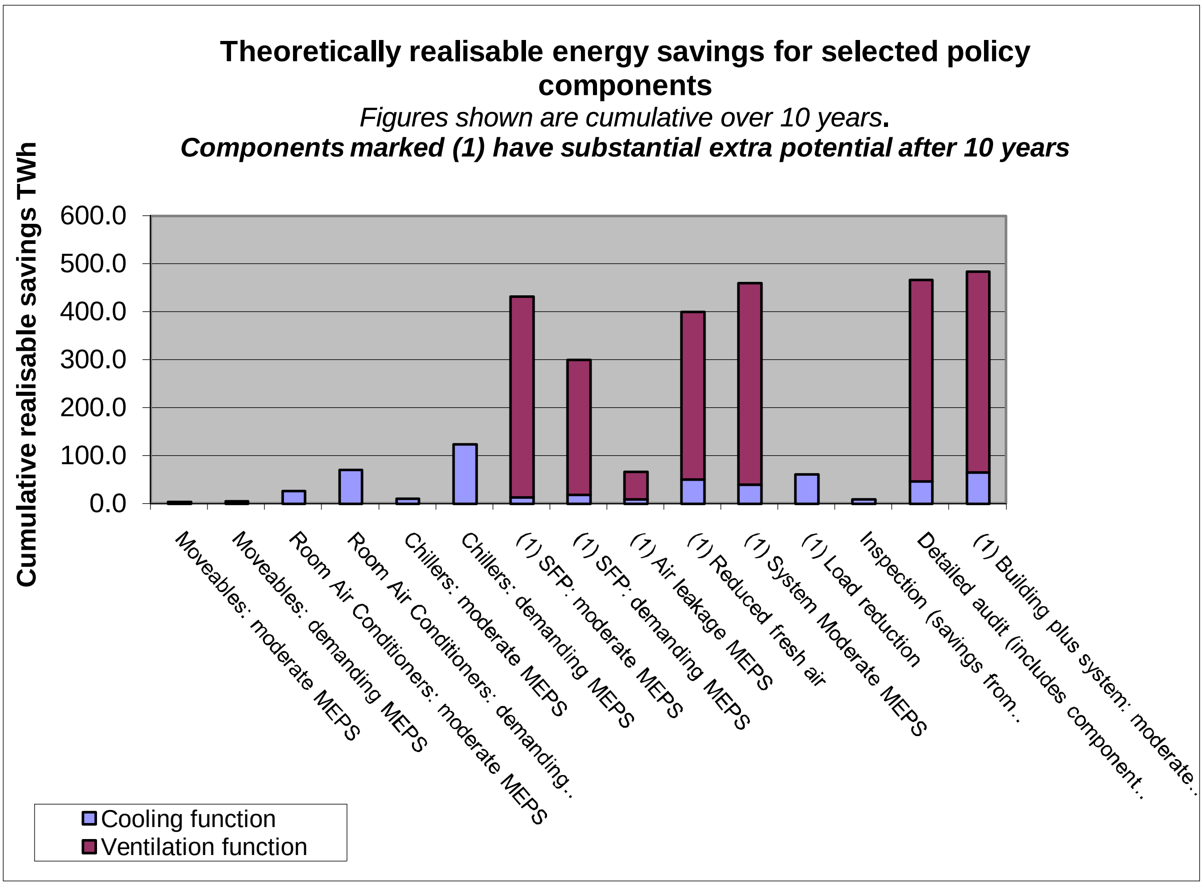

Figure 55: B5.5: Showing the realisable savings for policy components

B5.4.2 Constraints and Interactions

The modelling process takes account of the important constraint on rates of implementation imposed by product replacement rates. However, for some policy instruments, there are other constraints, typically where the implementation rate is restricted by rates of major building or system refurbishment or replacement. Table 114 shows where an additional constraint has been applied and Table 115 below provides more information.

For policy instruments other than MEPS (or those triggered by MEPS), the impact is not dependent on product replacement rates but rather on voluntary actions by owners and users. In these cases (for building envelope measures, for example), the Modelled Cases (other than BAT) reflect relatively low-cost measures that are most likely to be taken. The actual take-up rates are dependent on the economics of the upgrade for the individual owners, market conditions, incentives available, rate of growth of the market, equipment useful life, etc [144].

Where possible policy instruments combine the impact of more than one Modelled Cases in such a way that one measure reduces the scope of potential savings from another measure the following formula was used to adjust the savings:

% saving for a and b = 1-((1-% saving b)(1-% savings b))*

Policy Components	System Type(s)	Application	Relevant modelled cases	Derivation	Rationale
Moveables: moderate MEPS	Moveables	New Installations	M2		
Moveables: demanding MEPS	Moveables	New Installations	M3		
Room Air Conditioners: moderate MEPS	Room Air Conditioners	New Installations	RAC2		
Room Air Conditioners: demanding MEPS	Room Air Conditioners	New Installations	RAC5		
Chillers: moderate MEPS	Central Systems	New Installations	C3		
Chillers: demanding MEPS	Central Systems	New Installations	C5		
SFP: moderate MEPS	Central Systems	New Installations	C13	60% savings compared to modelled case	AHU replaced less frequently than chillers
SFP: demanding MEPS	Central Systems	New Installations	C14	60% savings compared to modelled case	AHU replaced less frequently than chillers
Air leakage MEPS	Central Systems	New Installations	C21	60% savings compared to modelled case	AHU + ductwork replaced less frequently than chillers
Reduced fresh air	Central Systems	All Installation	C23	30% savings compared to modelled case for new, 60% for existing	AHU/fans replaced less frequently than chillers, for some new installations this will already be taken into account
System Moderate MEPS	Central Systems	New Installations	C25	60% savings compared to modelled case	system replacement less frequently than chillers
Load reduction	All System	All Installations	C27	200% savings compared to modelled case	modelled case based on current a/c inspection - more specific envelope inspection would be expected to achieved greater savings
Inspection (savings from recommendations rather than implementation)	All System	All Installation	not modelled	9% of maximum realistic potential identified by harmonac keep cool studies.	
Detailed audit (includes component upgrades)	All System	All for inspection, New for component upgrade	Inspection + C25	as per inspection and system moderate MEPs	
Building plus system: moderate MEPS	All System	All Installation	C25 and C27	as per load reduction and system moderate MEPs	

Table 103: B5.58: Showing how policy components map onto Modelled Cases[145].

[144] The cost effectiveness of the modelled cases and the level (societal or end user) at which this is considered is provided in Section B3.

[145] The percentage values used to adjust the savings are based on BRE expertise gained from analysis of market data and practical field experience.

Figure B5.5 clearly show the energy using components associated with air movement efficiency improvements which are marked dark section of the bar. Efficiency improvements in air handling can be very significant. MEPS can also have a significant impact on energy savings.

In summary: Section B5 reports s the technical potential for energy savings for a range of specific Modelled Cases which are defined in Section B3. The realisable savings are substantial and fall into three main categories, all of which are important:

Reducing cooling loads via building envelop design, heat produced by equipment and lighting, temperatures maintained

Improving system efficiency via system design and selection of products, component performance and maintenance

Avoiding wasteful operation via adjustment of the duration of operation, physical extent of cooling provided

B6: OPPORTUNITIES AND POSSIBLE POLICY MEASURES

High levels of realisable savings have been identified by the Modelling Cases. Section B6 discusses possible policy measures that could be employed to realise at least some of this theoretical potential. The measures address the barriers that are identified as being important in Section A5. Appendix B1 contains a wider discussion of potential barriers to the reduction of energy consumption for air conditioning. Not all of these actually come into play: for example, there is clearly no shortage of technical options for reducing consumption.

The recommendations in Section A follow from consideration of the barriers, the potential savings and the policy options. Section B6 makes reference to these recommendations where appropriate.

B6.1 Policy Measures

Each of the following subsections addresses one type of policy measure and refers to the recommendations relating to it. Each subsection discusses the how the potential impact was determined, and issues that relate to the application of the recommendation..

Individual policy measures may impact on one or more of the three types of energy wastage: technical efficiency, effective operation or load reduction. They may be categorised as providing information; imposing minimum technical levels of performance or as incentives. They may also operate at different levels of application: complete buildings and systems; complete air conditioning systems; components of air conditioning systems. Tables B6.2 to B6.4 summarise this rather complex interplay, together with the modelling cases that apply in different situations. They also show where the policy components are already in place (to a greater or lesser extent). The tables also summarise the potential impact of the relevant Modelled Cases. In this column, the ranking is based on calculated theoretical realisable savings during ten years following implementation. As is noted on the tables, the impact of some policy components has been estimated from empirical data. An important caveat to the ranking is that nearly all components continue to generate extra savings after the ten-year horizon, and in some cases these are considerable.

Energy performance labelling and information provision (including user feedback)							
Policy component	Potential impact	Measured or calculated performance?	Relevant modelled cases	Impacts on			Comments
				Technical efficiency	***Operation***	***Load reduction***	
Moveable units		Measured	In base case	X			In place
Fixed self-contained systems		Measured	In base case	X			In place
Central systems labelling (whole system)		Calculated	Not modelled separately from MEPS	X			
Central system chillers	low	Measured	C1	X			Voluntary system in place
Central system AHUs (SFP)	low	Calculated	C10	X			Voluntary system in place
Central system pumps		Calculated	Not modelled separately from MEPS	X			
Central system terminals		Measured	Not modelled separately from MEPS	X			
System inspection and recommendations	significant	Observed	Not modelled: empirical information used	(X)	X	(X)	Required by EPBD
Building plus systems		Calculated	In base case	X		X	Implemented in some Member States for EPBD
Building plus systems		Measured	Not modelled	X	X	X	Implemented in some Member States for EPBD

Table 104: B6.2: Mapping of Model Cases onto Policy Measures : Information provision

Mandatory minimum energy performance requirements (labelling assumed to be a pre-requisite) applied to:							
Policy component	Potential impact	Measured or calculated performance?	Relevant modelled cases	Impacts on			Comments
				Technical efficiency	***Operation***	***Load reduction***	
Moveable units	significant	Measured	M1, M2. M3	X			Already proposed
Fixed self-contained systems	significant to high	Measured	RAC1, RAC2, RAC3, RAC4, RAC5	X			Already proposed
Central systems (whole system)	significant to high	Calculated	C25	X			Some Member States have requirements. EPBD Recast requires unspecified "requirements"
Central system chillers	significant to high	Measured	C3, C4, C5,	X			Some Member States have requirements
Central system AHUs (SFP)	low	Calculated	C12	X			Some Member States have requirements
Central system ductwork leakage	significant	Measured	C21, C22	X			Some Member States have requirements
Central system supply air rate	significant	Measured	C23			X	National requirements are common but need updating
Central system pumps	low	Calculated	C18	X			
Central system terminals	low	Measured	C15	X			
Building plus systems	high	Measured	C25, C27	X		X	Required by EPBD

Table 105: B6.3: Mapping of Model Cases onto Policy Measures : MEPS

Incentives for better efficiency or lower consumption (or penalties for poor performance)							
Policy component	Potential impact	Measured or calculated performance?	Relevant modelled cases	Impacts on			Comments
				Technical efficiency	***Operation***	***Load reduction***	
Moveable units	low	Measured	M4, M5, M6	X			
Fixed self-contained systems	low	Measured	RAC6, RAC7, RAC8, RAC9,RAC10	X			
Central systems (whole system)		Calculated	Not modelled	X			
Central system chillers	low	Measured	C6, C7, C8	X			Some Member States have tax incentives
Central system AHUs	low	Measured	C11, C13	X			
Central system pumps	low	Measured	C19	X			
Central system terminals	low	Calculated	C16	X			
Building plus systems		Calculated	Not modelled	X		X	Being considered in some Member States
Building plus systems		Measured	Not modelled	X	X	X	Being considered in some Member States

Table 106: B6.4: Mapping of Model Cases onto Policy Measures : Financial incentives

B6.1.1 Energy Performance Labelling and Information Provision for Products and Systems

The modelling results show small potential savings (based on the assumptions made, which are discussed below). No specific policy recommendations are made, but further work to investigate the impact of these types of instrument in business-to-business supply chains is recommended. (***Recommendation 20***)

The impact of mandatory energy labelling of moveable units and fixed room units, and the voluntary labelling of chillers and air handling units is included in the base case. The modelled savings attributable to mandatory energy labelling to the remaining products (cases C1 and C10) and systems are small.

This is a consequence of the assumption that the effect of labelling would be that a 5% proportion of purchasers would switch to A+++-rated products. This assumption reflects the business-to-business nature of the supply chain for the systems concerned (central systems and large packaged units). It is assumed that, in this situation, a proportion of specifiers (such as public bodies and organisations wishing to position themselves as being especially environmentally responsible) will require highly-rated products, but that most will not. This seems likely given the relatively short time horizons that many businesses apply to investment decisions and the fact that the system specifier is unlikely to be responsible for the running costs. This pattern is found with voluntary environmental labelling of buildings, which is perhaps the closest analogue.

Evidence on the impact of labelling on the share of the market taken by more efficient consumer products such as refrigerators or televisions is varied.[cxxviii] In some cases (including room air conditioners) the introduction of labelling has been followed by the appearance on the market of an increased number of highly-rated products and fewer low-rated ones and, in some countries, by a significant increase in the market share of more efficient products.

A comparison of the modelled impact of MEPS alone and MEPS plus labelling shows that the impact of labelling declines as the stringency of MEPS increases. This is the result of the reduced impact of switching from the lowest permitted rating (the MEPS) to top-rated products. Removal of products from the market represents the de facto introduction of MEPS.

Despite the apparently low direct impact, energy performance labelling is an important component of policy. Information to distinguish between more- and less- efficient products and systems is a necessary precursor to other policy components such as MEPS or financial incentives. Labelling requires education and consumer awareness; eventually, the energy saving concept and its connection to saving money is accepted, becomes familiar and easily comprehended by consumers. At the same time, manufacturers and distributors consider the added value of products with a better performance level and the market advantage that they offer. In practice, policy programmes for products typically start with comparative labelling and move on to introduce MEPS for example, in Brazil and the EU .

A rating figure based on nominal output under standard conditions can be misleading since, for air conditioning products, annual consumption is strongly dependent on part-load efficiency. Ratings based on standardised seasonal performance are preferable. These are already proposed for air conditioners of less than 12kW capacity. Even a single seasonal rating figure does not provide adequate information about component products (such as chillers) to system designers attempting to optimise overall system performance. For this purpose individual part-load performance figures are required. The relevant European test standard, EN14825 has recently been amended to include part-load performance testing, removing an important barrier to implementation.

New technologies such as inverter-type air conditioners (offering variable cooling or heating capacity) generally exhibit particularly high efficiency during partial output operation; the seasonal efficiency of these units is considerably higher than that of single speed equipment.

B6.1.2 Energy Performance Information Provision for Complete Systems: Calculated Performance

Energy Performance Information Provision for Complete Systems: Calculated Performance[146] has significant potential, but faces a number of implementation difficulties.
Recommendations 1,2 and 6 relate to ways of overcoming them

This situation was not explicitly modelled, but the impact can be assessed as being similar to the combined effect of the labelling of individual component products. As is discussed above, this is small but the approach can be seen as an essential pre-requisite for the introduction of MEPS, which have larger potential savings (and are discussed later).

For self-contained systems such as split systems this calculation amounts to the same thing as product performance labelling discussed above. For central systems it is more difficult, since these are designed specifically for particular buildings and the evaluation of performance of the complete system as installed and operated would need to be carried out individually for each installation.

In principle, a calculation of system efficiency is part of the implementation of the EPBD for building (plus system) energy performance requirements (and for building energy performance certification where this is done by calculation). A significant information barrier exists since there is no EPBD requirement to report the calculated air conditioning energy consumption or system performance. Some implementation software in some countries reports diagnostic information that includes this information. There is therefore a framework that could be used to overcome this barrier, at least for the situations where building energy performance labelling is already required. This would draw on the skills and quality assurance procedures that should already be in place for EPBD implementation.

Arguably, the main value of assessing system performance separately from whole-building performance is in applications that are not mandated by the EPBD: notably new installations

[146] The mandatory reporting of calculated system efficiency on Energy Performance Certificates, for the benefit of building owners and potential purchasers or lessees.

in existing buildings. This could be addressed by making installation or modification of air conditioning systems trigger application of elements of the EPBD (as it already triggers some elements of building energy performance standards or regulations in some Member States). In other words by treating the installation of air conditioning as subject to national building energy regulation in the same way that it is now usual to treat the replacement of building envelope elements such as windows. In this situation, the system design is more likely to be carried out by installers than by a separate design team. Currently they would be unlikely to have the appropriate training or accreditation (or perhaps independence) for regulatory purposes.

It appears from enquiries to Member States that the air conditioning energy calculation is rarely done convincingly within Member States' EPBD implementations at present. One serious barrier is the absence of a generally acceptable and practicable calculation methodology. Before this (and possible system-level MEPS) could be introduced, there is a need to test and compare those methodologies that are in use, and to agree or develop a common process. A suitable vehicle for then promulgating this would be a revised version of the relevant European Standard EN 15243.

B6.1.3 Energy Performance Information Provision for complete (Central) Systems: Observed Performance

Providing energy performance information for complete (central) systems based on observed performance (and the closely related option of observing whole-building performance) is one of the few policy components that can address operational energy waste and has a large improvement potential. There are barriers related to the visibility of some information - and also the generic energy efficiency barrier of motivating organisations and individuals to taking action.

It includes two overlapping areas: basic energy benchmarking and system inspection to identify specific possible consumption reduction measures. Regular system inspection at a fairly basic level is a requirement of the EPBD for systems of over 12kW capacity but implementation is currently patchy. [cxxix] Whole-building energy performance certificates (labels) are used by many Member States to meet the EPBD requirements for public display of energy certificates. Voluntary use of energy benchmarks is practiced by some energy managers: detailed analysis of consumption patterns is a service that is offered by specialist companies.

Recommendations 4 and 5 relate to inspections and audits, and ***recommendations 7, 15 and 16*** to different aspects of whole-building performance information,

This policy component was not explicitly modelled, as this would not have materially added to existing empirical information.

For system inspection, there is empirical evidence [cxxx] that the potential savings identified by the type of inspection required by the EPBD amount to only a small proportion of the potential savings, amounting to 34 TWh over a 10-year period. This estimate is derived by applying the proportion of possible savings from inspections that were found by the Harmonac study to the modelled estimates of potential savings in the present study. This is comparable with the potential savings from introducing moderately demanding MEPS for chillers and room air conditioners.

The same research demonstrated that it is very difficult to increase the potential savings from on-site surveys without more time-consuming, invasive and expensive system analysis. In case studies, detailed energy monitoring and analysis identified potential savings seven times greater than by inspection alone. This is a very large potential compared to other policy components (but implicitly includes many of them such as replacement of existing components with high-efficiency alternatives)

There are two significant barriers to achieving energy savings from inspections: the cost of the inspection; and motivating building owners to take action on all but the most straightforward of recommendations. These are related to each other. The market appears to have divided into owners who want a legal document at the lowest possible cost and those who prefer a more expensive inspection that helps them to save energy. The supply side of the market has inevitably responded to this.

Mandatory inspection can cover all or most air conditioning systems. It creates awareness of the need to take action but it only produces recommendations and does not guarantee savings in the way that changes to equipment efficiency can. The actual impact therefore seems likely to be low unless combined with incentives for action. Calculations by the Auditac project [cxxxi] suggested that universal inspection is probably not cost-effective. The EPBD Concerted Action reviewed this work and concluded that "… while inspections of larger installations are clearly cost-effective, inspection of smaller units, especially in moderate climates … are clearly not cost-effective.". The EPBD Recast allows Member States more flexibility in this respect.

One possible option would be the mandatory end-use metering and annual reporting of air conditioning energy consumption, with inspection or other investigations being triggered and required for systems with abnormally high consumption. This would complement the information available from on-site inspections.

Currently whole-building energy performance certificates are mainly confined to public buildings and do not separate energy use for different end-uses or functions. In principle, sub-metering and reporting of consumption could be made mandatory (perhaps limited to larger systems) and applied to a wider range of buildings. Remote recording and automated analysis and diagnosis of detailed consumption patterns to identify potential problems are being investigated by projects in Europe [cxxxii]and the USA.[cxxxiii]

B6.1.4 Energy Performance Labelling and Information Provision for Buildings

Energy performance labelling and information provision for buildings is a policy component that has a significant potential for reducing air conditioning energy consumption, since it impacts on both loads and system efficiency but implementation of existing requirements for air-conditioning is uneven. ***Recommendations 1, 2, 3, 13, 17 relate to this component***

Member States are already required by the Energy Performance of Buildings Directive (EPBD) to ensure that Energy Performance Certificates are produced whenever buildings are constructed, sold or let. These are based on the energy consumption of a building and its fixed building services (air conditioning, heating, lighting, and hot water production). In the majority of Member States these are based on calculated consumption, although some use measured consumption. The certificates have to be accompanied by recommendations for cost-effective improvements, which can include improvements to air conditioning systems or reductions in cooling load.

This policy component includes the effect of load reduction measures applied to the building in addition to the effects of system efficiency. The BAT modelling results reported earlier show that there are very considerable potential energy savings from load reduction measures. However, the most effective of these are applicable only to new buildings and those undergoing major refurbishment. Cost-effective recommendations are unlikely to exist for new buildings, and implementation of major changes in existing buildings is only likely (and then uncertain) at times of substantial refurbishment. In consequence, the potential impact each year is rather small. The 10-year realisable savings are estimated to be about 23 TWh.

The section addressing system-level information suggested the reporting of information on system efficiency that is internal to building energy performance certification. The same barriers, possible solutions and related issues apply here, but relate to air conditioning energy consumption rather than system performance. The distinction between the two is that reporting energy consumption rather than system efficiency allows the inclusion of the effect of load reduction measures applied to the building.

Limited take-up of recommendations is a generic barrier to achieving energy savings and has been discussed in many places, most relevantly in the EPBD Concerted Action. [cxxxiv] In the view of the Member State representatives, the most important actions would be "more communication"[147], "improve the quality of consultants" [i.e. assessors], "use other instruments". They felt that it is particularly important to emphasise the benefits of taking action to reduce energy consumption to building owners. These comments seem likely to be equally applicable to air conditioning recommendations as to other means of energy savings – possible more so since many building owners are likely to be unfamiliar with ways of reducing cooling energy consumption.

Measured whole-building annual consumption is publicly displayed for public buildings in many countries as a means of complying with one of the EPBD requirements. The process of generating a rating is relatively straight-forwards as it does not require a building inspection. As a result, frequent reporting is practical (in the UK annually, showing the last three years' results). Certification based on measured consumption reflects quality of management as well as the efficiency of the building and its systems. When the information is also displayed publicly, it acts as an incentive to efficient management. Requiring or encouraging this for a wider range of commercial buildings would expand its potential impact. Ideally this would be combined with the disaggregation of air conditioning energy from that of the building as a whole, which forms ***recommendation 15***.

B6.1.5 Policy Component: Minimum Energy Performance Standards (MEPS) for Products

As a policy component, product level MEPS offer substantial potential savings, unevenly distributed between different products and product groups. ***Recommendations 11, 12, 13 and 15*** relate to these policy components.

This subsection considers MEPS for products, whether these be components of central systems or complete self-contained air-conditioning systems. MEPS for central systems and their sub-systems, and for buildings are considered in later subsections. As can be seen from Table A4.2 above, many of the Modelled Cases were for MEPS applied at different levels to different "products" (including systems and buildings).

From a policy perspective, MEPS serve several purposes: to remove inefficient products from the market as a form of quality control; to reduce energy consumption by restricting purchasers' options to the more efficient products, and to encourage manufacturers to invest in technical innovation by system or product designers.

The Modelled Cases cover a full range of MEPS requirement levels. All Modelled Cases also assume that energy labelling would also be introduced. The implementation processes that would be required for MEPS (test processes, market surveillance etc) would make the introduction of energy labels a relatively low cost incremental addition. .

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147 Presumably from inspectors to building owners

In the list below, the term “chillers” is used as a shorthand way of describing cold generation for all air conditioning systems other than fixed and moveable room units of less than 12 kW cooling capacity. Most of the cooling in this category is provided by chiller-based central systems but it also includes rooftop units and larger split, multisplit and VRF systems. The calculated savings are aggregate figures for all these systems.

When estimating the realistic market potential for sales of new efficient models, we include replacement of existing units at the end of product life and filling the demand for new units to fill the growth in the market. For a saturated market, the first component could be estimated by taking the number of existing units in actual use and dividing by the expected lifetime of the product in years. The quotient would be the existing market replacement per year. Because the European market is expanding, this approach would be inaccurate and the market growth has been determined and factored into the impact using more sophisticated market modelling.

The list below categorises product-based MEPS cases according to their theoretical realisable savings levels over a ten year period after implementation. Because of the cumulative nature of savings, the first year savings represent only between 1% and 2% of the ten-year values: 0.1 TWh for moveable units, 1.1 TWh for fixed room units and 1.6 TWh for chillers. Complete replacement of the existing stock would require approximately 12 years for moveable and fixed room units and 20 years for chillers.

Cases with High Energy-saving Impact (over 70 TWh over 10 years)

- Demanding MEPS for chillers (removes over 90% of products from the current market, and therefore requires a significant lead time)

Cases with Significant Energy-saving Impact (between 10 and 70 TWh over 10 years)

- Demanding MEPS for fixed room units < 12 kW (removes about 80% of products from the current market)
- Less demanding MEPS for fixed room units
- Less demanding MEPS for chillers

Other Cases (less than 10 TWh over 10 years)

- MEPS for moveable units
- MEPS for terminal units
- MEPS for pumps

The modelling results support the importance of MEPS for fixed room units and chillers as important components of policy. The potential savings from applying MEPS to pumps, fans and terminal units used within central air conditioning systems were also assessed. By comparison with other possibilities, the impact in each case was small. However, MEPS applied to these products may be cost-effective, and the scale of savings for applications other than air conditioning may justify such measures. In this case, they should apply to air conditioning applications.

Based on the results of an Ecodesign Preparatory Study, proposals were initially put forwards for MEPS of 3.42 (SEER) for room air conditioners and 2.19 (EER) for moveable units, to be introduced 2 and 4 years after entry into force of the regulation. These were subsequently revised to 3.60 and 2.40 and will be introduced in 2013 and 2014 respectively.. Since the Preparatory Study was carried out, sales of A rated products and better have increased markedly in some important countries such as Italy, and the impact of the proposed requirements will be less than initially expected. Progressively more demanding requirements can increase the savings without unduly restricting the range of products on the market. The limit to this process should reflect a societal assessment of costs and benefits.

The levels of the originally proposed European MEPS for room units are classed as “less demanding” because changes to the market have significantly improved the aggregate energy efficiency of these products in the “base case” since the analysis underpinning them was carried out. The ten-year savings from the proposed MEPS have been modelled and are comparatively low because of the (more realistic) phased introduction compared to the theoretical instant application used for other cases. The MEPS levels adopted during 2011 are close to our modelled case for demanding MEPS and have significant realisable savings

MEPS for moveable air conditioners produce lower savings than for fixed room units or chillers but, if MEPS are introduced for fixed room units, it would seem consistent to also introduce them for moveable units. By the same token, “MEPS for chillers” implies application to the other product categories described above.

The modelling suggests that progressively tightening the proposed requirements for room air conditioners, and the introduction of mandatory requirements for chillers, could substantially increase the energy savings while staying within the bounds of current technology.

There is already a framework in place under the EcoDesign Directive for the mandatory energy labelling of smaller air conditioners and proposals to introduce mandatory MEPS for these products. In the Regulation, enforcement has two main arms:

- self-declaration “The manufacturer of air conditioners and comfort fans shall provide laboratories performing market surveillance checks, upon request, the necessary information on the setting of the unit as applied for the establishment of *declared capacities*, *SEER/EER*, *SCOP/COP* values and *service values* and provide contact information for obtaining such information.”

- limited testing “The authorities of the Member State shall test one single unit.”

This contrasts with the rather time–consuming and relatively expensive - but apparently more robust - independent testing of specific products and extrapolation of results to similar products of different capacity that is required by the current Eurovent Certification voluntary labelling scheme for other air conditioning products.

Two options are suggested for implementation

- Uniform demanding EU product MEPS. This would be an extension of the current EU requirements. It would be the most straightforward from the perspective of manufacturers, since it would apply to all products, irrespective of country or application. However, in some cases – less demanding climates and applications - it may impose costs that are disproportionate to the benefits.

- Uniform but less demanding European requirements combined with relatively strong national guidance (for example in the form of “deemed to satisfy” requirements in building energy standards) to encourage the use of more efficient products in climates that justify such levels of performance.

B6.1.6 Minimum Performance Requirements For sub-systems

MEPS for sub-systems is a policy component that offers significant potential savings, but they can only realistically be implemented at national level. ***Recommendations 9, 10 ,and 11*** relate to this policy component. ***Recommendation 2*** relates to coordination between national and European policy and is also relevant

Central cooling systems typically include several sub-systems in addition to the plant that generates cooling. The most important from an energy (and capital cost) perspective is the air handling sub-system. There are significant possibilities for reducing energy consumption by applying performance requirements to this sub-system. In this study, fan energy consumption is divided into two parts: energy use required to provide a fresh air supply; and the additional fan energy required in systems where part of – or all – the cooling service is provided by cooling air (which may include recirculated air). In addition to reductions in fan energy consumption, more energy-efficient air distribution reduces loads on the cooling plant itself (both by reducing distribution losses and because most of the energy supplied to fans also adds to the total cooling demand). In the summary below, all the savings have been combined. In every case, the largest savings are for the energy used to support the ventilation function.

The modelling shows that these measures have high – in some cases, very high - potential energy savings. The list below categorises ventilation-related cases according to their savings levels over a ten year period after implementation.

Cases with High Energy-saving Impact (over around 70 TWh over 10 years)

- Reduce ventilation fresh air rates to those needed for non-smoking premises
- Demanding MEPS for specific fan power

Cases with Significant Energy-saving Impact (between 10 and 70 TWh over 10 years)

- Less demanding_MEPS for specific fan power
- MEPS for ductwork and AHU leakage requirements

MEPS for specific fan power and for ductwork and AHU leakage already exist in the national building energy standards in some Member States, so there is no doubt that they are possible. Most Member States, however, do not appear to have such requirements. From a technical perspective Europe-wide requirements appear feasible. Practical application has to be at national building codes level, so implementation through the EPBD would seem to be the most feasible route.

There are limited opportunities to implement the measures other than for new systems (including major building refurbishments), so the timescale to penetrate the existing stock of systems would be slow – of the order of 30 to 40 years- but cumulative. This has been taken into account in the figures above.

Air leakage from ductwork and air handling units can only practicably be checked on site and fall more naturally into the scope of national requirements. In general, national building energy standards vary in scope and stringency. Uniformity of approach, while desirable, is practically difficult, but the publication of authoritative model codes could assist with (probably longer – term) convergence. This would be particularly applicable to air leakage, where several Member States have national requirement but others do not..

The reduction of fresh air rates for spaces where smoking is no longer permitted (but maintaining levels recommended by European Standards) would logically be implemented for new systems by review – and, where necessary, revision - of design codes. This might need to be supplemented by the provision of information to clients to explain the reasons for an apparent reduction in standard of service. Flow reduction should be possible in many existing systems, contingent on the possibility of maintaining adequate control and balancing. This opportunity should be a highlighted within inspection and energy audit schemes.

B6.1.7 Minimum Energy Performance Standards (MEPS) for Complete Systems

MEPS for complete systems is a policy component closely related to that relating to energy performance labelling of complete systems discussed in B6.2.6 above. The ***recommendations*** listed there (1,2, and 6) apply equally here.

This policy component encourages the use of system types to those that are inherently most efficient. Depending on the level of requirement, the system designer has an ability to trade off system type and component efficiency to produce the most appropriate or most cost-effective combination for a particular application.

The Modelled Cases show that the potential savings from improvements in component efficiency driven by system-level MEPS would be large. In addition, additional savings from changes to the choice of system are significant – of the order of 6 TWH over 10 years. Because major changes of system type are only possible in new buildings (before installation) and during major refurbishment, the potential from system changes would take several decades to be reached, and the estimated ten-year impact is rated as potentially significant (between 1 and 10 TWh). The dynamics of component replacement would be more rapid, as described under "product MEPS".

Unless set at very demanding levels, whole-system MEPS encourage designers to trade off energy-saving costs and benefits from different system elements. This encourages cost-effective solutions that are matched to particular buildings and climates. It also puts pressure on component suppliers to offer value for money: competition is not simply against other manufacturers of similar products, but also against competing ways of reducing energy consumption.

There are very significant practical constraints on this policy component. Because not all systems are suitable for all applications, MEPS would need to be contingent on the type of application (which may change during the life of a building) or be set at fairly weak levels. The ranking of system switching potential savings as "significant" is contingent on the practical constraints on the interchangeability of system types. It is possible that intangible constraints imposed by clients and their advisors (such as concerns about quality of service or property rental or resale value) could be more restrictive.

The previous observations (under energy labelling of systems) on the barrier presented by the lack of a generally accepted methodology for calculating system efficiency apply equally here. Similarly, the other comments in that section also apply.

B6.1.8 Minimum Energy Performance Standards (MEPS) for Buildings (and their systems)

MEPS for buildings and their systems is a policy component related to the provision of energy performance certificates for buildings and shares some barriers with that policy component. It has a large potential for reducing air conditioning energy use but implementation of existing requirements for air-conditioning is uneven and levels of ambition vary between countries. ***Recommendations 1,2, and 13*** relate to this policy component

Member States are required by the Energy Performance of Buildings Directive (EPBD) to implement minimum performance standards for buildings and their associated "building technical services" (HVAC, lighting and similar services). This applies to new buildings and when buildings undergo major refurbishments. The EPBD Recast also requires minimum performance requirements to be set for replacement building elements (including systems). [cxxxv]

This policy component provides the designer with maximum flexibility to trade off load reduction measures against cooling system efficiency (whether achieved through component performance or choice of system type), and cooling demand against heating or lighting energy demand. It is already a requirement of the EPBD, and potential savings have to be compared to this baseline.

This policy component encourages savings from load reduction, system choice and component efficiency and, since it combines the savings from all these sources, the absolute potential savings are large – over 100 TWh over ten years. As with MEPS for complete systems, this approach encourages the development of cost-effective design solutions – but now including load reduction measures – and incentivises component and system providers to provide good value for money.

Although the potential savings are large, whole-building requirements only affect new buildings and those undergoing major refurbishment. In consequence, the time required to impact a substantial part of the building stock is long – of the order of 30 years. In that time many of the system components will have been replaced, perhaps more than once. In that sense, policy components addressed at system components (and self-contained systems) are complementary to those addressed to complete buildings (or complete system). By the same token, the additional savings attributable to the whole-building components are reduced to the still substantial effects of load reduction.

B6.2. Choice of policy instruments

Selecting policy instruments – or packages of instruments – is not a simple task. Implicitly, choice of instruments means "in a practicable way and at a reasonable cost". These terms are necessarily imprecise, since the choice of policy instruments and the performance levels imposed is a question of balancing competing objectives. Issues to be considered include cost versus impact, complexity of implementation (including enforcement) and social equity. Each of these differs between instruments and, often, with specific details within them – the compliance level for MEPS, for example. If policy instruments are imperfectly designed they may not fully achieve their objective and may even create additional barriers. As policy instruments can be long-lived, it is critical to consider these issues during the policy development phase.

Amongst the issues to be considered are:

- Barriers come into play at different times. For example, market barriers are important when a purchaser is actively considering an acquisition.
- Policy instruments do not necessarily map one-to-one against the barriers (but may impact on several barriers) [148]

B6.2.1 Challenges

Policymakers and policy designers face somewhat conflicting challenges in the selection, development and application of instruments to improve energy efficiency. Meeting these challenges requires them to overcome a number of potential barriers of information, knowledge and resources. [149] [cxxxvi]

The challenges can be summarised as:

- Determination of clear objectives
- Balancing social equity against energy saving
- Balancing implementation and operational costs against benefits
- Balancing ease of application and technical precision
- Minimising "free-riding"
- Ensuring consistency between different instruments

The choice of policy options (and packages of policy instruments) requires trading off:

- Costs (direct, implementation, training, enforcement)
- Benefits (financial, environmental…)
- Perceived proportionality (the extent to which those affected perceive the cost to be appropriate to the benefits)
- Equity (cost and benefits to different groups)
- Consistency with other existing or planned instruments
- Uncertainty of impact

[148] Appendix B2 illustrates some of the ways in which policy measures interact

[149] Some of these issues are discussed in more detail – as they apply to product labelling and minimum performance requirements - in the CLASP Guidebook for Energy-Efficiency Labels and Standards for Appliances, Equipment, and Lighting

Although it may include the use of cost-effectiveness calculations, policy-making is only partially a matter of finding a mathematically "optimal" solution to a problem. It inevitably involves trade-offs between conflicting objectives – finding a solution that is acceptable from a variety of perspectives. Although economic and other calculations can inform the decision, this is essentially a political decision.

Addressing barriers by policy instruments is itself a complex process and the necessary trade-offs between competing goals can also represent barriers to achieving ideal target objectives. We can identify (at least) these types of barriers:

- inherent imperfections due to conflicting objectives, for example maximising savings while retaining equity between users
- imperfections in the process of defining and developing instruments, for example in defining the scope and purpose of an instrument
- imperfect implementation, for example through weak or difficult enforcement and the inevitable imperfections in the people who do the implementation, the funding available for implementing, the design of the programme itself, involvement of different ministries or agencies or levels of government, etc

A particular difficulty – and potential barrier – for building services systems is that policy-makers (and commentators) concerned with building energy use can overlook the importance of system energy efficiency. For new buildings, ensuring high system efficiency is often more cost-effective than further improving insulation or other building fabric changes – or of requiring renewable energy. The importance and difficulty of improving existing buildings is often remarked upon. [cxxxvii] Building services systems are replaced more frequently than many other components of buildings. First-time installations in existing buildings also represent a significant part of the air-conditioning market. Product and system performance requirements can therefore be important policies – provided that the need is recognised.

The table below is "parked" for possible use in the report

Recommendation Number	Recommendation	Potential Impact TWh ten year	Barrier type	Regulatory context	Comments
1	Closer liaison between national and European policy makers and between different strands of EU policy makers is needed.	Enabling step	General Policy Barrier	Integration of approach	
2	All assessments of policy instruments should be based on a common approach which reflects the costs and benefits to society as a whole.	Perhaps 60 TWh (interpolating from 11 and 12 below)	General Policy Barrier	Integration of approach	"Interpolation" here means a rough estiate of the proportion of the potential for 11 and 12 that could be missed
3	Member states that do not have convincing calculation methods for air conditioning - as required by the Energy Performance of Buildings Directive (EPBD) - should be required to implement them.	70 TWh taking "system MEPS" as a proxy	Information (lack of calculation procedure)	EPBD implementation: air conditioning efficiency	Excludes load reduction effects, which would increase the potential to 180 TWh
4	A consensus should be developed for a generally acceptable calculation procedure, ideally consistent with the procedures that are already in place in several member states.	Included in 3	Information (lack of calculation procedure)	EPBD implementation: air conditioning efficiency	Enabling step towards 3
5	Member states should be encouraged to strengthen implementation of air-conditioning inspections (under EPBD) where necessary.	30 TWh	Policy Implementation	EPBD inspections and audits	Depends on take-up of recommendations
6	The results of research into the most cost-effective way to carry out inspections, audits and similar procedures should be reviewed as they emerge.	70 TWh (Our of 100 TWh achieveable)	Information/EPBD policy barrier	EPBD inspections and audits	Depends on take-up of recommendations
7	Member states should introduce measures to incentivize the implementation of recommendations made as part of EPBD Energy Performance Certificates (EPCs).	For air conditioning assume similar to inspection: 30 TWh	Information provision to users	EPBD inspections and audits	Depends on take-up of recommendations
8	Where air conditioning energy consumption is calculated as part of an EPC, this – and the system efficiency - should be reported in the certificate.	Supports 7	Information provision to users	EPBD inspections and audits	
9	Sub-metering and reporting of measured consumption for major systems and items of plant should be required. When combined with the building area being cooled, a cooling index can be calculated for comparison with other buildings and for setting targets.	Take as intermediate between 5 and 6, say 45 TWh	Information provision to users	EPBD inspections and audits	Depends on take-up of recommendations
10	Member states should be encouraged to expand the use of measured energy ratings to a wider range of buildings, notably those with air conditioning, and to ensure that Energy Performance Certificates show both calculated and measured performance.	Not quantified, for air conditioning take as simlar to inspections: 30 TWh	Information provision to users	EPBD inspections and audits	
11	Proposals should be developed to progressively make MEPS for room air-conditioners more demanding. (This recommendation goes beyond those agreed in May 2011)	Up to 40 TWh	For MEPS: Motivation of purchasers. For level required: the use of an essentially end-user objective to set requirements	EcoDesign Directive	
12	Proposals should be developed to introduce mandatory labeling for chillers, to introduce MEPS and progressively make them more demanding. (A Preparatory Study is currently assessing this)	Up to 90 TWh	Motivation of purchasers	EcoDesign Directive	
13	Before introducing Europe-wide demanding levels of MEPS for any products, consideration should be given to implementing them via national building codes , possibly accompanied by more widely cost effective European "back-stop" requirements.	Unquantified: may be more practical means of approaching the potential figures for 11 and 12 than attempting to impose demanding Europe-wide MEPS	Requirement levels potentially constrained by equity considerations between countries.	EcoDesign Directive	
14	Energy performance labels should contain the key part-load performance data used in the ratings.	Unquantified: supports 4	Effective application of recommendation 4	EcoDesign Directive	
15	There is no compelling case for introducing MEPS for other components of central air conditioning systems.	Null recommendation			
16	MEPS for specific fan power should be introduced in those member states that do not already have such requirements.	30 TWh	Information and/or motivation	National Regulations	BAT would show bigger savings
17	MEPS for ductwork and air handling unit leakage should be introduced in those member states that do not already have such requirements.	20 TWh	Information and/or motivation	National Regulations	BAT would show bigger savings
18	To assist member states to introduce these requirements, model clauses and guidelines should be developed, based on the experience of those that already have them.	Unquantified, supports 16 and 17	Information for national regulators	National Regulations	
19	Fresh air design rates and design codes requirements should be reviewed in the light of smoking legislation and amended where appropriate (retaining compliance with relevant European standards).	Up to 120 TWh	Information for designers and system inspectors	National Design Codes	
20	System-level performance requirements should not be treated as a priority issue, but the case for them should be reviewed from time to time.	70 TWH in the absence of other policies: but substantially reduced by implementation of other recommednations	Scope of application of other policy measures	National Regulations	
21	Consideration should be given to studies to investigate the effectiveness of energy efficiency information-provision mechanisms in business to business supply chains.	Unquantified supporting recommendation	Information for policy design	Other Recommendations	
22	Consideration should be given to studies to investigate the relationship between product price trends, energy performance and the introduction of labeling or MEPS.	Unquantified supporting recommendation	Information for policy design	Other Recommendations	

Main Type	Subtype	Specific Barriers
Information	Motivation	Lack of awareness of benefits
		Lack of incentive to take up EPC recommendations
	New purchase	Insufficient information to inform new purchase
		Insufficient information about options for retrofit
		Calculation method for efficiency is absent or non-standard
		Part load efficiency information is missing
		No clear evidence of effect of labelling on product price
	Operation	Lack of disaggregated data on energy use for cooling
		Lack of measured data (e.g. through operational rating)
		EPC Calculation doesn't show a/c efficiency or usage
Financial	Capital	Lack of funding for investment
	Incentive	Split incentives (e.g. landlord vs. tenant)
Market	Availability	Best products are not easily available for new purchase
		Best retrofit solutions difficult to source
	Control	Low-efficiency products on sale (esp. chillers)
Policy Related	General	Disconnected criteria used in different policies
		Weak correlation between policies leads to confusion
		Choice of cost-effectiveness definition (user vs. society)
		Could reduce ventilation rates: now no smoking in buildings
	EPBD	A/C inspection regimes weakly enforced
		Uncertain benefits of universal inspection
	MEPS	MEPS standards need tightening
		Absence of performance standards for different elements

Table 107: B6.5: Summary of Market Barriers to Energy Efficient Cooling Systems

Table order needs to be consistent with text

B6.2.1.1 Financial: Capital.

A common problem with energy-efficiency investments is that, while they may be cost-effective over their lifetimes, they require significant initial investment. Upfront capital may be difficult to obtain, especially in competition with other business investments.

B6.2.1.2 Financial: Incentive

Split incentives frequently occur in the decision making process for cooling systems, as the majority of cooling systems are in commercial premises, many of which are tenant rather than owner occupied. In these instances it is the landlord who is required to finance any additional expenditure required to obtain efficient equipment whilst the tenant reaps the reward of lower operational costs over the lifetime of the equipment.

B6.2.1.3 Market: Availability

For products and systems, what is on the market locally may not reflect the full range that is produced, or could be produced if manufacturers could identify sufficient demand.

B6.2.1.4 Market: Control

For some products and components, most notably chillers, there is currently nothing to prevent the sale of low efficiency products

B6.2.1.5 Policy Related: General

If one looks at air conditioning in isolation from the building shell, interior structure, intended use, the heating system, ventilation and exhaust, etc., there is a risk that the performance of other building systems will be affected as well because of interactions among the components. This is where the first barrier to effective policy exists: at present, different areas of end-use efficiency policy are assessed using different criteria, and to a large extent, independently. In particular, building energy requirements are set at national level within the European EPBD framework, while product policy is determined centrally as part of internal market policy.

Furthermore the choice of cost effectiveness criteria (user or society) results in different ambition levels between Member States and between product and building (and renewable energy) policy. Ecodesign Preparatory Studies use a well-defined methodology that takes an essentially end-user perspective, which leads to lower savings than would be achieved if cost effectiveness was judged at the societal level. Many Member States base energy policy on more demanding societal tests of benefit. The EPBD Recast proposal for a cost-optimality test is designed to address this in the context of buildings but seems likely to be based on end-user cost-effectiveness and therefore result in weak levels of ambition.

There are also substantial potential savings associated with reducing fresh air requirements for spaces in which smoking is no longer allowed. Minimum fresh air rates may be part of building standards or standard design conventions.

B6.2.1.6 Policy Related: EPBD

The EPBD requires Member States to have whole-building energy performance requirements (equivalent to product MEPS) that include the effects of system and product efficiency and load reduction. They allow trade-offs to be made between different ways of reducing consumption and encourage the development of the most cost-effective combinations of measures for each building. The EPBD mechanisms relate to new buildings and major refurbishments and therefore have a slow, but cumulative impact. If product MEPS are in place, since they are complementary measures, these will reduce the potential savings attributable to whole-building energy requirements: however, the load reduction potential of product MEPS alone is substantial and these reductions will also be effective in the larger market of existing buildings and replacements.

The EPBD requires mandatory regular inspection of AC systems > 12kW, however implementation of this requirement is weak (although data is sparse) The 2011 EPBD Concerted Action report found that 8 of 20 respondents had inspection system in force or in preparation, a similar number rely on existing systems and 20% have no regulations. It also found that “most MS are convinced that there is room for improvement in their inspections scheme” (this applies to both boiler and air conditioning inspections).

There is also considerable uncertainty regarding the cost effectiveness of universal (as opposed to selective) inspection of air conditioning systems. Mandatory inspection is likely to be cost effective for poorly managed systems where the manager takes action in response to recommendations. Otherwise cost-effectiveness will be low. This conclusion was reached by the EPBD Concerted Action, having reviewed research results and resulted in the EPBD Recast allowing Member States more flexibility of application and encouraging the complementary use of measured data. The most cost-effective combination of measures such as inspections, detailed audits, analysis of consumption data, the use of diagnostic performance information recorded on-site, or remotely by product, is uncertain. Research into this is already in progress. [cxxxviii]

The EPBD requires the provision of a whole-building energy performance certificate (EPC) whenever a building is constructed, sold or let. It must be accompanied by recommendations for measures to improve consumption. These are mostly based on calculated consumption, but sometimes on measured consumption. However, in instances where it has been measured, the take up rate for recommendations is low.

B6.2.1.7 Policy Related: MEPS

Minimum Energy Performance Standards that are in place or proposed for air conditioning products and systems are set at levels that are not very demanding and consequently have little impact on the aggregate market efficiency of products sold. This is partly due to the time lag between performance levels being proposed and implemented, which means that the expected impact of MEPS is diluted by market driven efficiency improvements that have occurred between proposing and implementing MEPS.

B6.3 Summary of Recommendations

The recommendation for overcoming barriers to energy savings in cooling systems are summarized in the following Table B6.5.

Table 108: B6.6: Summary of Recommendations indicating potential savings and regulatory context

Study to assess barriers and opportunities to improving energy efficiency in cooling appliances/systems

APPENDICES AND REFERENCES

APPENDIX B1: BARRIERS, POLICY INSTRUMENTS, AND AIR CONDITIONING

Note! This Appendix has several sections. The section numbering needs to be revisited to accommodate this (The main headings are not numbered at present)

THIS APPENDIX ADDRESSES SEVERAL ISSUES. FIRSTLY, IT SUMMARISES THE TYPES OF BARRIER THAT POTENTIALLY PREVENT REDUCTIONS IN AIR CONDITIONING ENERGY CONSUMPTION. IT NEXT DISCUSSES THE TYPES OF POLICY MEASURES THAT COULD BE CONSIDERED, AND THEIR INTERACTIONS. FINALLY IT
ILLUSTRATES THE NATURE OF THE IMPACTS OF DIFFERENT TYPES OF POLICY MEASURE

BARRIERS to Reducing Energy Consumption (Main Heading needs number!)

1. Introduction

Barriers to the reduction of energy consumption by cooling systems do not differ in kind from those that affect many other areas of energy-efficiency policy. However, the provision of cooling services (along with ventilation, heating and lighting) has characteristics that are not present in some other areas. The service may be provided either by stand-alone products, or by more complex bespoke systems. Energy consumption is not simply a matter of product or system efficiency, but is strongly influenced by conditions of use, and especially by the design of the building in which a system is installed, as well as on the type of cooling system. Obtaining best overall value requires trades-off between the design of the building and its building services systems[150]. For complex systems this in turn involves further trades-off between the system components, which can be products in their own right.

This complexity leads to a range of potential barriers, which may apply generally or only to some types of system or particular market sectors, and may involve a number of actors: designers, manufacturers; purchasers, operators, and policy-makers. The relatively complex business-to-business supply chain further increases the number of potential barriers.

2. The Cost-effectiveness of Barriers from the Perspective of the End-user and of Society

Barriers to energy saving[151] can be viewed from different perspectives: what is a barrier in one sense is not necessarily so from another. The fundamental distinction is between the perspective of society as a whole (the “macro” economic perspective) and that of individual end-users (often represented in analyses as idealised end-users: the “micro” economic perspective)

[150] “Technical building systems” in the language of the EPBD.
[151] In the context of energy efficiency, the concept of a barrier implies that there is a degree of under-investment in an energy-saving technology – such as the purchase of an efficient air conditioner. The removal of a barrier should, therefore increase the take-up of a measure. In principle (if not always in practice) we can know what take-up is. We do not know what it might be in future, except where there are clear technical limitations. It is necessary, therefore, to estimate take-up in the absence of the imputed barrier(s).

2.1 The end-user perspective

This perspective is important when the objective of regulation is to address “market barriers” that prevent owners and occupants taking actions that are in their direct interest, but which they do not recognise as being so.

It is also important as a means of assessing the risk that regulation will be seen as unfair by significant groups of those subjected to it. Apparently similar households or businesses in identical buildings can have very different occupation patterns and temperature requirements, resulting in equally varied energy demands. Since the direct costs of energy efficiency measures do not generally depend on the occupants, a package of measures that is cost-efficient for one set of occupants may not be so for others. The extent of objections to regulatory requirements will depend on the number of end-users who feel disadvantaged, and by what extent.

Because of the practical difficulties of assessing the detailed end-user perspective, it is common practice to use instead an idealised end-user perspective[152]. This usually involves the definition of “typical” users and the assumption that the market barriers referred to above can be ignored. This makes the analysis more tractable but, in effect, hides differences between different groups of end-users and the resulting “social equity” issues. These are discussed later.

In the air conditioning market, “end-users” may be households, but more commonly will be businesses. One of the difficulties is to define a single “end-user”: the building owner, manager and occupants are typically separate and have different responsibilities and powers to influence.

The term “market barriers” is best used when addressing the viewpoint of the prospective purchaser or user. These are barriers that prevent the market from approaching the ideal state where all purchasers would acquire the products best suited to their needs. This ideal state would be the situation if all potential purchasers were rational economic beings, with complete knowledge, and were operating in a “perfectly competitive” market. Relevant policy options therefore address barriers to achieving this state [153]

2.2 The societal “macro” perspective

This is a basic approach to regulatory policy-making from an economic perspective. It is used when the justification for introducing energy performance regulation is to make organisations or individuals take actions that do not reflect their own direct interests (and are therefore unattractive as investments) but can be shown to be beneficial to society as a whole. This approach takes into account all the costs incurred by any part of society, and all the benefits that result irrespective of where they occur and to whom. There is no distinction here between costs and benefits that fall on different sections of society: it is the net balance that is important.

The societal perspective takes into account the cost (or benefit) to society of externalities that are not reflected in market prices (for example, by applying a “shadow” price for carbon) and applies (lower) social rather than private discount rates. In principle it should ignore the

[152] This is the convention in Preparatory Studies for ErP products

[153] The IEA report “Cool Appliances” **Error! Bookmark not defined.** identifies four definitions of cost-effectiveness (implicitly related to different types of barrier) with different levels of ambition:
Level 1: aiming to get consumers (and presumably firms) to invest in energy efficiency at discount rates more typical of their other financial investments.
Level 2: To encourage **manufacturers** to raise efficiency to a level where **consumers’** costs are minimised as calculated by engineering-economic analysis. (presumably for standardised “average” users.
Level 3: To raise efficiencies to levels where *social* costs are minimised. (Within the report this definition is explained as, for example, including savings in power station construction. Ideally these should be reflected in energy prices.); Level 4: As level 3, but also including the cost of environmental and social externalities

impact of subsidies and taxation. This has the result that performance levels mandated on the basis of a societal perspective may be cost-effective for society as a whole, while being unattractive as private investments.

While market barriers may still be present, there is the added problem that the desired performance levels are seen by many potential purchasers as uneconomic[cxxxix]. Since there is a rational barrier not to purchase such equipment, other policy instruments have to be deployed to overcome them.[154] These might be mandatory regulatory measures such as MEPS set at a more demanding level than most users would rationally choose; or price interventions such as subsidies or energy taxation.[155]

2.3 Social Equity Considerations

Markets are heterogeneous: some purchasers can justify higher–cost, higher performance products, but others - quite rationally - cannot. In an economically perfect market, each purchaser would invest in the product best matched to their needs - but these would not be identical. This is reflected in the range of competing products of different costs and levels of performance that find a place in the market. This also applies from a societal perspective: costs and benefits do not accrue equally to all.

A consequence is that many policy instruments - especially minimum performance requirements – cannot be optimal for everyone. What is cost-optimal for one person is unnecessarily expensive for another, but can have an insufficiently high performance for others. Put another way, apparent market barriers based on an analysis for an "average" end-user can be misleading. Some market participants may be making rational decisions for their particular circumstances. Minimum performance requirements may impose costs on them that are not balanced by the direct benefits perceived by them as end-users.

Somewhat similar, equity issues can arise with levies on energy costs - some people or organisations may be worse off overall, while others benefit. In the case of subsidies, "free-riders", who accept a subsidy for an action that they would have undertaken anyway, increase costs without stimulating additional action.

This balance between the expected benefit to society as a whole and unequal treatment of sections of it is essentially a political decision, and can be set at a wide range of different levels. At one extreme, there can be "no loser" rules - notably applied to utility price regulation - where it has to be shown that no-one is worse off, even though some users benefit more than others. At the other extreme are minimum performance requirements such as the Japanese "top-runner" programme for air conditioning, where future (minimum) performance requirements are set to reflect the most efficient products currently on the market and are explicitly focussed on driving product development with little concern for short-term cost-effectiveness. This is not to imply that such objectives are improper - they are commonly the basis of renewable energy policy, usually justified by the expected acceleration of new technology through "learning curve" effects and the consequent long-term societal benefits.

3. Energy Prices

The issue of cost-effectiveness is inseparable from that of energy pricing. Energy pricing is a fundamental energy policy instrument. Economic modelling of energy efficiency policy options suggests that, for similar economic costs, energy taxes would be expected to have a similar impact to mandated efficiency improvements (such as MEPS) [cxl]

[154] In practice, the extra costs imposed on purchasers cannot be ignored when setting socially acceptable minimum performance levels. Overall cost-effectiveness of any policy also has to take into account the costs of implementation and operation, and consequent costs or savings.

[155] In other situations the same justification can be used to require people or organisations to desist from actions.

For the businesses that comprise most users of air-conditioned buildings, energy is only a few percent of their expenditure: over the building life staff costs typically amount to 85% of costs.[cxli] Taken with perceptions of the impact on productivity, this results in the price elasticity of energy demand being low, especially in the short-term.

National policies vary considerably, with some countries imposing explicit carbon or general taxation on energy, some applying levies on energy suppliers, and other avoiding specific energy taxation. This results in significant differences in energy prices across Europe. Data for commercial buildings are not reported but for “small industrial customers” (2000 MWh/annum), the average unit price in the most expensive countries is more than twice that of the least expensive.[cxlii] For residential customers, the difference is even greater. This obviously has a substantial impact on the cost-effectiveness of energy efficiency measures. Subsidies for renewable energy (including feed-in tariffs) are not uncommon but have little impact on the air-conditioning market (other than increasing general energy prices if they are funded by supply levies).

Average price is only part of the picture, especially for larger commercial buildings (and industry). Typically, these consumers are on contracts with three distinct elements: a standing charge (measured in time units), a charge based on maximum contracted demand (measured in kW) and a consumption charge (measured in kWh)[cxliii]. Seasonal time of day tariffs (more commonly bilateral contracts in privatised markets), with prices varying by time of day and season, are common. Specific maximum demand charges for times that coincide with system peak demand also exist. In general, southern European countries have summer peak electricity demands while northern ones do not [156].

In summer-peaking countries in the South of Europe (which typically also have substantial numbers of air conditioning systems) these pricing structures can impact on the design and operation of air conditioning systems, providing an incentive for demand-side management with or without thermal storage[157].

See Section A5 for additional discussion relating to energy prices and peak demand.

This study does not examine the potential impact of increasing energy prices.

4. Barriers to Energy Saving in Air Conditioning

The market barriers that exist for purchasers and operators of cooling systems are summarised in the table and discussed in more detail below. As is apparent from the main body of the report, they apply in different degrees to different parts of the rather complex air conditioning market.

Lack of motivation	Lack of recognition that there can be significant benefits from reduced energy consumption and that these will not be offset by concomitant disadvantages.
Lack of information	Purchasers may not recognise that they have a choice or that energy efficiency is an important part of that choice, and that some products (or services) may be more appropriate to their needs than others.
Shortage of options	The range of products and systems on the market locally may not reflect the full range that is produced, or could be produced if there was sufficient demand. Building designers, specifiers and their clients may not

[156] Europe has substantial grid inter-connections, so, to a degree, peak demand in one country may be partially met from generation in adjoining countries.

[157] The energy efficiency implications of this are discussed in section B1

	be fully aware of the full range of possibilities for reducing energy consumption (this is most likely to apply to central cooling systems which tend to have a more complex supply chain). Similarly building operators may not be fully aware of the range of energy management strategies that they could adopt.
Lack of capital	Energy-efficiency investments may require significant initial investment even if they are cost effective within their lifetime.

4.1 Motivation

The primary motivation for installing air conditioning in occupied spaces is improved comfort – and, for commercial applications, the expectation of improved staff productivity or higher rental values. Frequently the operating costs are not borne by the same organisation (or person) as is responsible for the initial purchase. In a landlord/tenant situation, the benefits are divided: rental benefits accrue to the landlord, while the tenant has the comfort and productivity benefits (and faces the higher rent). Typically the tenant pays the energy costs but has no direct say in the choice of cooling system. (In principle, it could be a factor in the choice of building).

For the building developer, there is a clear motivation to limit initial cost but little market pressure to choose an efficient system. Even when the purchaser is also the user, the cost of energy is small compared to the size of the potential benefits[158].

During operation, similar considerations apply. Maintaining acceptable indoor conditions is a higher priority than the energy bills – which are small compared to staff salaries and total rent. Motivation for regular servicing is largely predicated on the risk of failure, and operating periods and temperatures are geared to staff satisfaction.

So the first barrier is the lack of recognition that there can be significant benefits from reduced energy consumption – and that these will not be offset by concomitant dis-benefits.

4.2 Information: New Purchase

The first information barrier is that a potential purchaser may not recognise that they have a choice, and that some products (or services) may be more appropriate to their needs than others.

Having recognised this, energy efficiency needs to be identified as an important part of that choice. For example, it seems likely that many purchasers of moveable air conditioners will be motivated more by price, availability, claimed cooling power, noise and – perhaps – brand name, than by running cost.

But simply recognising that the issue is important is insufficient: the would-be purchaser needs the ability to evaluate alternative offerings to identify the most appropriate (or at least to filter out the least appropriate). This can become a complex and time-consuming process and it is probably unrealistic to expect purchasers of relatively inexpensive products to be prepared to devote much time or resources to it. On the other hand, purchasers of high-value systems or equipment may carry out formal cost-benefit appraisals of options, but will need

[158] "Even when the purchaser is also the user, the cost of energy is small compared to the size of the potential benefits"

detailed information on the costs, capabilities and performance of the relevant options in order to do so.

Building managers and operators require different information that is better focussed on the day to day running of the building and its systems. This includes feedback on actual energy consumption, some means of rating this (either in relation to other, similar buildings or to previous consumption of the specific building), and knowledge of possible operational improvements. Ideally this would also allow comparison between different services (heating lighting, cooling, and so on) in order to prioritise actions.

4.3 Information: Building and System Operation

Building designers, specifiers and their clients may not be aware of the full range of possibilities for reducing energy consumption. This is perhaps especially likely for central cooling systems, which have a relatively complex supply chain and numerous potential ways of wasting energy[cxliv] [159].

Equally, building operators may not be aware of the range of energy management strategies that they could adopt.

In essence these are information barriers that can be addressed by a variety of means including publicity, systems and building inspections, demonstration projects, case studies and procurement programmes.

4.4 Shortage of Options: Supply Chain and Product Availability

The section above assumes that a prospective purchaser has a significant choice between options. For products and systems, what is on the market locally may not reflect the full range that is produced, or could be produced if manufacturers could identify sufficient demand.

4.5 Lack of Capital

Having identified and evaluated possible options, there remains the question of funding. A common problem with energy-efficiency investments is that, while they may be cost-effective over their lifetimes, they require significant initial investment. This may be difficult to obtain, especially in competition with other business investments.

4.6 Split Incentives

Split incentives occur where decisions on equipment purchase or operation are taken by one agent, but the energy costs are met by another. They exist in the supply chain (specifiers and users often being different) and more generally in landlord/tenant relationships. Even where purchasers and users are within the same organisation, the capital and operating budgets are usually separate.

4.6.1 Supply Chain Split Incentives

Air conditioning procurement is predominantly by relatively long business to business supply chains. Each link in such a chain is a potential split incentive barrier.

[159] EN 15243Error! Bookmark not defined. lists over 40 “energy-wastage mechanisms” for central air-conditioning systems.

Formal efficiency requirements in procurement procedures can help to overcome the supply chain barrier by making the client's requirements visible through the supply chain. Energy labelling is important as an enabling mechanism for this.

In principle, the split incentives in the supply chain can be addressed by placing responsibility for procurement and operational costs with the same organisation, such as an Energy Services Company (ESCO). ESCO (and the related Energy Savings Performance Contracts) activity appears to be increasing and might perhaps be encouraged by policies such as tax incentives. Such policies do not appear to be common, except in the form of market leadership by some larger businesses and public authorities.[cxlvi]

4.6.2 Landord/tenant Split Incentives

The landlord/tenant relationship is perhaps the best-known example of split incentives: the capital costs and operating costs of tenanted space are often the responsibilities of different parties.

One approach to the landlord/tenant barrier is the development of leases constructed to apportion responsibilities more effectively. "Green leases" seem to have originated in Australia, where they are not uncommon[cxlvii]. In Europe, the UK is apparently the leading country, although they also exist in France and possibly elsewhere[160]. Typically, they include additional powers and obligation on both parties. Extracts relating to air conditioning from model documents produced by the Better Building Partnership are shown in the box below.

There appear to be no legal requirements for such leases – their use is driven by commercial considerations and perceived reputational risks, especially for larger funds and institutions. Without legislation, they seem likely to "evolve slowly and with limited effect"[cxlviii].

Green Lease: Extracts from Model Documents from Better Building Partnership[cxlix]

1*. Best Practice Recommendations*

- Owners and occupiers should agree to consider alterations that reduce the need for air conditioning (e.g. night time purging, specify free-cooling).

2. *Model Memorandum of Understanding*

- Where the Landlord controls the hours of operation of any heating, lighting or air conditioning services to the Building and/or the Premises, the Tenant will provide to the Landlord details of its hours of occupancy of the Premises and its requirements for heating, lighting and air conditioning services for the Premises and will keep the Landlord informed of any changes in such requirements.

Ensure that, wherever practicable, the settings of the system are adjusted and regularly reviewed with a view to minimising unnecessary provision of heating, lighting or air conditioning services to the Building and the Premises and to reflect the information provided by the Tenant under paragraph 4.1 above.
The Parties to give reasonable consideration to alterations that reduce the need for air conditioning and other energy consumption.
Programming cleaning times to minimise the use of lighting, heating and air-conditioning resources.

3. *Model Lease Clauses*

[160] In the UK, the proposed Carbon Reduction Commitment penalises building owners for high energy consumption, which may be the result of tenant actions

•The Landlord and its servants or agents or contractors shall be entitled at all reasonable times and on reasonable prior notice to the Tenant to enter and remain on the Demised Premises for
a) the purpose of taking reasonable steps to review or measure the Tenant's energy and water use and its waste production or waste management save where up-to-date information in this respect has already been provided to the Landlord by the Tenant;
b) carrying out works which are agreed by the Tenant (acting reasonably) and are aimed at more effective management of, or reducing, energy or water use or waste production and for setting up and managing recycling schemes (provided that such works cause as little disruption as reasonably possible and when complete do not adversely affect the Tenant's beneficial use and occupation of the Demised Premises and that any damage caused by such works is made good)
c) for the purposes of preparing EPCs or DECs or undertaking an air conditioning inspection and for such purposes the right to carry out the necessary tests on equipment.

BOX: Decision-making processes

Motivated prospective purchasers of high-value systems or equipment may carry out formal cost-benefit appraisals of options, but it is more likely that purchasers of lower value products (and perhaps less motivated purchasers of higher value ones) will evaluate the options informally. In economic terms, they perceive the "transaction costs" – the value of time spent obtaining and evaluation information and decision making – to outweigh the potential benefits.

We can view high-efficiency version of familiar products either as "new" products entering the market or as new version of familiar products. The difference is perhaps one of marketing approach. Analysis of the way that new products penetrate a market[cl] identifies two main features that can be summarised as "propensity to innovate" and "propensity to copy others". Absence of either of these can be seen as an information barrier: but each calls for a different set of information – or, at least a different balance of information. Typically, consumers are divided into five groups (the Everett Rogers diffusion of innovations theory):

Innovators – venturesome, educated, multiple info sources;
Early adopters – social leaders, popular, educated;
Early majority – deliberate, many informal social contacts;
Late majority – sceptical, traditional, lower socio-economic status
Laggards;

Each of these sees different barriers – or perhaps more accurately sees the same barriers as presenting different scales of obstacle.

Innovators and early adopters are likely to be less concerned by formal cost-benefit issues and more susceptible to information that highlights benefits and emphasises the aspirational aspect of ownership. On the other hand, products seen as novel, may have greater perceived (and perhaps actual) performance risk, may be difficult to obtain[161] and may need specialist installation or maintenance. This barrier can be addressed by product and installer accreditation schemes and performance guarantees, or counter-balanced by visible "rewards" for ownership or by subsidies. These groups are perhaps more interested in technical performance – either simplified in the form of energy performance labelling, or more detailed technical explanations.

Other groups form the majority of potential purchasers and are likely to be more influenced by example than by analysis. Their basic need is to have confidence in the product that they purchase. Initial price may well be more important to them, as they probably see themselves as being in a commodity market characterised by similar competing products. Brand, official accreditation (perhaps including energy labelling) and subsidy are likely to be important. In effect, purchasers are relying on the apparent experience of previous buyers to reassure

[161] They may, for example, need to be imported from other markets in which they are more attractive.

themselves that risks are low. The wisdom of the resulting decisions will depend on the degree of similarity between the real needs of the copied and the copiers – and on the quality of those preceding decisions (made on a similar basis).

At the other end of the scale, assessment for large investments may include formal life-cycle cost-benefit assessment. It is often claimed that energy-efficiency investment decisions made by firms (the likely purchasers of expensive systems) are unreasonably cautious. More specifically, it is claimed that the required rates of return are too high[162]. While inappropriate criteria may well be sometimes applied, part of the perceived gap may be rational, and reflect the different perspectives between firms and commentators. There are several reasons why firms may be more risk averse than (usually economic) commentators think is reasonable. The value of an air-conditioned building may well be higher than that of a non-conditioned one, but there is scant evidence that an energy-efficient one has a premium value. Businesses often move premises (or may go out of business) within the lifetime of an air-conditioning system, so the sunk cost represents a potential future loss.

The problem of split incentives for energy efficiency investment is widespread. This arises where the benefits accrue to different organisations to those making the investment. Typically, this is in the form of a landlord-tenant relationship. If landlords are unable to recoup the value of savings, they will naturally be disinclined to invest. Lease conditions can reduce this barrier.

Small and medium-size businesses in particular, often have restricted abilities to raise capital for illiquid assets, partly because they are seen as relatively risky borrowers facing uncertain futures. Larger businesses will be concerned about their financial gearing and may have more profitable competing investment opportunities. Access to capital is a barrier that can, in principle, be addressed either by loan schemes specifically tied to energy-efficiency measures, or by third party finance from ESCOs.

Policy Instruments: Components of Policy Packages

cooling altogether). This is obviously not something that

1 POLICY MEASURES

For cooling systems, energy consumption can be reduced in three main ways:

Reducing cooling loads	building envelop design, heat produced by equipment and lighting, temperatures maintained
Improving system efficiency	system design and selection of products, component performance, maintenance....
Avoiding wasteful operation	duration of operation, physical extent of cooling provided...

Different barriers are associated with each of these areas and different instruments may therefore also be appropriate.

1.1 Policy Instruments

[162] These may be stated explicitly or implicit in payback periods or other criteria.

The policy instruments that can address barriers to the reduction of air conditioning energy consumption are summarised below

Energy Labelling and information provision	
Application level	Effect
Product level	Energy labelling overcomes information barriers that prevent purchasers from recognising the value and energy efficiency of a product. Although the impact of energy labelling is uncertain it is a necessary precursor to some other policy options such as financial incentives and access to subsidised loans.
System Level	Determining an efficiency metric for central systems is problematic. If made feasible, it could assist designers and specifiers to recognise whether they were acquiring efficient systems
Building design	This is already required under the EPBD, but implementation for air conditioning is patchy. This level of labelling takes into account load reduction features of the building design
Building operation	The provision of efficient buildings and systems alone may not be sufficient because buildings are rarely operated as efficiency as they might be due to motivation or information deficiencies. Therefore this instrument entails energy consumption reporting coupled with the provision of benchmarks. Additional energy audit and system inspection requirements would aim to identify technical and operational scope for improvement.
Minimum Energy Performance Standards	
Component level	This is the application of minimum performance requirements to products that form part of an air conditioning system. However, compared to stand-alone appliances this method is complicated in systems because the performance of individual components often depends on the design of the whole system. Therefore it is more useful at eliminating the worst products than for identifying optimal levels of performance.

Component level – non energy consuming	Components that do not directly consume energy, such as controls and ductwork and pipework systems, can have significant indirect impact on system energy consumption. Metrics for these components can be defined but are difficult to apply.
System level	Central plant air conditioning systems comprise many components and it is difficult to physically measure the performance of a complete system sufficiently robustly and completely to produce a performance metric. This is complicated by many systems providing several services - e.g. heating, cooling, ventilation and humidity control, which makes the apportionment of energy to individual services, never mind components, very difficult. Most systems are bespoke which makes sample testing inappropriate. Therefore some form of standardised calculation process seems to be the most appropriate approach. However, it is arguable that a system plus building calculation sets a more useful boundary (see below).
Building level	This is an integrated approach that takes account of the HVAC system design and the influence of the whole building design as well as other services such as lighting. Since it covers load reduction features of buildings as well as system efficiency, it provides a more complete and coherent picture of performance than do requirements for air conditioning systems alone.
Product Pricing and Purchase Incentives (access to capital)	
Grants subsidies and scrappage schemes	Focussed subsidies/rebates and tax incentives for energy efficient products – should be performance and energy consumption based. Scrappage schemes that accelerate the replacement of less efficient products by more efficient ones. Requires a performance metric and would be easier to implement with a labelling scheme in place – endorsement or comparative based on the type of product and the range of efficiencies available in the market place. Capital constraints can be overcome by loan schemes, typically repayable from reduced energy bills, or energy performance contracts.
Removing Split Financial Incentives	
Green leases	The terms of green leases are formulated to overcome the problem of where landlords bear the cost of improvements, but the tenants reap most of

	the benefit.
Energy Pricing	
Increase the cost of energy	Increase the cost of energy to reflect the social cost of externalities. In practice energy is a price inelastic good and the impact of price changes is usually weak in the short term. This policy also has potential equity issues (see below).

Table 2: Policy instruments available to address the barriers identified in relation to the uptake of energy efficient cooling systems

1.2 Equity Issues

Potential equity issues associated with the policy instruments for cooling systems identified above are summarised in Table 1;

Policy Instrument	Equity Issue
Energy labelling and information provision	*Basic provision of information raises few equity issues. Subsidised tailored investigations favour the target group which might be seen as inequitable. The provision of information itself only raises equity issues to the extent that the cost of mandatory actions in relation to the potential benefits may differ between different organisations or individuals. Mandatory actions based on such information can raise such issues. For example, generic benchmarks may not be good indicators of operational performance because the building design or the business need of the occupants differs from those of other buildings of the same apparent "type". The value of mandatory system inspections is also likely to differ significantly between buildings and systems*[cli]
Minimum performance requirements for Components Products and Systems	*Because both the demand for cooling and the operational performance of cooling systems differs significantly between different climates, buildings types and occupancy patterns, the impact of minimum performance requirements will vary considerably in terms of the cost to the user and the energy savings that result. For example, setting a high minimum performance level for cooling products that might be cost effective for the user and/or societal perspective for a building in a hot climate which has a high cooling demand may not be cost effective for buildings in cooler climates where the cooling demand is low.*
Minimum performance requirements for Building	*In practice, similar buildings often have very different usage patterns – and these may change as occupancy changes. Therefore, in the context of minimum performance requirements (and related energy labelling) the familiar equity issues previously discussed arise. Unlike most appliances, the location of a building is fixed and climatic adjustments are limited only by data availability. An additional equity issue arises with buildings (or any product for which there is a significant second-hand market). The costs of compliance fall on the builders and thus onto the initial building owners (or existing owners of refurbished buildings – major refurbishment are usually subject to minimum energy performance requirements). Unless the higher performance demanded by regulations attracts equivalent extra value in the market (there is scant evidence for this), the value of older buildings is likely to rise, with owners of new buildings implicitly subsidising those of older ones.*

Product pricing and incentives	*Subsidised loans need to be screened to ensure that they are used in situations where energy savings are likely to accrue rather than being used for like for like replacements – or for other unrelated purposes. Failure to deliver savings could result from inherently low demand air conditioners may be installed in infrequently used rooms of buildings), or from high capital costs. In the latter situation, they may be used to complement subsidies for high performance (and high cost) products that are socially desirable but financially unattractive to the end-user.*
Removing Split Incentives	*Green leases clearly alter the relationship between landlord and tenant but, as a voluntary agreement do not seem to raise equity issues. Even if they were made mandatory, it is not clear that there any significant issues would arise.*
Energy Pricing	*In general increased energy prices (for whatever reason) impact more on poorer households than on the better-off. While these households are probably less likely to own air conditioning, it is difficult to construct simple price tariffs that distinguish between end-uses.*

Table 109: 1: Potential equity issues associated with the policy instruments identified for cooling systems

3.Impact

The likely impact of an instrument is clearly of significant importance. There do not appear to be any assessments of instruments specifically targeted at air conditioning. A report for UNDP SBCI[clii] assessing policy instruments for reducing greenhouse gas emissions from buildings rated the impact as below. The ratings shown below are the class (high, medium, low) containing the mode (exceeded by 50% of instruments assessed, excluding “unknown”) for each class of instrument. The data comes from the MURE database. It should be noted that, within each type of instrument there were examples of high, medium and low impact, suggesting that the detail (and perhaps scope) of the instrument is important. Table 2 indicates the expected level of impact that different policy instruments are expected to have on the energy performance of cooling systems

Instrument type	**Impact**
Cooperative voluntary measures	Low
Grants, subsidies	Medium
Loans	Medium
Tax exemptions	Low
Taxes	Medium
Information/education	Low
Legislative - information	Medium
Legislative – normative: buildings	High
Legislative – normative: appliances	Low (this finding may result from consideration of examples with only “mild” MEPS)

Table 110: 2: Expected levels of impact of various types of policy instruments on energy performance of cooling systems.

4.Policy Packages and Interactions

Policy instruments can be applied individually, but their impacts are not generally independent of each other. Reducing loads, for example, decreases the (absolute) potential for savings from improving efficiency. Some instruments are necessary precursors to others; however, few, if any, policy options are mutually exclusive. Instruments may also be packaged together to improve coverage, or to alleviate equity issues. For example, building-level performance requirements are unlikely to impact significantly on purchase decisions for moveable air conditioners, while product performance requirements clearly will. For all these reasons coherent packages of instruments (and policies) are generally recognised to be more effective than individual instruments[cliii].

The following sections provide diagrams that illustrate precedents and dependencies for three groups of instruments: products, “building & system” and operation and maintenance.

The key relationship here is the need for reliable product performance information. There is an obvious direct need for this type of information in order to enforce minimum performance requirements and to administer energy labels, and such instruments routinely demand reliable product performance information. But the information is also needed (and easily available) for any financial instrument that is intended to encourage the purchase of high efficiency products or discourage the purchase of low-efficiency ones)

4.1 Product Level Dependencies

A barrier in some cases is a lack of reliable information and processes. In order to calculate the overall performance of the air conditioning system, it is necessary to have relatively detailed reliable and accessible information on component performance. It is equally important to have accepted and practicable calculation procedures.

These are both currently a weaknesses in European practice. Access to detailed product performance is uneven, usually requiring contact with manufacturers who may not always present information in the same form. While several countries have developed calculation processes for use in EPBD-based building energy codes, there has been very little cooperation or comparison between them. This is highlighted in the Recommendations section of the report

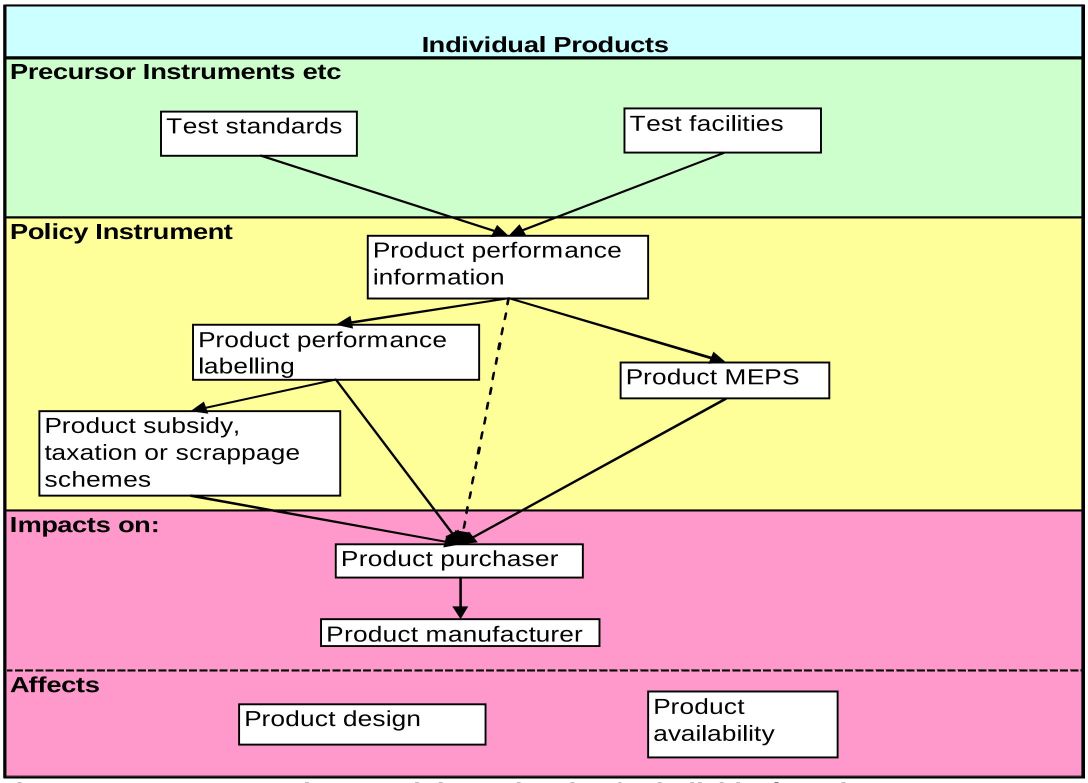


Figure 56: B5.10: Precedents and dependencies for individual products

Building & System Level Dependencies

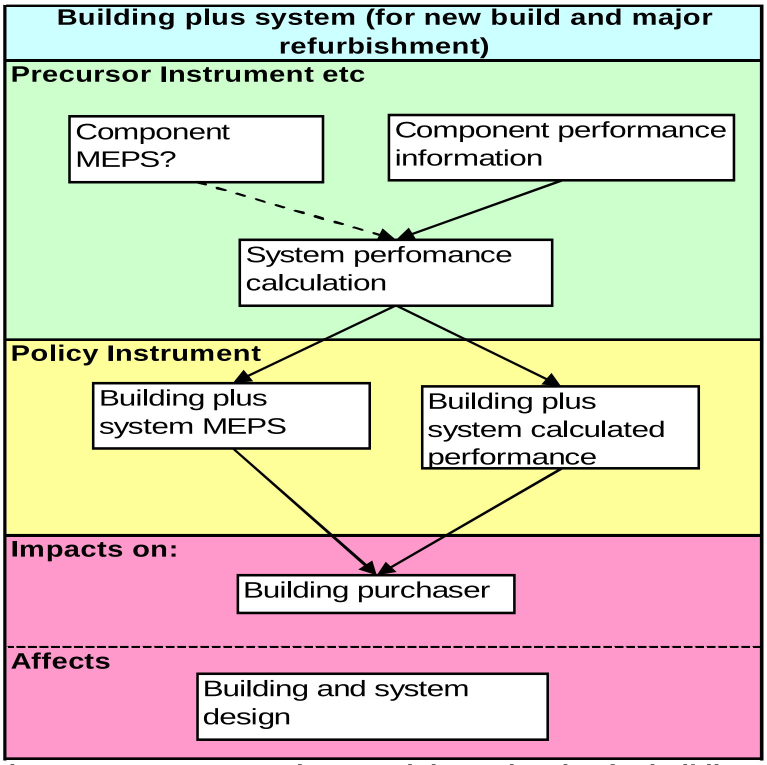


Figure 57: B5.11: Precedents and dependencies for building, plus system

Similar types of dependencies come into play for whole-building policy instruments.

Operation and Maintenance Dependencies

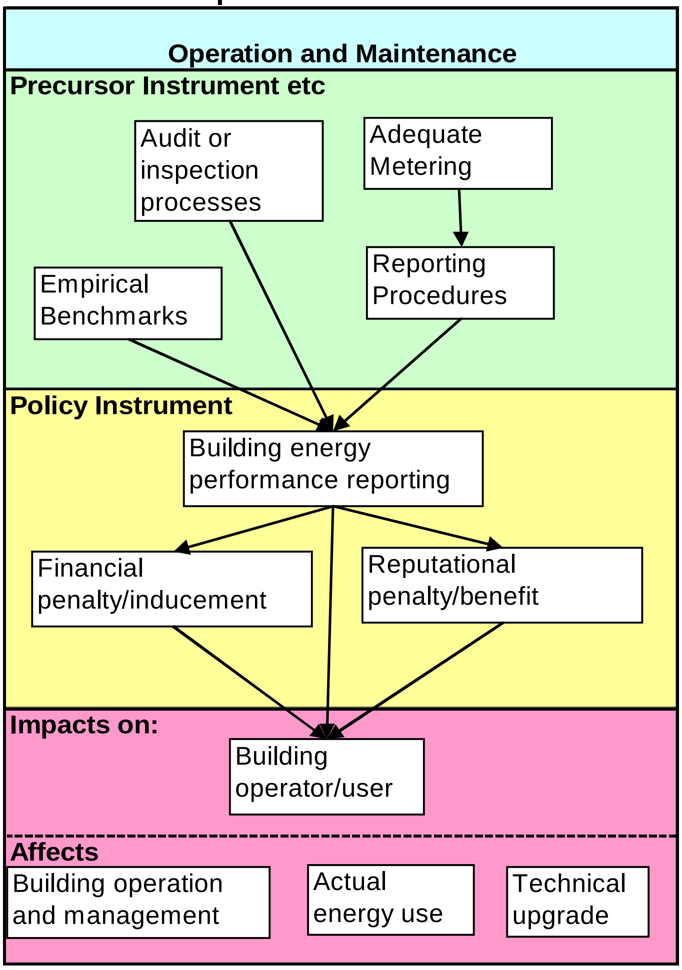


Figure 58: B5.12: Precedents and dependencies for operation and maintenance

4.2 Intervention Points

There are several points at which policy instruments can influence decisions that affect air conditioning energy consumption.

For ***moveable units*** these are simply

- the decision to purchase (or replace)
- day to day operation of the unit

Building +system level performance regulation and information provision will have, at most, a weak influence on product choice for these products.

For ***fixed room units*** we can separate purchases into

- new buildings
- first-time sales into major refurbishment of existing buildings
- first-time sales into other existing buildings
- replacements

The main policy instrument difference between these is whether or not building +system level performance regulation or information provision applies. EPBD requires it to apply to new buildings and major refurbishments, but it would not generally be applied to existing ones (this is at national discretion). Where it applies, it should constrain cooling loads and also encourage the use of more efficient equipment.

Other intervention "points" are

- problems with day to day operation
- replacement of CFC refrigerants: this would impact on efficiency and is a trigger to prompt consideration of replacement. In theory this should no longer be an issue.

Central systems are more complicated. The replacement of components (especially those which are energy-using products in their own right) is an additional intervention point to those that apply to room air conditioners. Since system performance depends on system type and design as well as component performance, there is a possibility that system-level intervention can also be made

- during day to day operation
- when replacing CFC refrigerants: this would impact on efficiency and is a trigger to prompt consideration of replacement performance regulation or information provision to have an impact.

As for fixed room units, we can separate purchases into

- new buildings
- first-time sales into major refurbishment of existing buildings
- first-time sales into other existing buildings
- replacements

4.3 Instruments, Impacts and Intervention Points

The relationship between the impact of each possible policy instrument, intervention points, and the mechanism by which energy consumption would be changed is summarised in the following Table 3. The inter-relationship is more complex for central systems than for other types of system, and the number of instruments that could potentially be applied is also greater. In the section of the table that covers minimum performance requirements, the areas where we feel that the impact is likely to be strongest have been shown in bold.

Intervention point	Impact of Policy Instrument							
	MEPS				**Product Information and labelling**	**Operational Information, labelling**	**Product Price and Finance**	**Energy Price**
	Product or component	System	Building + system	Other equipment				
	Moveable air conditioner							
Purchase	Product choice			Cooling load	Product choice		Product choice	Product choice
Existing product				Cooling load		Operation and use		Operation and use
	***Room air conditioner*:**							
Installation in new building	Product choice		Product choice	Cooling load	Product choice		Product choice	Product choice
Installation in existing building	Product choice		Product choice	Cooling load	Product choice		Product choice	Product choice
Replacement	Product choice		Product choice?	Cooling load	Product choice		Product choice	Product choice
Existing installation				Cooling load		Operation and use		Operation and use
Change of refrigerant	?	?	?	?	?	?	?	?

Products which appear in principle to be technically feasible but which have not been demonstrated to be so. These possible products which require development and probably research represent BNAT. ***Central system***								
Installation in new building	Component choice	System choice	System choice, cooling load	Cooling load	Component choice, system design		Product choice	Compone nt choice, system design
Installation in major building refurbishment	Component choice	System choice	System choice, cooling load	Cooling load	Component choice, system design		Product choice	Compone nt choice, system design
First-time installations in existing building	Component choice	System choice	System choice	Cooling load	Component choice, system design		Product choice	Compone nt choice, system design
Replacement system (limited options)	Component choice	System choice	System choice	Cooling load	Component choice, system design		Product choice	Compone nt choice, system design
Component replacement	Component choice	Component choice?					Product choice	
Change of refrigerant	?	?	?	?	?	?	?	?
Existing system				Cooling load		Operation and use		Operation and use

Table 111:3: Identifying where different combinations of policy options and intervention points have the potential to act on the cooling

Market Transformation Impacts (New section needs numbering!)

This section illustrates schematically some basic features of the impact of different types of instruments that operate by changing the distribution of products or systems that are sold..

It considers the nature of the impact of measures aimed at

- Product Performance:
    - Minimum performance requirements
    - High Performance Products
    - Product life
- Purchaser or Specifier Incentives and Information

1.1 Product Performance

For a given service, a market can be characterised in terms of the relative numbers of products of different levels of performance that are sold, as illustrated below.

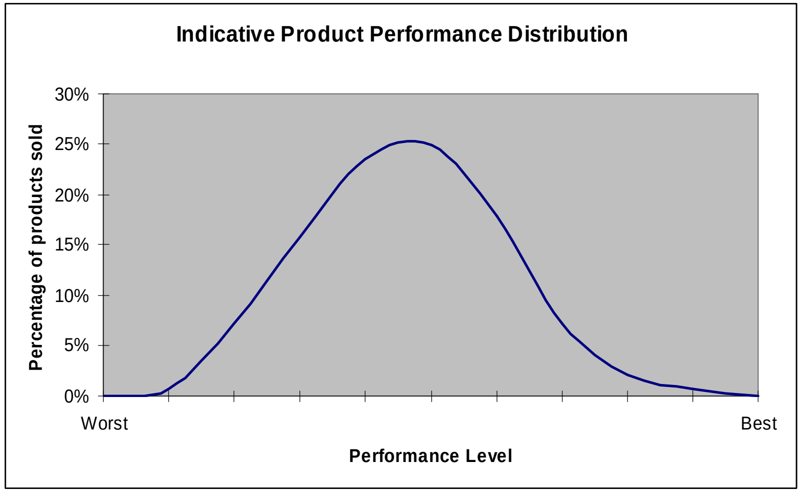


Figure 59: B5.6: Schematic Depiction of Product Performance Distribution

If we confine ourselves to one aspect of “performance” such as energy efficiency we can, in principle, quantify the “worst to best” scale

Different market interventions impact on this distribution in different ways.

Minimum performance requirements impact the range of products that may be placed on the market, and alter the left-hand, low performance tail of the distribution, as illustrated below.

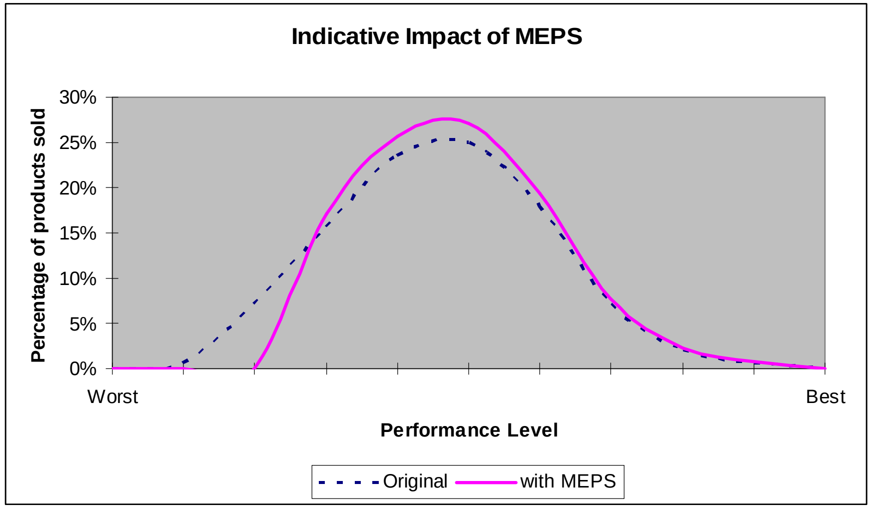


Figure 60: B5.7: Indicative Impact of MEPS

Technical innovations that improve the best available performance or financial incentives that make it more attractive, impact on the right hand, high performance tail of the distribution. Public procurement programmes may encourage manufacturers to put high performance products into production.

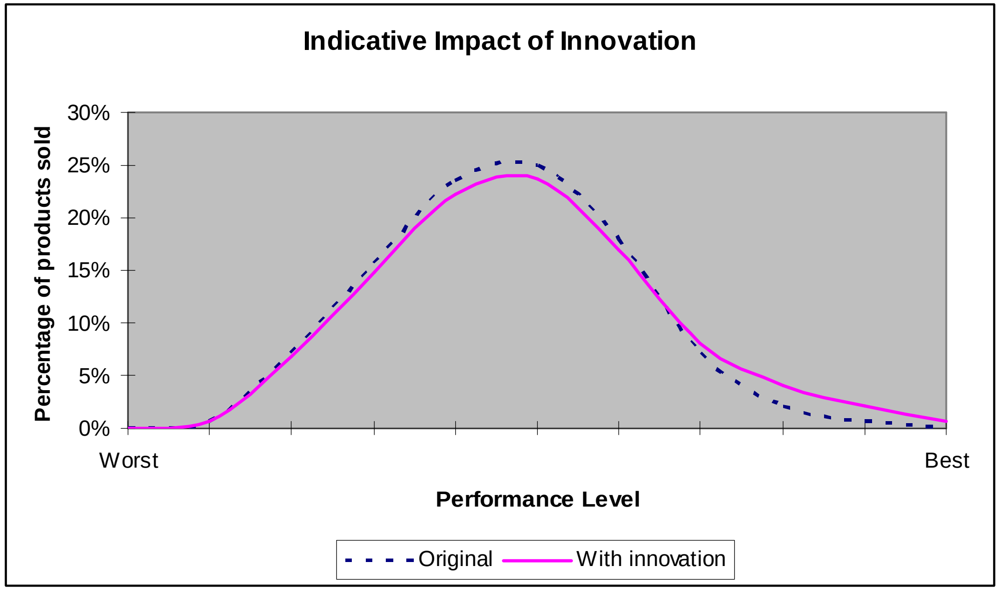


Figure 61: B5.8: Indicative Impact of Innovation

For long-lived products such as cooling systems (and especially buildings), the impact on total energy demand of measures that alter the distribution of products placed on the market, (or the propensity of purchasers to choose higher-performance products), is slow.

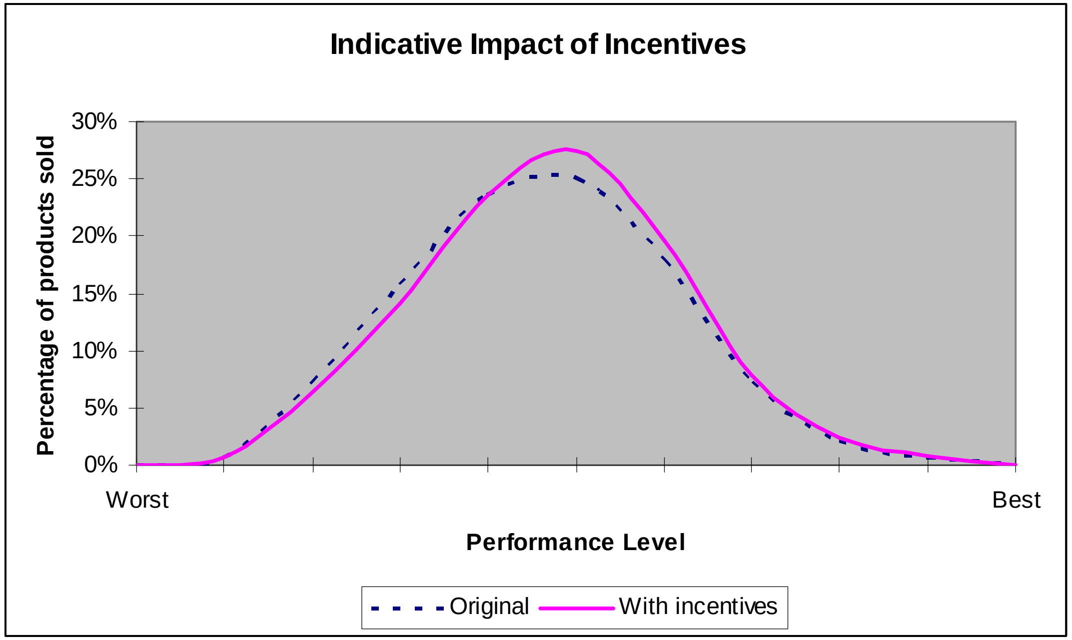
Product performance may also deteriorate with time, especially if equipment is inadequately maintained, resulting in the performance of the installed stock being worse than that of newly-installed products.

Measures to encourage the replacement of older products by those of better performance, (such as scrappage schemes/incentives), to maintain the performance of products (servicing and maintenance), or to upgrade them (component replacement, for example) are therefore also potentially important policy instruments.

1.2 Purchaser or Specifier Incentives and Information

While it is conventional to view the distribution as representing the products that manufacturers choose to place on the market, at a more fundamental level, the distribution of product sales actually represents a distribution of consumers' preferences (whether they are businesses or individuals). Purchasers will typically judge "performance" on more than one criterion – including noise levels, comfort, appearance, initial cost as well as energy efficiency.

Therefore, policy instruments that encourage general product improvement that includes improved energy efficiency, and brings this to the attention of purchasers and specifiers, have the potential to move or reshape the distribution. Such instruments include energy price rises [163], untargeted subsidies, and provision of information such as energy labelling. The nature of the impact will clearly depend on the particular structure of an incentive or measure, and the quality of its implementation.



[163] For which the impact depends on the price-elasticity of demand

Figure 62: B5.9: Indicative Impact of Incentives

APPENDIX B2: SELECTION OF ASSUMPTIONS FOR DEMAND REDUCTION THROUGH IMPROVED BUILDING DESIGN AND BETTER OPERATION AND MAINTENANCE

Introduction

Data from existing studies were re-analysed in order to assess the potential energy savings from improved building design. In particular, information was used from the recently-completed Harmonac study, which was based on on-site studies supported by modelling where appropriate, and the KeepCool and KeepCool2 projects, which are based purely on simulation results.

Importance of Different Ways of Reducing Cooling Energy Consumption Identified by the Harmonac study

The Harmonac project carried out detailed measurements, analysis and modelling of 42 existing air conditioned buildings of a range of types[164] in 7 European countries. Re-analysis of the data showed that there was an average potential for savings of 114 kWh/m^2 [165] per annum of cooling energy consumption. This is a considerable potential and the savings are split between load reduction, improved technical efficiency and better operation. Improvements to system performance (including replacement of components where applicable) accounted for the biggest share of the potential, but this was still less than 40% of the total. Reductions in demand through the use of more efficient lighting and equipment and building envelope changes (notably improved solar shading), and by better maintenance and (especially) operation were almost as large. Thus, while system performance offers considerable potential savings, it is by no means the whole story. Smaller potential savings of11 kWh/m^2 per annum were identified for ventilation associated with air conditioning. Potential savings at the design stage were not considered, since the project was concerned with existing systems.

[164] Full descriptions can be found in the Harmonac Final Report and in the detailed on-line database of buildings that it has produced.

[165] This figure is derived from the project report by eliminating savings in other services, notably heating, and direct savings from improving the efficiency of lighting and equipment. The savings were reported in terms of primary energy consumption and have been converted to electricity consumption using the primary energy factor of 3.31 used in the study.

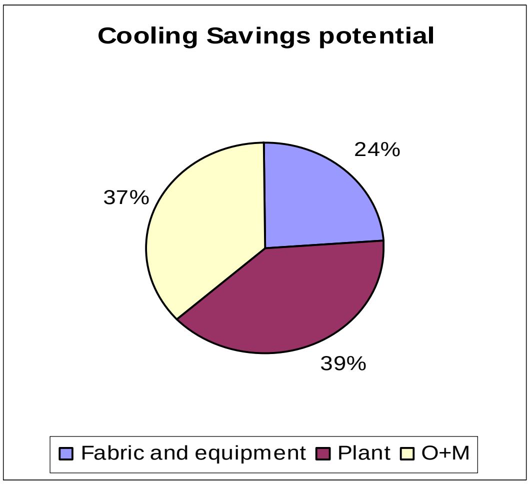


Figure 63: B5.13: Distribution of the source of cooling savings potential

Building Fabric and Equipment Measures: the KeepCool II and Ecofys Studies

The Harmonac results are similar to those from simulation studies carried out by the KeepCool II project. This project only examined the potential for reducing cooling energy consumption in existing buildings by decreasing loads[166]. It screened potential measures for their likely impact and applicability and then modelled the effects of a number of measures on the annual cooling demand of two office buildings (one a 12-storey mainly open-plan building and the other a 20-storey cellular building) in 5 cities, representing different climates: Palermo, Lisbon, Milan, Paris and Stockholm. The measures are not mutually exclusive, though some interactions are likely, with the overall impact of combinations of measures generally being less than the sum of the independent measures. The project examined some packages of measures, not reported here. The “base case” assumptions vary between countries, aiming to be representative of local practice. Thus the calculated reductions vary not only because of climate, but also because of construction tradition.

As might be expected, the results are to differing degrees variable with climate and building. They are reported as reductions in cooling demand, and it needs to be borne in mind that – apart from all-air systems – the fan energy required by the air conditioning system will be unchanged.

The largest impacts are from the provision of additional ventilation through automatic window opening (thus avoiding the energy penalty of mechanical ventilation) during both day and night, and the reduction of solar gains using external shading (especially with automatic control) or low-transmission windows. Reflective roofs and walls, insulated roofs, more efficient lighting and equipment all had the potential to reduce cooling loads, but not generally on the same scale. Similar results for office buildings were obtained by a study carried out by Ecofys[167]. The impacts of the measures are not simply additive.

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Reduced Solar Gain: Blinds

High quality, automatically-controlled external blinds typically reduced annual cooling demand by typically 25 to 50 kWh/m^2 per annum, compared to a base case with fairly inefficient internal blinds. The savings were somewhat less with less efficient external blinds, but the key performance factor is the quality of control. With manually operated blinds, typical savings fall to between 10 to 20 kWh/m^2 per annum, even with high quality blinds. Although the report does not comment on this, automatic blinds often cause irritation to users, and may not always be acceptable. The impact of high-performance windows is discussed below.

Enhanced Ventilation

The provision of additional ventilation has the potential to reduce annual cooling demands by up to 75% in appropriate buildings and climates, but in other circumstances may not reduce cooling demands at all. The largest percentage savings are obtained when additional ventilation is permitted during both night and day in cooler climates, and depends on automatic window opening rather than on the use of ventilation fans. Absolute savings are less climate-dependent but are associated with the same conditions. Typical values are between 25 and 40 kWh/m^2 per annum. The use of mechanical systems to provide ventilation requires energy to drive the fans and this reduces the net savings significantly – typically to 20 to 30 kWh/m^2 per annum when additional ventilation is provided during both night and day. Night-only ventilation further reduces the savings. The modelling procedure assumed good control of ventilation (for example, to avoid over-cooling the building overnight) and did not consider issues of air distribution (for example from automatic windows).

Improved Equipment and Lighting Efficiency

The use of more energy-efficiency office equipment (or less of it) had a smaller impact – typically around 10 kWh/m^2 per annum. Improved lighting efficiency showed a similar pattern, but lower savings of around 2 kWh/m^2 per annum.

Reflective Surfaces and Added Insulation

The project examined the impact of adding reflective finishes to walls and roofs. This measure typically reduced consumption by 5 to 10 kWh/m^2 per annum – but by twice this amount in the sunniest and warmest climate. Physically, the impact of a reflective surface will be highest where insulation levels are lowest – typically in warmer climates. Insulating the roof had a negligibly small impact – sometimes reducing and sometimes increasing cooling consumption. Insulation has two opposing effects: reducing heat gains during warm, sunny periods; and decreasing heat losses. During cool, sunny periods decreased heat losses will increase cooling loads. "Base case" assumptions varied between countries from the well-insulated (U-value = 0.2 $W/m^2.K$) to the poorly insulated (U = 2 $W/m^2. K$)[168].

[168] In absolute terms, these results are comparable with those calculated by Ecofys for an office in Munich and Madrid[167]. The headline results for Madrid do not give this impression, because they express the savings due to insulation as a proportion of consumption ***after*** reducing heat gains considerably by shading.

Windows

Installing high-performance windows typically reduced cooling consumption by around 20 kWh/m^2 per annum. Variations of “base case” assumptions are especially marked for windows, varying between single and triple glazing. Because of this the impact of the installation of low heat loss windows with good solar shading will differ between countries, quite apart from climatic differences.

Dwellings

The Ecofys study also examined the impact of reduced heat gains and extra insulation in houses. The study considered an example dwelling in Munich and Madrid. Although the presentation focuses on the impact of insulation[169], the simulation results tell much the same story as KeepCool: shading (“reducing heat loads” in the terminology of the Ecofys report) has a substantial effect in warm climates; thereafter extra insulation can further reduce cooling demands in warm climates, but is largely ineffective in cooler ones. The effect of thermal capacity was not examined in this study.

Operation and Maintenance

From the Harmonac study, the most frequently identified opportunity was to clean or upgrade filters, but the biggest potential savings were by switching systems off when they are not needed. This was frequently identified and often reduced consumption by large amounts.

Summary and Commentary

The Harmonac, KeepCool II and Ecofys results all suggest that it is technically possible to substantially reduce – and, in combination with reduced loads from equipment, perhaps to sometimes eliminate – the need for mechanical cooling in offices[170, 171]. This would require the use of good quality, automatically controlled, external shading and the provision of additional ventilation.

However, as the reports note, the measures will not be universally applicable. Installation of these high-impact measures represents significant investment and disruption and is probably most likely in the context of a major building renovation or in new buildings. The widespread practical potential seems more likely to be in the form of lower cost, less disruptive – and less effective – measures such as reducing solar gain with glazing films or operating existing ventilation systems for longer hours.

Identifying the Potential in Existing Buildings

In addition to the 42 detailed Case Studies, the Harmonac study also carried out 400 air conditioning system inspections of the type required by the EPBD. These were not restricted to system performance issues: inspectors were given a long checklist of possible energy conservation opportunities that covered demand reduction, system performance and operation and maintenance issues.The distribution of estimated savings from the opportunities identified looks very different to that for potential savings shown earlier as can be seen in the figure below.

[169] The study was financed by Eurima.

[170] But not necessarily the energy demands for ventilation systems.

[171] The project also intended to address small retail premises and apartments, but we have not been able to locate the results for these buildings.

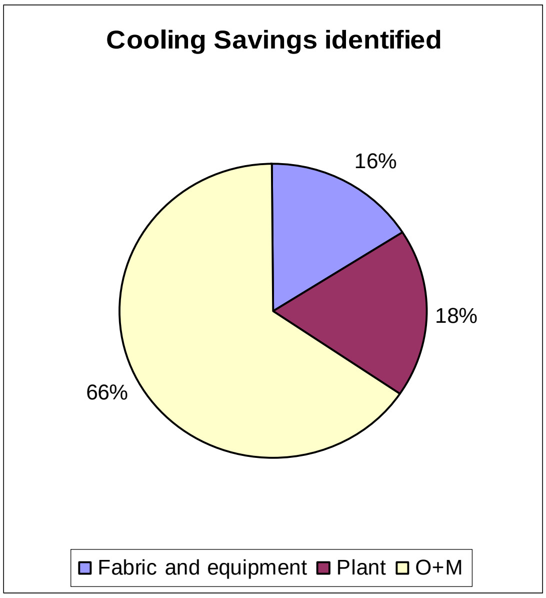

Figure 64: B5.14: Distribution of the source of cooling savings identified

The inspection procedure identified 23% of the potential savings from better operation and maintenance, 9% of those from load reduction and only 6% of the potential system improvements. Notwithstanding a number of caveats about the comparison[172] it seems clear that the first barrier to savings – recognising that opportunities exist – is substantial.

Inspections of this type may be considered a fair proxy for the level of investigation that building operators are likely to carry out (if they do anything). Harmonac showed that systems inspections of the type required by the EPBD only identify about 9% the potential system performance savings. Deeper investigation would be expected to identify more of the potential opportunities, but would only be economically justifiable where there is a priori evidence of substantial probable savings. Modelling cases were included to probe the potential impact of such approaches.

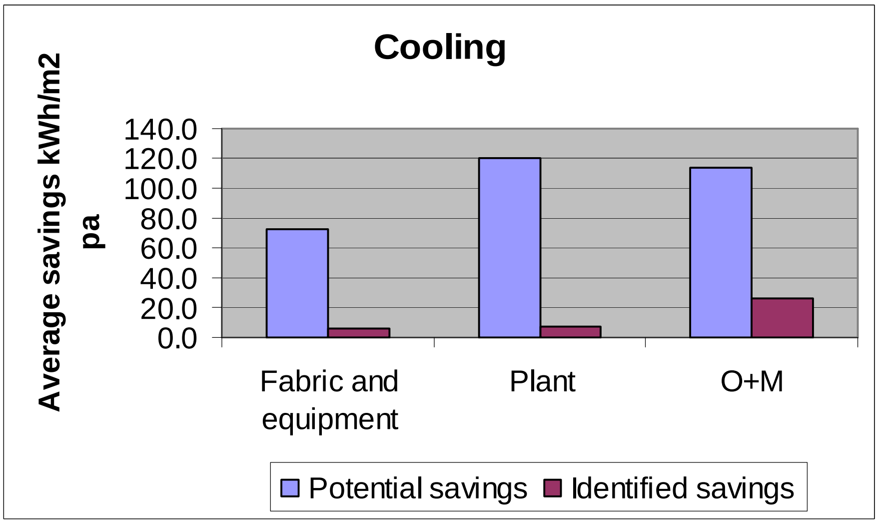

Figure 65: B5.15: Average savings split into fabric and equipment, plant, and operation and management

[172] The comparison is not strictly accurate since the samples are different (but overlapping). However, the scale of the difference is sufficiently large to make the point.

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