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TSB Research Project

Design for Future Climate – Developing an Adaptation Strategy

Admiral Headquarters Cardiff

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Design for Future Climate Change

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Development of a Climate Change Adaptation Strategy - Admiral Office Headquarters

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Project Introduction and context

Published on the 31st of March 2010, Departmental Adaptation Plans (DAPs) set out the adaptation strategy for each government department in accordance with the key risks posed by projected climate change. In response to these publications, the Technology Strategy Board (TSB) launched a competition to fund the development of strategies that could be used to adapt UK buildings to the changing climate. A broad interpretation of the term ‘adaptation’ was advised by TSB, but the technologies, systems and processes relating to building comfort, construction, water management and occupancy factors were outlined as key fields of investigation. Parameters were also set regarding the type of building project for which the adaptation strategies should be devised. These specified that the building project should be worth more than £5 million and must be aiming to achieve a BREEAM 2008 Excellent rating.

BRE Wales & South West are retained by Admiral Insurance as the sustainable design advisor on the design and construction of their new office headquarters in Cardiff and a proposal was submitted to TSB to develop an adaptation strategy for the building. The building fitted the criteria outlined by TSB and Admiral were themselves committed to the goals of the project, having just signed a 25 year full maintenance lease on the building. Admiral were also aware of the potential impact of the Carbon Reduction Commitment (CRC) scheme on their business, and the project presented a good opportunity to plan for economically viable Carbon reduction strategy that meets their business needs.

BRE was successful in its application and a 90 year adaptation plan was devised in co-operation with the technical design team, the developer and the end user. An integral role was also played by the BRE Trust supported team whom are based at Cardiff University and have technical expertise in building energy modelling and analysis.

Executive summary

Top Recommendations for Admiral's Building Managers

1.	Specify low-energy ICT equipment in line with existing replacement schedule. This will reduce the largest electrical load in the building and decrease the internal heat gains, and subsequently lower the cooling load.
2.	Apply an adaptive comfort strategy, allowing the cooling set point to be raised. Increasing the temperature range between which neither active cooling nor heating is required, resulting in considerable energy savings.
3.	Reducing the occupancy density as working patterns change would also reduce this cooling load, but would need to be carefully balanced against the commercial output of the available floor space.
4.	Specify a highly-efficient M&E system at the time when replacement is required.
5.	The development of future adaptation strategies should be completed early in the design stage, allowing physical alterations to be made to the design that would not be cost-effective to implement as part of a retrofit strategy.

- Detailed energy modelling was carried out upon the building according to an accurate specification of its current design and use profile. This was completed under a base case (present) climatic scenario and for three future scenarios; 2030, 2050 and 2080, using climate files created by Exeter University, from the UKCP09 datasets.

- This revealed that the greatest energy loads in the building were for lighting and equipment, and that the sizeable cooling load was set to increase under a warmer, more humid climate. Moreover, the dense occupancy and the correspondingly high levels of ICT equipment resulted in considerable internal heat gains, and were compounded by large radiative solar gains.

- The infiltration rate and performance of the building fabric would not allow the building to significantly discharge this heat, accounting for the high cooling load. This may be viewed as a problematic function of what are usually considered central tenets of sustainable design in the UK I.e. although limiting heat loss and improving air tightness are widely-accepted to be good-practice construction principles, this ideology was actually detrimental to the energy performance of the studied building.

- Various physical and occupant factors were independently adjusted to examine their impact on the building's ongoing energy performance, and inform the development of a robust climate adaptation strategy. Once the effect of these changes had been observed, a meeting was held with the design team to discuss which of these could be adopted, considering the practical issues relating to the client's core business, and the building's design and maintenance requirements. These changes were taken forward to the final stage of the strategy development, where an economic appraisal was made according to the modelled financial savings that each would incur and a prediction of the capital costs that would be required to implement them.

- It emerged that the overall strategy should focus upon creating a more efficient building use profile rather than implementing physical building changes.
- In this respect, adjusting occupant factors within a tolerable range was the most sensible method to adopt as these produced considerable savings and did not require capital investment. Applying an adaptive comfort strategy (thus allowing for an increased cooling set-point) and reducing internal heat gains by lowering the occupancy rate were found to be amongst the most effective and agreeable adaptations to implement.
- Purchasing highly efficient ICT equipment and lighting in line with the existing replacement cycles was also advised. Not only would this reduce the cooling demand, but it would directly reduce these energy loads, which form the largest proportion of the building's overall demand.
- The final adaptation to consider was in specifying a more efficient M&E system that would reduce the electrical cost of providing the chilled air to the building. It was suggested that a 5% improvement be sought at an estimated uplift cost of £640,902.
- The physical building adaptations modelled were not shown to be cost-effective and so were not included within the adaptation strategy. However, the value of implementing changes from the outset was far higher and in certain cases it may have been prudent to have changed the initial specification of the building had the project timescales allowed it.
- Specifying glazing with a low g-value and high u-value, reducing radiative gains and allowing increased heat transmittance through the building fabric would have been one such adaptation. Therefore, it is recommended that this glazing type be sought under future projects of this matching the use profile of this building.
- Utilizing thermal mass in the building's cooling strategy would necessitate the specification of a concrete frame. Again, whilst it would not be cost-effective, or indeed practical to retrofit thermal mass into the existing steel-framed building, it may have been sensible to specify a concrete frame in the initial design. Indeed, Admiral's new office development in Newport, which has been procured later than the Cardiff scheme covered in this report, is being developed with a concrete frame specified throughout.
- For future studies of this kind, it is suggested that a Building Information Modelling (BIM) approach would simplify the process and would allow modelling of future adaptations to be to be more readily completed using up-to-date climate data.

Building Profile

The project has developed an adaptation strategy for the new headquarters of Admiral Insurance, Wales only FTSE 100 Company. The building is designed to hold 3,000 staff and is c. 200,000 sq ft in size, with a total construction value of approximately £30m. It will be located in Cardiff City Centre, between the St Davids 2 shopping centre and the Motorpoint Arena. It is situated on a restrictive island site, surrounded on all sides by public rights of way as shown below in Figure 1. The development will rise to eleven storeys above ground level and will incorporate two storeys of basement parking and some retail usage on the ground floor (see Appendix 1 for building plans and images). Consequently, the building will have deep pile foundations, reaching 12.5m into the substrate.

Figure 1 Illustrative Masterplan of Office Location

As an island site, the building has elevations that face in all directions and given the shape of the site, and the scale of accommodation required, there is limited potential to adjust the building form to maximise or minimise any particular orientation. Therefore, the design of the façade had to balance the requirements of its high profile, city centre location with the varying demands of mitigating external climatic conditions, considering factors such as solar exposure, noise and localised pollution. The site, combined with the client's call centre operation (and hence a need for good acoustics), also restricted the capacity of the design to consider any practical natural ventilation strategies. Lastly, as a prime central location, the external design of the scheme had to be acceptable to Cardiff's planning authority as a landmark building.

Admiral's business operations are predominantly office based as a call centre, providing insurance services across the UK and internationally. The activity of their staff is primarily computer based and when at capacity, the building will have a high occupancy rate of approximately 1 person per 6m2, roughly twice the occupancy commonly highlighted in the British Council for Offices Guide. The combination of these factors equates to a high use of ICT (Information Technology & Communications) equipment, with computers, screens, telephones and peripherals needed for all staff. The heat gains resulting from both the high occupancy rate itself and the considerable use of ITC equipment will create a considerable heat load internally.

Thus, the primary concern with regards to the building's climate change risk exposure related to internal comfort factors and whether these could be maintained under projected changes in climate. Consideration was also given to potential changes in working practices and how these might impact upon both energy use and the internal climate.

Research Strategy

The development of an effective, practical and financially viable adaptation strategy involved three distinct stages. The first sought to assess the likely effects of projected climate change upon the planned building and determine which adaptations would be most effective in mitigating these impacts. The second stage considered the practical implications of implementing these adaptations and aimed to establish which of these could realistically be applied within the given timescale. To conclude the study, the final stage required the formulation of a full financial appraisal, in order to inform the development of an overall adaptation strategy. A brief synopsis of the actions carried out at each of these stages is provided under the following sub-headings.

<u>Stage One – Theoretical Modelling</u>

The first stage aimed to provide a sound scientific foundation, on which to develop the adaptation strategy. As this would underpin the development of the overall plan it was vital that the data generated was as accurate and reliable as possible. Therefore, this stage entailed a rigorous process of theoretical building modelling using specialist software and utilizing the most recent and sophisticated climate data projections. The work itself, carried out by the BRE Trust team at Cardiff University involved a two step process. The first examined the building's current susceptibility to changing climate using the existing construction specifications and operational profile. In the second phase, various features were incrementally adjusted in order to understand the effect these had on the building's energy performance over time, and identify which of these would have the most significant impact. The results of this process were then taken forward to the second phase of research.

<u>Stage Two – Practical implications</u>

Having developed a theoretical understanding of the building's performance, the results of the modelling process were presented to the design team, tenant and developer. The effects of each adaptation were compared and a discussion was held as to which of these could practically be implemented, considering the inherent restrictions relating to the building's construction, its maintenance cycle and the business requirements of both the tenant and the client. The limitations of the research were also discussed and the difficulties associated with making these predictions were acknowledged.

<u>Stage 3 – Economic appraisal</u>

In the final stage of research, the agreeable adaptations from stage two were taken forward and a financial appraisal was made with regards to their feasibility and the timescales at which they should be implemented. Calculations of the potential savings made through reduced energy consumption were made and were weighed against the estimated capital costs of implementing the adaptations. EC Harris provided these cost estimates and payback calculations were made accordingly. In light of this financial evaluation, a plan was devised, detailing which adaptations should be made at each point in time. This also outlined the likely capital costs that would be incurred, alongside the estimated changes in energy consumption and the combined financial savings over a 10-year period.

Project Focus

Having developed an understanding of both the building's physical attributes and the likely implications of the climate projection data, it became clear that the focus of this study would be primarily on the 'comfort' rather than the 'water' and 'construction' challenges outlined in Gething's report on the adaptation agenda for the built environment[1].

Due to the height of the building and the subsequent depth of the foundations required to support this, it was considered at proposal stage (and subsequently verified) that it is extremely unlikely that projected climate change would have any significant impact upon the substrate as to bring about any ground heave or subsidence of consequence to the building.

As the building is being commercially designed for a 60-year lifespan, the warranty used to cover the materials and fixings used in the external construction will have been sufficient to extend over the 25 year maintenance and replacement cycle that would immediately concern the tenant. That is to say that financial risks associated with these aspects have been managed as these will be covered under a warranty for the entire duration of Admiral's tenancy. Therefore, the challenges relating to material performance and weatherproofing will have already been assessed by the manufacturers, limiting any significant risk to the client. Of course, the replacement of these materials at 25 year intervals will also use warranty-covered materials/systems which are presently unknown and consequently it is beyond the scope and possibilities of this project to assess such changes.

The final set of 'Construction' challenges outlined by Gething relates to the construction and build processes once on site. As the Admiral HQ building is being built now (I.e. under present climatic conditions), and is not due to undergo any further construction in the foreseeable future, the risks identified here are not relevant to this project.

Considering the 'Water' challenges outlined in the Gething Report, those relating to flooding were not deemed relevant to this case study. Whereas more rurally located buildings may need to consider flood defence and adaptability, the proposed building lies in the heart of the Capital city of Cardiff, itself lying behind the Cardiff Barrage. Furthermore, the building is not a dwelling requiring refuge, but a workplace reliant on 3,000 staff and considerable power and IT infrastructure across the city and beyond in order to operate. Taken in combination, it was deemed unrealistic to assess the resistance to flooding at a building level, as this challenge would only effectively be addressed at the city scale where the relevant sub-stations, staff and communications interchanges were also part of the protected area, and hence the function of the office could realistically be maintained.

The UKCP09 climate data for Cardiff does not indicate an increase in wind speeds. Nevertheless, even if this was to occur, the building design will have already undergone wind loading calculations in order to obtain a building permit and the materials specified will be guaranteed under warranty for the near future. Therefore, it is unlikely that either the building fabric or the above-ground structural stability of the building will be at risk and hence this challenge should not require detailed investigation.

As it became clear that we were heading towards a warmer, more humid climate and that the building is projected to have high internal heat gains coupled with a high performing building fabric, it emerged that the main area that the project was likely to address would be those relating to 'comfort' and particularly the challenges of 'keeping cool'. Moreover, by addressing the building envelope and the

[1] Gething (2010) "Design for Future Climate, an adaptation agenda for the built environment", TSB

building's use profile, the main focus was upon developing a commercially viable strategy to reduce energy demand reduce energy demand and CO_2 emissions.

Theoretical Building Modelling

Climate Change Risks

To understand the risks posed by climate change it was necessary to forecast the performance of the building through the use of thermal modelling software. Using the current climate as a benchmark, the outputs were compared with those for future climatic conditions to examine the impact on the various energy loads in the building. Integrated Environmental Solutions' (IES) Virtual Environment™ (version 6.4.0.7) was the software used to complete this modelling process, which was based upon a detailed specification of the building and its use.

The modelling process utilized the climate datasets generated through the PROMETHEUS research project that was carried out at the University of Exeter. This project formulated a robust, peer-reviewed methodology[2] for the creation of probabilistic future reference years using the UK Climate Projection 09 (UKCP09) data files. These files form the most recent and sophisticated set of climate projection data available for the UK, superseding the projections made under UKCIP02. Under UKCP09, the very nature of the data files was transformed as a result of the fundamental change in the methodology used to formulate the projections[3]. Whilst UKCP02 was derived using one variant of one (Met Office) model, UKCP09 is derived from a collection of variants of the Met Office Hadley Centre global model, together with an ensemble of another 12 international models4.

Above all, this has allowed the projections to incorporate a measure of uncertainty in order to account for the inherent imprecision of climate modelling and the limitations of using a single estimate (as was the case under UKCIP02). As such, it allows users to understand the likelihood of different levels of climate change occurring, and can be seen as the relative degree to which each climate outcome is supported by our current evidence and understanding[5].

PROMETHEUS facilitated the use of these projections by consolidating the outputs of 100 samples of hourly future weather files over three 30-year periods to produce three separate projections (2030, 2050 and 2080). Further variables were added (wind speed, wind direction, air pressure and cloud cover) and a Test Reference Year (TRY) and Design Summer Year (DSY) were created for each period, for various locations throughout the UK. These were then converted into a suitable file format to allow them to be used in building simulation software packages such as IES-VE.

In order to allow a further degree of sensitivity to the projections, the UK Climate Projection datasets have been calculated in accordance with different levels of CO2 emission rates (emissions scenarios). Under UKCP09, the number of emissions scenarios was reduced from four to three as the Medium-High (A2) and Medium-Low (B2) scenarios used under UKCP02 were combined to form one Medium (A1B) projection. Only a Medium and High emissions scenario were made available under the PROMETHEUS project as recent research has shown that it is increasingly improbable that a Low emissions scenario will occur[2].

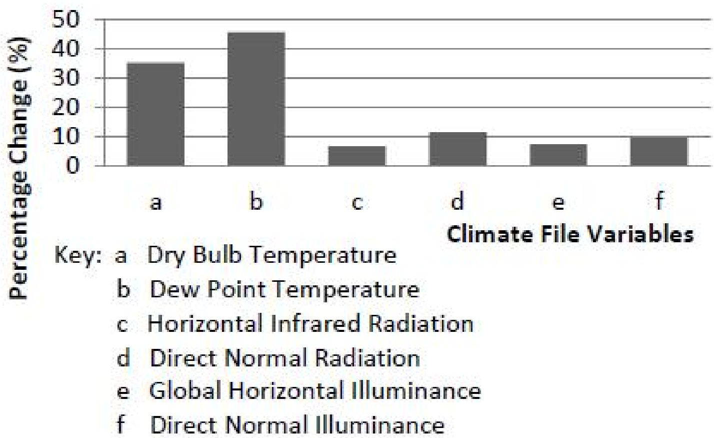
In the initial stage of this project where the building was modelled according to its current specifications (to assess its sensitivity to changing climate), the Medium emissions scenario and a

[2] M. Eames, T. Kershaw and D. Coley *Building Serv. Eng. Res. Technol,* 32, 127-142 (2011)
[3] DEFRA (2012) Assessing the differences - UKCIP02 & UKCP09
http://ukclimateprojections.defra.gov.uk/media.jsp?mediaid=76750&filetype=pdf
[4] Jenkins, G. J., Murphy, J. M., Sexton, D. M. H., Lowe, J. A., Jones, P. and Kilsby, C. G. (2009). *UK Climate Projections: Briefing report*. Met Office Hadley Centre, Exeter, UK.
[5] DEFRA UKCP09 Online Briefing Report (available from http://ukclimateprojections.defra.gov.uk/)

50% probabilistic percentile was used so that the results were not based on extreme situations. This was later changed to a High emissions scenario when the building adaptations were tested. This change occurred as subsequent advice from Exeter University highlighted recent figures published by the Intergovernmental Panel on Climate Change (IPCC), which showed that climate change had been more extreme than originally predicted and that consequently the High scenario is deemed more likely to occur. This also meant that the impact of these variations could be observed against a ‘worst case scenario’, which would emphasise their relative impact within the sensitivity analysis.

It is worth noting that this change in emissions scenario did not impact upon the accuracy of the project as the building modelling was completed in two distinct stages, first assessing the current building’s sensitivity to changing climate, the second examining the impact of adjusting various physical and occupant factors. As no direct statistical comparisons are made between the two datasets, there was no risk of drawing invalid comparisons. Of course, the initial building (current specifications) modelled against baseline climatic conditions did not change as the climate files used were for existing climate data and were not based upon projections. All modelled cases were based upon TRY files for Cardiff.

Graph 1 shows a comparison of the key variables between the present and 2080 TRY files used in the project. It is evident that the Dry Bulb and the Dew Point temperatures are expected to increase considerably, signalling a shift to a generally hotter, more humid climate. The radiation variables shown are projected to change far less, but may still have a significant impact upon the building’s internal comfort factors by increasing the external heat gains. Although not shown on Graph 1, wind speed is not forecast to change significantly within the modelled timescale. In fact, the high emissions, 50% probability level data for 2080 shows a small reduction in wind speed of about−0.1 m/s over the UK[6].



Graph 1 Percentage change from Control TRY to 2080 TRY, based upon a medium emissions scenario and a 50% Cumulative Density Function (CDF)[7]

The Modelling Process

The initial building specification was provided by Arup and was of a sufficient detail required to generate an EPC certificate and demonstrate compliance with building regulations Part L and Part J. This included the fundamental geometry of the building and the HVAC specification, which was provided by Hoare Lea. However, a number of values provided by the model were generated through the National Calculation Method (NCM) methodology, which is used to formulate a Simplified Building

6 Sexton, D. M. H. and Murphy, J. (2010) “UKCP09: Probabilistic Wind Speed Projections” Met Office Hadley Centre

7 Cemesova, A. Hopfe, C and Rezgui, Y. (2011) Cardiff University Interim Report, “Client driven sustainability analysis of a Welsh office building using future climate scenario modelling”

Energy Model (SBEM) for non-residential buildings. As such, the model contained certain assumptions pertaining to the building attributes and its use due to the simplified nature of the underlying methodology. Hence, in order to remove any erroneous predictions and improve the accuracy of the model, certain features were added and adjusted which were obtained through further research and consultation with the client. These are displayed below in Table 2.

Table 1 Added and adjusted parameters used in the formulation of the base case model

The geometry of the surrounding buildings
The actual material properties of the building fabric (these are detailed in Appendix 3).
Internal heat gains resulting from the actual predicted building use as specified by the client, including;
An occupancy rate of 5.9 m^2/person
An occupancy Schedule of 8am to 11pm and a 15% occupancy rate in the remaining hours
Occupant sensible heat gains of 73 W/person
Lighting gains of 10 W/m^2
Equipment gains of 23.5 W/m^2
A boiler efficiency of 88% (as declared by the manufacturer)
A coefficient of performance of 5.72 was used for the chiller (as declared by the manufacturer)
A ground temperature of 11C°
An infiltration rate of 0.25 air changes per hour (ach)
A heating Set point of 20 °C
A cooling Set point of 24 °C

Using this specification, the building was then modelled in IES-VE using the aforementioned 1990 TRY file to provide the baseline case, against which future climate scenarios and potential building adaptations could be compared. Figure 2 shows a screenshot of this model, with the surrounding buildings shown in pink. In all, the building was initially modelled under 4 different climatic scenarios, namely a base case and 3 future dates using the available PROMETHEUS data:

- Baseline Case – 1990 (1961-1990)
- Medium Emissions scenario - 2030 (2020-2049), 2050 (2040-2069) and 2080 (2070-2099)

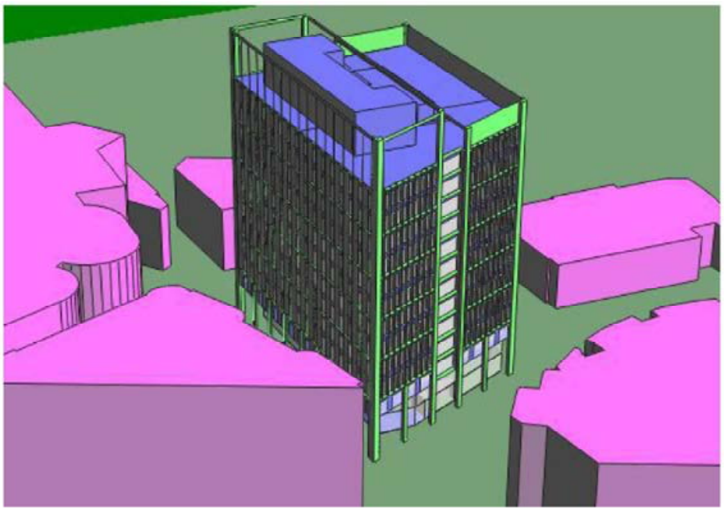
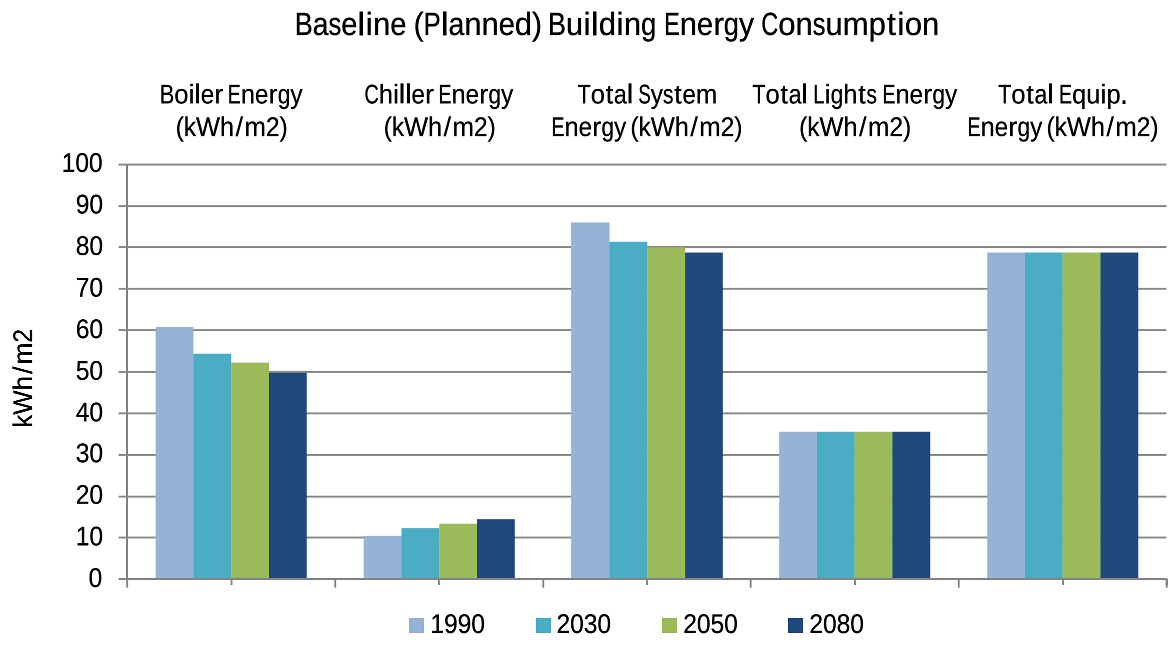


Figure 2: Model of the Admiral Office headquarters and it surroundings – taken from IES-VE

Baseline Modelling Results

The results of the base case modelling were generated in IES-VE using the present building specification in order to assess its exposure to future climate change. The Baseline energy consumption of the planned building under present, 2030, 2050 and 2080 conditions is shown below in Graph 2.



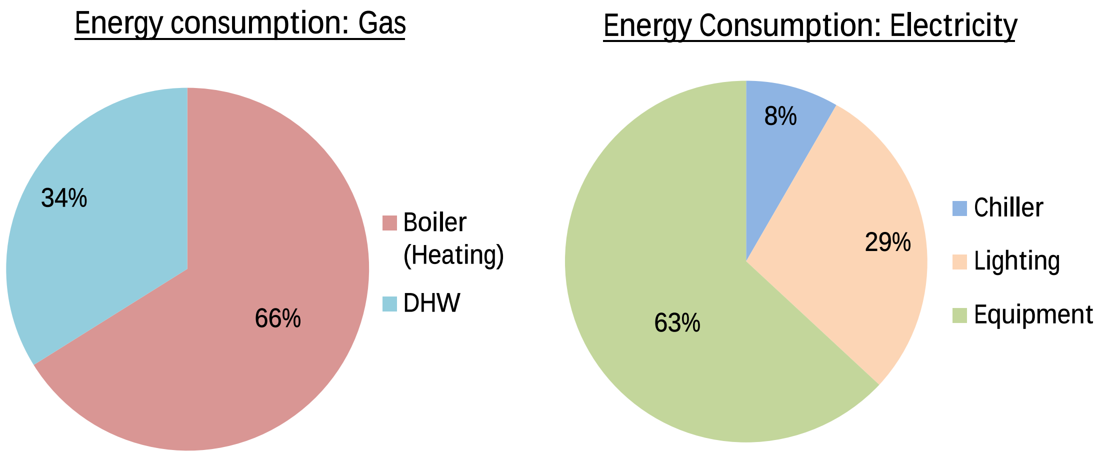
Graph 2 Baseline building energy consumption under current and projected climatic conditions

The graph shows the boiler energy consumption required to meet both the sensible heating and Domestic Hot Water (DHW) loads. The figures are based upon a boiler efficiency of 88%, and also account for a nominal amount of transmission losses. As the Coefficient of Performance (COP) for the Chiller was far higher at 5.72, the energy required to meet the cooling load was much lower than the total cooling demand. Total system energy consists of the total Boiler Energy consumption, Chiller Energy consumption, the Domestic Hot Water Secondary circulation pump and the Auxiliary energy consumption (energy consumption due to fans and pumps, control gear and any other HVAC-related equipment).

Lighting and Equipment loads have been treated as constants, as precise changes in these are hard to predict. Although it is likely that the lighting load will decrease as efficiency increases and controls improve over time, the extent of this improvement is somewhat unknown. Predicting future energy use in equipment was particularly difficult as many variables will impact upon this figure. Whilst it is generally expected that office power management and (ICT) equipment efficiency will improve, there are many complicating factors that prevent a straightforward calculation being made to predict a future energy load[8]. Gains in efficiency may to some extent be offset by an increase in the amount of equipment used (e.g. increased use of screens), whilst changing work patterns including an increase in remote working may have the opposite effect of reducing the energy demand in the building.

An important consideration in examining the energy performance of the building was that different fuel sources are used to meet the different energy loads within the building. Below, Graph 3 shows the composition of the energy consumption by Gas and Electricity in the base case (1990) building.

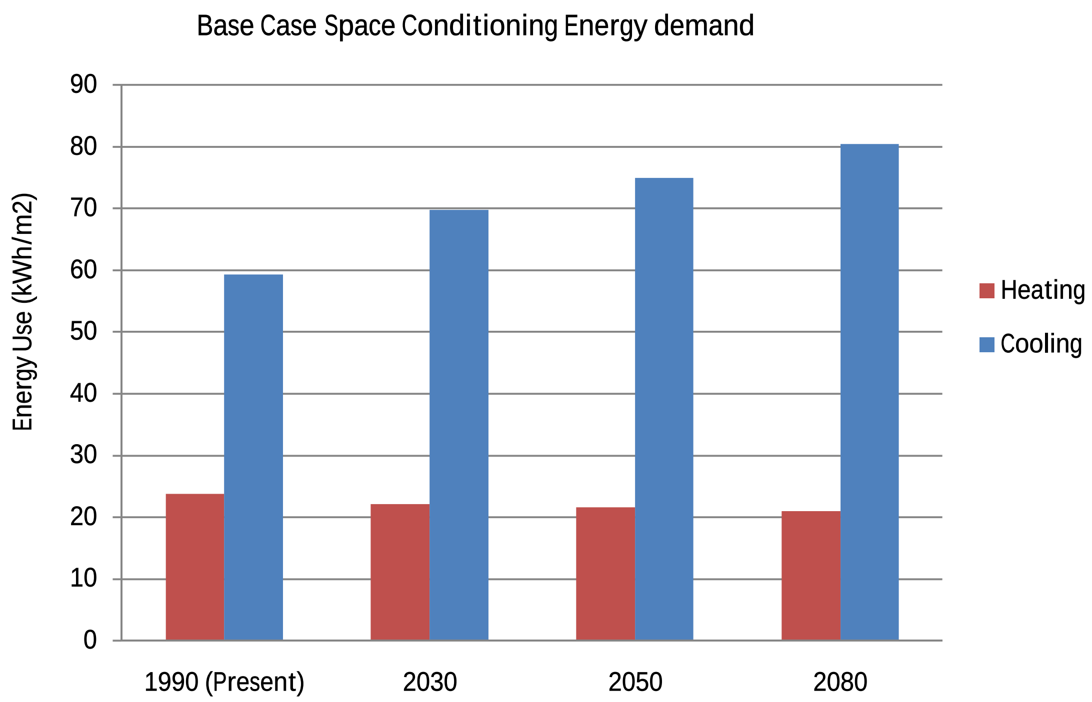
[8] Johnston, J. (2009) "An Investigation into the Energy Consumption of Future Office Buildings around the world", MSc Thesis: University of Strathclyde



Graph 3. Breakdown of energy consumption by Electricity and Gas

In examining the figures, it is evident that the majority of Gas consumption is used by the boiler in providing heat, whilst only a relatively small proportion of electrical energy is used to provide active cooling. Hence, it is apparent that the although the lighting and equipment loads have been treated as constants (for reasons explained above), they are by far the most significant electrical loads and are something of an elephant in the room when it comes to addressing the building's energy use.

Whilst Graph 2 and Graph 3 shows the total baseline energy consumption for the building, it was necessary to further scrutinize these figures in order to better understand the energy demands of the building. In particular, the exact space heating and cooling demands had to be determined so that comparisons could be made in the next stage of the project where the effect of altering individual parameters was to be tested. As these loads are dependent upon the complex interaction between various factors (climate, building fabric, internal heat gains, HVAC efficiency etc), they are dynamic and are sensitive to changes within these criterion. Furthermore, as this study set out to develop a building adaption strategy that was both practical and commercially feasible, a good understanding of these loads was needed in order to develop a robust financial appraisal of each adaptation and the overall plan.



Graph 4 Base case space conditioning energy demand

Graph 4 shows the baseline heating and cooling demand for space conditioning under present and projected climate scenarios. As such, the graph does not include the energy demand for DHW (32kWh/m2), which although high as a percentage of the total heating demand, was fairly typical for an office of this type[9]. However, as the DHW load should not be affected by the changing climate, it was treated as a constant and did not need require close scrutiny in this research. Hence, although it was included within Graph 2 for completeness, it was necessary to remove this load from further examinations of the building's energy demands as the dynamic heating and cooling loads became the main focus of the study.

The remaining heating demand is made up of heat losses occurring through Auxiliary ventilation losses (17.2kWh/m^2) and conduction through the building fabric (6.09kWh/m^2).

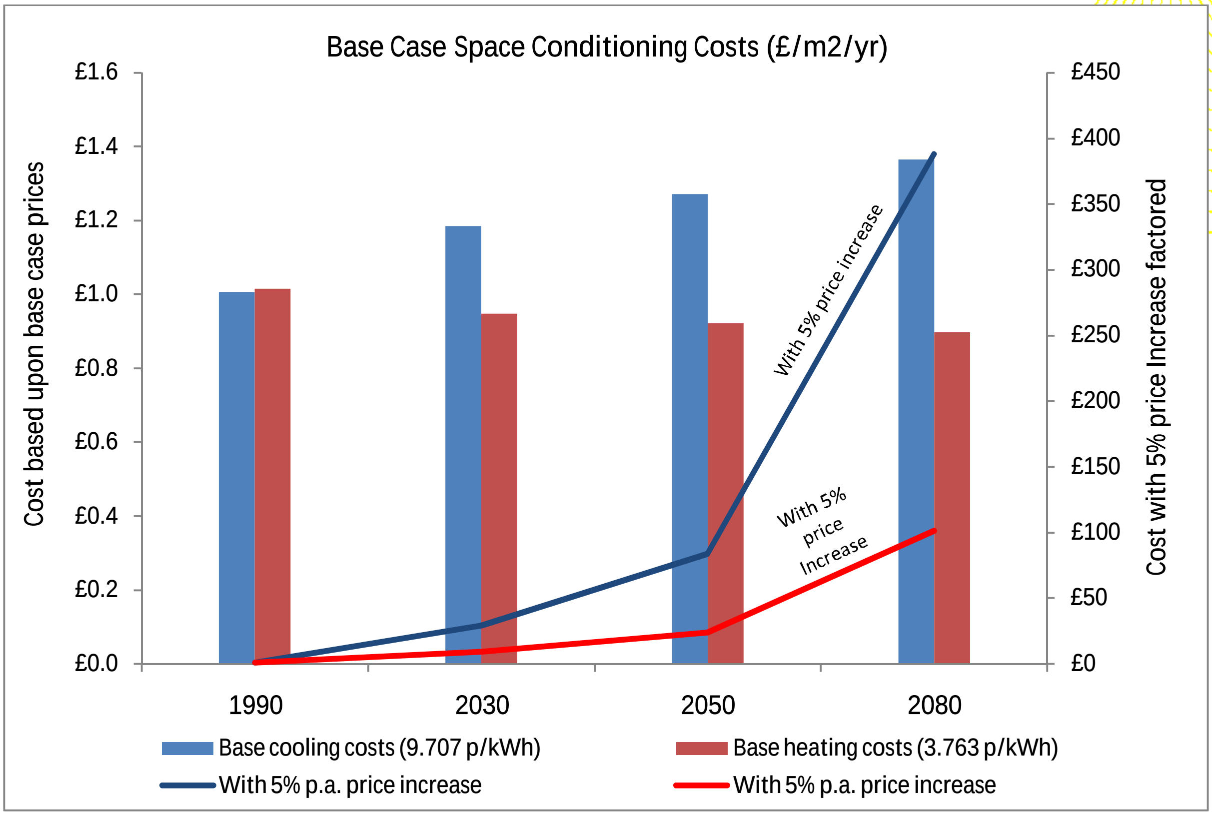
Although Graph 2 showed a high boiler energy demand when compared to that of the chiller, it is clear that once the DHW load and the boiler inefficiencies have been stripped away, there is actually a far higher energy demand for space cooling than heating. Indeed, the overall energy demand for cooling far exceeds that for heating under all climatic scenarios. Furthermore, the graph shows that under an increasingly warm, changing climate, the cooling load is set to rise significantly, whilst the Heating load shows a modest decline towards 2080 conditions.

[9] Energy Efficiency Best Practice programme (2000) 'Energy Consumption Guide 19: Energy Consumption in Offices' Crown Copyright

Discussion

When viewed in isolation, it is clear that the cooling energy demand is considerably higher than the heating demand. Although this does not correspond with the boiler and chiller energy consumption, due to huge differences in system efficiencies, this remains an important difference, particularly when operational costs are considered. That is to say that there are expected to be great differences in the running costs of each system as the chiller will be powered by electricity and the boiler by gas. As an energy source, electricity is generally more costly than gas (calculations in this research were based upon costs of 9.707p/kWh for electricity and 3.763p/kWh for gas – as supplied by Admiral) and it is predicted that the costs required to cool the building are likely to increase far above the heating costs under future climatic conditions. Graph 5 shows the projected space conditioning costs for the building under each modelled climatic scenario. The columns display the energy costs based upon the base case prices outlined above, whilst the line chart has a 5% per annum price increase factored into the energy costs. The rising cost of cooling is exacerbated when this price increase is factored, making it clear that the cooling load is the primary area that needs to be addressed in the development of an adaptation strategy.

Given the unavoidable complexity in forecasting future energy prices, it is advised that the costs displayed in Graph 5 should be treated tentatively, with an acknowledgement that inherent price volatility is likely to significantly alter the accuracy of the actual figures. Furthermore, future projections become progressively more uncertain into the future as it becomes increasingly difficult to make accurate predictions based on our current knowledge. Nevertheless, using the graph as demonstrative guide is sufficient in understand that there is a clear trend towards increased expenditure on building cooling and that this is projected to increase as a proportion of the total space conditioning costs.



Graph 5 Base Case Space Conditioning Costs – Based upon base energy prices and a price increase of 5% p.a.

As previously stated, space conditioning loads are dependent upon a range of factors and the baseline energy modelling showed that they were indeed, highly sensitive to the changing climate. However, it is this sensitivity that should allow significant energy savings to be made through building and occupancy adaptations, which are examined in the next stage of this report.

Under its current specification, it is likely that the high cooling load results from a combination of both physical building factors and aspects of the building's use profile. Its dense occupancy, coupled with a correspondingly high use of ICT equipment will have contributed to large internal heat gains. These will have been supplemented by external heat gains, and in particular solar gains resulting from a high glazing ratio and a complete absence of shading in the building design.

Due to the performance of the building fabric, with low u-values and an infiltration rate of 0.25ach, the heat transfers to the outside of the building are low and hence there is limited potential for passive cooling. Furthermore, initial modelling completed by Arup had shown that passive cooling; involving the use of chilled ceilings, combined with a natural ventilation approach would have been insufficient to meet the large cooling demand of the building. For this reason, this adaptation was not assessed in the next stage of the project as it had already proved unsatisfactory.

Due to the use of a steel (rather than a concrete) frame, the building has only a small thermal mass, which in any case is covered by ceiling tiles and is not utilized as a thermal energy store. Without this thermal mass the building is not able to significantly absorb and release the heat energy gained during busy, daytime periods and so it cannot extend the lag in ambient temperature beyond the working hours of the building's occupants. Therefore, the working hours may also be viewed as a contributory factor in the high cooling load as these currently coincide with warmest times of the day when cooling is most needed.

Having developed an understanding of the building's characteristics, and its vulnerability to future climate change, it was now necessary to test the effect of various alterations in the IES building model, to establish the best way of addressing the key energy loads required for heating and cooling. This process and the findings from this stage of the project are discussed in the following chapter.

Adaptation Analysis

Theoretical Adaptation Modelling

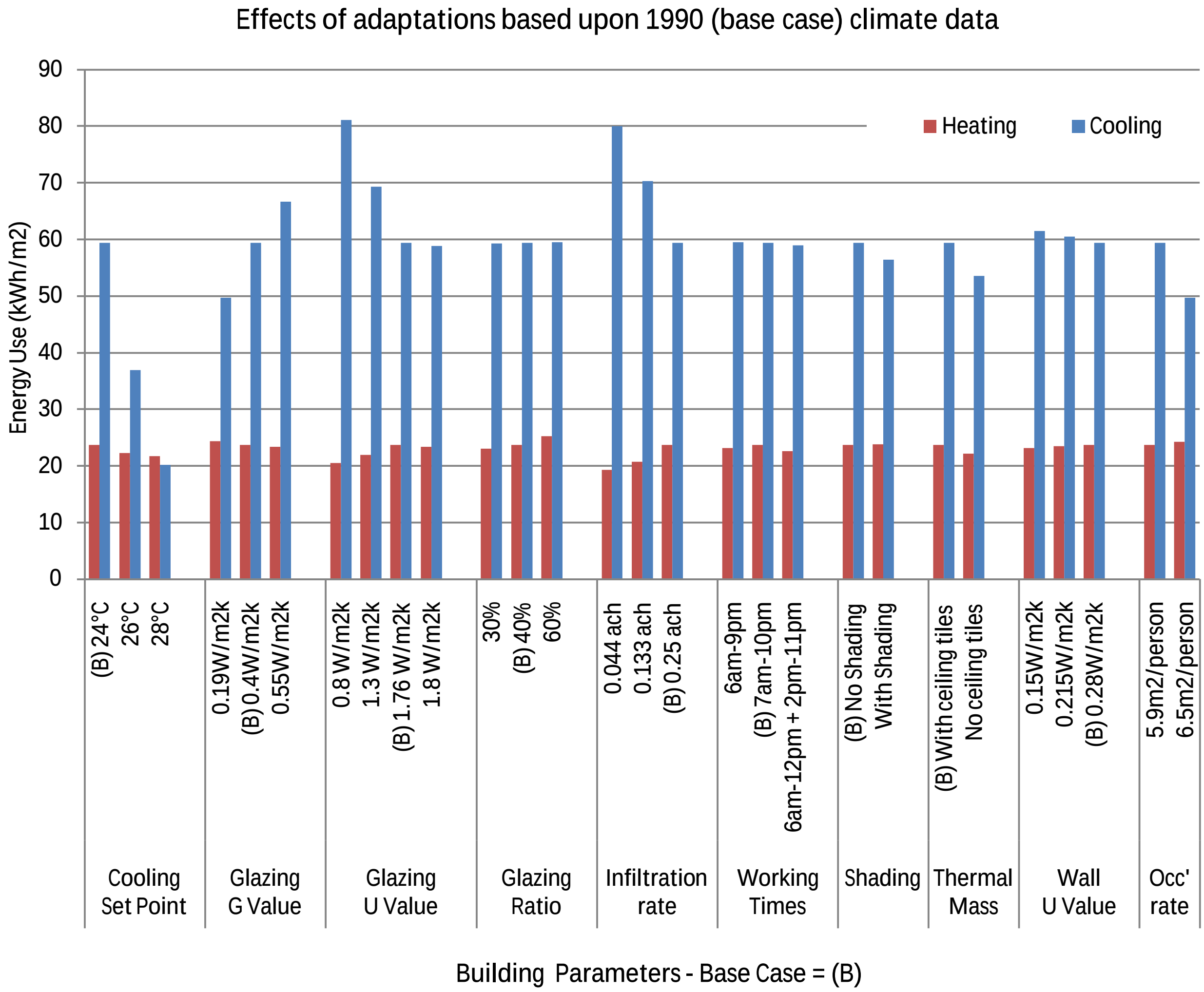
A sensitivity analysis, independently testing the effect of altering various physical and behavioural parameters was completed in order to determine their significance. The selection of these parameters was jointly agreed by the BRE Trust and the design team, whilst the actual figures used in the modelling were determined by both the design team and the tenant. These aimed to mirror best and standard practice values and are shown below in Table 2 and Table 3. The 'High Emissions' climate change scenario was used in this modelling process as subsequent advice from both Exeter University and the IPCC suggested that this was in fact more likely to occur. Using this scenario also allowed an examination of the building's sensitivity to a worst case scenario, which would emphasize the relative impact of adjusting each parameter. The impact of these adaptations were tested in isolation and not in combination with other measures as there would have simply been too many permutations to test.

Table 2 Physical parameters adjusted – Base case indicated by 'B'

Adjusted Physical Parameters	
Glazing g-value	**(0.4W/m2k) B**
	(0.19W/m2k)
	(0.55W/m2k)
Glazing ratio	**40% B**
	30%
	60%
Glazing u-value	**1.76 W/m2k B**
	0.8 W/m2k
	1.3 W/m2k
	1.8 W/m2k
Infiltration	**0.25 ach B**
	0.083 ach
	0.133 ach
	0.044 ach
Shading	**(No Shading) B**
	(With Shading)
Thermal mass	**with ceiling tiles B**
	no ceiling tiles
External wall u-values	**(0.28W/m2k) B**
	(0.15W/m2k)
	(0.215W/m2k)

Table 3 Occupant parameters adjusted – Base case indicated by ‘B’

Adjusted Occupant Parameters	
Cooling set point	**(24°C) B**
	(26°C)
	(28°C)
Working hours	**(7am-10pm) B**
	(6am-9pm)
	(6am-12pm, 2pm-11pm)
Occupancy levels	**(5.9m2/person, 23.5W/m2) B**
	(6.5m2/person, 21.3W/m2)

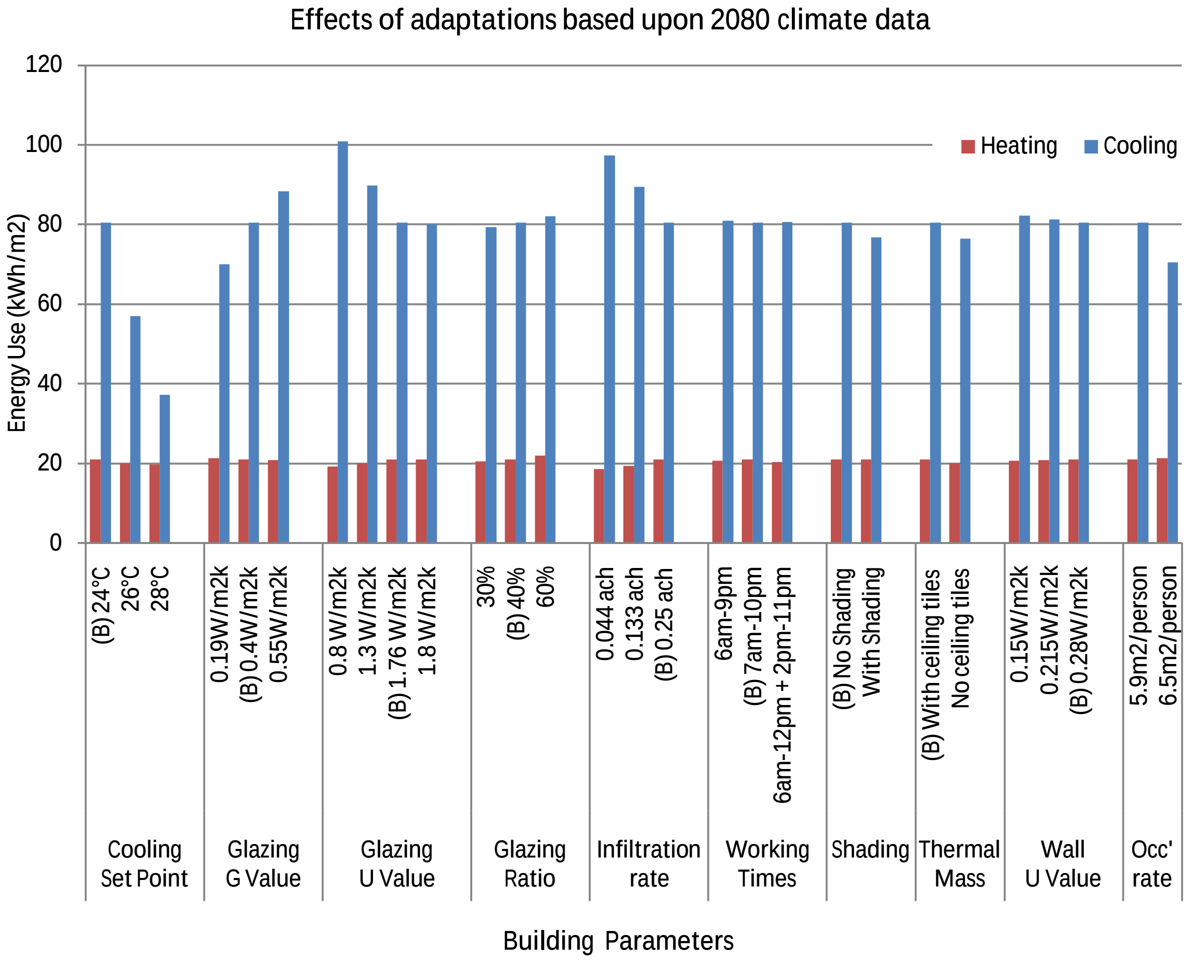


Graph 6 Impact of modelled adaptations upon heating and cooling energy demand under base case climate conditions

Graph 6 shows the impact of each adaptation upon the energy demand for heating and cooling under current climatic conditions. These are shown against the specified parameter for the planned, base case building, which is identifiable by the 'B' next to the column label. It is apparent that although making physical changes to the building does have the potential to reduce the cooling energy demand, adjusting the use profile factors of the Cooling Set Point and the Occupancy Rate were by far the most significant adaptations to make under a base case climate scenario.

The impact of these adaptations under 2080 conditions is displayed below in Graph 7.Graphs showing the results of the 2030 and 2050 modelling are available in Appendix 4. When modelled under future climate scenarios, the impact of the adaptations upon the cooling demand remained fairly constant. This was despite a general trend towards an increasing cooling energy load overall I.e. although the overall cooling demand was projected to increase, the actual impact upon the cooling energy demand remained constant and so the relative impact of the adaptations was somewhat reduced.

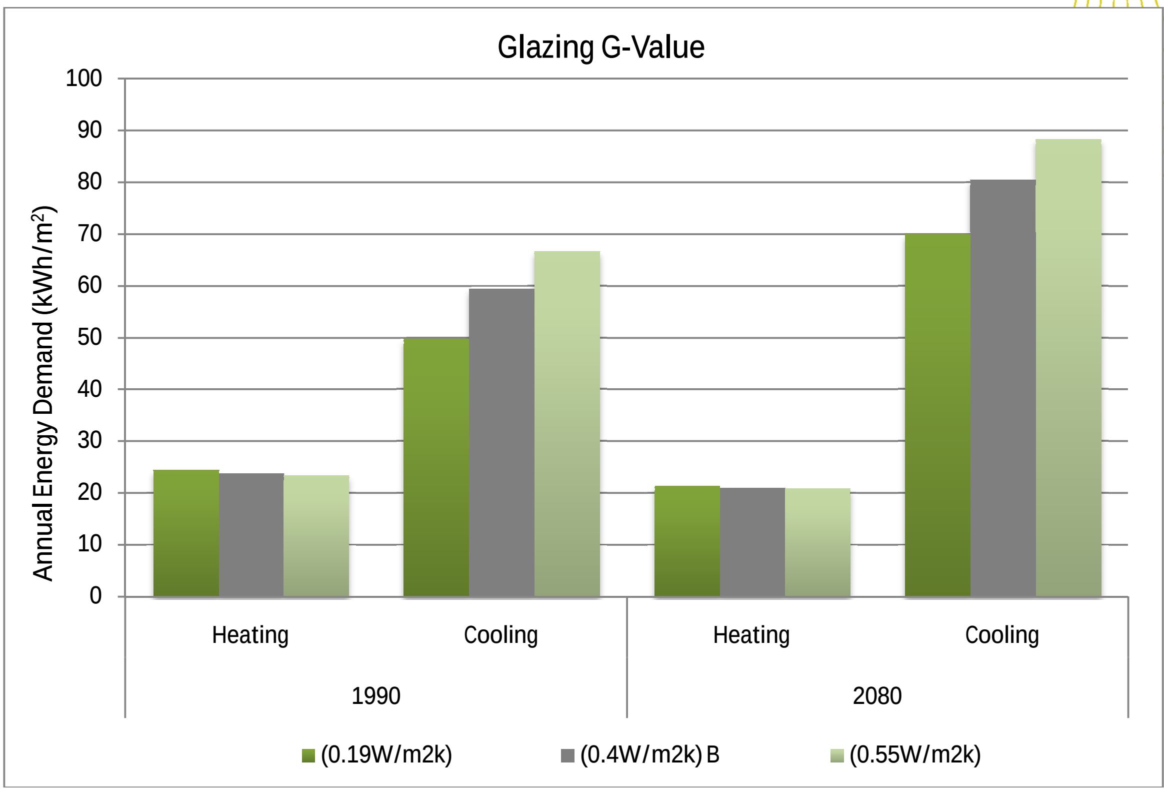
Although the adaptations had a small impact upon the heating demand under 1990 conditions, this effect was gradually reduced as the overall heating demand decreased under the warmer climate conditions present in the 2030, 2050 and 2080 models.



Graph 7 Impact of modelled adaptations upon heating and cooling energy demand under 2080 climate conditions

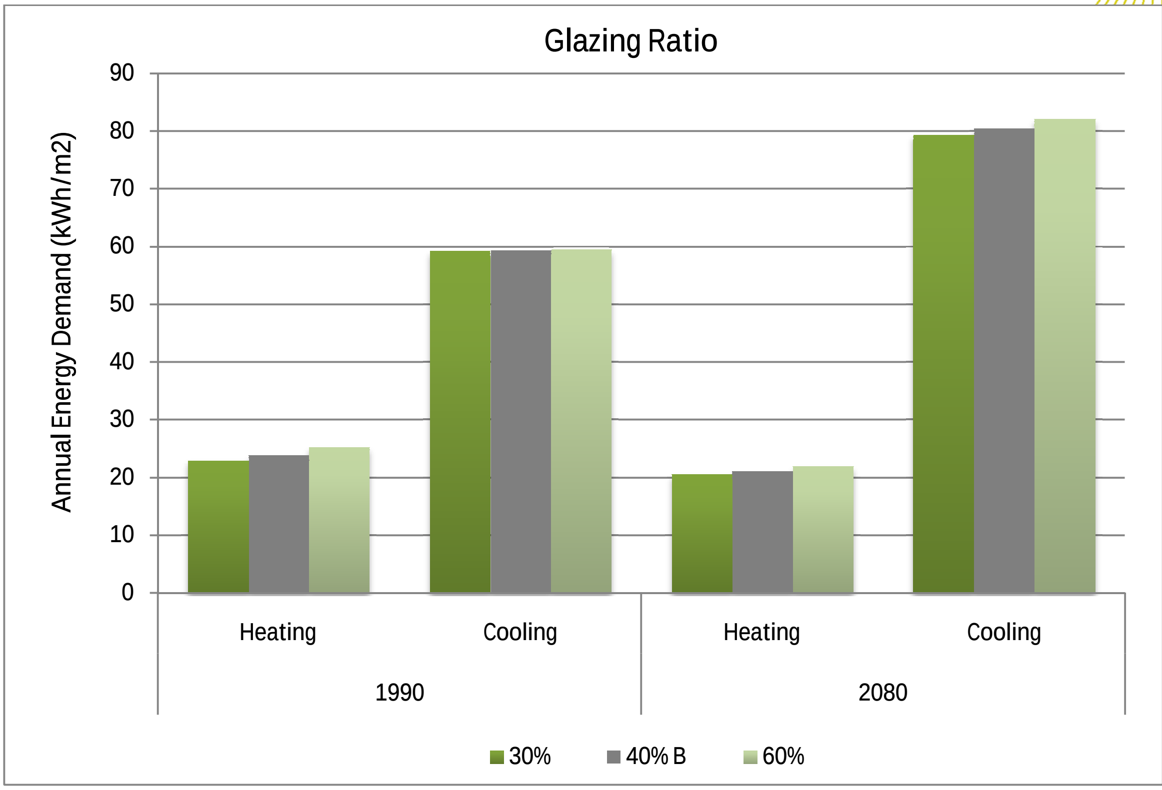
Having completed the theoretical modelling of the adaptations under present and projected climates, the data was presented to the client and design team, the tenant and the developer in order to inform a discussion about which measures could practically be implemented, regardless of required capital costs. The impact of each of these adaptations will now be explained in more detail. A description of the discussion held over their suitability and whether or not they were deemed suitable to adopt is also provided. These adaptations have been divided into two categories; 'Building fabric' and 'Occupant factors'.

Building Fabric Adaptations



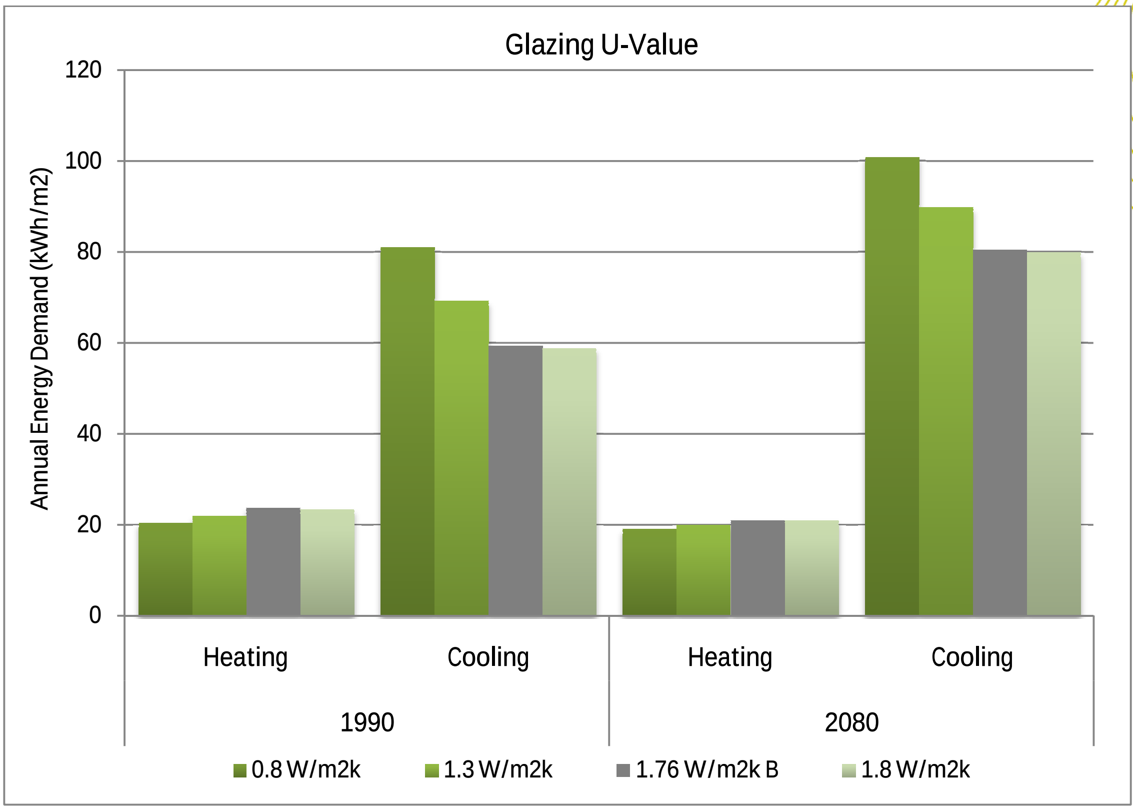
Graph 8: Effects of Glazing G-Value adaptations on heating and cooling demand under Base Case and 2080 conditions

Graph 8 shows that reducing the G-value to 0.19W/m2k resulted in a relatively significant drop in the cooling load of the building. This is explained by the fact that a reduced G-value will lead to decrease in radiative solar heat gains, thus reducing the need for active cooling during warm times of the year. Conversely, this decrease in solar gains has led to a negligible increase in the heating load of the building, which is to be expected. Nonetheless, this is far offset by the decreased cooling load and when presented to the client, it was decided that this adaptation could in principle, be adopted now i.e. during the design stage, and/or when replacement Glazing is required (probably by 2050). However, during the workshop an important issue emerged as the practical outcome of reducing the G-Value would be to increase the tint on window. Hence, this adaptation would need to be balanced against a reduction in light entering the building and a tolerable balance between these would need to be determined. Moreover, it was noted that the modelled impact of this adaptation under future climate projections is based upon the assumption that the building's performance remains consistent with its current use. I.e. that it still has high internal heat gains and that the characteristics of the remaining building fabric are unchanged. Should any changes in these occur, remodelling of the building would be required to accurately determine these impact of this adaptation.



Graph 9 Effects of Glazing Ratio adaptations on heating and cooling demand under Base Case and 2080 conditions

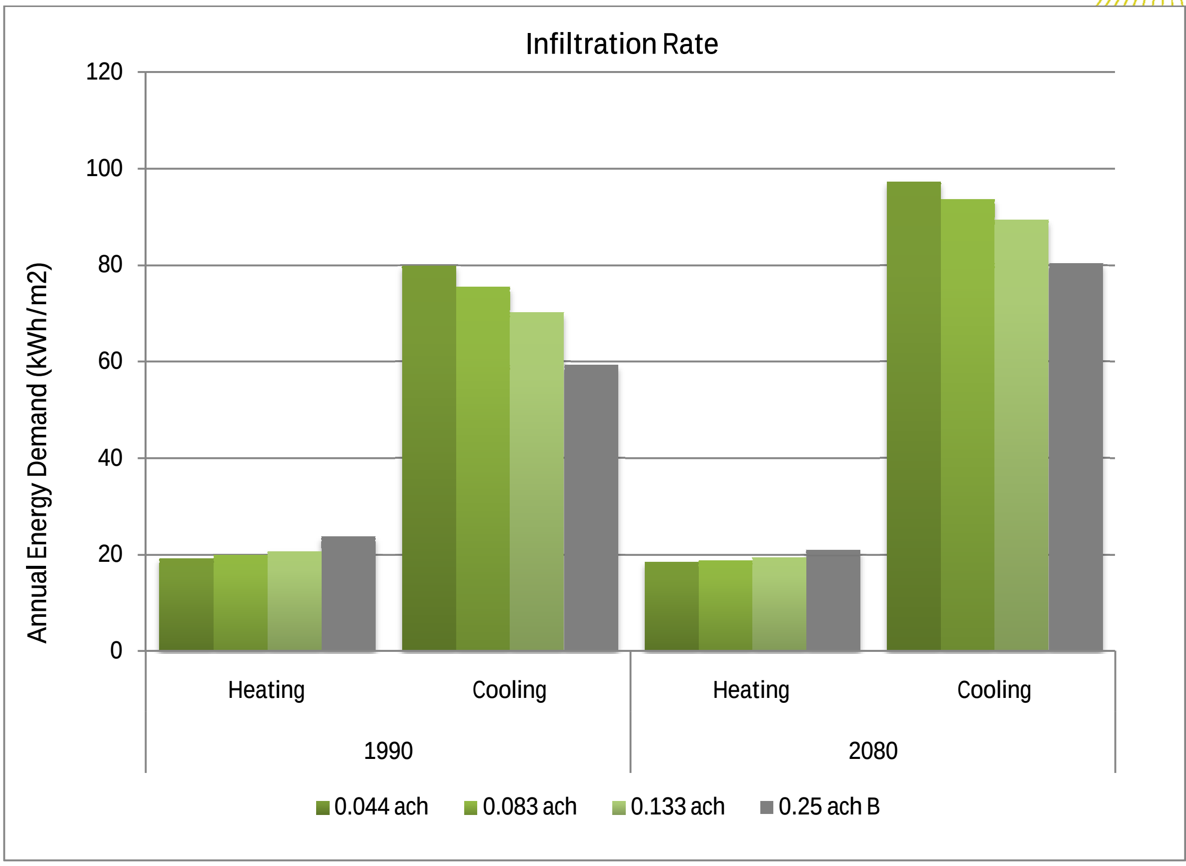
Changing the glazing ratio had only a small impact upon the space conditioning energy demand. This suggests that the internal heat gains are far more significant than those occurring via solar gains, although the changing climate may also be a factor. Furthermore, due to the design of the building, implementing this change is likely to be rather complicated and hence it was deemed unlikely that this adaptation would be worthwhile in either practical or economic terms. Therefore, it was considered unnecessary to pursue this building adaptation and it was subsequently dropped from any further investigation.



Graph 10 Effects of Glazing U-Value adaptations on heating and cooling demand under Base Case and 2080 conditions

Although changing the Glazing U-Value had only a minor impact upon the heating energy demand, the cooling demand was quite dramatically affected by this adaptation. Graph 10 shows that lowering the U-Value of the glass will significantly increase the energy demand for cooling, which in turn, will lead to an overall increase in the space conditioning energy demand. This is because in lowering the U-Value of the glass, the thermal resistivity is increased, limiting heat transfer through the building fabric. This is particularly important when the high internal heat gains are considered as the building will hold this heat for longer, resulting in a warmer working environment. This increased heat retention will extend the lag time and the overall demand for active cooling.

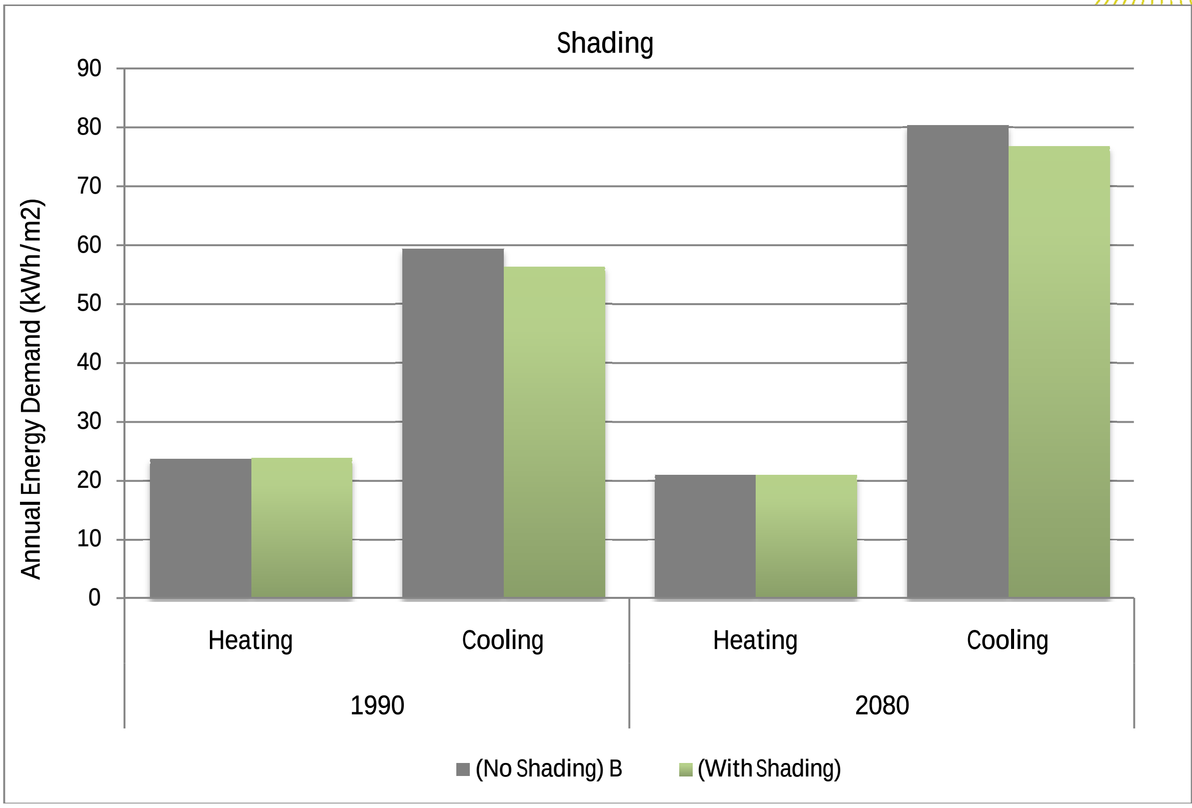
It was therefore clear that reducing the U-Value of the Glazing was not a sensible option to pursue. However, as a full glazing replacement is required in order to implement the abovementioned G-value reduction, it was suggested that an increased Glazing U-Value could also be implemented at this point and at no extra cost. Hence, it was recommended that this material property should be an important consideration when selecting the replacement Glazing.



Graph 11 Effects of Infiltration rate adaptations on heating and cooling demand under Base Case and 2080 conditions

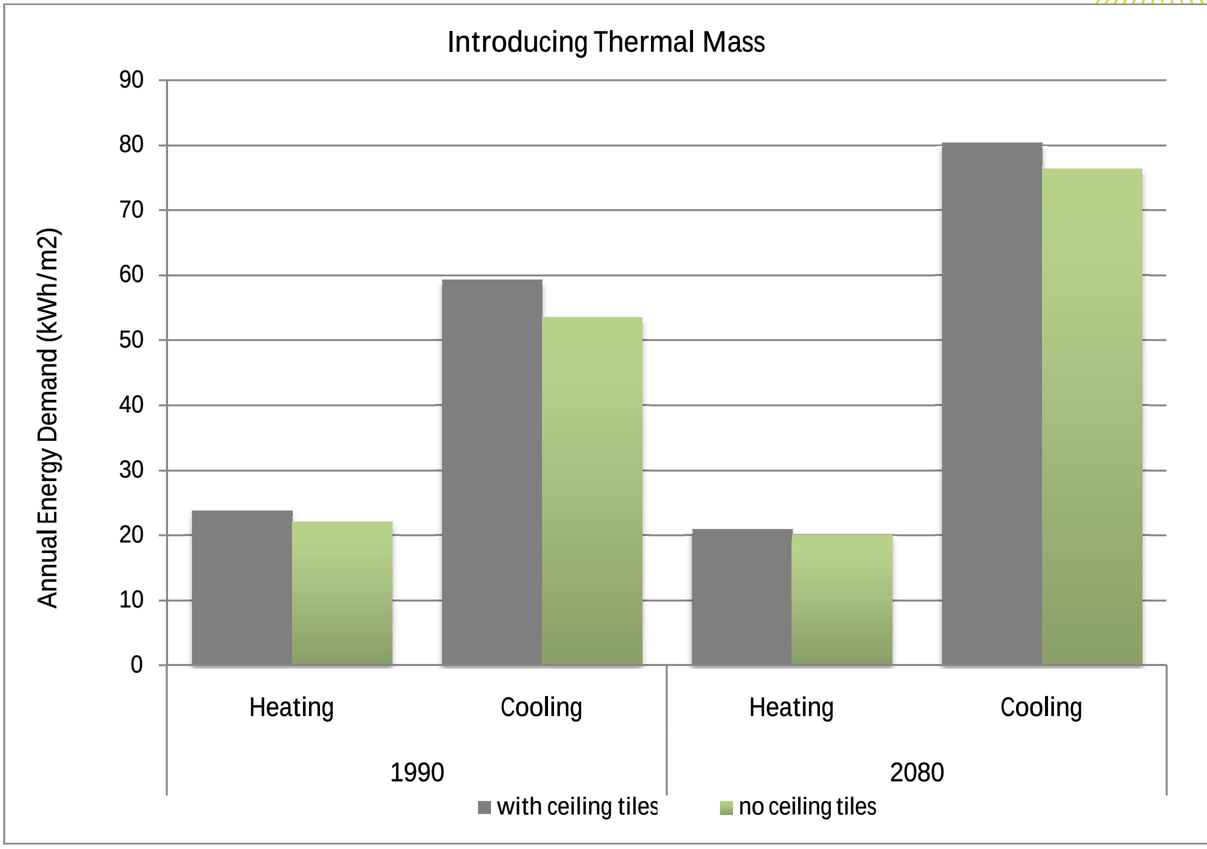
Graph 11 shows that reducing the number of air changes per hour (ach) by improving the building's air tightness will result in significant increases cooling demand. Conversely, the heating demand will decrease gradually, albeit by much smaller amounts. This increased cooling demand is due to the fact the warm air created by the high occupancy rate and ICT use cannot dissipate quickly to the outside of the building. As with reducing the U-value of the building fabric, the result is increased heat retention leading to an extended lag time and increased demand for active cooling.

Interestingly, this somewhat contradicts one of the key principles of low energy building design in the UK, where achieving a high level of air tightness is seen as a key tenet in reducing energy demand. This is because buildings in this country are usually designed to be air tight in order to prevent heat loss and reduce the heating demand. However, as this building has such high internal heat gains, the heat lost through air changes is actually positive for this building as it reduces the (larger) demand for space cooling. Nonetheless, if a natural/passive form of ventilation could be used in the building, then the relative impact of changing the fabric's air tightness would be much less and indeed this was a recommendation put forward by the BRE Trust team and Cardiff University[7]. Moreover, Graph 11 highlights the significance of the internal heat gains and the need to reduce these where possible.



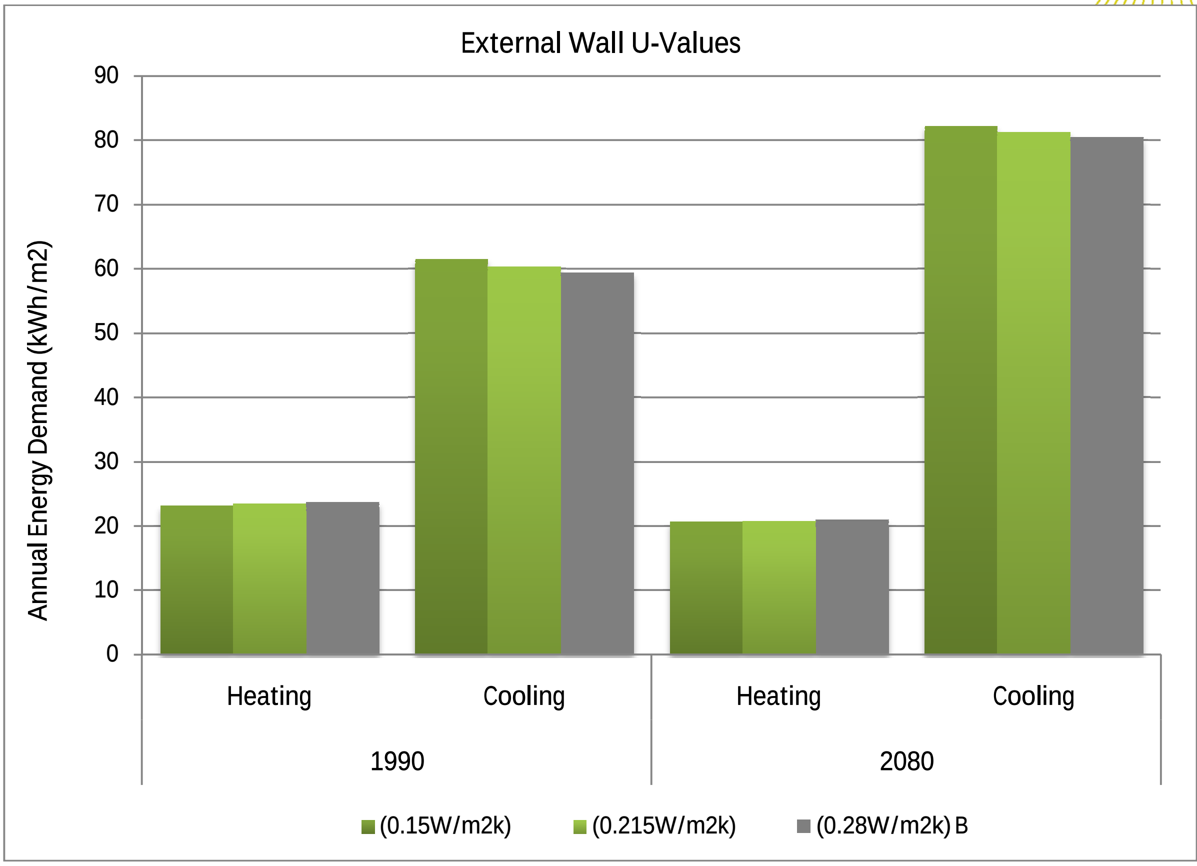
Graph 12 Effects of introducing building shading on heating and cooling demand under Base Case and 2080 conditions

Providing shading from solar gains did reduce the demand for cooling, whilst having no impact upon the heating demand. This is likely due to the fact that the shading will limit solar gains during the summer months (the cooling season) when the sun is high in the sky, but that the low, winter sun will not be obstructed. It was recommended that at the time the windows are replaced, provision should be made for shading so long as the additional cost of doing so does not outweigh the modelled benefits for a given time period. This recommendation was acknowledged by the client and design team, but was not factored into the final cost calculations due to uncertainties over the capital costs required and whether it would indeed be feasible.



Graph 13 Effects of introducing Thermal Mass on heating and cooling demand under Base Case and 2080 conditions

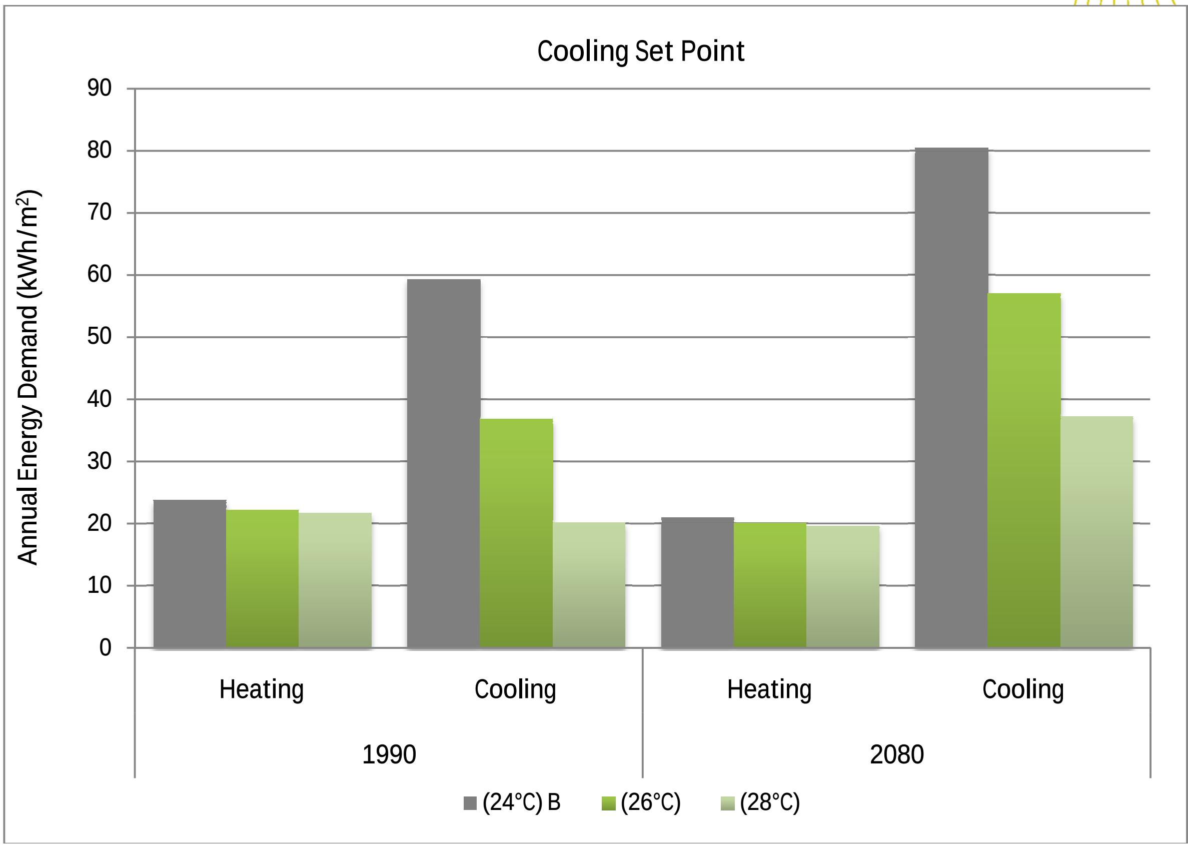
Exposing the thermal mass by removing the ceiling tiles in the IES model resulted in a marked reduction in the cooling demand. However, it must be noted that there were considerable limitations in the reliability of this data, and in the use of modelling software to predict the outcomes of this alteration more generally. Indeed, modelling this adaptation in IES is rather simplistic, allowing only a yes/no preference for the use of thermal mass alongside the associated removal of ceiling finishes. However, in practice utilizing thermal mass would have required the exposure of a concrete frame in the construction (there being no other element in the construction that could reasonably provide any thermal mass). By the time the findings of this research were presented to the client, a steel frame had already been tendered and the benefits of exposing this type of construction (with less concrete hence less thermal mass) are much reduced. Thus in reality, the benefits of this adaptation on the planned building could only be realised through retrofitting thermal mass, which would necessitate a major reworking (probably including sub-structural reinforcement) at a very high cost. Alternatively, this could have been implemented earlier in the design process if the project had opted to specify a concrete frame construction. The latter would be more likely, but in this instance even if the information had been available at the appropriate time the projected saving would be sufficiently small to be outweighed by primary construction factors such as building programme and capital construction costs (the price balance between steel and concrete). Hence, although this was simple in modelled terms, making the actual adaptation would likely be much more difficult. Thus, although this adaptation was carried through to the next stage of the project for costing by EC Harris it was deemed highly unlikely that a financially viable case could be made for its inclusion in the adaptation strategy.



Graph 14 Effects of reducing the External Wall U-Value on heating and cooling demand under Base Case and 2080 conditions

As has already been observed in the case of Glazing, lowering the U-value of the building fabric reduces the heat transference through the structure and, consequently the cooling demand increases as the building cannot expel its high internal heat gains. Graph 14 clearly demonstrates that the same is indeed true for external walls, as improving the performance of the wall is actually detrimental to the building's energy use. Conversely, it was estimated that the costs and practicalities involved in increasing the wall's U-Value (in order to reduce the cooling demand) would far outweigh the potential savings that could be made. Furthermore, it was reckoned that the noise and disruption caused by the need to re-clad the building would actually be detrimental to the client's core business. Therefore, it was decided that the U-value of the external wall should not be addressed in the adaptation strategy and the adaptation was dismissed.

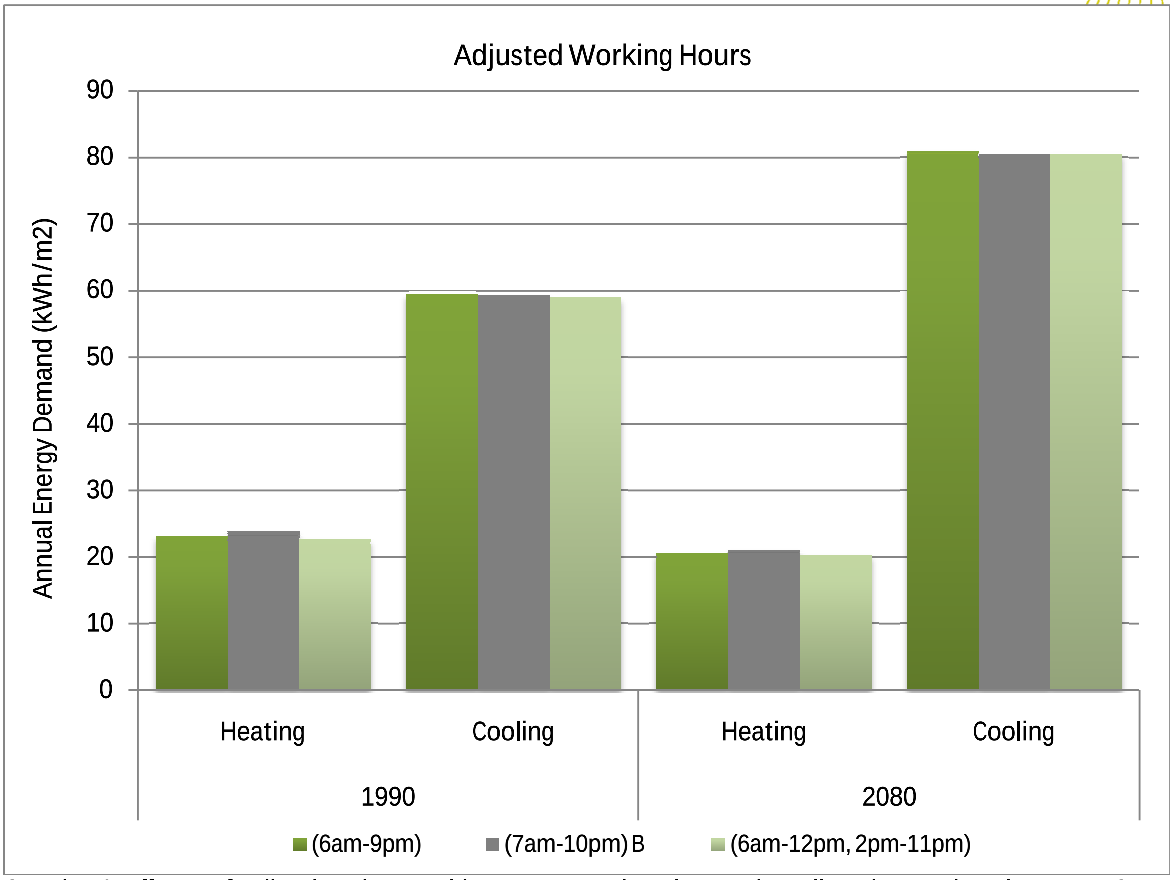
Occupant Adaptation Factors



Graph 15 Effects of adjusting the Cooling Set Point on heating and cooling demand under Base Case and 2080 conditions

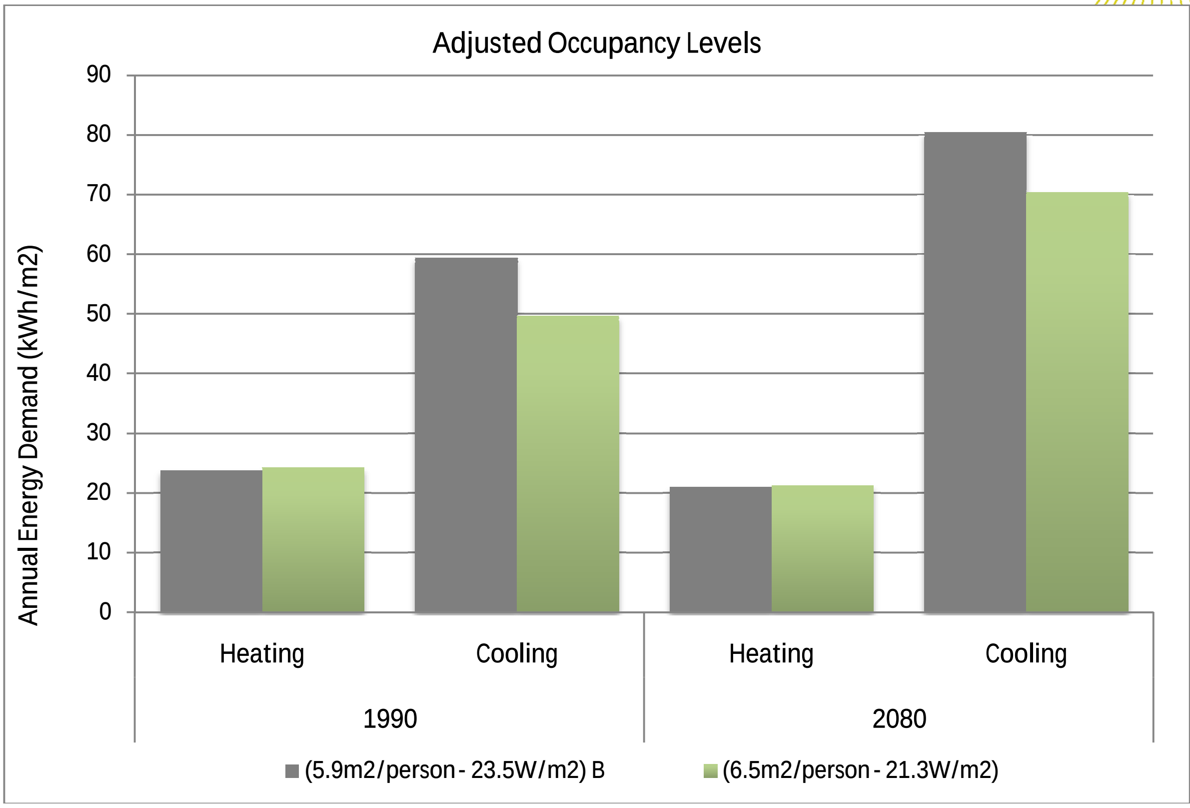
Adjusting the cooling set point was by far the most influential method that could be used to reduce the building's space conditioning demand. Increasing the set point results in reduced demand for cooling and also causes a small reduction in heating demand. Of course implementing this change would not incur any cost and so it was a simple decision to take this adaptation forward into the final development of the overall strategy.

However, increasing the set point may have a considerable impact upon the comfort levels within the building. Thus, in making this adaptation care must be taken to find the optimum, tolerable level, balanced against the productive output of the workforce. On this point, It was noted that as external temperatures are expected to rise, it is possible that people's tolerance to higher temperatures may increase, making such a change more acceptable[7].



Graph 16 Effects of adjusting the Working Hours on heating and cooling demand under Base Case and 2080 conditions

Adjusting the occupancy schedule was considered in an attempt to limit building use during the hottest hours of the day and thus reduce the cooling load. However, Graph 16 shows that in both adapted cases, this had only a negligible impact upon energy demand. Furthermore, it emerged during discussions that such adjustments to the working hours would not be detrimental to the client's core business, which would require its employees to be present during daytime hours (including the two hours over lunch, which were excluded under one modelled adaptation). Hence, on both counts it would not have been sensible to implement this adaptation and it was discounted accordingly. Of course, reducing the total working hours may have had a more significant impact but again, this was not considered acceptable to the client's business needs.



Graph 17 Effects of adjusting the Occupancy Levels on heating and cooling demand under Base Case and 2080 conditions

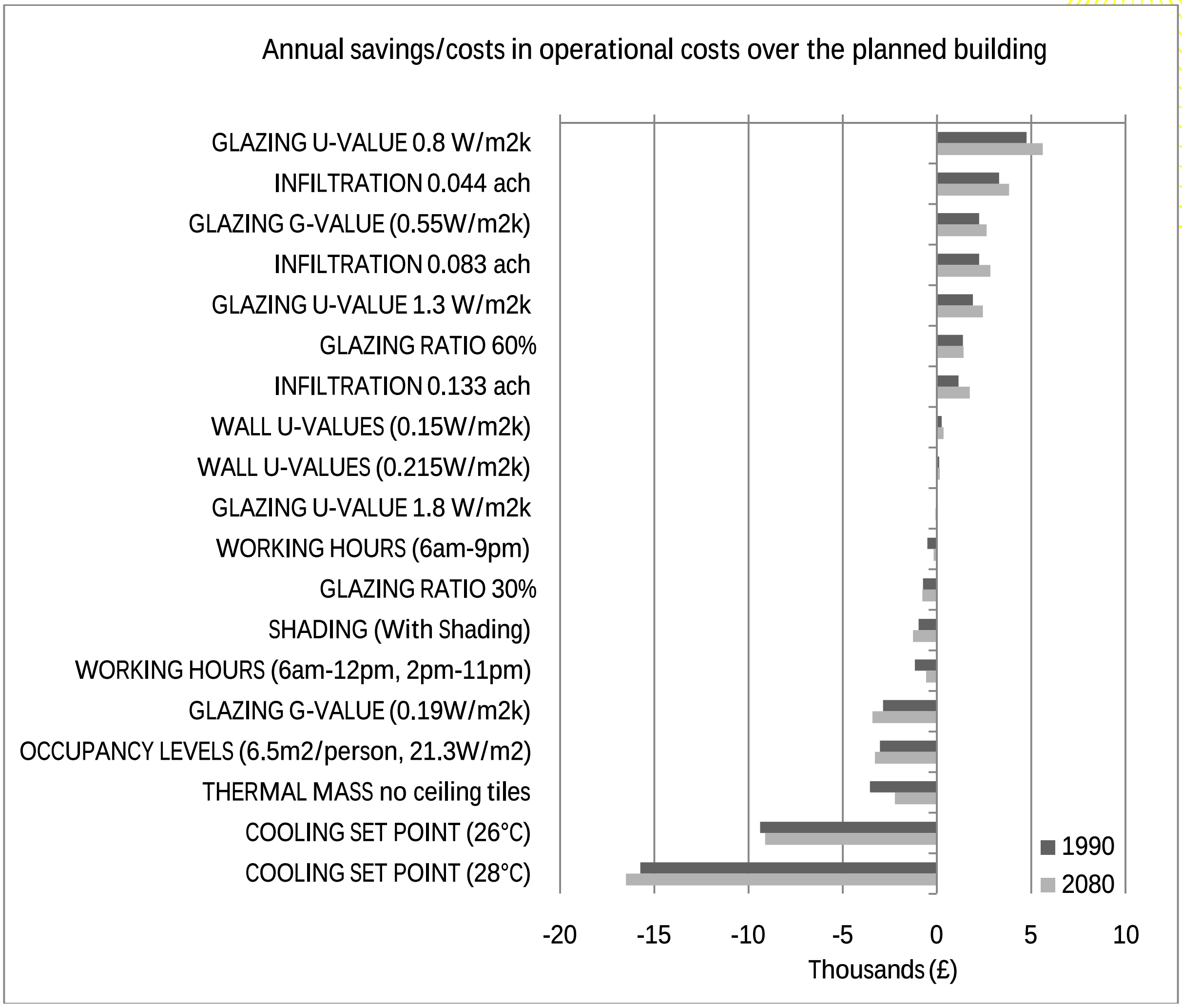
Due to an acknowledgement that working patterns are forecast to change, with remote working becoming more prevalent, a reduced occupancy level was monitored to determine how this might impact upon the building's energy demand. Graph 17, shows that an increase of 0.6m^2/person does indeed reduce the cooling demand by a significant amount, due to the reduction in internal heat gains emitted by the people themselves and the equipment they require for their work. Furthermore, this adjustment would likely lead to a reduction in the building's other energy loads e.g. ICT equipment. This adaptation was taken forward for further consideration. However a full appreciation of the wider implications of making this change would be required in order to ensure that establish the overall impacts. For example, rather than reducing the occupancy density (to account for increasing home working) it may be more sensible to maintain the current rate, but sub-let the newly available office space to a new occupant in one portion of the building.

Financial Appraisal

Having established the impact of each adaptation on the building's energy demand, it was possible to develop a financial appraisal based upon a cost per kWh. As previously stated in the description of the baseline modelling process, these costs were calculated using a price of 9.707p/kWh for electricity and 3.763p/kWh for gas. These were the current prices that the client has negotiated with their Energy Service Company, and which they currently pay at their other office buildings. In fact, by recent standards these may be considered good value, as the 2012 Digest of United Kingdom Energy Statistics cites an average net selling value of 10.220p/kWh for electricity and 2.615p/kWh for gas, excluding VAT at 20% and any associated Carbon taxes[10].

It is acknowledged that the figures used are subject to volatility, and that the outputs of the model will be sensitive to changes within these. As such, it is advised that the actual figures here be treated only as indicative costs, rather than precise financial projections. Nevertheless, the figures serve to demonstrate which adaptations would bring about the biggest savings and which would increase the running costs of the building. Below, Graph 18 shows the complete annual costs and savings incurred through implementing the modelled adaptations (heating and cooling costs combined).

[10] Department of Energy and Climate Change (2012) "Digest of United Kingdom Energy Statistics 2012" National Statistics Publication.



Graph 18 Annual Energy Costs and Savings through implementing each tested adaptation

Unsurprisingly, Graph 18 shows that the operational costs and savings are closely aligned with the energy cooling demand projections made for each adaptation. This was due to the price of electricity (used for cooling) being far higher than gas (used for heating), and because the modelled adaptations caused only small changes in heating demand by comparison. It is clear to see that the simple measures of adjusting the cooling set point are by far the most effective, particularly when we consider that implementing these would not incur any additional capital cost. Lowering the occupancy levels and adjusting the working hours were also forecast to make small financial savings, although these were deemed unsuitable measures to adopt, based upon the client's current business requirements. Introducing thermal mass and reducing the Glazing G-Value were the only physical building measures that would allow any significant savings to be made.

However, in order to form a full financial appraisal of these changes, estimated capital costs were needed in order to understand whether these adaptations would be financially viable to implement. The additional costs over a deemed industry standard are displayed below in Table 4 and Table 5. These were provided by the project partner EC Harris, and show the relevant changes along the suggested timescale. However, this assessment was somewhat limited by factors on cost analysis as Hoare Lea highlighted that there were too many variables on projections past 2030 for any meaningful results to be drawn. Hence, this appraisal was restricted to include only the adaptation measures that were deemed feasible by the tenant, the developer and design team, and occurring before 2050. A full breakdown of these costs is available in the attached Appendices on the _Connect portal.

Table 4 Additional capital cost of adaptations against energy consumption for heating and cooling and the estimated 10-yr energy cost savings – 2012 - 2030

YEAR	ADAPTATION MEASURES	CAPITAL COST OVER & ABOVE INDUSTRY STANDARD (NEW BUILD)	CAPITAL COST TO IMPROVE*** REFURB	COMBINED CAPITAL COST TO IMPROVE NEW BUILD	COMBINED COST REFURB	ANNUAL CHANGE IN BOILER ENERGY FOR SPACE CONDITIONING (kWh)	ANNUAL CHANGE IN CHILLER ENERGY FOR SPACE CONDITIONING (kWh)	COMBINED ENERGY COST SAVING OVER 10-YR PERIOD Based upon 5% price increase p.a.
2012	Glazing - Lower g-value glazing (0.19w/m2k); Higher u-value glazing (1.8w/m2k)	£ 1,102,109	**£ 2,875,066**	**£ 1,102,108**	**£ 2,875,066**	10,702.90	37,557.00	**-£40,790**
2030*	Increase cooling set point by 1°C to 25°C	~	~	~	~	~	~	~
	Reduce staff levels to 8m2/person	~	~	~	~	~	~	~
	Reduce working hours to 13 hours total	~	~	~	~	~	~	~
	Lighting changed to LED throughout (internal heat gains of 4w/m2)**	£ 179,452	**£ 179,452**	**£ 900,698**	**£ 2,052,470**	3511.00	-199031.50	**-£241,350**
	M&E Plant, with 5% improvement on efficiency over 2030 industry standard**	£ 640,902	**£ 640,902**					
	Expose thermal mass	£ 80,344	**£ 1,232,116**					

*Capital costs for 2030 made on the assumption that advanced technology now will be industry standard technology in 2030 and that energy costs will not significantly deviate in relation to capital costs given inherent need for energy in manufacture and transport
**Higher spec. products for 2030 - Only 'to improve' if part of standard refurbishment measures (e.g. equipment and lighting)
***Only 'to improve' if part of standard refurbishment measures (e.g. equipment and lighting)

Table 5 Additional capital cost of agreed adaptations against energy consumption for heating and cooling and the estimated 10-yr energy cost savings – 2050 - 2080

YEAR	ADAPTATION MEASURES	CAPITAL COST OVER & ABOVE INDUSTRY STANDARD (NEW BUILD)	CAPITAL COST TO IMPROVE*** REFURB	COMBINED CAPITAL COST TO IMPROVE NEW BUILD	COMBINED COST REFURB	ANNUAL CHANGE IN BOILER ENERGY FOR SPACE CONDITIONING (kWh)	ANNUAL CHANGE IN CHILLER ENERGY FOR SPACE CONDITIONING (kWh)	COMBINED ENRGY COST SAVING OVER 10-YR PERIOD Based upon 5% price increase p.a.
2050	Increase cooling set point by 1°C to 26°C	~	~	~	~	45,536.70	-200901.80	-£223,742
	Reduce staff levels to 10m2/person	~	~					
	Reduce working hours to 12 hours total	~	~					
	M&E Plant, with 5% improvement on efficiency over 2030 industry standard	N/A	**N/A**					
	Lighting changed to LED throughout (internal heat gains of 4w/m2)	N/A	**N/A**					
	Glazing likely replaced now (but no information available on performance)	N/A	**N/A**					
2080	Increase cooling set point by 1°C to 27°C	~	~	~	~	73,305.20	-176371.30	-£180,647
	Reduce staff levels to 12m2/person	~	~					
	Reduce working hours to 11 hours total	~	~					
	M&E Plant, with 5% improvement on efficiency over 2050 industry standard	N/A	**N/A**					
	Lighting changed to LED throughout (internal heat gains of 3w/m2)	N/A	**N/A**					

Devising the Adaptation Strategy

Following the meeting with the design team, the tenant and the developer at which the results of the BRE Trust's theoretical modelling were presented, a selection of costs was provided by EC Harris. Consideration was given not only to the potential cost and energy savings that could be made, but also to the maintenance/replacement intervals of the building and to predictions of the client's future business activities and working styles. In addition to the modelled adaptations, a cost was provided for two extra improvements, which were proposed during the meeting due to their apparent suitability. These were; an improvement in lighting efficiency from 10 W/m^2 to 4W/m^2, and a 5% improvement in M&E plant efficiency. The latter adaptation consisted of an improved system with the possible addition of cold beams between floors. Having agreed these adaptations (in principle), the building was then remodelled accordingly under the corresponding climate files with a 'High Emissions' scenario selected. This provided the energy costs and savings, from which financial savings were extrapolated using the aforementioned costs and a price increase of 5% per annum.

From examining the cost figures, it became apparent that the physical building adaptations of introducing thermal mass and improving the glazing performance were unlikely to be cost effective adaptations to implement. As shown in the modelling results, the independent effect of introducing thermal mass to the building resulted in an annual saving of less than £4,000. Although the cost of opting for a thermally massive concrete frame from the outset (at an estimated cost of £80,344) may have been deemed a sensible option, the findings of this project were too late to influence the initial design and so the cost of exposing the thermal mass through refurbishment (at £1,232,116) would have been prohibitively expensive. This was due to the complexity of making this alteration as a retrofit, which would have required ceiling tiles to be removed, fittings to be replaced and soffits to be painted. Therefore, it was advised that this adaptation should not form part of the building adaptation strategy, but that the use of thermal mass should be considered at the outset of future developments of this type of building (Including new Admiral developments). Similarly, the additional cost of purchasing and installing the specified glazing would have far offset the projected operational savings.

Selected Adaptations

Having considered the financial appraisal of the possible adaptations, it appeared that the most suitable strategy to implement would be one which addresses the internal heat gains and adjusts the building's use profile within a tolerable range. The key physical features to address here were the lighting and equipment gains, which are presently specified as generating 10 W/m^2 and 23w/m^2 respectively. Although these presented a significant opportunity to make savings, it was not deemed sensible to alter these for the sole purpose of reducing internal gains, but rather that it would be to prudent to specify high efficiency lighting and equipment in line with the existing maintenance and replacement cycles. This would be a more economically viable strategy as the relative cost uplift would be reduced and because it would involve less disruption to the building and the workforce. As well as reducing the need for active cooling, an additional benefit of implementing this adaptation would be that the building's electrical consumption would also decrease significantly, and so in turn would the building's CO_2 emissions and running costs. This is particularly important when we consider that the model of the current building showed equipment usage to be 63%, and lighting to be 29% of the total electricity consumption.

Whilst this adaptation strategy does not specify the exact efficiency that should be sought, this would ultimately depend on the price. A cost-optimal solution, which balances the reduced cooling costs and system running costs against the relative cost uplift in specifying highly efficient equipment, would obviously be most preferable. Due to sheer size of the building and the costs involved in making these replacements, it may be necessary to re-model the building when this change is due (albeit at a small additional cost) and when real prices are known in order to determine the most favourable solution.

The secondary adaptations to consider would be in adjusting the occupant factors and use profile of the building. The modelling carried out in this project has shown that increasing the set point at which the chiller begins to provide active cooling will result in a significant reduction in energy use and running costs. Having observed the benefits of this adaptation, and considering that it will not incur any additional capital cost, the project team decided to adopt this adaptation on a gradual basis as the workforce acclimatize to the warming climate. The staggered approach suggested for use on this building was to increase this set point from 24°C to 25°C by 2030, to 26°C by 2050 and to 27°C by 2080. An assessment would need to be made as to whether or not these set point increases are tolerable according to the client's core business and the productivity of the workforce. Interestingly, Admiral have a 'relaxed' attitude to dress code, which research shows should be conducive to increased thermal comfort and a wider tolerable range in both heating and cooling set points[11]. Thus it is recommended that this policy should continue, in order to make such building adaptations more acceptable to the occupants.

The final adaptation considered was a lowering of the occupant density and the overall number of daily working hours i.e. the amount of time that the building is at full occupancy. As working patterns are expected to change, with greater flexibility and remote working predicted, it was envisaged that the overall occupant density of the office space is likely to decrease. Of course, the precise occupant density resulting from this change is something of an unknown, and it may be possible for the client to compensate for this by reducing the total amount of office space they require. Ultimately, the savings made through a reduced occupant density would need to be weighed against the productivity of the floor space in order to establish an optimum density level. Nevertheless, assuming it is not possible to maintain full occupancy in the face of changing working patterns, it may be permissible to allow for a decreased occupancy due to the reduced cooling demand that this facilitates. Therefore, although it is not possible to outline a strict timescale for this adaptation, the results of this project may be used as a guideline from which the client can estimate the likely savings that this change may bring about.

[11] Newsham, G. (1997) 'Clothing as a thermal comfort moderator and the effect on energy consumption', Institute for Research in Construction, National Research Council Canada, Ottawa

Conclusions and Recommendations

Having examined the modelled outputs of the building's energy use under present and future climate conditions, it became apparent that the largest energy loads were those for lighting and ICT equipment. Furthermore, although these were not sensitive to the changing climate, they did have a significant impact upon the space conditioning loads due to the considerable internal heat gains that they created. Unsurprisingly, as a warmer, more humid climate was forecast, the biggest effect of this change was to increase the demand for active cooling. Hence, the internal gains resulting from lighting and equipment, coupled with those caused by a high occupancy rate served to exacerbate this effect and increase the energy demand on the chiller. Therefore, due to the sheer size of these loads and their effect on increasing the cooling demand, it became clear that these should be prioritized within the adaptation strategy. As both lighting and ICT equipment will require replacement within a relatively short timescale, it is recommended that the efficiency of these should be greatly improved in line with this re-purchasing schedule. As the trend of increasing efficiency in the lighting and ICT industries is expected to continue, the cost of implementing this adaptation should become more favourable as efficient products become more main stream.

With more specific regards to the cooling load, the project showed that the most effective method of reducing this was to increase the temperature set point at which the chiller would begin to provide space conditioning. This was also the most cost-effective solution to implement as this change would not incur any capital costs. An optimum temperature will need to be determined, that is tolerable to its occupants and does not affect their working output. Similarly, although adjusting the occupancy rate and the working hours would also reduce the cooling load, the savings made here would need to be balanced against the overall output of client's core business to ensure that they were indeed making best use of their available office space. The final adaptation worth implementing here was to opt for a highly efficient chiller, in order to reduce the electrical demand required to satisfy the load. Again this change should be cost-evaluated and should only be implemented at the time that a replacement is required for the existing system (typically 15-20 years)[12].

The project showed that in general, adapting the physical properties of the building would only facilitate relatively minor energy savings. Moreover, having developed a financial appraisal based on the capital costs, and the savings incurred through each adaptation, it emerged that it would not be cost-effective to implement these changes as part of a retrofit/refurbishment approach. However, if the project had been completed at the conceptual stage of the development, then it may have been possible to specify certain changes from the outset, which could have reduced costs to a financially viable level. For this reason, it is recommended that for future projects, the development of an adaptation strategy should be completed at the conceptual stage as this is when it has the most potential to influence the design. Additionally, it was suggested within Cardiff University's report on the project findings that using a Building Information Modelling (BIM) approach would have simplified the process and would have allowed future adaptation modelling to be completed more easily.

Because the financial appraisal showed that the modelled physical building adaptations would not be economically viable to implement, the overall strategy has centred on creating a more efficient building use

[12] CIBSE (2000) Guide to ownership, operation and maintenance of building services

profile. Moreover, the project findings highlight the importance of considering energy and climate change from the outset of the development process. In this respect, it was advised that for Admiral's impending developments, the findings from this project should be considered and this approach should be adopted. In fact, one of the positive outcomes of this project was that it did indeed inform the design approach to the Newport scheme and that a concrete frame has been specified for this construction. Moreover, the findings of this project could, in principle, be applied to the design, operation and maintenance of telephone exchange buildings, or any other buildings with a high performing building fabric and considerable internal heat gains.

Learning from working on this contract

Essentially, the project followed a simple, step-by-step approach that was both methodical and straightforward. The research utilized robust datasets and powerful modelling software, and was completed with the co-operation of the BRE Trust-sponsored Cardiff University team, and the project partners involved in the design and construction of the studied building. First, the initial building specification was modelled under present and future climate scenarios in order to understand the building's energy profile and establish its susceptibility to the changing climate. The next step was to adjust various physical and occupant adaptations in the model to observe their impact and understand the practicalities around their implementation. Once the most feasible adaptations had been selected, these were taken forward to the final stage where estimated costs were provided by EC Harris and a full financial appraisal was made, based upon the capital costs and the savings that each adaptation would incur. Consideration was also given with regards to the timescales at which these could be implemented in accordance with the building's maintenance and replacement cycles, the tenant's ongoing business requirements and the changing climate.

The Project Team

The project was led by BRE Wales and South West and involved a range of organisations from the building's design and development process. The BRE Trust-sponsored research team at Cardiff University provided the theoretical underpinning to the project and completed the building modelling process in IES. A brief description of each of the project partners and their role is provided below;

BRE Trust – Cardiff University

As the Building Systems and Informatics team are one of five BRE Trust-funded University Centres of Excellence, they were well-placed to deliver the work required for this project in a reliable and scientific manner. The team completed the building modelling using IES-VE and this improved upon the basic model supplied by Arup as a more detailed specification was provided by Admiral and the project Architect, Glenn Howells. Additional geometry of the surrounding buildings was input and the process utilized the climate datasets provided through Exeter University's PROMETHEUS project. The results of this process were refined and presented to the design team, the tenant and the developer providing the basis for the strategic discussion and the subsequent financial appraisal.

Thus, as stated, the work of this team provided the academic foundations to the project and hence it was essential that their methodology was robust so that reliable results were generated through the research process. Whilst much of the work was carried out by BRE Trust-sponsored PhD students, their actions were overseen by academic tutors within the department and the research has since been documented within the academic paper referenced in this report[7].

In all, the work completed by this team was accurately completed and was essential to the success of the project. Thorough analysis and clear data presentation informed the design team discussion and allowed sound decisions to be made with regards to development of the strategy. As the financial appraisal was based upon the modelling outputs, their work was also integral to the investment plan and thus the accuracy of this data was of paramount importance.

Admiral Group

Admiral Insurance Group are Wales' only FTSE 100 Company and are to be the tenants of the new office building. Since its launch in 1993, the company has grown significantly and now operate internationally, employing over 6000 staff. Their core business is in providing private car insurance both online and via the telephone, and so their new headquarters in Cardiff will predominantly function as a call centre operation. Hence, the development of the building had to satisfy this purpose and any adaptations made to the building had to consider this building use.

As Admiral commissioned the building of the office under the agreement that they will sign a 25 year tenancy agreement, they have had an active say in its design in order to ensure it meets their business requirements. As such, they have been influential in the development process and have a vested interest in ensuring low operational costs and in making long-term plans for its adaptation. For this reason, the head of the company's Estates Department attended all of the project meetings and participated strongly in the discussions around what changes would be suitable to make based upon their envisaged building use and business operations. For example, using a midday break to reduce the cooling demand was discounted as it was deemed to conflict with important working hours for the business. Hence, ultimately, the devised adaptation strategy had to be commercially satisfying to Admiral, whereby any energy savings achieved through building adaptations needed to be balanced against the output of their core business activity. Thus, overall, Admiral's role has been important in ensuring that the adaptation strategy is commercially viable and that it does not conflict with their envisaged use of the building.

Stoford

Stoford are the developer on the project and have a wealth of experience in delivering a range of schemes for a various tenants. The company has a 'green policy', aimed at delivering low energy buildings in an efficient manner, and aims to achieve a BREEAM Excellent rating and an EPC level A for all its buildings. Hence, whilst the company's primary motivation is to achieve a financial return on the scheme, they displayed an interest in the findings of the project and engaged in design team discussions relating to the possible adaptations. Working to their client's brief, Stoford's role in the project was similar to Admiral's in ensuring the commercial viability of the build.

Glenn Howells

As the Architect on the scheme, Glenn Howells were engaged in project discussions and advised on issue relating to design, Planning and the aesthetic quality of the building. Herein, advice was given on how certain adaptations would alter the building's appearance, and whether or not this would be acceptable to the city's planning department. This was valuable to the project as it helped guide the strategy towards a solution that was not only acceptable and feasible to the client but also to the local authority, who had a keen interest in the development given the its central, landmark location. They also advised on how adaptations would need to be implemented, which in turn, fed into the financial model as this informed the capital cost estimates made by EC Harris. For example, the team explained that to retrofit thermal mass into a steel-framed building would be a complicated process, involving lots of disruption, which would hence incur high capital costs and would be unacceptable to the client.

Arup

The building's Mechanical and Electrical design and specification was completed by Arup. The company has an international reputation, and has vast experience within the field. The company provided the initial building model for use in IES-VE. This included the geometry of the construction and the HVAC specification. As this model was only used to generate an EPC certificate, more data was required in order to complete a detailed study of the building's energy performance under future climate. Nevertheless, the model provided the key features required to commence the research and was thus integral to the project. The company also had a representative at the design team meetings, whom contributed to the discussions around the possible adaptations that could be made.

Hoare Lea

Hoare Lea are a large firm providing Mechanical and Electrical consultancy, and are retained by Admiral as expert advisors for their current developments. Their role in the development has been to ensure the quality of the work and the specification completed by ARUP was of an acceptable standard and suitable to the Admiral's business requirements. In this sense they had an incentive to lower the operational costs of the system and to advise on the optimum specification and the most suitable adaptations to implement.

They were represented at the design team meetings and advised on the likely developments in the efficiency of lighting and equipment, and on the viability of installing an improved M&E system. Furthermore, the team advised that because of the number of variables (climate, system and equipment efficiencies, capital costs, and energy prices) the reliability of future projected cost models past 2030 would be insufficient to allow for a detailed adaptation strategy to be planned past this point. Therefore, the projected predominantly focused upon a more medium-term strategy that, with only tentative recommendations made for the long-term.

EC Harris

As a leading Built Asset consultancy, EC Harris are highly-regarded and were appointed as quantity surveyors on the scheme. Consequently, their role within the research project was to provide detailed cost estimates for the adaptations that the design team had deemed practical to implement. A description of what the company would consider 'Industry Standard' for new-build and refurbishment was provided and the associated costs of these were compared with the improved, tailored specification that was outlined in the adaptation strategy.

As these costs formed an integral component of the financial appraisal, it was vital that they were truly representative of the costs that the adaptations would actually incur. As the estimates provided by EC Harris included a thorough breakdown of where the likely costs would be incurred, and incorporated preliminaries and overheads, BRE were satisfied that these were indeed reliable estimates. Thus, the role of this partner was well fulfilled and was essential to the success of the project.

Reflecting on the Approach

The overall research strategy applied within the project was straightforward and effective. The project partners were well placed to contribute to the development of the building adaptation strategy and each completed their relevant tasks thoroughly and dependably. The project utilized the most up-to-date and sophisticated computer software to develop a detailed model based upon a comprehensive, reliable dataset of the building's actual attributes. The climate data used was of a similarly high calibre as it was derived from the most recent projections made by the Met Office under UKCP09. Whilst it must be accepted that the sheer number of variables, make the formulation of a robust adaptation plan extremely difficult, BRE were satisfied with approach and with the tools and methods used in the development of the strategy. There were however, a handful of limitations in these tools that is worth reporting.

IES-VE

The software does not accurately reflect the implications of exposing thermal mass, given the complexity of actually implementing this adaptation work in practice. In this sense, the software appears to be somewhat rudimentary in assessing more passive design principles involving thermal mass and hence it may not be suitable for use on such buildings.

UKCP09 and the Weather Generator

The Weather Generator does not support batch file conversion and hence it would be very time consuming to generate detailed data using the tool. Whilst the UKCP09 data is of a very high quality, the use of the data in IES would have been extremely difficult impossible without the work of the PROMETHEUS project and hence it is recommended that this data could be made more usable in future developments.

As previously stated, the findings of the project can be more widely applied to other densely occupied office buildings with considerable internal heat gains and a high performing building fabric. The findings could be applied to both the design and operation of such buildings as the research found that whilst certain adaptations would not have been feasible to implement through a refurbishment approach, it would have been sensible to have incorporated them into the initial design and construction. Conversely, for existing buildings with a high cooling load, the research has highlighted the importance of specifying efficient lighting and equipment, and the effectiveness of implementing an adaptive comfort approach to the control of the heating and cooling systems. These were particularly important, given that the climate is predicted to become warmer and more humid. Moreover, the project has highlighted the fact that the underlying ideology of good-practice construction in the UK may not apply to all types of commercial office buildings. That is to say, that although limiting heat loss and improving air tightness are widely regarded as key characteristics of low energy buildings, these features was actually detrimental to the energy performance of the studied building. Nevertheless, it is worth expressing that although rather illuminating, the findings of the project should not be generalized across all buildings of this kind and a thorough modelling process would still be required in order to understand the performance of a given building.

As improvements in technological efficiency and changing working patterns occur over time, it is possible that the performance of building and the composition of their energy loads will be different to those of today. For this reason, remodelling of the building is advised under such conditions using the relevant data for the presently unknown variables. Therefore, it is recommended that the model be maintained and that future development of adaptation strategies should be devised using a Building Information Modelling (BIM) approach from the outset of the project, wherever possible. As this model could be easily accessed by the building's future tenants and owners, it would allow for such remodelling to occur more quickly and easily and would incur less cost than would otherwise be the case. Indeed, it is regrettable that this style of approach could not have been utilized under this project, due to the construction approach being applied on the scheme.

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Appendix 1: Plans and images of the new Admiral Office headquarters

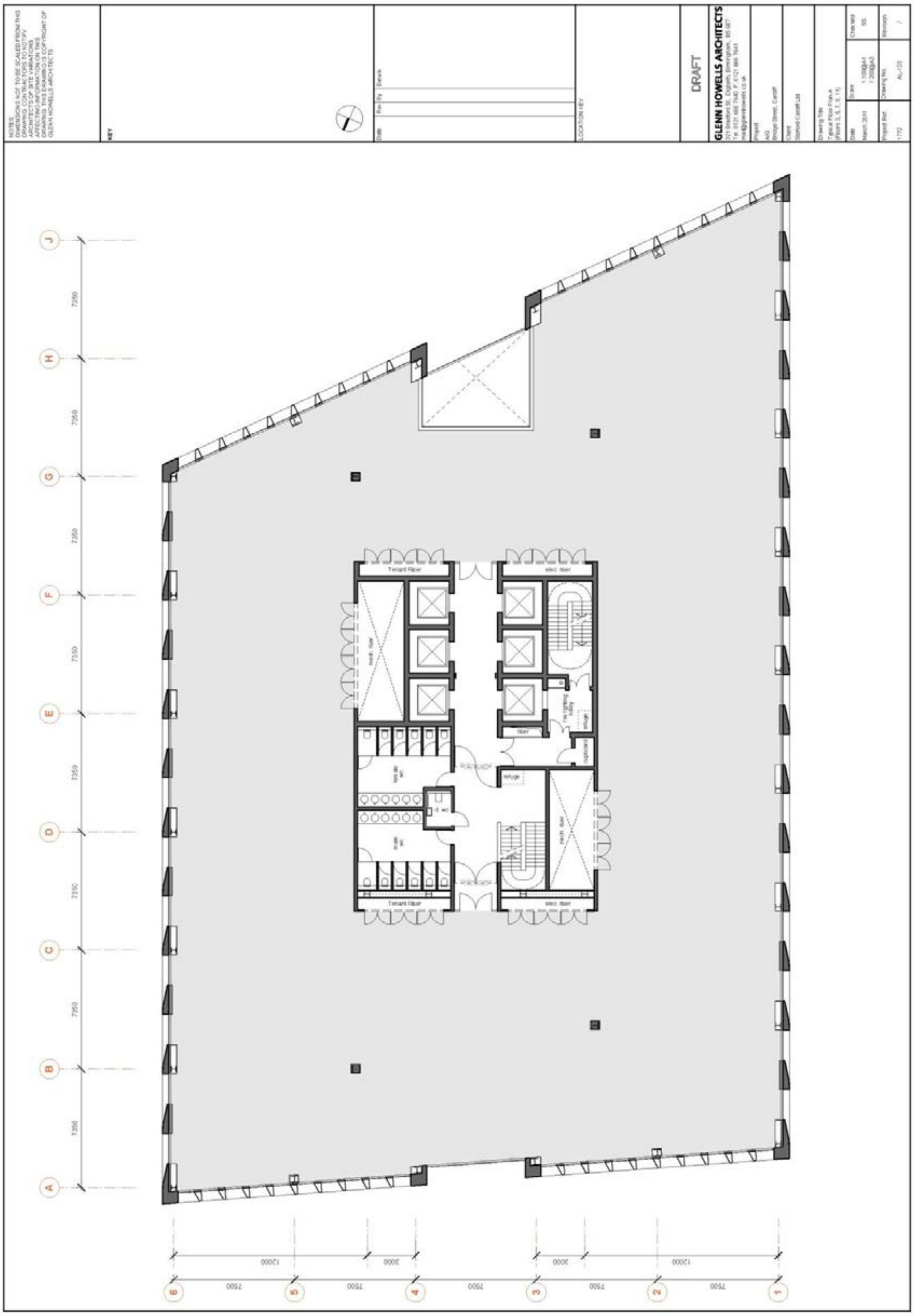
<u>Illustrative Masterplan of Office location</u>

Admiral Office External Entrance View

External View between Motorpoint arena and St David's 2 Shopping Centre

Admiral Office Internal Atrium View

Internal Floor Plan



Appendix 2: Flow diagram showing the method used in the PROMETHEUS project to create the probabilistic weather years

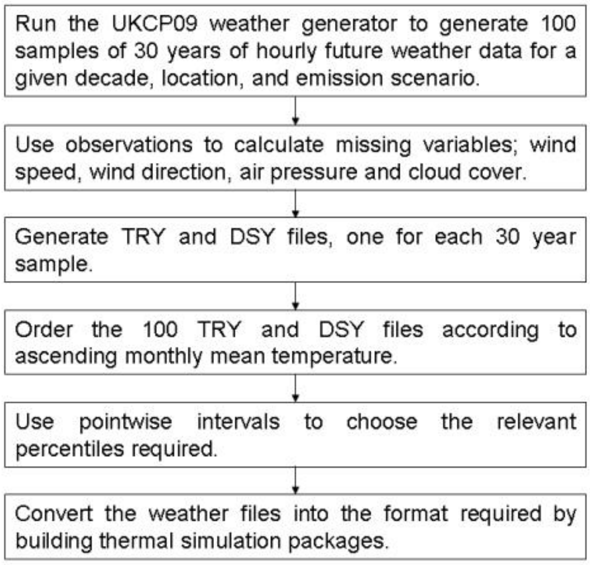


Figure 6 Flow diagram showing the method of creating future probabilistic weather years from the UKCP09 weather generator

M. Eames, T. Kershaw and D. Coley *Building Serv. Eng. Res. Technol.,* 32 127-142 (2011)

Appendix 3: Material properties of building fabric

Roof:	Admiral Roof 20% BRegs (U=0.2)			U Value:	0.2004
	Thickness (m)	Conductivity W/(m·K)	Density kg/m³	Specific heat capacity J/(kg·K)	Resistance (m2K/W)
STONE CHIPPINGS	0.01	0.96	1800	1000	
FELT/BITUMEN LAYERS	0.005	0.5	1700	1000	
CAST CONCRETE	0.15	1.13	2000	1000	
GLASS-FIBRE QUILT	0.13	0.03	12	840	
Cavity	0.1				0.17
CEILING TILES	0.01	0.056	380	1000	

Internal Partition:	13mm plaster 105mm brick 13mm plaster		U Value:	1.6896
	Thickness (m)	Conductivity W/(m·K)	Density (kg/m³)	Specific heat capacity J/(kg·K)
PLASTER (LIGHTWEIGHT)	0.013	0.16	600	1000
BRICKWORK (INNER LEAF)	0.105	0.62	1700	800
PLASTER (LIGHTWEIGHT)	0.013	0.16	600	1000

External Wall:	Admiral Wall 20% BRegs (U=0.28)		U Value:	0.2803
	Thickness (m)	Conductivity W/(m·K)	Density (kg/m³)	Specific heat capacity J/(kg·K)
BRICKWORK (OUTER LEAF)	0.1	0.84	1700	800
DENSE EPS SLAB INSULATION - LIKE STYROFOAM	0.058	0.019	30	1400
CONCRETE BLOCK (MEDIUM)	0.1	0.51	1400	1000

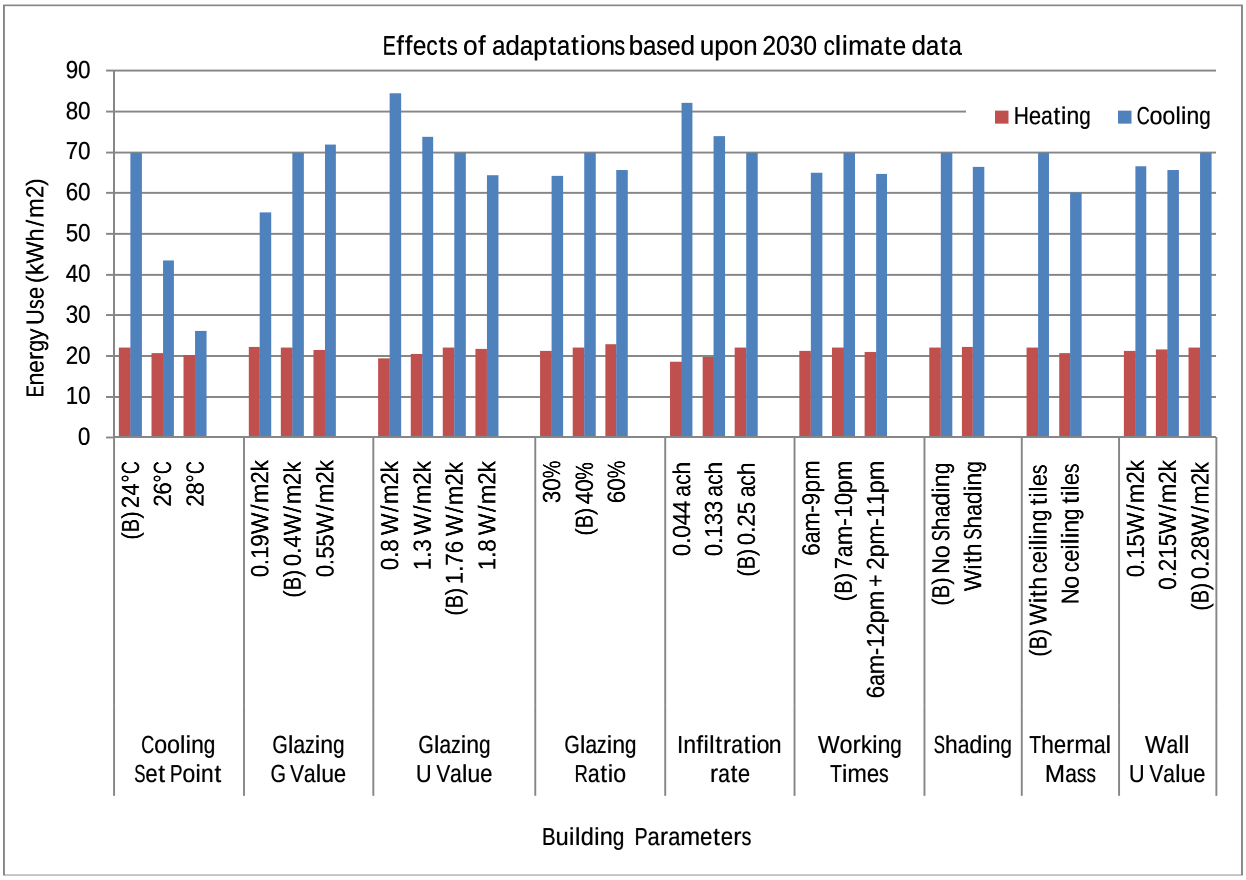
Ground Contact:	Admiral Floor 20% BRegs (U=0.2)		U Value:	0.2002
	Thickness (m)	Conductivity W/(m·K)	Density (kg/m³)	Specific heat capacity J/(kg·K)
LONDON CLAY	0.75	1.41	1900	1000
BRICKWORK (OUTER LEAF)	0.25	0.84	1700	800
CAST CONCRETE	0.1	1.13	2000	1000
DENSE EPS SLAB INSULATION - LIKE STYROFOAM	0.065	0.018	30	1400
CHIPBOARD	0.025	0.15	800	2093
SYNTHETIC CARPET	0.01	0.06	160	2500

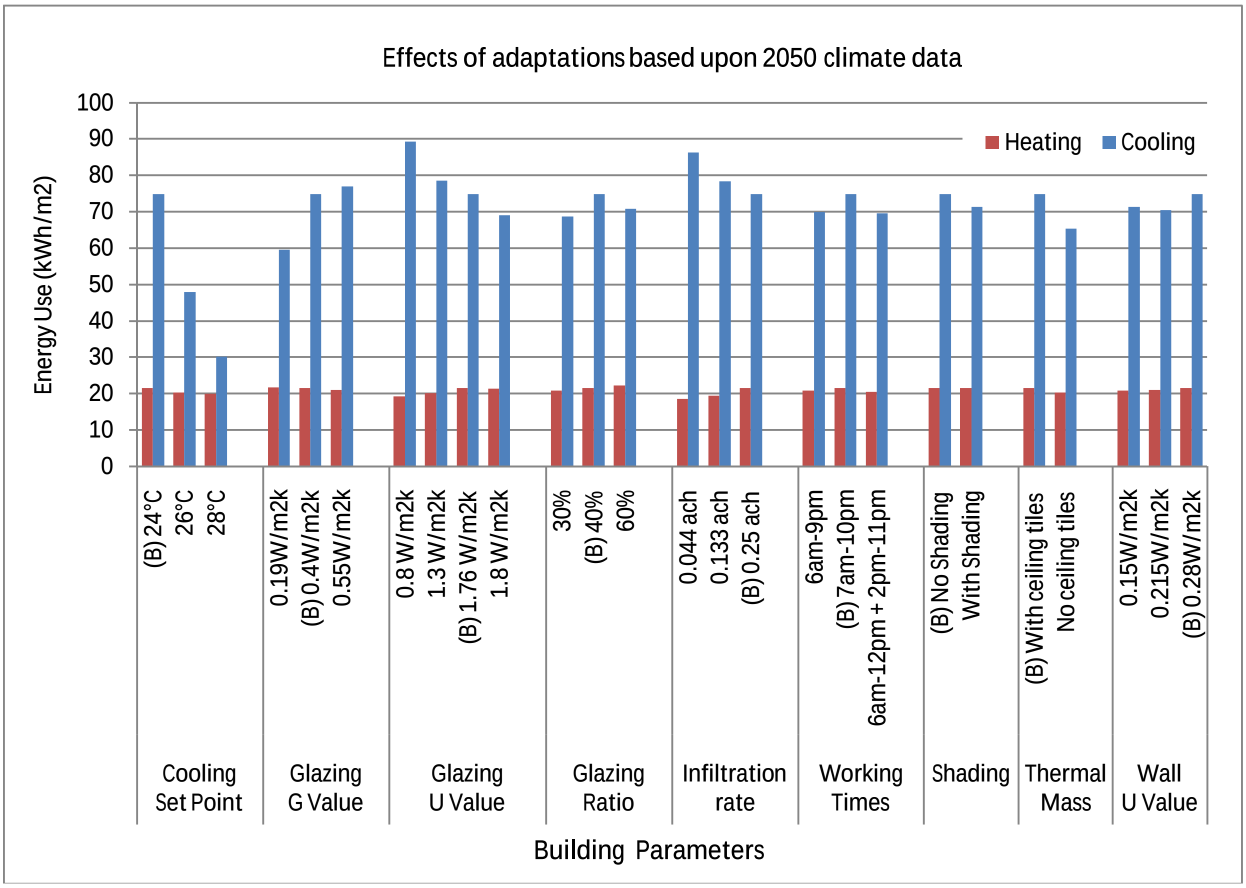
Internal Floor/Ceiling:	**Carpeted 100mm reinforced-concrete ceiling**	**U Value:**	**2.2826**	
	Thickness (m)	Conductivity W/(m·K)	Density (kg/m³)	Specific heat capacity J/(kg·K)
SYNTHETIC CARPET	0.01	0.06	160	2500
CAST CONCRETE (DENSE)	0.1	1.4	2100	840

External Windows:		**U Value Glass Only (W/m2K)**	**1.7351**	**U Value Including Frame (W/m2K)**	**1.7604**			
	Thickness (m)	Conductivity W/(m·K)	Pane coating side	Resistance (m²K/W)	Transmittance	Outside Reflectance	Inside Reflectance	Refractive index
PILKINGTON K 6MM	0.006	1.06	Uncoated		0.4	0.09	0.09	1.526
Cavity	0.012			0.395				
CLEAR FLOAT 6MM	0.006	1.06	Uncoated		0.78	0.07	0.07	1.526

Internal Windows:		**U Value Glass Only (W/m2K)**	**1.7503**	**U Value Including Frame (W/m2K)**	**1.8518**			
	Thickness (m)	Conductivity W/(m·K)	Pane coating side	Resistance (m²K/W)	Transmittance	Outside Reflectance	Inside Reflectance	Refractive index
Clear Float 6MM	0.006	1.06	Uncoated		0.82	0.07	0.07	1.526
Cavity	0.012			0.3				
Clear Float 6MM	0.006	1.06	Uncoated		0.82	0.07	0.07	1.526

Appendix 4: Adaptations based upon 2030 and 2050 climate conditions





Effects of adaptations based upon 2050 climate data
Heating
Cooling
Energy Use (kWh/m2)
100
90
80
70
60
50
40
30
20
10
0
(B) 24°C
26°C
28°C
0.19W/m2k
(B) 0.4W/m2k
0.55W/m2k
0.8 W/m2k
1.3 W/m2k
(B) 1.76 W/m2k
1.8 W/m2k
30%
(B) 40%
60%
0.044 ach
0.133 ach
(B) 0.25 ach
6am-9pm
(B) 7am-10pm
6am-12pm + 2pm-11pm
(B) No Shading
With Shading
(B) With ceiling tiles
No ceiling tiles
0.15W/m2k
0.215W/m2k
(B) 0.28W/m2k
Cooling Set Point
Glazing G Value
Glazing U Value
Glazing Ratio
Infiltration rate
Working Times
Shading
Thermal Mass
Wall U Value
Building Parameters