Waterman

PROJECT ANGEL

Final Report for Technology Strategy Board
Design for Future Climate Change: Adapting Buildings

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Comments Final for Issue

Our Markets

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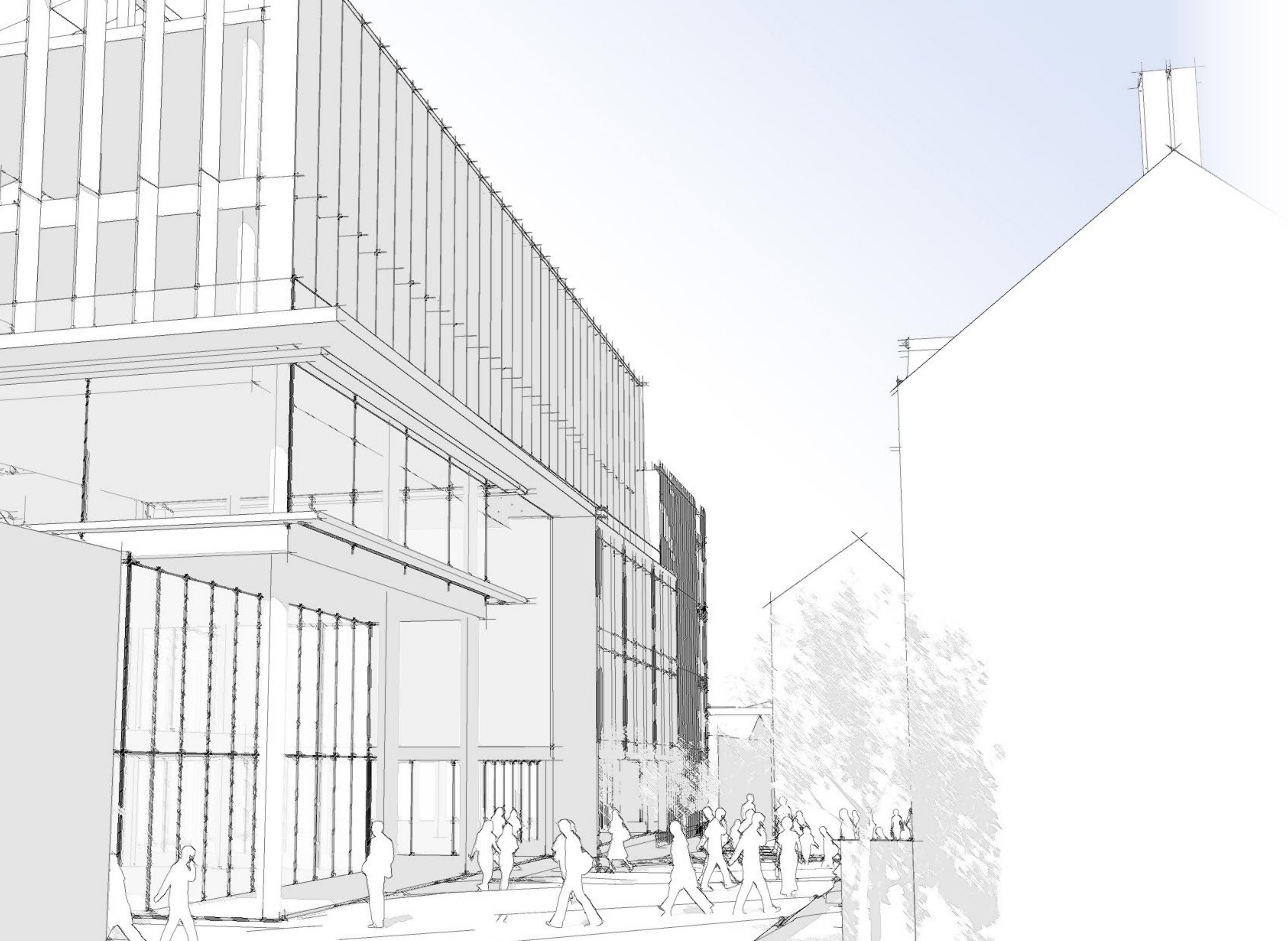

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Executive Summary

Waterman Energy Environment & Design Ltd (Waterman EED) has been awarded funding by the Technology Strategy Board (TSB) to prepare a climate change adaptation strategy for Project Angel

Building Profile
Project Angel comprises a new office building that would house Northampton County Council (NCC) staff. The development is a square perimeter building encircling a central atrium with an Ethylene tetrafluoroethylene (ETFE) roof. The proposed building comprises 10,041m^2 of office space for NCC, 3,813m^2 of lettable office space and 878m^2 of retail space.

The building varies from 3-5 stories around the perimeter, and is currently designed to have a predominantly glazed façade. The building would be mechanically ventilated, incorporate a small Photovoltaic array and would have two roof areas set aside for use as green roofs/ amenity spaces. NCC would like the building to achieve a BREEAM ‘Excellent’ rating.

Climate Change Risk Exposure
A climate change risk assessment, based on UKCP09 climate information, was carried out for Project Angel. This showed that the greatest risks of climate change faced by the building would be overheating, water stress and increased exposure to extreme weather events including flood and drought. Following the risk assessment, this study has focused on overheating risk.

Current guidelines on overheating in offices suggest that internal temperatures should not exceed 24°C±2°C (i.e. internal temperatures must not exceed 26°C) for mechanically ventilated buildings. In order to ensure that buildings being designed and built today can still be effectively used in the future, they need to be designed to take into account the increased temperatures associated with climate change. With regards to overheating this means ensuring buildings can maintain internal temperatures in line with the recommended building guidelines. Related to this are increased energy consumption and carbon emissions if increased cooling is required as well as the need for retrofit or upgrade of the building and M&E systems to ensure the building is performing. Overheating of buildings has been linked to reduced productivity and in severe cases has been known to have serious health effects on building occupants.

In order to mitigate the overheating risk, the following climate change adaptation strategies have been investigated:

The following climate change adaptation strategies have been investigated:

- Changing the percentage of external glazing;
- Changing the G-value of external glazing;
- External shading devices;
- Green Roofs; and
- Phase Change Materials (PCM)

Project Angel Adaptation Strategy
The benefits of the above climate adaptation strategies have been investigated by using dynamic thermal models to assess the baseline building against the Prometheus weather files. Overheating, energy and carbon emissions were used to judge the buildings ‘adaptation’ to the future climate scenarios. The strategies have also been compared in terms of the capital cost and carbon emissions.

All strategies showed some reduction in overheating, energy and carbon emissions. The study found the greatest benefits to result from reducing the G-value of the glazing and reducing the amount of external glazing. Using both of these techniques alone the modelled building did not exceed 26°C in any of the future climate scenarios.

The final adaptation strategy involves a combination of a reduced glazing percentage and a lowered G-value. The G-value varies across different areas of the façade depending on the levels of incoming solar gains in the control year. The proposed dimming lighting, this greatly reduced the energy consumption of the final design strategy and also made it easier to determine the impacts of reduced solar gains on available daylight.

The end result is a development that uses around 35% less energy than the baseline building and does not overheat. The proposed design also shows a far lower increase in energy use across the different weather files and climate scenarios than the baseline building. In the worst case scenario the proposed development shows a 6% increase in energy use between the control file and 1980 whilst the baseline building shows a 30% increase in energy use over the same period.

Lessons learnt
The initial timescales set for the project have slipped greatly, largely due to internal client issues resulting in the client putting the design process on hold in 2012 and appointing a new design team in 2013. As such the client has prioritised other projects over Project Angel. As the design process and this study have not run concurrently, it has been hard to tailor the design to their aspirations. Instead, through close communication with the original project architects, the design options that most suited the clients original aspirations where chosen to be taken forward at each stage.

As the study did not have sufficient time to wait for the re-appointment of the design team there has been some confusion towards the end of the process as to role the findings have to play in the final design of the building.

The findings of this study suggest that a building designed to meet Part L through sensible use of building fabric and solar gains analysis, rather than simply through the use of renewables, is likely to be resilient to increases in external temperature.

How can the findings be extended to other buildings
It is possible to extend the general principles of the findings to other buildings. For instance, for developments that have a large glazing area and solar exposure, reducing the internal gains will reduce overheating. The most effective way of reducing solar gains was shown to be reducing the glazing area and G-value. However it is also important to take into account the interrelationship between solar gains and daylight, as well as local variables such as external temperature that will also pay a key role in determining the effectiveness of adaptation strategies.

Figure 1: Project Angel Site Plans

The development being investigated for this study is called Project Angel (hereafter referred to as the Development). The Development comprises a new office building that would house Northampton County Council (NCC) staff. The Project Angel site (hereafter referred to as 'the Site') occupies an area of approximately 2.3ha and is located on the edge of Northampton City Centre. The Site is bounded by Angel Street to the north, Fetter Street to the east, St John's Street to the south and commercial properties on Bridge Street to the west. The Site is currently used predominantly as a car park with several single storey vacant brick buildings and garages located in the centre of the Site. There are also several two storey buildings on the northern boundary of the Site fronting Angel Street which are currently in commercial use. Access and egress to the car park is from Angel Street, with an additional access from St John's Street. The Site slopes from approximately 7m to 8m AOD from Angel Street down towards St John's Street (See Figure 1).

Land uses surrounding the Site are a mixture of offices, shops, bars and restaurants on Bridge Street (with possible residential uses on the upper levels of these properties); to the north is the County Club and the offices and car park of NCC and County Hall and to the east of the Site on Fetter Street are a number of commercial and light industrial uses such as a motor servicing and repair garage. To the south of the Site along St John's Street are the residential apartment development of St John's Court and the junction of St John's Street with Victoria Gardens with a former church (now restaurant) and warehouse beyond.

Key aims for the redevelopment of the Site are to create a development that would facilitate the regeneration of the area, strengthening the economic vitality of the town centre; and to create a low carbon, BREEAM 'Excellent', flexible office space capable of accommodating all of Northampton County Council (NCC) staff in a single location. The new Development would therefore include enough office space in order to relocate the majority of NCC staff in to a single office space, and potentially other NCC services (e.g. Library) as well as providing community space, commercial office space and retail space.

In total the Development would provide 10,041m2 of council office space, 3,813m^2 of lettable office space and 878m^2 of retail space. The proposed building is a 3-5 storey perimeter building that encircles a central atrium space which is to be used as a semi-public space (see Figures 2-6). The aim of the atrium is to provide a semi-public multi-functional space for the occupants and public.

There would be an accessible roof space on the east side of the 4th storey which is currently proposed to be used as amenity space for building occupants.

The NCC office space would be accessed from Angel Street whilst sub-let office space would have a separate access facing onto the Bridge Street gyratory. The retail units would be located on the ground floor and have a level threshold along St John's Street with some car parking spaces and drop off for deliveries, and for refuse collection along Fetter Street. Small retail units and a gym may also be situated along Angel Street to bring life into this area and highlight the Council's entrance on Angel Street.

The building façade would be predominantly glazed on all sides, with small unglazed areas spread throughout. The current design does not include any green roofs however it would use a combination of efficient cooling from chilled beams and a photovoltaic array on the 5th storey Fetter Street roof to reduce CO_2 emissions (see Section 2 for further information).

The building has been designed to meet BREEAM 'Excellent'. In order to achieve this level in BREEAM, a building must exceed a 25-30% improvement over Part L 2010; thus the base building was already designed to minimise energy consumption and attain a high standard of sustainability throughout.

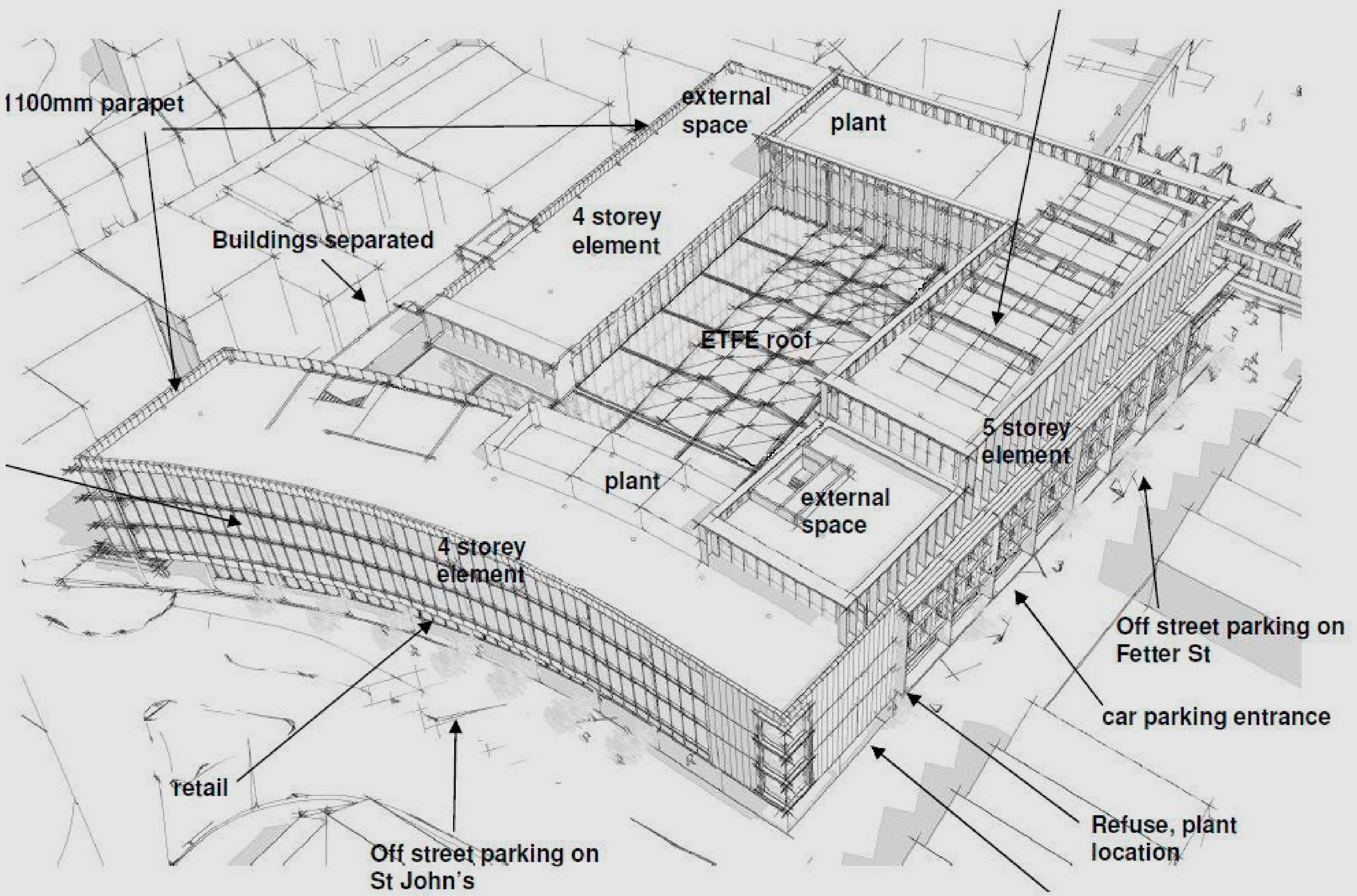


Figure 2: 3D view of RIBA Stage C design used for study

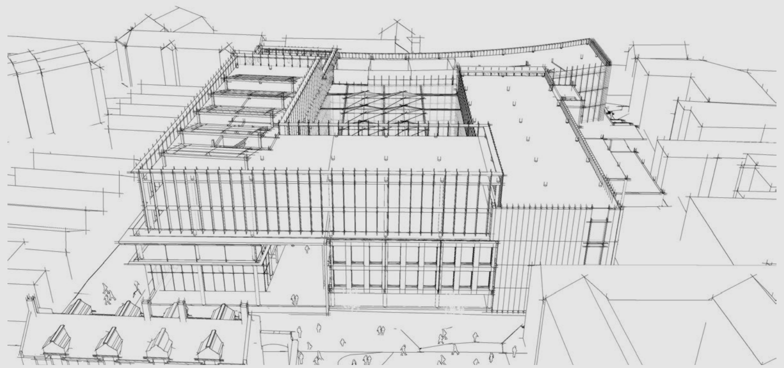


Figure 3: North Elevation

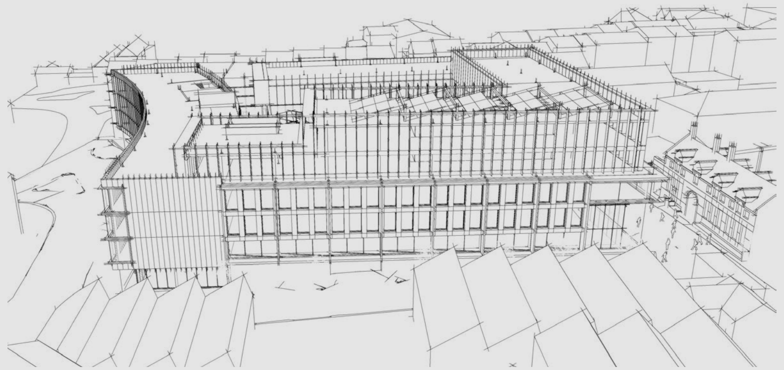


Figure 4: East Elevation

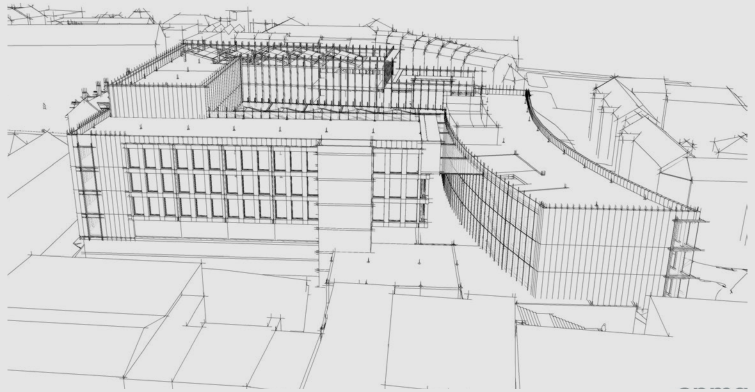


Figure 5: West Elevation

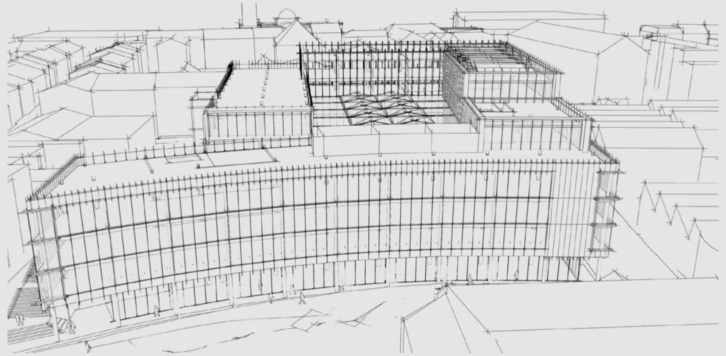


Figure 6: South Elevation

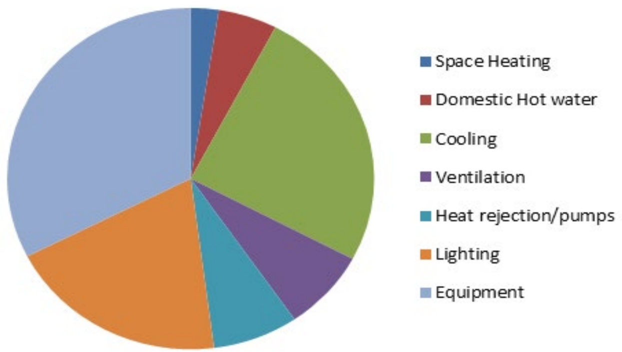


Figure 7: Breakdown of energy use in Project Angel in control year

Building Element	Performance Assumptions
Ground Floor	0.20 W/m²K
External Walls	0.20 W/m²K
External glazing	0.65 W/m²K
Roof	0.20 W/m²K

Table 1: Baseline Building Fabric Performance Assumptions

1.1 Mechanical Services

A breakdown of the energy consumption in the baseline building can be seen in Figure 7. From this it is clear that the main energy consuming uses within the building are cooling (25% of total energy use), lighting (20%) and equipment (unregulated energy, 33%). Space heating and domestic hot water consumption only accounts for approximately 8% of the total energy use within the building. It is expected that due to climate change, cooling will represent a larger proportion of the total energy consumption of the building in the future.

It is proposed that ventilation would be provided through roof mounted air handling units with variable speed drives to supply fresh air at a rate of 14 l/s/m^2. The supply air would be distributed via the core riser into the floor void where it will be distributed into the space via floor grilles, perimeter detail floor terminals or upstanding proprietary terminal units. It is anticipated that the passive cooling available from the supplied fresh air would be insufficient for the space and additional cooling units would be required. Thus chilled beams would also be used, with a cooling set point of 23°C. Condensing gas fired boilers are proposed for the supply of Low Temperature Hot Water (LTHW) for heating and domestic hot water (DHW) use. In order to reduce the demand on the mechanical plant an efficient building fabric with low air permeability is proposed, thus reducing unwanted losses and gains through the building fabric.

Impact / Probability	Insignificant	Minor	Moderate	Major	Catastrophic
Highly Likely	Low	Medium	High	Extreme	Extreme
Likely	Low	Medium	Medium	High	Extreme
Possible	Low	Low	Medium	High	Extreme
Unlikely	Low	Low	Medium	Medium	High
Slight	Low	Low	Low	Low	Low

Table 2: Risk Rating

Risk Rating	Action
Low	No action
Medium	Minor works required
High	Major works required
Extreme	Unavoidable risk

Table 3: Risk Rating Interpretation

2.1 Assessing Risk

The climate change risks for Project Angel have been assessed using a risk rating based on a multiple of the potential impact and the probability of the impact occurring. All climate prediction data in this report is based on UKCP09 Grid Square 1510 cumulative distribution function data. Table 2 shows how the overall risk was determined for each key climate change factor and Table 3 details the level action required with each risk level.

These risk ratings have been applied to the following three key risk areas in the built environment as identified by Bill Gething in his 2010 report 'Modelling for Future Climate Change' and specifically consider Project Angel (i.e. an office building within Northampton)[i] :

- Designing for comfort;
- Construction; and
- Managing water.

For the purposes of presenting the scenarios, the probability of occurrences being above the defined parameters of the weather data are given, with the emissions scenario stated. Therefore, "High 10" relates to the Prometheus data (see Appendix 3 Modelling report for more information) for the high emissions scenario and 10th percentile (i.e. there is a 90% chance that temperatures will be greater and so 90% chance of occurrence). The data used for the risk assessment has been extracted directly from the UKCP09 climate projections[ii].

[i] Gething, B., Design for Future Climate Change: Opportunities for adaptation in the built environment, Technology Strategy Board, 2010.

[ii] http://ukclimateprojections.defra.gov.uk/

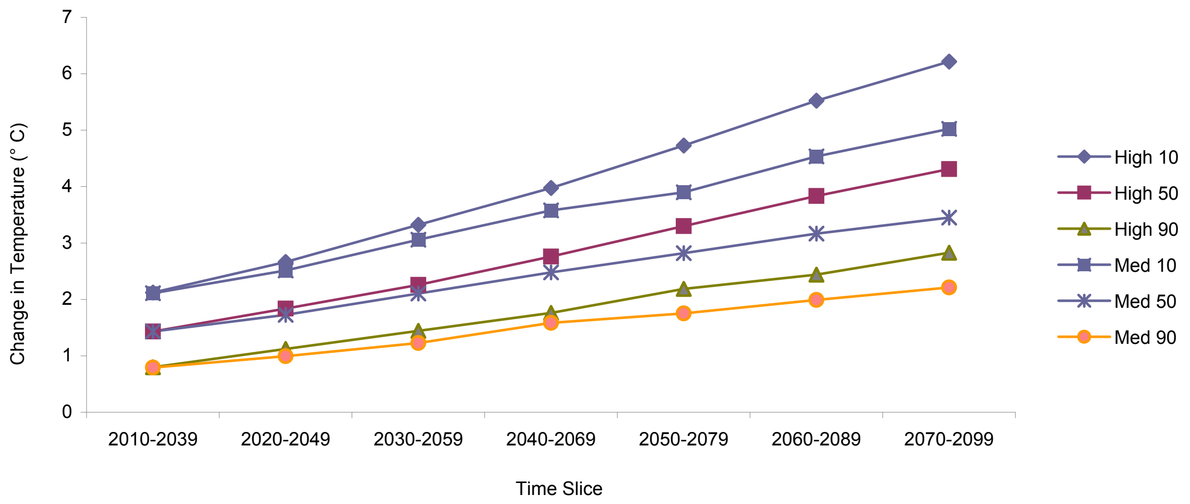


Figure 8: Annual change in mean temperature (°C) over time utilising high and medium scenarios based on probabilistic data[ii]

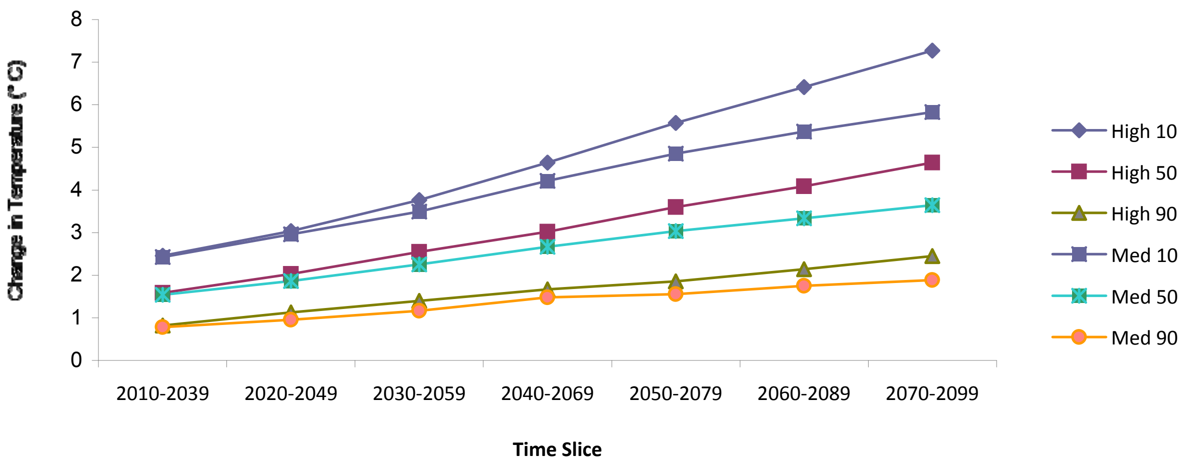


Figure 9: Change in mean daily maximum temperature (°C) over time utilising high and medium scenarios based on probabilistic data[ii]

2.1.1 Designing for Comfort

The annual change in mean temperature for Northampton over time is shown in Figure 8. This demonstrates that there is a 90% likelihood that based on medium and high emission scenarios the mean annual temperature in Northampton is likely to rise by between 2.2 °C and 2.8 °C by 2080 (see Figure 8). There is a 50% likelihood that on medium and high emission scenarios the mean annual temperature in Northampton is likely to rise by between 3.4 °C and 4.3 °C by 2080.

The change in mean daily maximum temperature approximately equates to day time temperatures. Figure 9 shows that there is a 90% likelihood that based on medium and high emission scenarios the change in mean daily maximum temperature in Northampton is likely to rise by between 1.8 °C and 2.4 °C by 2080. There is 50% likelihood that on medium and high emission scenarios the annual temperature in Northampton is likely to rise by between 3.6 °C and 4.6 °C by 2080.

The probability of overheating is greatest during the summer months. Figure 10 shows the mean summer temperature change over time. The graph shows that there is a 90% likelihood that based on medium and high emission scenarios the change in mean summer temperature in Northampton is likely to rise by between 2.2 °C and 2.5 °C by 2080. There is a 50% likelihood that on medium and high emission scenarios the mean summer temperature in Northampton is likely to rise by between 3.8 °C and 4.8 °C by 2080.

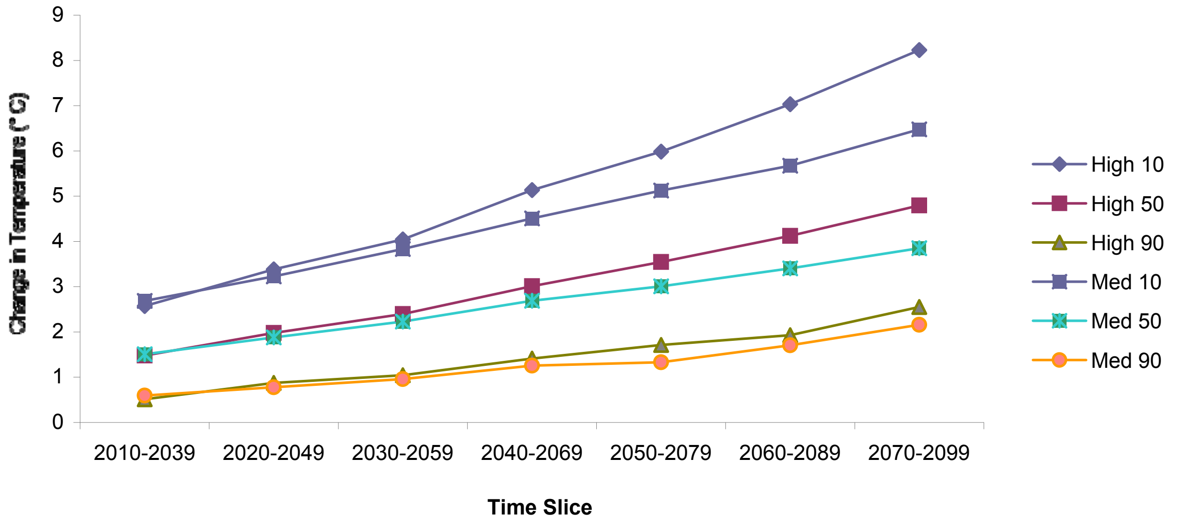


Figure 10: Change in mean summer temperature (°C) over time utilising high and medium scenarios based on probabilistic data[ii]

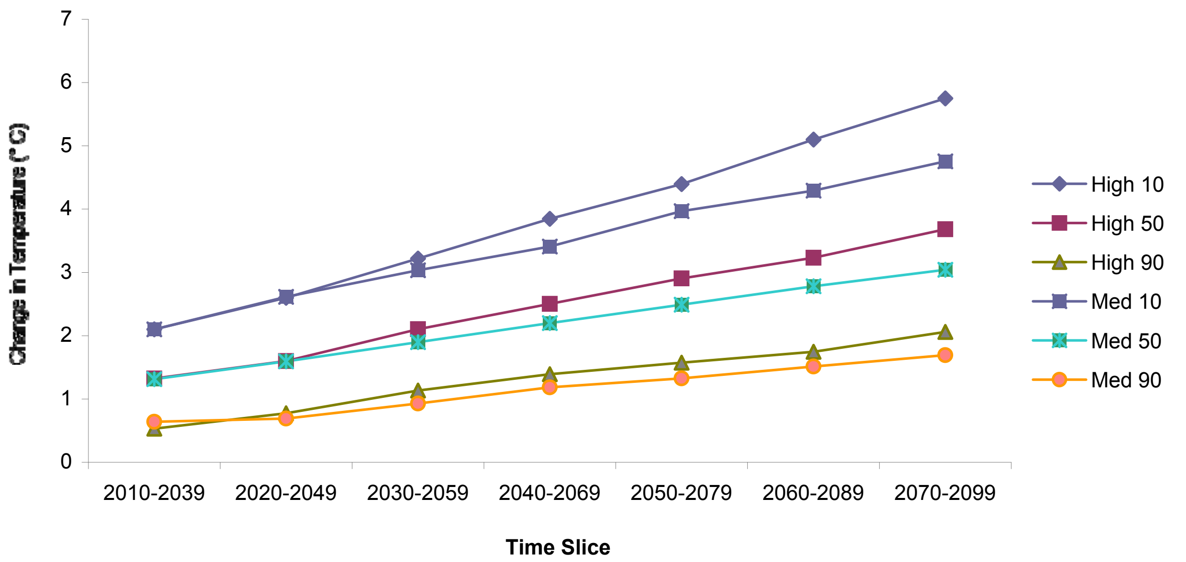


Figure 11: Change in mean winter temperature (°C) over time utilising high and medium scenarios based on probabilistic data[ii]

The major risk associated with increased annual temperatures is buildings overheating, which can cause physical discomfort and in extreme cases could lead to loss of life for vulnerable groups. For instance, the heat wave that hit Europe in 2003 resulted in the deaths of more than 37,000 Europeans[iii]. One of the main issues was that night-time temperatures remained high negating the effect of night-time cooling of buildings. Project Angel is unlikely to be used by vulnerable groups, however high internal temperatures will affect the productivity of workers[iv], cause heat stress and in extreme cases may result in the building being closed down affecting economic performance.

Buildings are currently modelled to achieve Building Council for Offices (BCO) internal temperature guideline of 24 °C +/- 2 °C . A study undertaken by the Chartered Institute of Building Services (CIBSE) and Arup defined a comfortable office temperature as 25°C, hot as 28°C and 35°C as a temperature above which there is a significant danger of heat stress. These temperatures assume a relative humidity of 50% and hence at higher humidity the perceived temperature will be hotter, and lower temperature thresholds should be considered. Overheating for the CIBSE and Arup study was defined as where the building exceeds 28°C for greater than 1% of the buildings operation.

The risk of overheating for this study has been assessed on the basis of exceeding the BCO guidelines in thermal models. The baseline building modelling for Project Angel showed that the building did not overheat until 2050, where it exceeded the required temperature range for the BCO guidelines for 3 hours a year. In 2080 the building overheated for 15 hours. Therefore the overall risk rating of overheating for office buildings in Northampton by 2030 is 'Low', by 2050 is 'Medium' and by 2080 is 'High'.

In addition to keeping the internal temperature cool, there is also a need to ensure external spaces are also kept cool. External temperatures may be exacerbated by the urban heat island effect. Consequently the same risk ratings as internal overheating have been attributed to maintaining cool external spaces. For Project Angel this would comprise the atrium/ courtyard area in the centre of the Site and the roof level amenity space, with the risk ratings for these external spaces being 'Low' by 2030, 'Medium' by 2050 and 'High' by 2080.

As shown in Figure 11, the trend is for milder winters, which are not considered to pose a risk. The need for space heating will be reduced; however this could impact on the efficiencies of some HVAC systems for example systems utilising heat recovery.

[iii] 'Summer Mortality: Deaths up in August Heatwave',Office of National Statistics, February 2005. www.statistics.gov.uk/cci/nugget.asp?id=480

[iv] Effect of Temperature on Task Performance In Office Environment, Olli Seppanen, William j Frisk, QH Lei, Helsinki University f Technology

[V] British Council for Offices, 24°C Study: Comfort, Productivity and Energy Consumption, January 2008

[vi] Beating the Heat: Keeping UK Buildings Cool in a Warming Climate, J N Hacker, S E Belcher and R K Connell, UKCIP Briefing Report, UKCIP, 2005. www.ukcip.org.uk under Publications

2.1.2 Construction

MLM have undertaken a Phase II Geotechnical and Contamination Assessment Report[vii] for the Project Angel Site which states that the ground underlying the Site is made up of, 'made ground', natural infill, Northampton Sands and Whitby Mudstone. The Northampton Sands were found to have low swelling / shrinkage potential whilst the Whitby Mudstone was found to have moderate swelling / shrinkage potential. The report recommends piled foundations suitable for the soil type, consequently the risk of ground issues with regards to climate change is considered low.

External damage by heating and cooling cycles needs to be considered when choosing materials. However, it is thought that materials currently available such as concretes and steels would be suitable for the predicted heating and cooling cycles for Project Angel. Consequently external structural damage is considered to be of low risk. Further, various materials are used in different climates around the world which withstand changes greater than that predicted for the UK.

Northampton is in a sheltered area of Britain with driving rain speeds of 33 litres/m2 per spell, based on maximum 'wall spell index' derived from BS8104 . It is anticipated that driving rain and wind speeds will increase in the future as a result of climate change however it is deemed to be a low risk for Northampton. However, it is prudent to design for driving rain and higher wind speeds where these would not add substantial costs to construction[i].

[vii] MLM, Project Angel Phase I Geotechnical and Contamination Assessment Report, May 2012

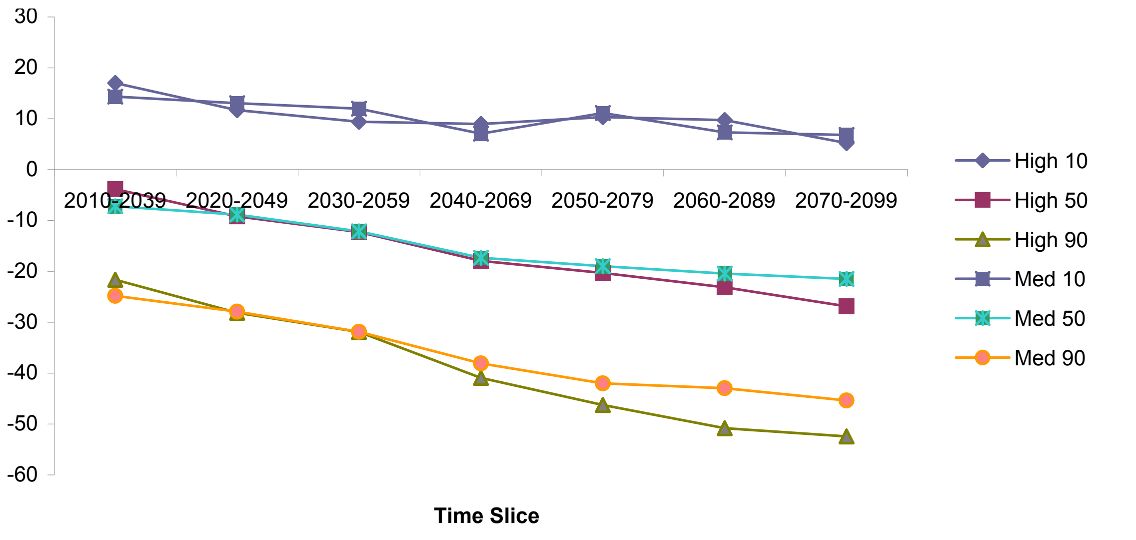


Figure 12: Percentage change in summer precipitation over time utilising high and medium scenarios based on probabilistic data[ii]

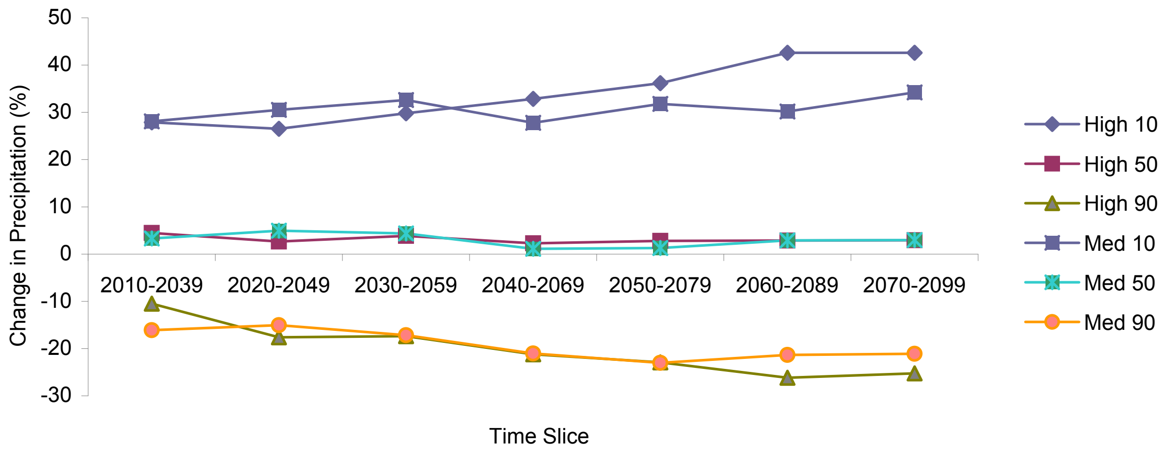


Figure 13: Percentage change in precipitation on the wettest summer day over time utilising high and medium scenarios based on probabilistic data[ii]

2.1.3 Managing Water

The total annual precipitation in the UK is unlikely to change dramatically as a result of climate change however there are likely to be wetter winters and drier summers.

The percentage change in precipitation during the summer season shows there is a 90% likelihood that based on medium and high emission scenarios, precipitation in Northampton is likely to reduce by between 45% and 52% by 2080. There is a 50% likelihood that on medium and high emission scenarios the percentage change in summer precipitation in Northampton would reduce by between 21% and 26%.

The percentage change in precipitation during the wettest summer day shows there is a 90% likelihood that based on medium and high emission scenarios the percentage change precipitation on the wettest day in Northampton is likely to reduce by between 21% and 25% by 2080. There is a 50% likelihood that on medium and high emission scenarios the percentage change in summer precipitation in Northampton would reduce by approximately 2% for both scenarios.

The percentage change in precipitation during the winter season shows there is a 90% likelihood that based on medium and high emission scenarios increase in precipitation in Northampton is likely to increase by between 46% and 62% by 2080. There is a 50% likelihood that on medium and high emission scenarios the precipitation in Northampton would increase by between 21% and 28%.

The percentage change in precipitation during the wettest winter day shows there is a 90% likelihood that based on medium and high emission scenarios the precipitation on the wettest day in Northampton is likely to increase by between 3.5% and 7.45% by 2080. There is a 50% likelihood that on medium and high emission scenarios the in summer precipitation in Northampton would increase by approximately 22% and 28%.

As can be seen in Figure 12 there is the potential for greatly reduced rainfall during the summer months resulting in localised drought. The risk rating for drought is based on the reduction

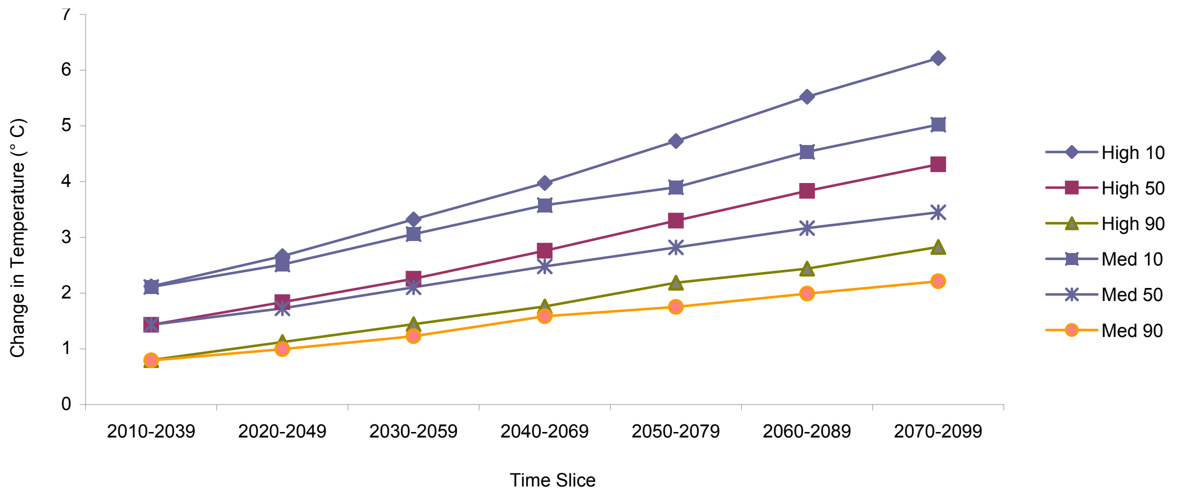


Figure 14: Percentage change in winter precipitation over time utilising high and medium scenarios based on probabilistic data[ii]

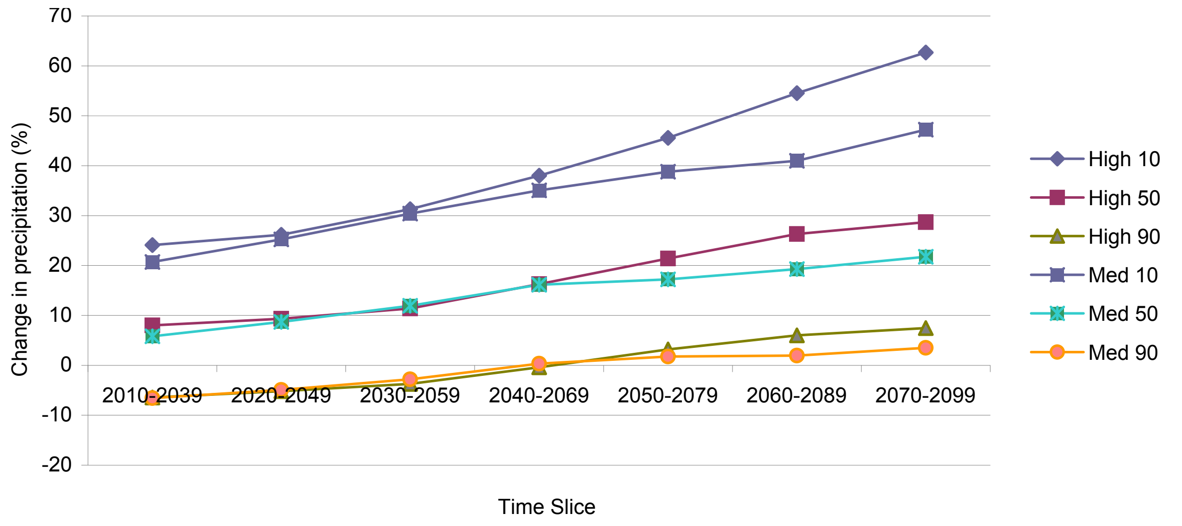


Figure 15 Percentage change in precipitation on the wettest winter day over time utilising high and medium scenarios based on probabilistic data[ii]

in precipitation during the summer months. Project Angel is a high water stress area[xi]; water demand in high stress areas exceeds the volume licensed for extraction with the shortfall being made up from ground water.

For the purposes of this risk assessment and in accordance with Gething (2010) Design for Future Climate Change: Opportunities for adaptation in the built environment, a reduction in summer rainfall of less than 20% is considered to have an insignificant impact, between 20% and 30% is considered to be of minor significance, between 30% and 40% is considered to have a moderate impact, and between 40% and 50% is considered to a major impact and in excess of 50% a catastrophic impact[i].

Therefore the overall risk rating of summer drought for buildings in Northampton by 2020 is 'Medium' and by 2080 is 'High'.

Figure 13 shows that the most likely outcome of the predicted climate change models is that there would not be an increase of precipitation on the wettest summer day. The medium model with a 10% likelihood shows that there would be an increase of 28% by 2020, 32% by 2050 and 34% by 2080.

As a requirement of planning and the Environment Agency[x xi], the drainage design for Project Angel would need to take into consideration climate change and flood risk mitigation (such as surface water attenuation and sustainable drainage), which would accommodate extreme flood events including a 30% allowance for climate change. This precautionary response to the uncertainty about climate change impacts is likely to mitigate for the predicted increase in rainfall (as set out by the UKCP09 data sets). Therefore a 'Low' risk rating has been applied

As there is thought to be a high risk of drought in the area, the building design should still include water conservation measures in order to reduce its potable water demand. This is possible through the use of low flush volume toilets, aerated taps and rainwater harvesting.

Parameter	1990 to 2025	2025 to 2055	2005 2085	2085 to 2115
Peak Rainfall Intensity	+5%	+10	+20	+30
Peak River Flow	+10%	+20	+20	+20

Table 4: Percentage change in precipitation on the wettest winter day over time utilising high and medium scenarios based on probabilistic data[ii]

[ix] Identifying Areas of Water Stress: Consultation Document, Environment Agency, 2007, p9. http://publications.environment-agency.gov.uk/pdf/GEHO0107BLUT-e-e.pdf

[x] Department for Communities and Local Government, National Planning Policy Framework, March 2012

[xi] Environment Agency National Planning Policy Framework – Flood and Coastal Change Risk Management, March 2012

2.1.4 Summary of Findings

The main risks for Project Angel are therefore predicted to be overheating and summer drought (i.e. water stress). Winter flooding and maintaining a cool external environment is also a concern for the medium to long term. By 2050, internal overheating and maintaining cool external spaces are 'Medium' rated risks and by 2080 drought is a 'High' risk.

Further investigation is required to establish the extent to which soils are vulnerable to expansion and shrinkage and what long-term effect this could have on the building. However, the use of piled foundations should mitigate for this issue[vii].

Drought issues would be addressed by best practice water conservation measures including water efficient fittings and fixtures, rainwater harvesting and re-use and grey water recycling. This study does not specifically address drought as the client is more concerned with the issues associated with overheating, however design options which benefit drought risks will be highlighted.

Additionally, as stated above, it is prudent to design for driving rain and higher wind speeds where these would not add substantial costs to construction as this will increase the life span of the building envelope. This should be considered in future design development and is not covered in the scope of this study.

This study therefore focuses on the overheating risk associated with hotter summers and milder winters for both internal and external spaces.

Climate Change Factor	Risk for Northampton		
	2020	2050	2080
Internal Over Heating	Low	Medium	Medium
Maintaining cool external spaces	Low	Medium	Medium
Soil swelling / shrinkage	Low	Low	Low
External structural damage	Low	Low	Low
Driving rain	Low	Low	Low
Flood risk	Low	Low	Low
Drought	Medium	Medium	High

Table 5: Risk Matrix

2.2 Modelling the Building and Testing the Adaptation Strategy

This study has used two forms of computer software to analyse the effects of climate change scenarios and different design solutions. The first, Integrated Environmental Solutions (IES) Virtual Environment (VE) suite of software, is dynamic thermal modelling software. The second, ENVI-met has been used to model the micro-climate effects of green roofing, the findings from which have been fed back into IES VE to assess the impact of green roofs on the internal conditions of the building. A baseline building based on the RIBA Stage C building design (provided by the project Architect (CPMG)) has been used as the point of comparison for the various adaptation design options.

In order to model future climate scenarios Prometheus[xii] weather files have been used. The Prometheus weather files are produced for specific locations across the UK. However, there is no weather file for Northampton, thus the Bicester weather file was chosen as it was the closest weather file available to the Site and it is therefore considered to be representative of conditions in Northampton.

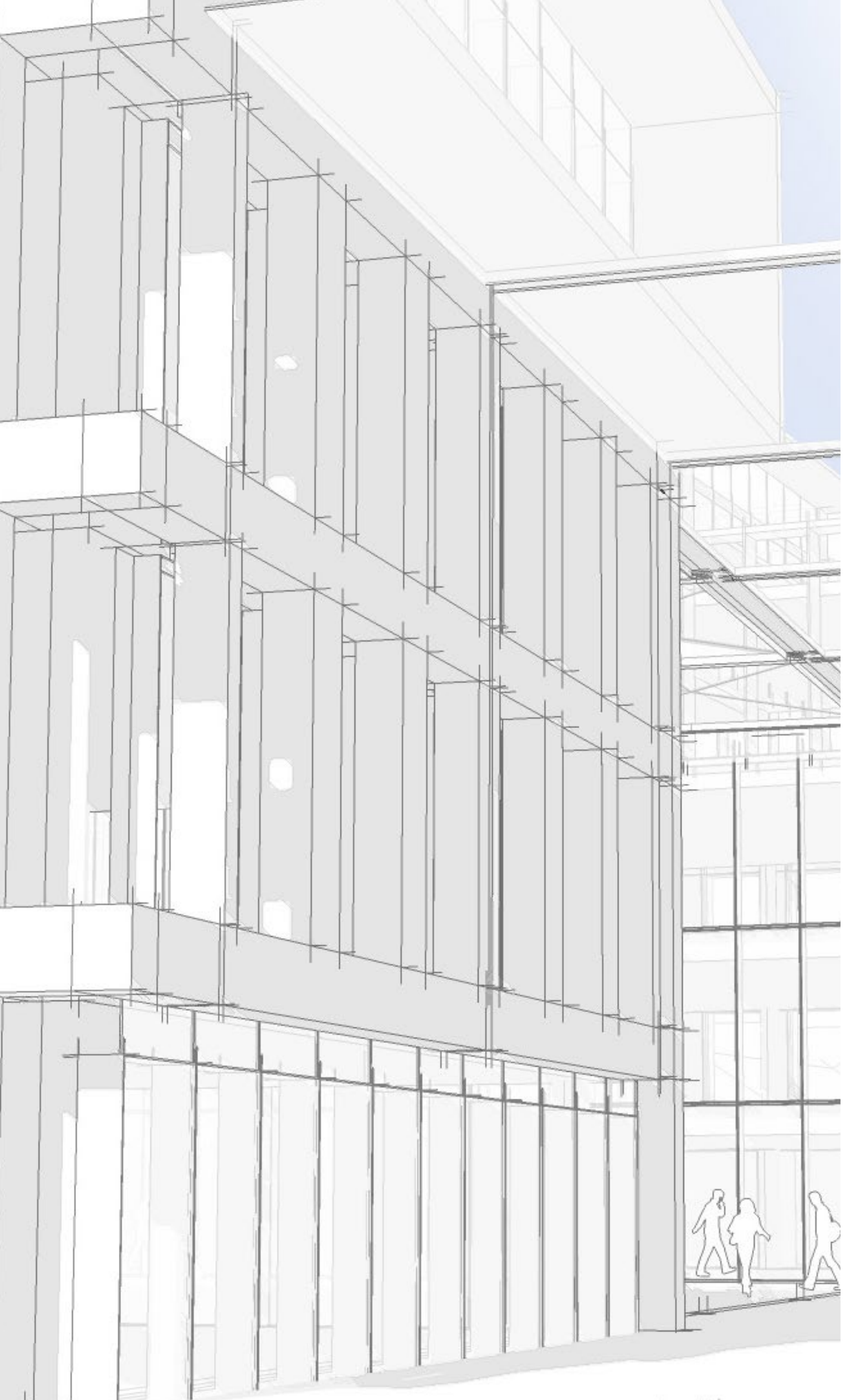
The Prometheus weather files have been produced by Exeter University and are based on the UKCP09 climate predictions produced by the Met Office in 2009. For each year there are high and low emission scenarios and the probability of the weather data being representative of actual future data is also considered. The probability of certain climate changes occurring was determined using UK Climate Projections (UKCP09) data, which provides probabilistic projections. The predictions provide data for 10%, 33%, 50%, 66% and 90% probabilities. These percentages are the probability that the actual climate change will be less than defined. Hence for the 10th percentile, it is 90% likely that the climate change will greater. The opposite is true for the 90th percentile, with a 10% chance that the climate change will be as defined, and a 90% chance that changes will not be as severe. Finally, weather data is defined for the years 2030, 2050 and 2080, as well as the control file which represents the current climate.

There are also three emissions scenarios represented in Prometheus weather files; High, Medium and Low. The emissions scenarios were established through the Intergovernmental Panel on Climate Change (IPCC) in order to establish future climate changes. These were originally created in 1992, and have subsequently been reviewed and amended with the current scenarios being established in 1996. They describe four different storylines to determine the changes in human growth and energy demands, as well as the means through which energy is provided, be it through fossil fuels or greater amounts of renewable technologies.

These scenarios are based on the A1 storyline, a climate projection which describes a future with very rapid economic growth. The A1 scenarios develop into three groups that describe alternative changes in the source and use of energy, and are defined as: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B). The weather data defines these three scenarios as high emissions (A1FI), medium emissions (A1B), and low emissions (A1T).

Recent evidence from the European Energy Agency predicts that some countries that have signed up to the Kyoto protocol will not meet their targets[xiv]. Further, the recent unsuccessful attempts to create legally binding carbon reduction targets in the recent Rio+20 summit reiterate this conclusion. Therefore the 'medium emissions' and 'low emissions' scenarios were not considered in this study as there is very little chance of emissions being reduced to the required levels in the short-term. For the purpose of the initial options review the 90th percentile, high emission scenarios have been used, in order to provide a 'worst case' scenario. The weather data for the years 2030, 2050 and 2080, as well as the control file have been used. The control weather file represents the average weather profile from 1961 – 1990.

The final adaptation strategy for the development and the baseline building would be modelled against all the climate scenarios represented in the Prometheus weather files.



2.3 Other factors Affecting the Adaptation Strategy

It is the desire of Northampton City Council (The Client) that the building remains mechanically ventilated, This is driven by the letting agent's suggestion that should the client wish to let the office space in the future (instead of keeping it for their own use) it would be more valuable if it is mechanically ventilated rather than naturally ventilated.

The Client is also working to a limited budget, as such the financial implications of any climate change adaptation measures must be taken into account when developing a suitable adaptation strategy .

3.1.1 Design Considerations

The following initial design options were considered for the study going forward to address comfort and overheating issues[viii].

Designing for Cooling – Building

- Shading – manufactured, building form and planting;
- Glass and film technologies;
- Green roofs / transpiration cooling;
- Reflective materials;
- Conflict between maximising daylight and overheating (mitigation verses adaptation);
- Secure and bug-free night ventilation;
- Interrelationship with noise and air pollution;
- Interrelationship with ceiling height;
- Role of thermal mass in significantly warmer climate;
- Enhancing thermal mass in lightweight construction;
- Energy efficient / renewable powered cooling systems;
- Groundwater cooling;
- Enhanced control systems – peak lopping; and
- Maximum temperature legislation.

Designing for Cooling – External Spaces

- Built form – building to building shading;
- Access to external space – overheating relief;
- Shade from planting and manufactured shading;
- Interrelationship with renewables;
- Shading parking / transport infrastructure; and
- Role of water – landscape / water bodies.

Designing for Warmth

- Building fabric insulation standards;
- Relevance of heat reclaim systems; and
- Heating appliance design for minimal heating – hot water load as design driver.

Designing Options Considered for the Study

Following from the above risk assessment, a risk assessment workshop was carried out with the design team on 11th January 2012 (see Section 4.2 for a full list of design team members). The workshop outlined the following adaptation strategies as areas that would be most applicable for Project Angel:

- Percentage of glazing and G values (with potential future replacement of glazing with solid panels);
- Variations of shading on the south east and west elevations;
- Base scheme has been future proofed to allow M&E retro fit in the future (space allocation for additional plant). Investigate the tipping point for M&E retro-fit and the effect accepting higher internal comfort criteria would have on the life of the M&E plant;
- Use of Phase Change Materials (PCM) for future internal partitions; and
- Investigate the effect of differing sizes and type of green roof.

3.1.2 Study Findings

Green roofs

There were two main benefits seen from the addition of green roofs to Project Angel. Firstly, the reduction in Mean Radiant Temperature (MRT) above the surface of the roof; as part of the green roof on Project Angel would be designed for amenity access, the reduction in MRT would be beneficial for individuals who wished to use the space during the summer months. The second benefit is a reduction in the number of days exceeding 26°C in 2080, although only a small reduction in overheating was observed in the study.

Green roofs were highlighted as presenting the greatest opportunities for retro-fitting buildings (with suitable structural designs) and provide a multifaceted adaptation climate change strategy (i.e. a building that is likely to suffer from increased extreme rainfall events and internal and external overheating) as well as providing biodiversity enhancements. Furthermore green roofs have additional value if they are also used as external amenity space.

However with the decrease in summer rainfall set out in the UKCP09 climate predictions drought tolerance is a likely issue that will arise with green roofs when looking at future weather scenarios. Furthermore during periods of low water use, green roofs may also require additional irrigation; this would in turn have negative impacts on water availability during periods of drought.

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This would have greater implications for intensive green roofs than extensive green roofs.

Glazing percentage
Reducing the percentage of glazed façade had a large impact on the overheating of the building. By reducing the glazing to 65% the overheating reduced by approximately 60% in 2050 and 80% in 2080. The improvement in the building fabric (through replacing the glazed façade with a solid build up) improved the U-value thereby reducing the heating load of the building. This was the only adaptation strategy that showed an improvement in both heating and cooling loads of the building.

Reducing the amount of glazing on the façade would also reduce other issues that may be associated with a fully glazed façade such as glare. Furthermore, reducing the amount of glazing is the only design scenario that resulted in a reduction in the cost of the development. 2%, 3% and 5% savings were seen in the 65%, 50% and 25% glazing scenarios compared to the baseline building. Due to the reduced capital cost, reducing the amount of glazing on the façade presents itself as a good adaptation strategy whilst having a minimal impact on the capital costs. However reducing the glazed façade also has a tipping point at which the increases in the lighting demand and fabric performance (lower u-value buildings stay warmer in summer as well as winter) outweigh the benefits seen by reducing the incoming solar gains. Reducing the Glazing below 65% was shown to increase the energy use, in particular through electrical lighting. It is important to weigh the importance of daylight against the impacts of solar gains.

G- Value
Reductions in the G-value of the external glazing were found to result in a decrease in the summer overheating in 2050 and 2080 and, in turn, a reduction in the cooling load and associated carbon emissions. It is also likely that a building such as the baseline building used in this study will experience glare issues. By reducing the G-value of the glazing there would be reduced glare with the building; this is especially important in areas where computers will be used.

As with the amount of glazing on the façade, the benefits of the increased G-value also have a tipping point at which the impact on lighting load and associated internal gains outweigh the benefits of the decreased solar gains. For this reason the G-value in the proposed design was modified depending on the incoming solar gains.

Shading
Shading can reduce solar gains without the need to reduce the light transmittance of the glazing, and hence daylight levels are likely to be higher than for an equivalent solar control glass. 1m horizontal shading showed a small reduction in the number of hours spent overheating when applied to one façade, which increased when the shading was applied to the south, east and west façades. However, the reductions in overheating and cooling demand were only small and the shading was also associated with an increase in the winter heating loads.

Vertical shading was found to be less effective at adapting the building to climate change than horizontal shading. Furthermore vertical shading was also shown to have a worse impact on heating loads than horizontal shading, showing a larger increase in the energy demand from heating. This is thought to be due to the angle of the sun at different times of the year. In the summer, when the sun is high in the sky (and thus solar gains are coming from above at the hottest times of the day), horizontal shading would provide more protection. However in winter (when solar gains are beneficial), when the sun is lower in the sky (and thus the solar radiation travels in a more horizontal plane) the vertical shading provides the greatest reduction in incoming solar gains.

Mid plane blinds were also investigated as part of the study. These were shown to reduce the amount of incoming solar gains. However, the energy savings observed in many scenarios was negated by the increased lighting loads. As such mid-pane blinds were not used in the final design.

Other Findings
By incorporating daylight linked dimming control into the lighting design the cost and benefits of the various strategies become more apparent. Only when a dimming strategy rather than absolute on/off lighting strategy was used were the differences in daylight availability between the different strategies apparent.

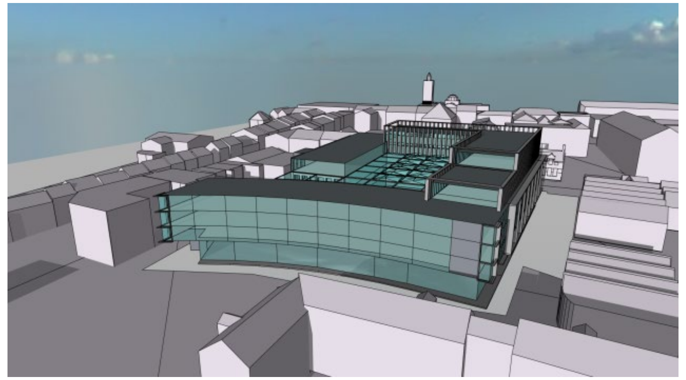


Figure 16: Render of proposed building design

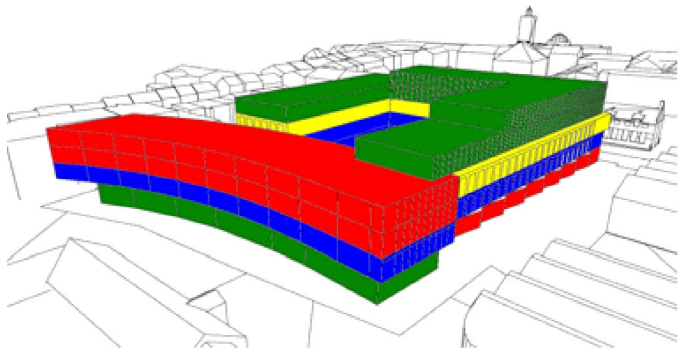


Figure 17: Suggested modification of g-values required to adapt building to climate change. Green = 0.25; Yellow =0.3; Red= 0.35; Blue = 0.4

3.1.3 Adaptation Strategy

The final building has been designed to reduce the amount of solar gains entering the development whilst minimising the impact of reducing the incoming solar gains on available daylight. The result is a building with a slightly reduced glazing area and modified G-values. The proposed design has 69.2% of the total façade glazed, compared with 82.4% in the original design (see Figure 17). Furthermore the glazing within the proposed building design has a G-Value of between 0.4 and 0.25 across the facade depending on the amount of incoming solar gains whereas in the baseline building the G-Value is 0.6 across all the glazing (see Figure 17). The proposed design also incorporates daylight sensored dimming lights, rather than the on/off lighting used in the baseline building. The differences between the baseline building and the final proposed design are outlined in Table 6.

The result of the proposed adaptation strategy is a development that demonstrates resilience to increasing external temperatures and maintains an acceptable level of indoor thermal comfort across all design scenarios. The proposed design strategy offers a building that has a substantially lower energy use than the baseline building and has been based on the principles of minimising the incoming solar gains whilst maximising the available light in the development.

Key to the success of the strategy has been introducing a lighting control system that is responsive to external light levels, and dims in accordance with incoming solar gains. The main limiting factor observed when investigating reducing the glazing area/g-value beyond that used in the proposed design was the impact this had on the lighting loads of the Development.

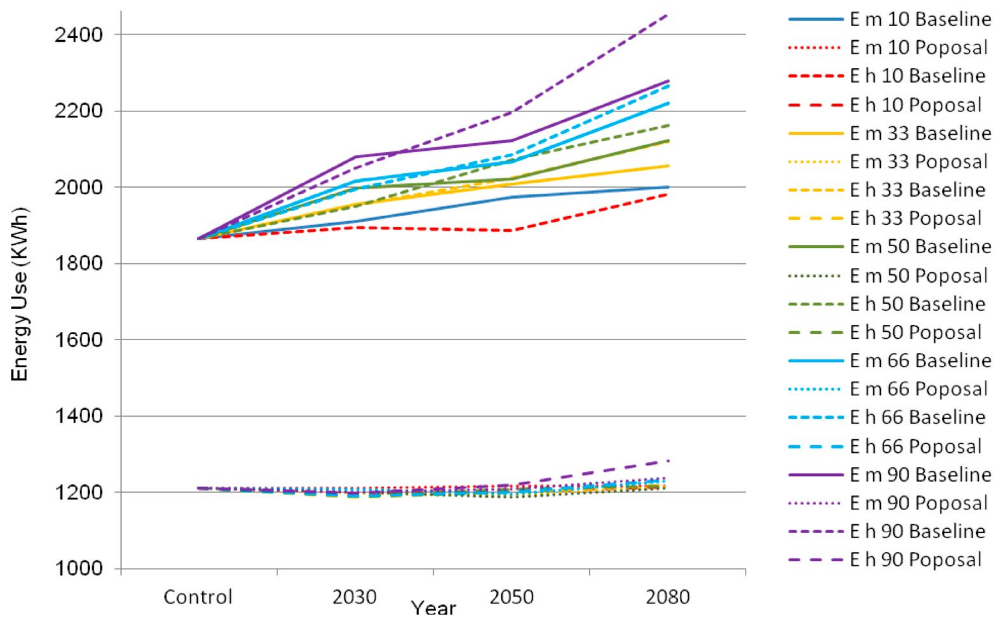
Figure 18 shows a comparison of the energy use in the baseline building and the proposed design for all climate projections available for the site from Prometheus. The graph shows a distinct difference in the energy consumption between the two designs with the proposed design using over 35% less energy than the baseline building in the control year. Furthermore variations in the energy consumption of the proposed design are far smaller both between climate scenarios and between the control and 2080 than the baseline building. This suggests that the proposed development is more resilient to fluctuations to changes in the climate than the baseline building.

Overheating analysis also showed that at no time during the assessment does the proposed design overheat, unlike the baseline building which overheats from 2050 onwards (see Table 7).

Modelling Element	Assumptions	
	Baseline	Final Building
Building Fabric	Ground Floor – 0.20 W/m^{2}K External Walls – 0.20 W/m^{2}K External Glazing – 1.50W/m^{2}K *(82.4% of the façade is glazed, G-value 0.60)* Roof – 0.20 W/m^{2}K	Ground Floor – 0.20 W/m^{2}K External Walls – 0.20 W/m^{2}K External Glazing –1.50W/m^{2}K *(69.2% of the façade is glazed, G-value 0.40 – 0.25 depending on solar gains)* Roof – 0.20 W/m^{2}K
Internal Gains	Lighting - 9.0 W/m^2 Equipment – 15 W/m^2 Occupancy – 6m^2/person, 70W sensible, 70W latent per person	Lighting - 9.0 W/m^2 Equipment – 15 W/m^2 Occupancy – 6m^2/person, 70W sensible, 70W latent per person
External Shading	N/A	N/A
Green Roof	N/A	N/A
Ventilation	14 l/s per person fresh air supply	14 l/s per person fresh air supply
Air Permeability	3.0 m^3/m^2.hr @ 50Pa	3.0 m^3/m^2.hr @ 50Pa
Time Profile	Internal gains and system operation hours set to 08:00 – 18:00, Monday to Friday. Lighting on daylight sensors.	Internal gains and system operation hours set to 08:00 – 18:00, Monday to Friday. Lighting on daylight sensors w/ dimmers.
HVAC Sytems	Chilled Beams with displacement ventilation throughout Heating via condensing gas-fired boilers Cooling from electric heat pump Plate heat exchanger for ventilation (65% efficient) Instantaneous electric point of use hot water	Chilled Beams with displacement ventilation throughout Heating via condensing gas-fired boilers Cooling from electric heat pump Plate heat exchanger for ventilation (70% efficient) Instantaneous electric point of use hot water

Table 6: Comparison of Baseline and Proposed Building

Figure 18: Graph showing the energy use for the proposed and baseline design for all weather files. M=medium emissions scenario, h= high emissions scenario, Number refers to the likelihood of the weather being as predicted.



Scenario	Internal Air temperature (°C) - hours in range					
	> 23.00	> 24.00	> 25.00	> 26.00	> 27.00	> 28.00
Baseline Building (Control)	1	0	0	0	0	0
Proposed Building (Control)	0	0	0	0	0	0
Baseline Building (2030)	5	3	0	0	0	0
Proposed Building (2030)	0	0	0	0	0	0
Baseline Building (2050)	30	16	6	3	3	2
Proposed Building (2050)	0	0	0	0	0	0
Baseline Building (2080)	47	27	20	15	11	3
Proposed Building (2080)	0	0	0	0	0	0

Table 7: Table showing overheating comparison for high emissions 90th percentile weather file for the baseline and proposed design

3.2 Timescales of Implementation

It is the intention of the proposed design that the adaptation measures would be implemented from the outset as part of the strategy used to achieve BREEAM 'Excellent'. In order to achieve BREEAM 'Excellent' the Development must demonstrate a 25% improvement over Part L 2010. As such all adaptation measures will be required in order for the development to achieve BREEAM 'Excellent' unless more renewable technologies are used.

3.3 Cost benefit analysis and risk mitigation of implementing adaptation measures

Lowering of the G-value across the façade will increase the initial cost of the development. However this would be slightly mitigated by the decrease in glazing area which was shown in the Capita Symonds cost comparison to reduce the capital expenditure of the development. Furthermore as the proposed development is modelled to use over 35% less energy than the baseline building there will be a reduced running cost associated with the proposed development. In many cases a reduction in the running costs of a development would not be a strong motivation to spend more on the capital cost, however as the development will be built and occupied by the client, they will be able to realise the benefits of the reduced running cost.

3.4 Measures being implemented in the building design

Due to the Development being placed on hold and a new design team being appointed during this TSB study it is not currently known what, if any of the measures investigated in this study would be installed as part of the final building. However the client has confirmed that the findings of the study will be taken into account in the re-design of the Development.

4.1 Approach to the Study

Waterman Energy Environment and Design Ltd were appointed in 2012 by the TSB to carry out the Design for Future Climate Change: Climate Change Adaptation study. At this point Waterman EED was already on the design team for the Project Angel Development, providing Environmental and Sustainability Services. The study intended to run alongside the building design, using Waterman's in- house Building Services Company to provide the required thermal modelling and then maintain a close decision making relationship with the design team appointed for the Project Angel development.

However soon after Waterman EED was appointed by the TSB, the building design was placed on hold by the Client and later the design team was disbanded. In order to continue the TSB study, Waterman EED and Waterman Building Services continued with the study using the Stage C Drawings whilst maintaining contact with the Architects (CPMG) and the Client. In November 2012, following the issue of the interim technical report to the TSB, Waterman EED met with the Client and two members of the new project management team, David Stuart (Lendlease, Project Manager) and Liz Pickard (Consarc Architects, Architectural Advisor) to disseminate the findings to date and discuss the future of the Project Angel Development. Following from this meeting it was agreed with the new design team that the findings of the study would be taken into account in the future development of the building design.

Although it no longer evolved alongside the building design, the study was based on the same design that the teams would be moving forward from Stage B with. As such the findings of the study would still be relevant to the design.

As there was no design team from April 2012- March 2013 the strategies taken forward were discussed with the original architect (CPMG), the cost consultant (Capita Symonds) and the BRE for embodied carbon analysis. Using these measures (architectural merit, cost, and embodied carbon) the thermal/energy benefits of each adaptation strategy was compared.

From these discussions it was decided to pursue the G-value and glazing percentage design modifications as the climate adaptation value provided by the green roof, Phase Changing Materials (PCMs) and shading devices was not found to be significant enough in comparison to their financial/carbon costs.

During the initial analysis it was noted that the baseline building did not pass Part L due to solar gain issues. As such the G-value and glazing percentage of the baseline building was reduced in order to bring the solar gain levels to the point of compliance with Part L. The G-value, and glazing percentage were then remodelled on the new baseline building in order to determine the most effective climate change adaptation strategy. Mid-pane blinds were also included in the new strategy as discussions with the engineers and architects highlighted the necessity for occupant controlled shading; as mid-pane blinds would have greater benefits than internal blinds they were added to the modelling exercise.

The effect of the glazing percentage, G-value and shading was also modelled to include the impact the various strategies had on energy use through internal lighting. Until this stage only the 90% high emissions scenario files were used to model the strategies. However during the final stage of the modelling and analysis the strategies were modelled against all the UKCP09 climate predictions in order to develop the most suitable strategy over the life of the building, depending on the degree of climate change that occurs.

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4.2 Design Team Members

The TSB Design for Future Climate Change design team is as follows:

Emily Low	Waterman Energy, Environment & Design Ltd
Joanna Bagley	Waterman Energy, Environment & Design Ltd
Jordan Kirrane	Waterman Energy, Environment & Design Ltd
Tom Webster	Waterman Energy, Environment & Design Ltd
Jonathan Purcell	Waterman Building Services
Neil Rollinson	Waterman Building Services
David Stewart	Lendlease
Liz Pickard	Consarc Architects
Vanessa Lythe	Northampton City Council
Ajay Chauhan	CPMG Architects Ltd
Sean Starling	Capita Symonds
Flavie Lourie	BRE Global

4.3 Project Plan and How it Changed

Activity	Stage	Date Originally Suggested	Date Deilvered	Comments
Project Inception and Risk Assessment	1	Jan 2012	Jan 2012	N/A
Options Appraisal on Promising Adaptation Measures	2	Feb 2012	Jan 2012	N/A
Options Testing (and initial reporting)	3	May 2012	October 2012	This stage was delayed due to the Development being placed on hold, with no timelines being available for the project going live again. As such it was decided in June 2012 that the study would go ahead using the drawings that were frozen at stage C.
Preferred Options Design	4	August 2012	March 2013	Following concerns from the TSB regarding the lack of design team associated with the study, the study was placed on hold awaiting confirmation from the Client regarding the new timelines for appointment of a design team and the extent to which the study would be able to influence the building design.
Climate Change Adaptation Strategy Report	5/6	November 2012	June 2013	
Case Study	7	February 2013	August 2013	
Dissemination Activities	8	May 2013	October 2013	

Table 8: Project plan

4.4 Resources and Tools (Strength and Limitations)

The main tools used for the project were the Prometheus weather files produced by Exeter University, IES VE thermal Modelling Software and ENVI-Met, a CFD model used to model the cooling effect of vegetation.

IES VE allows the user to simulate multiple different scenarios against the predicted future weather data. The building form is accounted for and the applied thermal mass and fabric properties are dynamically calculated to provide data sets for set timed intervals. This enables a good level of detail in the analysis and comparison of results thereof to establish benefits and make decisions about the design of buildings. The modelling approach does have some limitations however. The method used for this analysis does not allow for dynamic modelling of the space conditioning systems, and hence certain efficiencies at part loads and fan performance etc is limited to the input defined. Furthermore, the conditioning loads are defined for a fixed volume of the space, for which identical internal conditions are assumed throughout the space, i.e. it is homogenous. Whilst this does deviate from the real life environment, the computing power and time for equivalent simulations using microclimatic data are very time consuming and are more suited to assessing individual areas of buildings.

Time profiles are used to define all elements, and as such it is difficult to determine occupant interaction for manually controlled aspects, or the thermal comfort of an individual. When a time profile and respective formulae assigned to that profile determine that energy is to be consumed, the software instantly switches on that gain, or system, and hence the lead time is not always accounted for, or run on times.
However, the basis of the modelling provides a robust set of simulations to establish the beneficial comparisons of the different scenarios modelled.

The weather data used is estimated based on multiple factors, devised in the Prometheus project at Exeter University, which define the anticipated economic growth with regards to population, improved future efficiencies, family sizes etc, along with the impact to the global climate to establish scenarios to best approximate the future weather. Whilst this is therefore unknown, the future weather data does again provide grounds for comparison. The initial input to the weather files however is based upon recorded data and hence represents averaged real life data, closest to the site.

The Prometheus climate files offer an excellent source of data for modelling against future climate predictions, however the sheer amount of variability in the climate files means that the amount of data generated becomes unmanageable. Thus, to reduce the amount of scenarios that were included in the data sets would increase the usability of the information.

Due to the fact that ENVI-met is still in Beta the software is hard to use and extremely buggy, however it was the only tool available to the team at the start of the study that could be used to model the cooling provided by green roofs. It was not possible to extract the information on the cooling at membrane level from the model; as such cooling above the plants had to be used and as a result the benefit of the cooling provided to the internal space by the green roof is considered likely to have been underestimated. If a similar study is carried out in the future it would be better to use recorded data for the cooling provided across the membrane of a green roof, rather than modelled. This information would then be input as a temperature modification to a surface in IES.

4.5 Analysis of Process

The initial timescales set for the project have slipped greatly. However this is largely due to internal client issues resulting in the client putting the design process on hold in 2012 and appointing a new design team in 2013. As such the client has prioritised other projects over Project Angel. As the design process and this study have not run concurrently, it has been hard to tailor the design to the client's aspirations. Instead, through close communication with the original project architects, the design options that most suited the clients original aspirations where chosen to be taken forward at each stage.

The difficulty in modelling Green Roofs and PCM meant that the strategies where not fully represented in the study, narrowing down the adaptation strategies that could be investigated. Due to the time slippage resulting from the design being put on hold, it was not possible to find new ways to model the effectiveness of the green roofs and PCM and they had to be discounted from the study.

4.6 Clients: Influencing (or not) the Decisions Made in Building Design

Due to the development being re-designed, the impact of the study on the final development has yet to be seen. The client has confirmed that the finding of the study will be taken into account in the re-design of the building.

The client had two main restrictions on the scope of the adaptation measures. The first restriction was that the Development must remain mechanically ventilated; the second was that the development must remain predominantly glazed. Although external shading had been investigated in the study the client has also expressed a preference for it not being used in the final building design.

Extending Adaptation to Other Buildings

5.1 How can the findings of this study be applied to other buildings

The Study generated several general findings that were not site specific and could be applied to buildings universally:

- Solar Gains vs. Daylight: The relationship between a building's cooling load and its solar gains is not as simple as it may seem. Measures that reduce incoming solar gains also work to decrease the available natural daylight therefore resulting in an increased requirement for natural lighting; although many fully glazed buildings will have an issue with meeting the glare requirements of Part L in any event (i.e. too much daylight). It is therefore important to bear in mind the trade-off between solar gains and daylight when looking to develop adaptation strategies for buildings as they can increase lighting load and the internal gains associated with internal lighting.

- Negative impacts of improving fabric performance: Measures that increase the fabric performance of a building, for instance reducing the glazing area and replacing it with a solid build up also have a tipping point at which they become less effective, not only due to increasing the internal gains and lighting demand, but also because the improved building fabric traps in heat during the cooling period and increases the energy needed to cool the space

- Horizontal vs. Vertical Shading: The study found that horizontal shading fins had a twofold benefit over vertical shading. Firstly horizontal shading had a greater impact on reducing the summer cooling load in the development. Secondly although both horizontal and vertical shading were found to increase the heating load in winter, the increase in heating load was significantly greater in vertical shading than horizontal shading.

5.2 Limitations in applying this strategy to other buildings

Unlike many buildings in city centres Project Angel has no shading from other buildings thus it has full exposure from solar gains to the South, East and West facades. This increased the emphasis of the study on the best way to reduce the incoming solar gains rather than focusing on other solutions to minimise summer overheating that may be more suitable in other situations. Furthermore the use of local weather files means that the impact of the adaptation strategy would not be likely to be the same in different locations. However, the general findings of the study outlined above (see section 5.1) are likely to be significant across most buildings.

5.3 Buildings in the UK suitable for adaptation measures outlined in this study

The general findings of this study are applicable to buildings that have issues with overheating as a result of solar gains. This will increasingly become a large proportion of the new commercial building stock as many buildings are built with predominantly glazed facades. However, the extent to which buildings are overshadowed by adjacent buildings will influence the impact of findings. It is important to tailor the adaptation strategies of buildings to their specific location.

It is also important to remember that the building looked at in this study was mechanically ventilated and that this remained so at the request of the Client. Thus the findings of this study are specific to buildings that are mechanically ventilated.

Extending Adaptation to Other Buildings

5

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5.4 Resources, tools and materials developed

Throughout the process of this study the following research, tools and materials were developed:

- Climate change risk assessment report: This report examined the site specific climate change risks for Project Angel and was used to determine the most suitable climate change adaptation strategies to be investigated.
- Climate change adaptation screening tool: An Excel based tool has been developed based on the climate change risks and adaptation strategies outlined in Bill Gething's Design for Future Climate Change: Opportunities for adaptation in the built environment i.
- Case study report: The Case Study Report will summarise the findings presented in this document. Focusing on the costs and benefits of the different adaptation strategies investigated and the impacts that have been shown to have on the Project Angel development.

5.5 Further needs required in order to provide adaptation services

There is currently a lack of commercial demand for climate change adaptation services. It is unlikely that there would be a commercial demand for such services until there is a regulatory or planning requirement for the ability of a development to adapt to climate change to be assessed. Regulations could come in the form of Building regulations, for instance it could be covered by Part L, or alternatively it could be driven by local authorities through the planning system.

Another barrier to providing adaptation services is the current plethora of climate change projection options (high emissions or medium emissions; 10th,30th,60th and 90th percentile predictions). This means that the amount of data generated becomes unmanageable. Thus, reducing the amount of scenarios included in the climate change projection data sets would increase the usability of the information.

Due to the fact that many commercial buildings are not designed, owned, occupied and operated by the same people it often means that beyond meeting planning permission requirements, energy consumption, running costs and long term thermal comforts are not always taken into account by developers when designing new buildings.

Furthermore there is a lack of tools available for early stage building modelling that allow for the building design to be easily modified based on high level assumptions (i.e. glazing area, orientation, G-value). Instead many of the tools require more in depth modelling which takes more time and is thus more costly.