Technology Strategy Board

Design for Future Climate (D4FC) - Phase 2

Swim4Exeter Project

Exeter

Final Report

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This document has been produced by Gale & Snowden for the Swim4Exeter D4FC scheme and is solely for the purpose of detailing to the TSB the Climate Change Adaptation Strategies investigated and developed for the scheme.

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Executive Summary

1. What is the building profile?

The building project is the design and build of a new state of the art indoor public municipal pool facility in Exeter, including a main National/County standard swimming pool and a learners' pool with supporting facilities together with dry sports facilities. The project was at feasibility study stage and aimed to evaluate various design options for three potential sites in the centre of Exeter in relationship to climate change risks to inform the selection of the most appropriate site to locate a new state of the art Indoor Public Municipal Pool Facility for Exeter. Advantages and disadvantages with regards to thermal comfort, water management and impacts on construction under future climate scenarios have been analysed as part of this study.

2. What is the risk exposure for the building to the projected future climate?

A climate risk radar was used to analyse and visualise the risks related to climate change for a swimming pool building with regards to thermal comfort, water management and construction.

Comfort

Typically in a swimming pool building a range of significantly different temperature zones need to be accommodated with the least possible energy demand. Zoning and careful consideration with regards to layout will be required. Current design standards in the UK typically do not take into account this level of zoning and changing areas are often directly connected to pool areas and reception areas, affecting comfort and overheating, and at the same time increasing the energy demand for heating, humidity control and ventilation.

For each of these zones, individual thermal comfort ranges and upper temperature limits have been established to analyse the risk and frequency of overheating under various climate scenarios and to develop mitigation strategies to minimise overheating.

Water

Swimming pools consume large amounts of water and the amount of water consumed by a pool of this size would be sufficient to sustain 140 households. Considering the expected change in rainfall patterns under future climate scenarios, i.e. ~50% less rainfall in summer and longer periods of drought, maintaining adequate water supply for a municipal swimming pool will prove challenging. A key element of this project will be to look at how the water consumption can be reduced through design and changes in operating a swimming pool to further reduce the water demand.

Construction

The stage of this project did not allow for an in-depth analysis of construction related impacts or further development of construction details and specifications. A purely qualitative assessment was carried out. It is to be understood as a recommendation for further investigation during the next stages of this project and to flag up some of the opportunities that this project offers to minimise construction related risk from changes in future climate.

3. What is the adaptation strategy for the building over its lifetime to improve resistance and resilience to climate change and thus extend the commercial viability?

The following key areas were assessed using IES dynamic modelling and the PHPP (Passive House Planning Package):

- Building Orientation
- Single sided ventilation vs. cross flow ventilation
- Construction strategies – heavy weight, medium weight, light weight
- Intelligent ventilation control – windows closing when external air temperature is hotter than inside
- Solar shading strategies
- Zoning to reduce internal gains and minimise energy losses
- The role mechanical ventilation heat recovery (MVHR) can play to support passive ventilation strategies in a mixed mode approach
- The role of MVHR coupled with ground cooling

The results from this study indicate that the wet areas of a pool require heating almost all year round even under future climate scenarios. Selecting a site and window design that enables south facing orientation would allow for an optimum balance of heating and cooling requirements for current and also future climate scenarios. If at the same time the relative humidity is to settle around 65% in the pool hall this can offer dehumidification energy savings which would result in lower air change rates, lower fan power, lower energy loads on evaporative cooling/ dehumidification systems and also generate considerable water savings. However, it is important that the optimum Relative Humidity (RH) is realised for both users' comfort and to protect the fabric of the building. Thermal bridge free detailing will further reduce the condensation risk and help protect the building fabric.

The dry sports and admin areas will be prone to overheating and will benefit from a north facing orientation and thermal separation from the pool area through careful zoning and layout. These areas would also benefit from direct access to the outside. Implementing cross ventilation and ground cooling will further reduce the risk of overheating for these areas.

The water consumption of a pool building can be considerably reduced if the low water use, filtration, water re-use strategies and strategies to reduce evaporation from pool water as set out in this report are implemented.

4. What is the best way to conduct adaptation work?

The chance to develop the climate change adaptation strategy alongside with the design of the building proved most valuable. Instead of checking and making recommendations for adapting a completed design, where most of the important decisions had already been made, this approach allowed for maximum flexibility.

The team built on their experience from their previous D4FC project that received funding in the first round of D4FC projects. Again, an invaluable resource proved to be the 'study tour' at the beginning of the project to visit exemplary buildings in more extreme climates that could be representative of a future UK climate. Strategies that were found successful for the extra care project were transferred and validated for the swimming pool project. Methodologies like the risk assessment process were fine tuned and further developed and aspects like, for example, the lack of guidance on overheating criteria were investigated in more depth. A better understanding of the strengths and limitations of the different assessment and modelling (IES and PHPP) tools used to simulate summertime performance gained from the Extra Care project allowed for a more efficient use of these tools and analysis of the results. The requirement to mitigate climate change related risks became part of the client's brief and a key performance indicator of the design.

5. How can this work be used to extend adaptation of other buildings?

Whilst leisure facilities (the nature of this project) are unique in that they contain various comfort zones in one building, the majority of overheating strategies detailed herein such as insulation, mass, shading control, ground cooling, and ventilation are equally applicable to a wide range of commercial and residential buildings to limit overheating. Each building type however would have to be assessed for their vulnerability to climate change in its own right. The fundamental differences between different building types need to be taken into account when carrying out thermal simulations. Typically there are different activity and clothing levels, different internal gains, different comfort temperatures and occupancy patterns and control.

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1.0 Building Profile

The following chapter provides an overview of the adaptation project, the sites, key aspects of the design, its context, project drivers and special features or aspects which will affect the resistance and resilience to climate change. Further information, drawings and reports from a study tour to the first Passivhaus pool in Bamberg are included in Appendix 1.

1.1 The Project

The aim of the Swim4Exeter project is to evaluate various design options for three potential sites in the centre of Exeter in relationship to climate change risks to inform the selection of the most appropriate site to locate a new state of the art Indoor Public Municipal Pool Facility for Exeter. Advantages and disadvantages with regards to thermal comfort, water management and impacts on construction under future climate scenarios have been analysed as part of this study.

The project is at feasibility study stage which provides a unique opportunity in its climate change adaptation appraisal as nothing, in terms of design and flexibility and climate change adaptation is 'set in stone'. Therefore climate change risks have been considered at the earliest of the concept design stages and influenced the design accordingly.

The passive design approach has paid particular attention to the sun cycle around highly glazed facades and the swimming pool's responsiveness to changing temperature conditions. Glazing areas/ratios and building form have been assessed to maximise daylight and optimise solar gains against differing orientations. Shading strategies, various ventilation strategies, innovative low energy cooling strategies such as ground cooling (earth tubes, piped exchangers), radiative night sky cooling and phase change materials have been investigated together with various integrated landscape design opportunities that help moderate the micro climate.

1.2 The Building

The building project is the design and build of a new state of the art indoor public municipal pool facility in Exeter, including a main National/County standard swimming pool and a learners' pool with supporting facilities together with dry sports facilities.

Exeter City Council currently operates three public swimming pools within the city. One of these pools, *the Pyramids,* which is the city club's main swimming pool, is nearing the end of its useful life. Built in 1939, it had a makeover in 1980 with Egyptian tiling and decoration and a new children's pool and improved changing facilities in the basement were added, hence 'The Pyramids'. Notwithstanding its age and need of major refurbishment works, the Pyramids still remains a popular destination for many active swimmers. A previously prepared development study suggested that for economic reasons the refurbishment of the existing pool is not viable. The city council has therefore decided to de-construct the Pyramids and develop a new replacement pool. The new pool's location is to remain within the centre of Exeter and in close proximity to the Pyramids' site.

The new pool is to accommodate a 25m eight-lane county standard main pool, a 13m by 7m learner's pool a leisure pool with water features, changing and staff facilities, reception restaurant/café and offices. In addition a dry sports facility with two dance studios, a fitness studio and adequate changing facilities is to be allowed for. The outline brief is included in Appendix 1.

This new building will set itself apart from other public swimming pools in the UK with its energy-saving Passivhaus design. This will be achieved by a compact design, a high performance thermal building envelope and very efficient building services equipment – it is intended that the building will be the first Passivhaus certified swimming pool in the UK. It is the intention of Exeter City Council to provide a low environmental impact building that employs best practice in low energy and healthy building design meeting the needs of the Exeter Community.

1.3 Project Drivers

Exeter City Council wishes to provide a municipal pool for the people of Exeter and its surrounding population to assist in maintaining and improving their health and welfare. Such a pool will be just as important in future climate scenarios as it is now.

Swimming is recommended by the NHS as a '*great form of all-round exercise for every age and ability and an ideal way to stay active and healthy*.' Regular swimming builds endurance, muscle strength and cardio-vascular fitness. It can reduce the risk of chronic illnesses, such as heart disease, type 2 diabetes and strokes. It can serve as a cross-training element to regular workouts. Swimming exercises almost the entire body - heart, lungs, and muscles - with very little joint strain and can be continued for a lifetime. Swimming burns calories at a rate of about 3 calories a mile per pound of bodyweight resulting in approximately 240 calories in 30 minutes of moderate swimming activity.

Spending time in a group workout, whether water aerobics or a master's swim practice, is also a social outlet. It can be a form of meditation generating a feeling of well-being. Many swimmers find an in-direct benefit from swimming. They develop life skills such as sportsmanship, time-management, self-discipline, goal-setting, and an increased sense of self-worth through their participation in the sport.

Sport in general is considered an important element to addressing health issues connected to modern office working conditions and the generally conceived lack of exercise connected with it. According to the NHS about 9.3 million working days were lost due to work-related back pain and other musculoskeletal disorders in 2009.

Local sports clubs and high quality facilities are essential to engage people of all age groups to participate in sport activities. As swimming is suitable for all age groups and ability and when carried out on a regular basis is highly regarded by health professionals to address the lack of exercise in modern life, to improve health and to reduce the risk of chronic illnesses. Through engaging people of all ages, sport forms and strengthens local communities across all groups of the society.

And in the end who does not appreciate a swim, on a hot summer's day? As long as comfortable indoor temperatures can be maintained and sufficient water supply can be warranted, a municipal pool can play an important part to assist people in adapting to future climate scenarios as an opportunity to cool down and refresh during heat waves and hot summers, provided a comfortable indoor environment can be provided. In most Mediterranean countries a swimming pool typically forms part of any residential development, whether it is a private house or an apartment block.

1.4 The Context - Swimming Pools in the UK

The UK's sports sector buildings spend £700 million on energy every year, resulting in annual emissions of 10 million tonnes of carbon dioxide (CO_2). Typically, indoor pools are in constant use – they are open almost every day of the year. They are buildings with large volumes, and they:

- contain large open areas of warm water which are constantly being agitated by bathers or water features
- have constantly high internal temperatures up to 32˜C
- need substantial ventilation and cooling systems to maintain comfortable conditions, to help regulate evaporation and emissions of chemicals from the pool water and to protect the fabric of the building.

Indoor swimming pools are high energy users and can be prone to overheating. They operate at high temperatures with only very little comfort tolerance of 2-3˜C (when assessed in accordance with BS EN 7730). Temperatures are commonly maintained at high levels and additional detrimental solar gain is usually managed by energy intensive mechanical means.

The climate adaptation intent is to design a low energy pool that relies on minimal heating and air conditioning to maintain stable comfortable internal temperatures. The building use, its envelope, orientation, glazing ratio and thermal mass of the pool water will be investigated to establish how energy use can be reduced to a minimum and at the same time higher temperatures in the future climate can be accommodated.

1.5 Energy Requirements

To maintain a comfortable internal environment, a typical swimming pool in the UK consumes up to 1,300 kWh/m² of energy for heating and hot water and 260 kWh/m² of electrical energy for lighting, pumps and ventilation (Source: BRE Good Practice Guide 219). Based on current energy prices for gas and electricity this will result in total annual energy costs of £90/m². For a swimming pool building as proposed with this project this would result in total annual costs of £315,000 and represent a substantial proportion of the overall running costs – equal to approximately 25%-30% of overall running costs only exceeded by staff costs of ~35%. Parts of these running costs are typically covered by public subsidies, and pool buildings in the UK generally operate at a loss.

In changing climates, energy intensive buildings that do not have the means to adapt to future weather scenarios will become inoperable and too expensive to run and maintain. Energy consumption will increase as will operating costs. Swimming pool buildings by their very nature fall into this criteria of energy intensive buildings. They are currently high energy users and are prone to poor comfort control and overheating. Temperatures are commonly maintained at high levels and solar gain is usually managed by energy intensive mechanical means.

Research carried out in other European countries and built examples suggest that the energy consumption can be greatly reduced by means of passive design, including thermal bridge free detailing, high levels of insulation and air tightness. In combination with an integrated well designed services strategy further reductions of up to 50% are realistic.

1.6 Low Energy Swimming Pools Examples

As part of the D4FC work the team visited the first Passivhaus pool in Bamberg, Germany that opened in November 2011 and took part in a ‘Low Energy Swimming Pool Workshop’.

The design of the swimming pool visited was based on the current weather files for Germany and its design did not take into account future climate change in the same manner as this project. However, considering its location in central Germany it is likely that the design weather file that has been used for the energy modelling of the pool in Germany is one that has higher air temperatures, and could be representative of a future UK climate change scenario. Gale & Snowden's research carried out for the first round of D4FC funded projects has shown that a central German summer weather scenario is very similar to the Exeter 2050 data (high emission scenario) / 50th percentile.

No air conditioning was required for the Passivhaus swimming pool visited in Bamberg and still it was designed and orientated to optimise solar gain in winter with large glazing areas in a southerly direction (approximately 30% glazing ratio).

Due to the continuous high internal temperature requirements swimming pools need to be heated all year round and as a result of this any solar gains are expected to be beneficial most year round. However these high temperatures paired with the associated high levels of humidity intrinsic to swimming pools take internal comfort levels to their limits. The maximum acceptable temperature threshold under typical pool conditions would be 35~C when determined using the Predicted Mean Vote method (discussed further in section 2.2) from BS EN 7730 which leaves only a few degrees tolerance above a typical temperature of 32°C.

The main approach in current UK swimming pool design to deal with overheating and close control of internal temperatures is to design in and control solar gain, through orientation, overhangs, external controllable shading and cooling systems. Issues of overheating were not a concern with the Passivhaus pool at Bamberg and in fact it had been orientated to optimise solar gain for winter periods. Overheating was addressed through good solar control such as external shading systems and good ventilation control. It is apparent that, in a climate in Germany that has hotter summers than the UK, the Passivhaus approach of super insulating and ensuring the envelope is air tight does not lead to issues of overheating.

A super insulated envelope, as well as keeping heat in, can also keep heat from solar gain out. This is conclusive with research carried out by Gale & Snowden under the D4FC phase 1 programme.

1.7 The Sites

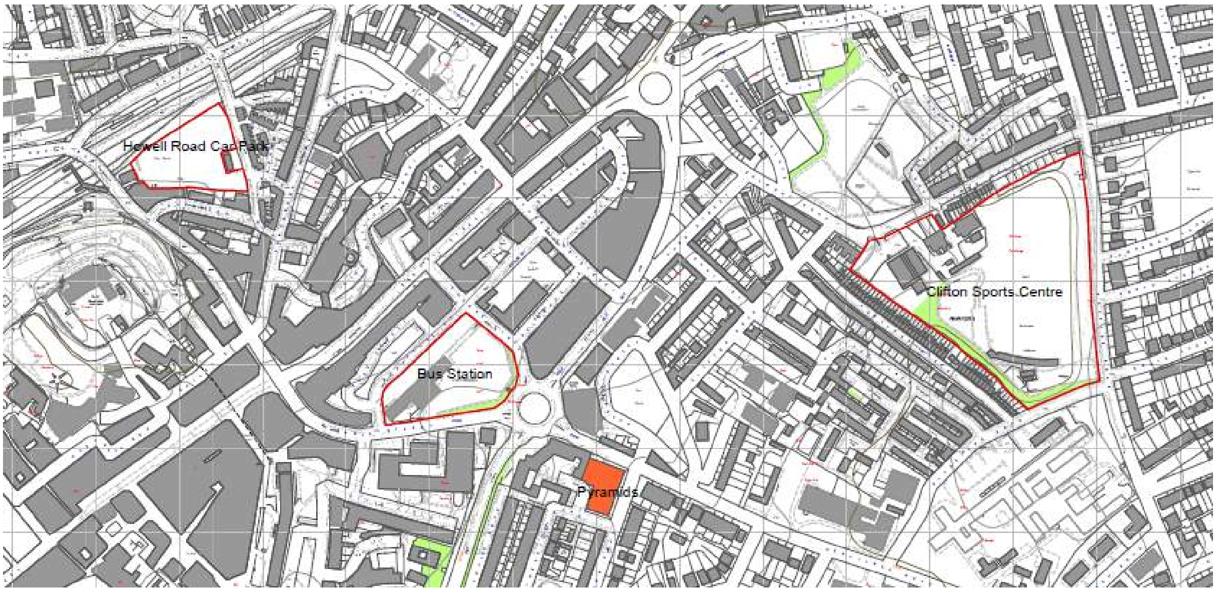


Figure 1: Map of Exeter city centre showing the location of all three available sites

Three sites had been identified by the client i.e. Exeter City Council, for locating the new swimming pool building which are described more fully below:

1.6.1 The Central Bus Station: De-construction and Redevelopment of Exeter's Existing Central Bus Station

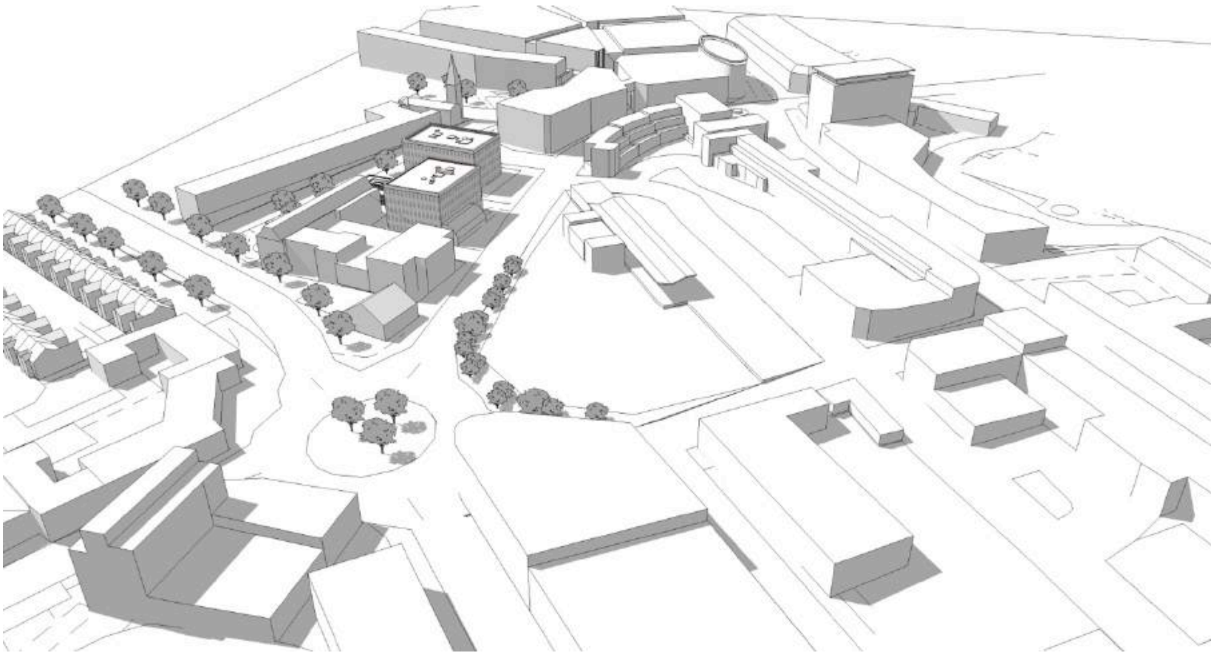


Figure 2: Site Plan of Existing Central Bus Station Site

The proposed development site is defined by Sidwell Street, Paris Street and Cheeke Street, which includes the Bus and Coach Station site.

The adopted Exeter First Review Local Plan allocates this block of land for comprehensive redevelopment that includes an enhanced bus station, retail floor space, commercial leisure uses, entertainment uses, short-stay car parking, non-family housing and other uses.

The adopted Exeter Core Strategy recognises the site as the key development opportunity within the City Centre and identifies the site as suitable for mixed use development including retail and it will include a new integrated Bus Station.

The site is sloping to the south and surrounded by 4-5 storey retail, leisure and office developments. An initial computer assisted shading study indicated that good solar gains could be achieved along the south eastern boundary, whilst most other parts of the site will be predominately overshadowed by adjacent buildings or proposed development.

The Environment Agency's flood risk assessment of the area shows that the site is of low flood risk. An archaeological survey has identified areas of archaeological interest within the site and further investigations are required.

1.6.2 Clifton Hill: An Extension to the Existing Clifton Hill Sports Grounds

The site is part of Exeter's 'Mont-le-grand' conservation area. In the 19th-century a brickworks was situated on the Clifton Hill Sports Centre site. Since then the area was used as an athletic running track during the 1970s, before the Exeter Arena was opened. The site also accompanies a dry ski slope and golf driving range. The sports centre was built in 1984. An industrial design with 'porthole' style windows, it offers a sports hall, a dance studio, fitness suites, badminton and squash courts and soft play areas. The Clifton Hill Leisure Centre, which was built as a result of a competition won by the Council when bidding for limited Government funding for a sports facility, is regarded as a fine example of modern design from the internationally acclaimed architectural practice Nicholas Grimshaw and is therefore to remain.

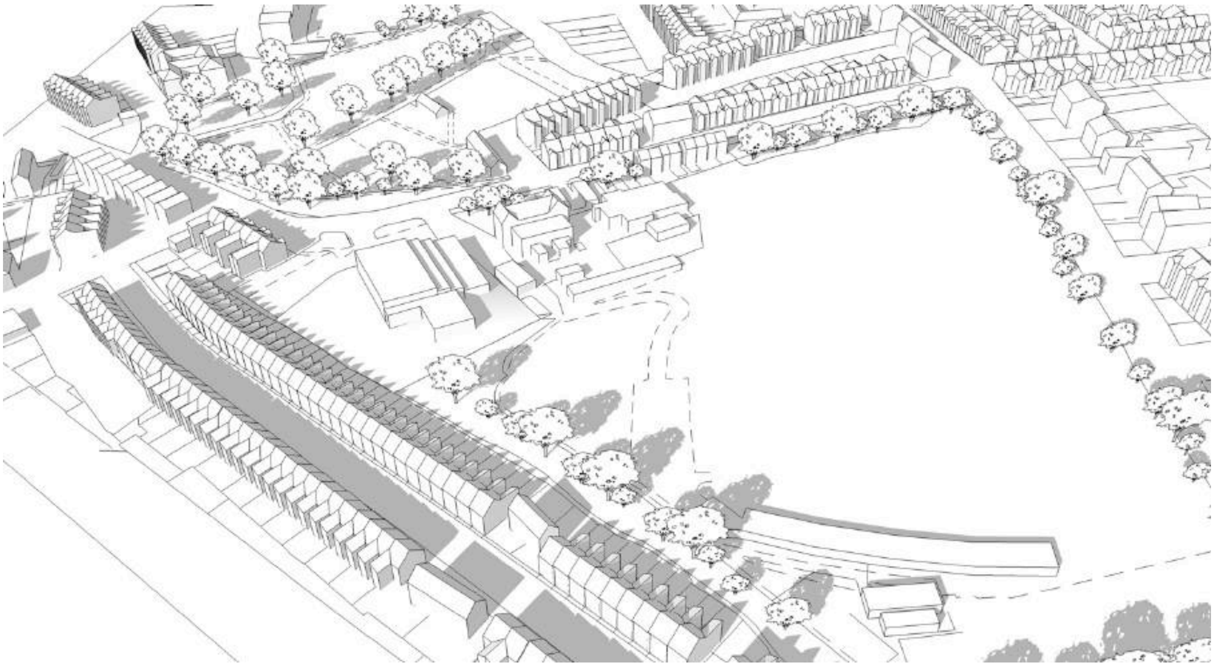


Figure 3: Site plan of existing Clifton Hill site

The Environment Agency's flood risk assessment of the area shows that the site is of low flood risk. A public sewer crosses the south eastern part of the site. This sewer will most likely need to be diverted with the development going ahead.

The contamination survey confirms that the majority of the site has been part of a former landfill site and is not suitable for other use but car parking. This limits the available site for the swimming pool to the area directly behind the existing sports centre.

1.6.3 Howell Road: New Development at Howell Road Car Park, Exeter

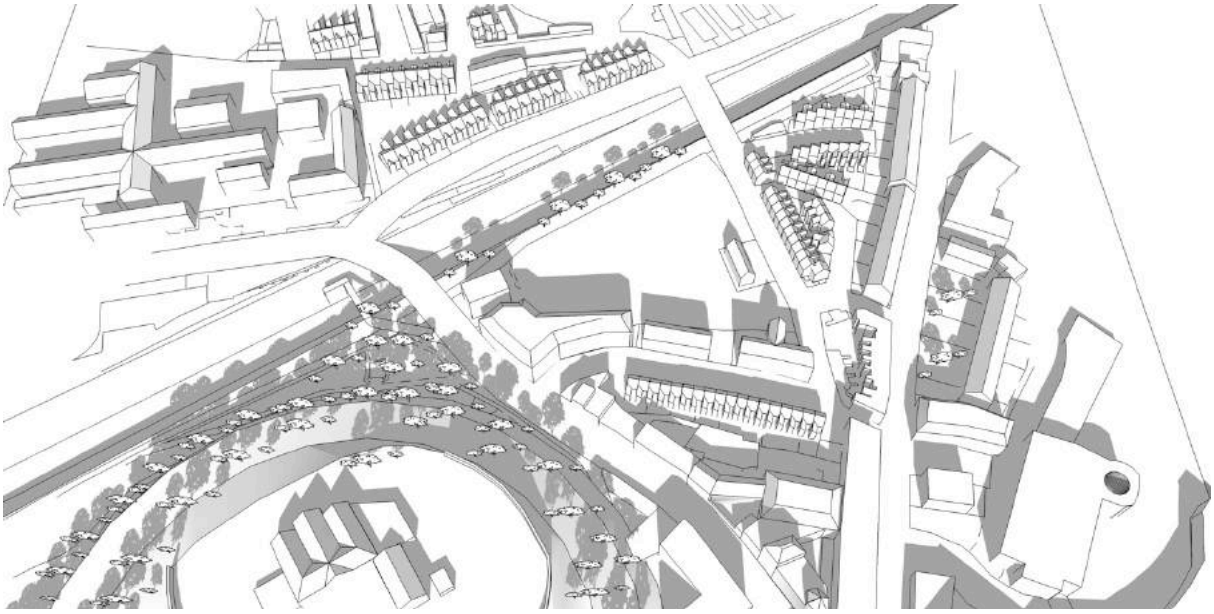


Figure 4: Site plan of existing Holwell Road site

Howell Road is one of the city centre's car parks and located along the city's main railway line. Various underground services, sewers and rights of ways across the site considerably limit the available space for new development. An initial computer assisted shading study indicated that good solar gains could be achieved if the new pool was to be located in the northern corner of the site. Most other parts of the site are overshadowed by adjacent 4-5 storey buildings along the southern, eastern and western boundary. The Environment Agency's flood risk assessment of the area shows that the site is of low flood risk.

1.7 Design

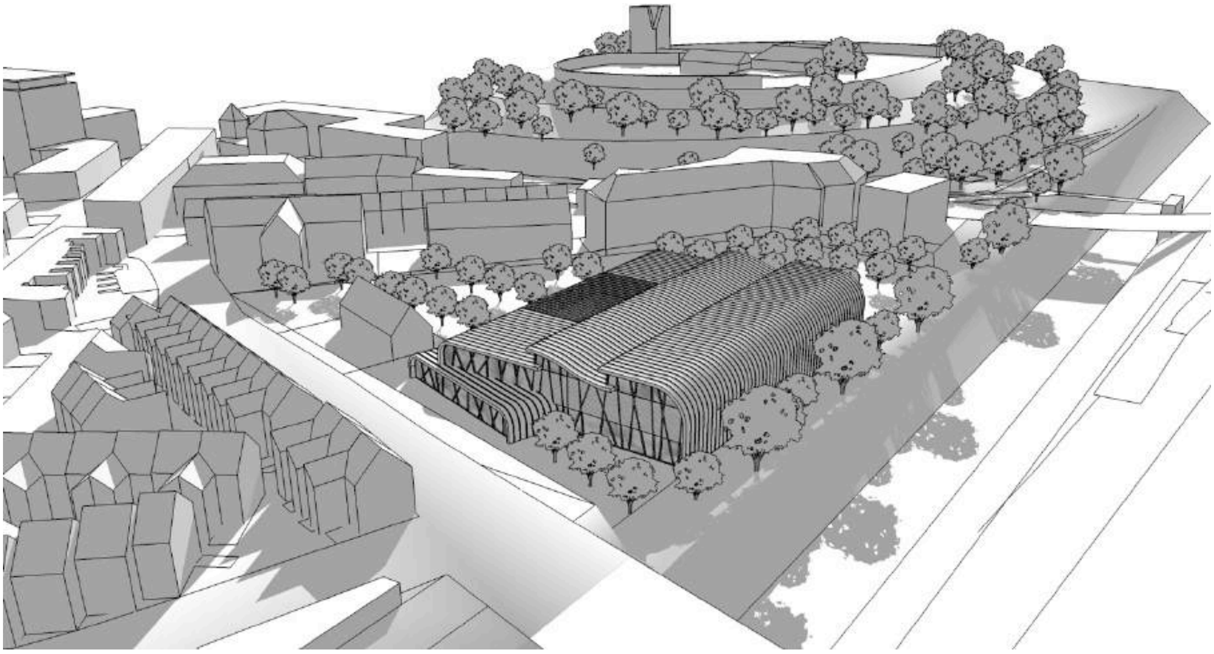
Building on Gale &Snowden's experience from the D4FC phase 1 programme (the Extra Care 4 Exeter Project) and the observations from the study tour the team decided to follow the Passivhaus methodology when developing the initial designs for the Swim4Exeter project. These initial concept designs were then analysed using IES dynamic and PHPP modelling to assess the designs under UK climate conditions, to identify potential conflicts under future weather scenarios and to further progress the designs.

Further design criteria were considered to optimise natural ventilation, external shading and the integration with the landscape to reduce overheating by moderating the local microclimate.

The following is a short introduction to the initial concept designs for each individual site. Adaptation strategies and site selection will be discussed under section '3.1 Site Choice and Adaptation Assessment'. Full drawings are included in Appendix 1.

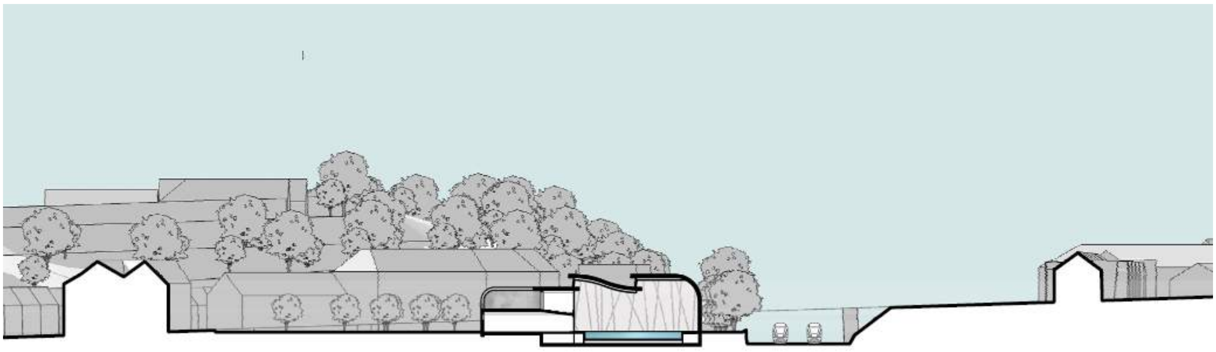
1.7.1 Proposed Design at the Howell Road Site

Due to substantial underground services and existing rights of way to the southern and western part of the site and to optimise solar gains the building has been located in the northern corner. Direct pedestrian and cyclist access is provided directly off Howell Road with the foyer located on this site.



A double height space along the north western part of the proposed building (along the railway line) accommodates the pool facilities; the dry sport area is located above the changing facilities along the south eastern elevation.

All windows are deliberately orientated away from the railway to minimise impacts from noise and pollution, with the double height pool area acting as a buffer space for the dry sport facilities. The pool area will be predominantly glazed to the south west and will receive additional solar gains via two banks of roof lights spanning across the whole length of the building. These top level windows could also be utilised for ventilation.

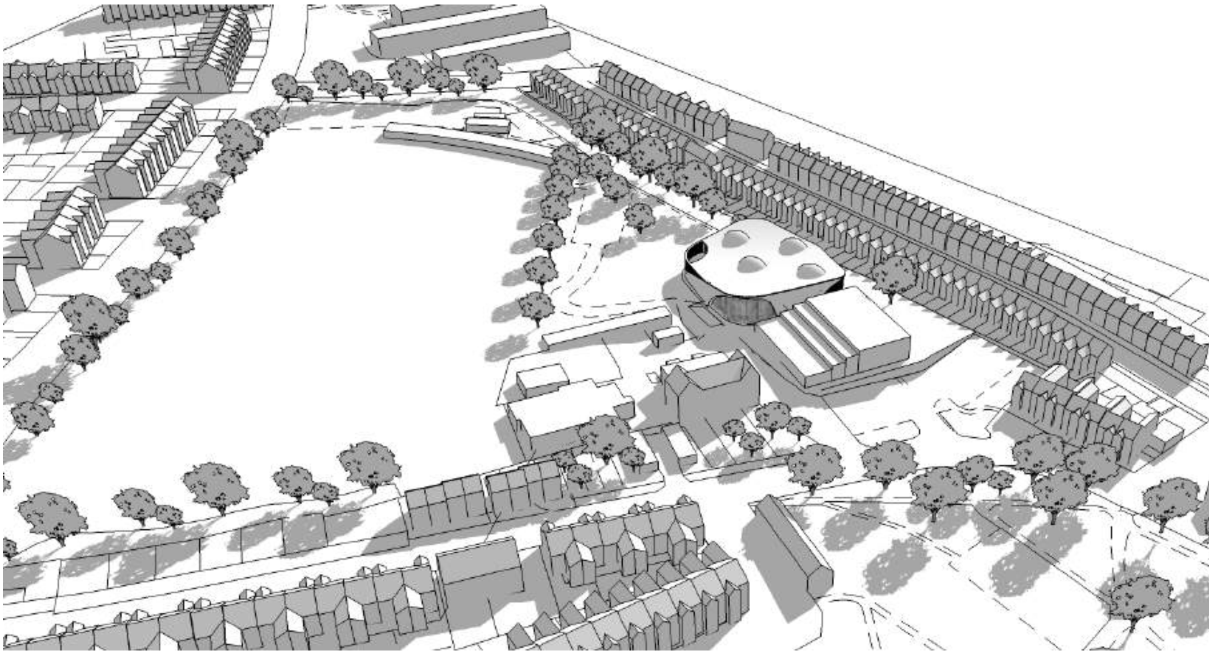


The dry sports areas are located on the first floor along the south elevation with adequately sized window openings to allow for best practice daylight levels and for additional, secure natural ventilation.

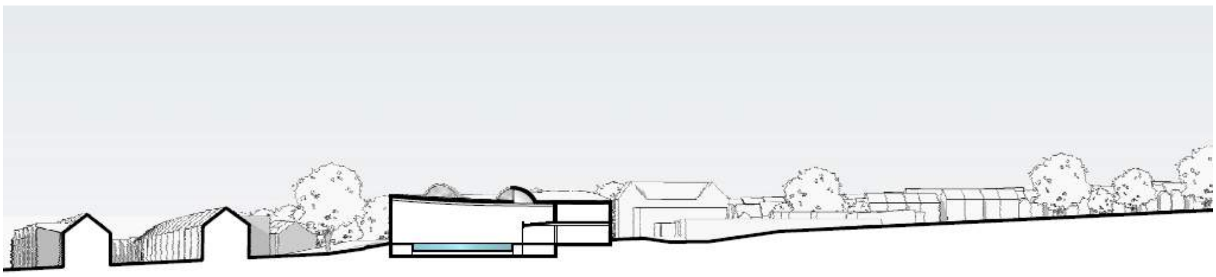
A central 'cut-away' on the first floor forms a roof terrace that will be directly accessed from the spectator gallery. It is envisaged that this area could accommodate a small outdoor pool for regular use by swimmers. Also, in the event of galas this space could be used as an outside catering space.

1.7.2 Proposed Design at the Clifton Hill Site

The space available on the Clifton Hill site was defined by the existing sports centre to the north east, the contaminated zone to the north west and a 'privacy zone' to the south, i.e. a local plan requirement to keep a certain distance from residential properties. The proposed design maximises the use of the available space and forms a respectful, contemporary extension without entering a competition with the existing sports centre.



A new combined entrance will be provided in the northern corner and pool facilities will be located in the south facing part of the building to maximise the potential for solar gains and to minimise the energy demand.

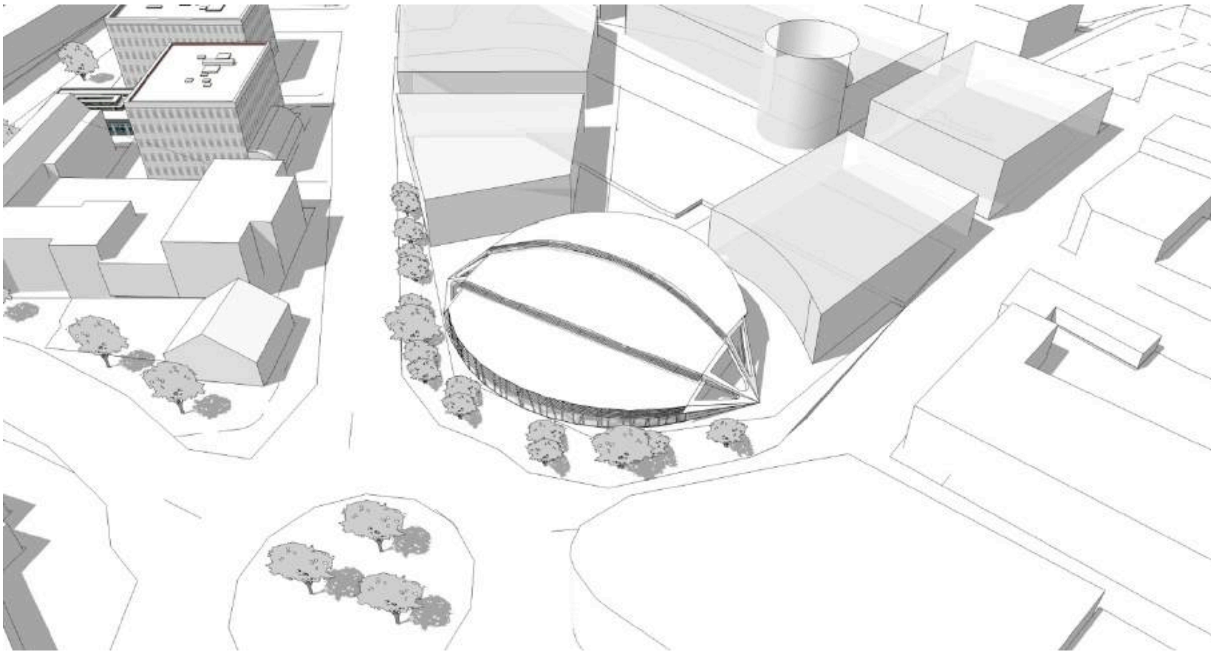


The dry sport facilities are located on the first floor together with a spectators viewing area that could also be used as a resting area and the sauna facility. A roof terrace has been allowed for in the eastern corner on the first floor overlooking the green space. This space will be directly accessed from the spectator gallery. Again, it is envisaged that this area could accommodate a small outdoor pool for regular use by swimmers. Also, in the event of galas this space could be used as an outside catering space.

Because of site constraints reducing the available building space only a reduced brief can be accommodated and no leisure pool facility has been allowed for. However, the site offers opportunities for an improved landscape design including water elements and SUDs and this will be further discussed in the following sections.

1.7.3 Proposed Design at the Central Bus Station

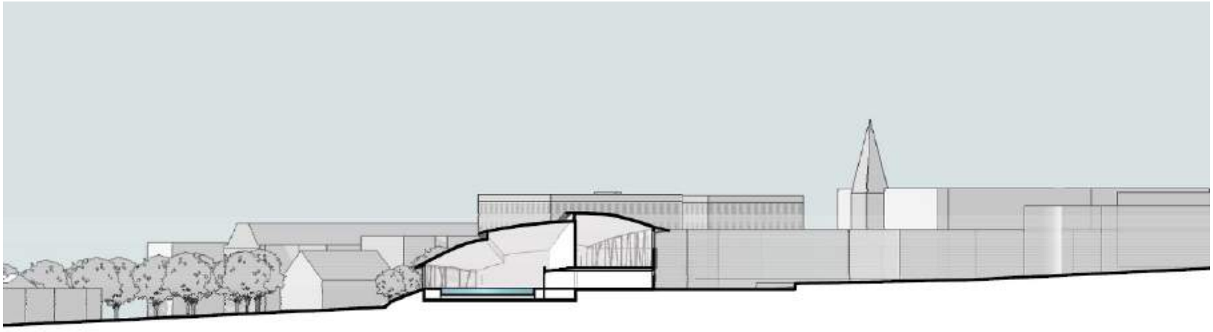
For the central bus station site the swimming pool would form part of a larger redevelopment project. Exeter City Council's 'Core Strategy' has identified the future use for this site as retail led development with additional office, residential and commercial leisure use. The swimming pool represents one of a range of potential leisure uses for this site that are currently being investigated.



The bus station site represents one of the city centre's arrival points and gateways. Any proposal for this site will have to tie in with the rest of the development and would have to be of high architectural quality. The site closest to the roundabout has been identified as most appropriate for a leisure facility of this nature due to its high solar exposure and available solar gain throughout the year. For this site the swimming pool would need to be designed as a landmark building. Because of its city centre location the accommodation brief has been extended to give space for a larger restaurant with kitchen facilities and a crèche area.

Pool facilities will be located in the south facing part close to the roundabout to maximise the potential for solar gains and to minimise the energy demand. Roof lights spanning over the full length of the pool area will provide additional solar gains and high level ventilation. The sloping topography of the site means that the building will be approximately 2 m higher than the roundabout level and bathers will be unaffected by traffic.

The dry sport facilities are located on the first floor together with a spectators viewing area that could also be used as a resting area and the sauna facility. Only limited space will be available for planting and landscape design.



1.8 Building Construction

The building is to be constructed to Passivhaus standard. This will include high levels of insulation achieving a maximum U value of 0.15W/sqmK for the roof, floor and external wall, high performance windows and doors with maximum overall U values of 0.8 W/sqmK, high levels of air tightness of 0.6 ac/h @ 50Pa, thermal bridge free detailing and highly efficient mechanical ventilation heat recovery.

Through its orientation and window arrangement beneficial solar gains that help to reduce the heating demand will be optimised.

1.9 Timescales

The project is currently at feasibility study stage. Concept design and site appraisals will be prepared from October 2011 to February 2012. Construction is planned 2013 – July/August 2015.

2 Climate Change Risks

This chapter starts with a brief over view of future climates in the UK and their associated risks to the project. It then discusses the requirements of the project in terms of comfort, water and construction and how future changing climates may impact these requirements. An analysis is made of the climate change risk assessment for a generic swimming pool type summarised using a 'climate risk radar'. Finally the chapter defines the climate data and climate scenarios used for the design of this building.

2.1 Future Climate and the Swim4Exeter Project

2.1.1 Increased Average Summer Temperatures

Weather recordings in the UK confirm that there has been warming over the UK since 1960 with greater warming in the summer than in winter. At the same time there has been a decreasing trend in cool nights and days and an increasing trend in warm nights and days. In general summer average temperatures over the whole of the UK have increased, making warm summer temperatures more frequent (Met Office).

Future trends for a high CO_2 emission scenario indicate that the South West of the UK is projected to experience an average summer temperature increase of 4-6°C by 2100 and an increase in UV radiation due to reduced cloud cover. The various models show a moderate agreement.

2.1.2 Changes in Rainfall

With regards to precipitation the UK shows a contrast between the North and the South. Whilst for the North an increase of 10% in precipitation is projected the South may experience decreases of up to 5%. Generally there is good consensus between the UK models for the North but only moderate for the South. This indicates some uncertainty about the transition zone between increasing and decreasing precipitation across Europe.

According to the latest reports from the Met Office, vulnerability to drought related to climate change is mainly focused on the South and especially the South East of the UK and these regions are projected to experience an increase in the frequency of droughts.

Generally rainfall extremes are projected to increase especially during winter and changes during summer are more uncertain.

2.1.3 Increase in Storm Severity

Some sources suggest an increase in storm intensity for the UK. Whilst the UK is susceptible for storms from the Atlantic, whether these are extra tropical cyclones or intense low pressure systems in winter, there is currently no systematic observational analysis for storms because wind data are not yet adequate for a robust analysis (Met Office).

2.1.4 Probability Assessment

The IPCC's fourth assessment report concludes that increases in the frequency and magnitude of warm daily temperature extremes are '*virtually certain'*. Extremes in the 21st century will likely increase by about 1°C to 3°C by the mid-21st and by about 2°C to 5°C by the late 21st century.

Furthermore it is *'likely'* that the frequency of heavy precipitation or the proportion of total rainfall from heavy falls will increase.

For the climate risk assessment for this project 'risk' is understood as the 'combination of the probability of an event and its impact', as defined in the risk management standard ISO/IEC Guide 73 (2002). The probability rating was based on the above listed observations from the fourth IPCC report and latest publications from the Met Office.

The predominant climate related risks to this project are therefore overheating followed by flooding and storm damage and water availability and demand.

2.2 Comfort

A pool building can typically be separated into three different temperature zones: The wet areas, changing areas and dry sports/offices/circulation areas. Sports England recommends the following operational temperatures:

- Public main pool 29˜C
- Learner pools 31˜C
- Pool areas should be 1˜C above pool water temperature
- Changing facilities 24˜C and
- Dry sport areas are ideally operated at 14-16˜C.

To maintain this range of significantly different temperatures in one building with the least possible energy demand, zoning and careful consideration with regards to layout will be required. Current design standards in the UK typically do not take into account this level of zoning and changing areas are often directly connected to pool areas and reception areas, affecting comfort and overheating, and at the same time increasing the energy demand for heating, humidity control and ventilation.

For each of these zones, individual thermal comfort ranges and upper temperature limits will need to be established to analyse the risk and frequency of overheating under various climate scenarios. A range of British Standards and guidance documents has been developed to assist in establishing the thermal comfort range and acceptable upper temperature limits for different types of buildings and uses.

Whilst all these standards follow similar principles and thermal comfort is always based on the same factors i.e. temperature, humidity, velocity, clothing and activity, they arrive at different conclusions with regards to acceptable upper temperature limits. The following standards have been considered when analysing the impact of overheating under future climate scenarios:

2.2.1 BS EN 7730: Ergonomics of the Thermal Environment

Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria

BS EN 7730 is based on Fanger's thermal comfort model. Optimal thermal comfort is established when the heat released by the human body is in equilibrium with its heat production. Based on air temperature, surface temperature, humidity, velocity, clothing and activity the PMV (Predicted Mean Vote) and PPD (Predicted Percentage of Dissatisfied) is calculated.

The PMV predicts the mean value of votes of a large group of persons on the following on a 7 point thermal sensation scale ranging from -3 (too cold) to +3 (too hot) with 0 being neutral. From this the PPD is calculated expressing the percentage of people dissatisfied with a given comfort condition. Even for a neutral condition a minimum of 5% of people will express dissatisfaction. Under this standard a 90% satisfaction rate is aimed for and this then defines acceptable upper temperature if the other factors are given.

The model described in BS EN 7730 is based on the heat balance model of the human body, which predicts that thermal sensation is exclusively influenced by environmental factors (temperature, thermal radiation, humidity and air speed), and personal factors (activity and clothing).

2.2.2 ASHRAE Standard 55

The purpose of ASHRAE Standard 55, *Thermal Environmental Conditions for Human Occupancy*, is "to specify the combinations of indoor space environment and personal factors that will produce thermal environmental conditions acceptable to 80% or more of the occupants within a space" (ASHRAE 1992).It is based on ISO 7730 and the standard establishes a comfort zone expressed in comfort charts. For a given clothing level and metabolic rate it provides the comfort zone in relation to humidity, operative temperature and dew point temperature.

Changes introduced in 2004 included a new adaptive comfort standard (ACS) that allows warmer indoor temperatures for naturally ventilated buildings during summer. The ACS is based on the analysis of 21,000 sets of raw data compiled from field studies in 160 buildings, both air conditioned and naturally ventilated, located on four continents in varied climatic zones (ASHRAE RP-884: Developing an Adaptive Model of Thermal Comfort and Preference).

2.2.3 BS EN 15251:2007

This is based on indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics.

The standard recommends parameters to be used when calculating design indoor temperatures, ventilation rates, illumination levels and acoustical criteria for the design of buildings, heating, cooling, ventilation and lighting systems. It describes a method to establish thermal indoor criteria (design indoor temperature in winter, design indoor temperature in summer) on the basis of given comfort conditions.

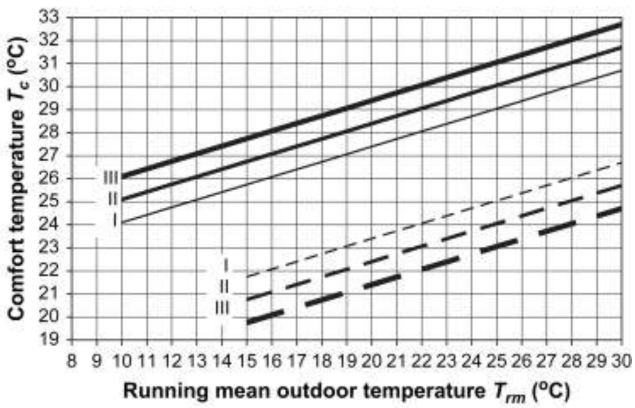


Figure 11: Temperature for Categories I-III in Relation to Mean Outdoor Temperature

Based on the level of user expectation a building is categorised on a scale of 1-4 with one being the highest (typically a space occupied by fragile and very sensitive persons) and 4 being the lowest (buildings of limited use). Based on the category and the mean outdoor temperature an upper temperature limit is calculated (see Figure 11).

EN 15251 is applicable mainly in non-industrial buildings where the criteria for indoor environment concern human occupancy and where the production or process does not have a major impact on the indoor environment. The standard is thus applicable to the following building types: single family houses, apartment buildings, offices, educational buildings, hospitals, hotels and restaurants, sports facilities, wholesale and retail trade service buildings.

EN 15251 can be categorized as an adaptive model. An adaptive model states that there is an optimal temperature for a given indoor environment depending on the outdoor air temperature. It takes into account that humans can adapt and tolerate different temperatures during different times of the year.

2.2.4 CIBSE Guides

Based on BS EN 7730 the CIBSE's recommendation (CIBSE Hand book A, Design *Criteria for Different Types of Buildings*) for summer temperature limits are as follows:

- Offices: 23˜C – 26˜C
- Swimming pools: 30˜C – 34˜C
- Dry sports: 14˜C – 16˜C

2.3 Water Use

The water consumption of a swimming pool is dependent on various factors: the strategy of water treatment and filtration will influence the amount of water used for backwashing, the ventilation strategy and internal humidity levels will affect the evaporation rate and the number of bathers and use patterns define how much water will be required for refilling of pool water, showers and WCs.

Because all these factors can vary considerably, there is only very little statistic information available on the average consumption of water in swimming pools. However, good practice guidance from Sports England and the PWTAG (Pool Water Treatment Advisory Group) recommends minimum requirements for water treatment, refilling, humidity levels and ventilation rates. BS 6465 describes a method to estimate the required WC, urinal and shower provisions. Combining this information with expected levels of occupancy allows the minimum required overall water consumption for a certain number of users to be estimated.

For a typical swimming pool the size of this project designed to good practice guidance, the average water consumption would be in the region of 70 m^3 per day or 26,000 m^3 per year. To put this in relation: According to information from the Environment Agency the average UK family consumes 500 litres of water a day (Source: Environment Agency). Therefore the amount of water consumed by a pool of this size would be sufficient to sustain 140 households.

Considering the expected change in rainfall patterns under future climate scenarios, i.e. ~50% less rainfall in summer and longer periods of drought, maintaining adequate water supply for a municipal swimming pool will prove challenging. A key element of this project will be to look at how the water consumption can be reduced through design and changes in operating a swimming pool to further reduce the water demand.

2.4 Construction

The stage of this project did not allow for an in-depth analysis of construction related impacts or further development of construction details and specifications. A purely qualitative assessment was carried out. It is to be understood as a recommendation for further investigation during the next stages of this project and to flag up some of the opportunities that this project offers to minimise construction related risk from changes in future climate.

Swimming pool buildings are typically wide spanning constructions and increased precipitation under future weather scenarios during winter months in the form of snow may affect the structural stability.

An increase in storm intensity might increase wind loading acting on the facades and again affect the structural stability. Increased UV radiation might cause certain types of materials to fail prematurely.

At the same time changes in rainfall patterns can lead to shrinkages of certain types of soil on which the building is founded giving potential for settlement. For this project no ground condition survey was available at this stage of the project and therefore no detailed analysis of potential impact from climate change on foundation design was carried out.

2.5 Climate Change Risk Identification and Assessment

To identify and assess potential climate change risks for this building project a site independent, generic, qualitative risk assessment has been carried out (Figure 12).

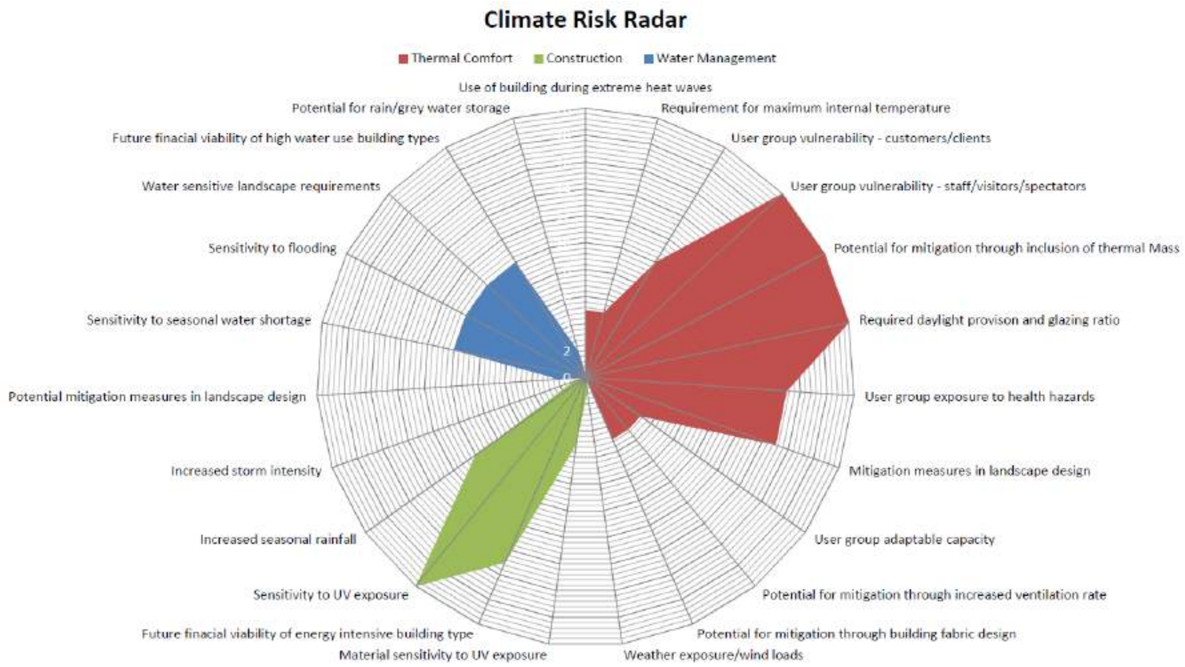


Figure 12: Graphical analysis of the climate change risk assessment for a generic swimming pool type building

The assessment represents a working document that identifies and quantifies climate change risks for a generic building type. The risks are based on the 'Design for Future Climate' report (B.Gething, 2010), Gale & Snowden's experience from their work on a previous D4FC project and the original bid for the Swim4Exeter project. The intention is to provide a holistic overview of the most likely climate change risks, however, not all of these will be further investigated as part of this project but only those identified in Gale & Snowden's and Exeter City Council's bid to the TSB.

The risks are structured in three main sections i.e. comfort, construction and water management. Each risk is rated on a scale of 1 to 5 for its probability and impact and as a result of the multiplication of these two factors is given a risk magnitude. Details are included in the appraisal matrix included in Appendix 2. A graphical analysis of all individual risk magnitudes (see Figure 12) visualises the overall vulnerability of this building type to specific aspects of climate change. The colours represent the three main sections i.e. comfort-red, construction-green and water management-blue. This assessment will then be used to also inform the decision on the selection of appropriate weather files from the Prometheus project.

2.6 Building Type Assessment

The initial impact risk assessment for a swimming pool type building shown in Figure 12 indicates the following:

- The user group is expected to be mainly healthy and non-fragile and will be able to cope with increased internal temperatures. It was found that pool users feel that higher temperature can be acceptable.
- The visitors group, however, might also include elderly and more fragile people, very young and staff and visitors will not have the same flexibility (i.e. fully dressed) to adapt to higher temperatures.
- Being a leisure facility users are expected to be relatively flexible in adapting themselves to even more extreme temperatures.
- Average required indoor temperature is 31˜C and therefore considerably higher than the average building. Swimming pools typically need to be heated all year round and therefore even in summer solar gains are beneficial to reduce heating demand. However, at the same time the operating temperature paired with high humidity levels is very close to the maximum acceptable threshold of 35˜C (determined using PMV method from BS EN 7730) and leaves only a few degrees tolerance.
- The use of thermal mass to stabilise internal temperatures is very limited as the thermal mass of the pool water is to be kept at a constant temperature of 30˜ C and its storing effect can therefore not be utilised for night time cooling.
- Swimming pools require good provision of day light and typically have large glazed areas to provide views and a connection to the outside increasing solar gains.
- The ventilation system needs to be designed to achieve average ventilation rates of 4-6 air changes which could be utilised to reduce the overheating risk
- Swimming pools are typically low rise buildings within fairly protected city/urban environments reducing the risk of being exposed to severe weather.
- Swimming pools require wide spanning roof construction of up to 21m making it prone to water ponding and increased snow fall under future weather scenarios

- Increased cooling demand paired with rising energy costs will affect financial viability under warmer future weather scenarios
- Swimming pools constantly require large amounts of fresh water for refilling the pool water and showers making it prone for longer periods of drought
- In principle the building type allows for the inclusion of water storage tanks, however, this will be site dependant

The analysis of the initial risk magnitudes indicates that the building could be classified as medium risk under the construction and water management section and higher risk under the comfort section.

2.7 Climate Scenarios and Future Climate Data

To thermally assess the exposure of the proposed design to climate change weather data provided by Exeter University's Prometheus project was used. The IPCC's fourth assessment report includes different socio-economic projections of CO_2 emissions. Based on these emission scenarios the latest climate projections for the UK have been developed, i.e. UKCP09. These incorporate climate models from the Met Office and others. The projections are probabilistic in nature instead of deterministic so as to allow users to assess the level of risk. Using this probabilistic data Exeter University has created a set of probabilistic future weather files for various locations around the UK including Exeter. Each of the weather files are equally likely and the different percentiles represents a different position within the range of the uncertainty of the climate models and again represent different amounts of climate change. Using a high percentile will cover a higher probability of climate change and therefore more extreme scenarios, ensuring a very robust adaptation strategy and reducing the overall risk. However, because each of the weather files are equally likely, choosing a higher percentile can at the same time lead to over engineered and more costly solutions. It is therefore essential to calculate the risk to identify the most appropriate weather file for a given project.

For the Swim4Exeter project the building type risk assessment has resulted in a medium to low vulnerability to change in temperature conditions and a higher vulnerability for construction and water management.

Together the design team and the client decided to use the high emission scenario, 50th percentile files for 2030, 2050, 2080 for the thermal modelling of the building and to allow for an increased risk scenario for water management and construction.

Although the building has been classed as a low to medium risk, with choosing the 50th percentile a higher probability climate change scenario has deliberately been identified as more appropriate. This is to take into account the current development of actual CO_2 emissions worldwide. Current trends already exceed the highest emission scenarios developed by the IPCC in 2006 which again formed the basis for the currently available probabilistic weather data UKCP09. It could be argued that the lower emission scenarios and lower percentiles are already outdated and therefore there is an increased likelihood of more extreme climate scenarios.

3 Adaptation Options

This chapter illustrates the climate change adaptation strategies, the building physics behind these strategies and how they can be implemented. A cost benefit analysis was carried out for each of the proposed strategies to assess their commercial viability.

The climate change adaptation strategy was developed in two stages. First, an assessment of the three available sites was carried out. This was a qualitative analysis of each of the three available sites looking at solar exposure, shading studies, ventilation opportunities and exposure to noise/pollutants, landscape opportunities to moderate the microclimate and flood risk and water management. Advantages and disadvantages of each of the three individual sites were discussed and their potential effect on the proposed designs under changing future climate conditions.

The second part was an analysis of potential building adaptations measures using IES dynamic modelling and PHPP (Passivhaus Planning Package) to look at energy and water performance optimisation and thermal comfort. Various strategies to reduce the risk of overheating and also potential adaptation measures were analysed and compared for their effectiveness, life cycle costs and practicality to implement. One generic pool design was modelled using IES dynamic and PHPP modelling to make best use of modelling resources and to allow the design team to investigate and analyse a range of potential overheating reduction strategies. This model was representative for all sites and various building orientations and ventilation strategies were modelled to allow for site specific implications. Drawings of the generic pool design are included in the Appendix 1.

Both, the site assessment and building adaptation assessment, then informed the ongoing design process and to develop viable options for the three sites.

3.1 Assessment of Available Sites

A desk study was carried out to assess site related key factors that will affect the building's performance under future climate scenarios. These include solar exposure, ventilation opportunities and exposure to noise/pollutants, landscape opportunities to moderate the microclimate, flood risk and on site water management.

3.1.1 Building Orientation and Internal Comfort Requirements

Due to the high internal temperature requirements pool buildings can benefit from solar gains almost all year round; maximising these solar gains together with a compact design and a high performance building fabric will help to reduce energy losses to a minimum. However within the swimming pool complex there will also be dry sport facilities that need to be operated at a considerably lower temperature than the pool building. Even if these zones can be thermally separated, continuous internal heat transfer between these zones is unavailable and will increase the risk of overheating for areas with lower temperature requirements. It is therefore important to maximise the potential to include strategies to reduce the risk of overheating for these areas. According to findings from Gale &Snowden's work on the first round of the D4FC programme these measure are most effective if considered at the earliest design stage.

3.1.2 Shading Study

A computer assisted shading study was prepared for each individual site using a 3 dimensional model of the design, including the surroundings and topography. All three sites allow for a design solution that will help optimise solar gains to the pool area throughout the year. However, on the Clifton Hill site there is a high likelihood that this will be compromised because of the close proximity of existing residential units and potential overlooking/privacy issues.

3.1.3 Ventilation

Whilst Clifton Hill and the Bus Station site offer good opportunities to include a natural ventilation strategy that maximises ventilation rates, the Howell Road site appears heavily compromised. Due to the close proximity of the railway line along the northern boundary and because of site restrictions that limit the available space on site only single sided ventilation will be possible for major parts of the building including large areas of the dry sport facilities. This will inevitably have implications on the building's potential to react to higher temperatures under future climate scenarios and other means of cooling will most likely need to be included.

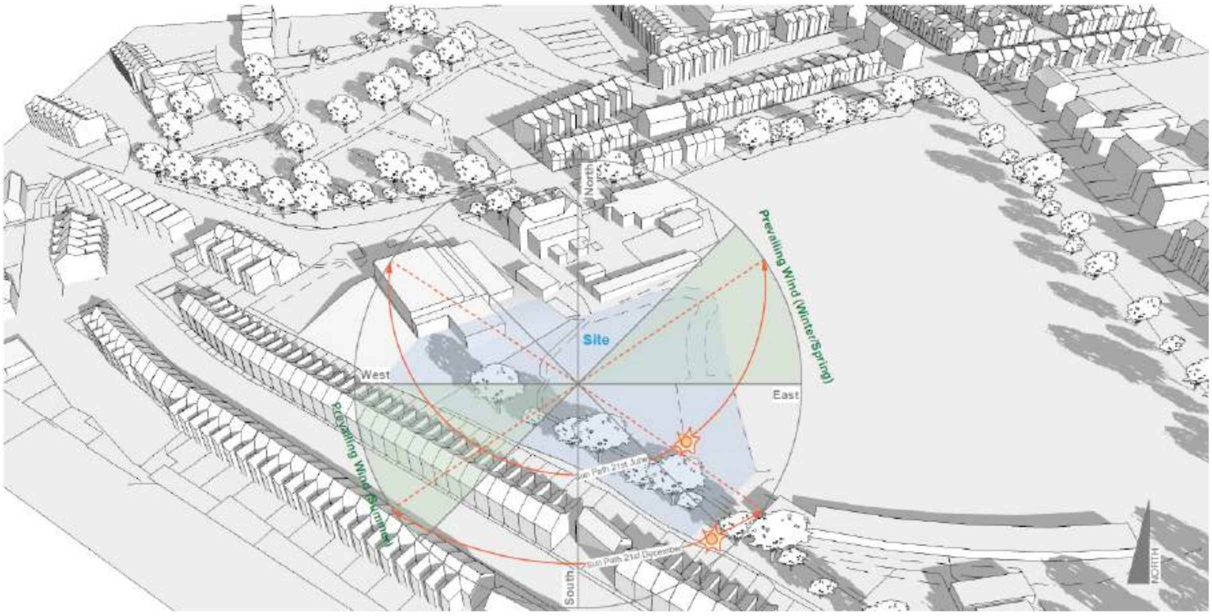


Figure 13: Overview of the Clifton Hill site

3.1.4 Flooding

All three sites are within flood zone 1 and there are no water courses adjacent or close to the sites and therefore there is a low risk of flooding for these sites. However, due to its large footprint and car parking requirements a greatly reduced runoff rate could represent a future risk to adjacent sites if SUDs are not dimensioned to allow for changes in rainfall patterns or if site restrictions do not allow for the installation of increased provision in the future.

Clifton Hill being the largest site has a greater potential to include water management systems like SUDs to further reduce the risk of flooding and also to retain water on site for use during periods of reduced rainfall.

Howell Road and the Bus Station site have only very limited potential to include SUDs schemes due to existing underground services and limited available space on site.

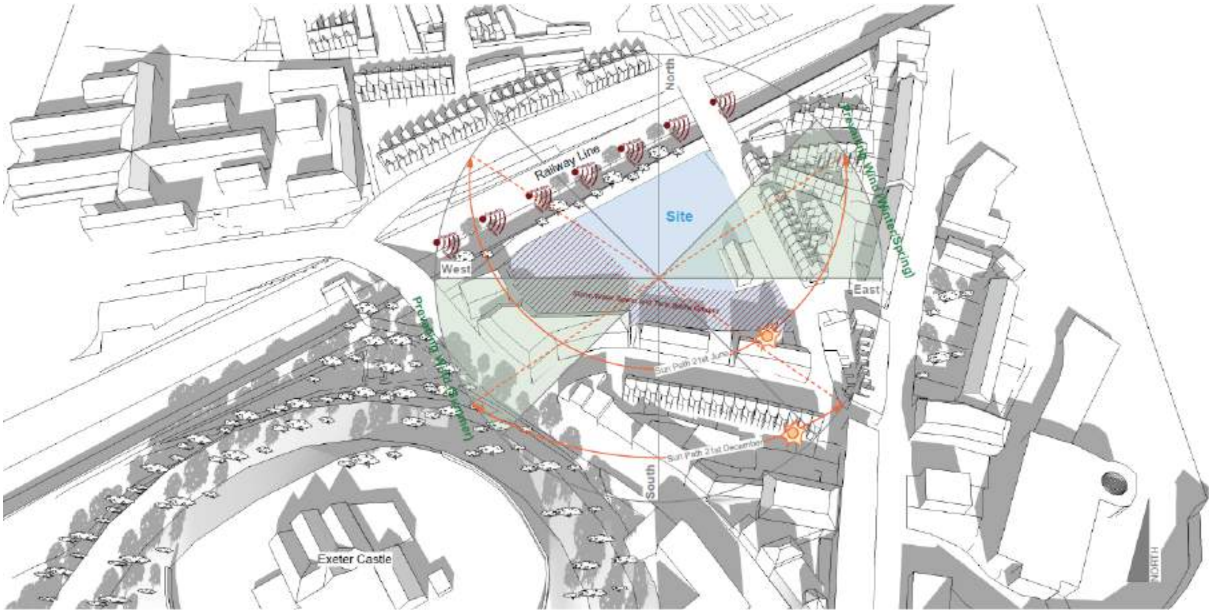


Figure 14: Overview of the Howell road site

3.1.5 Weather Exposure

South-west England is one of the more exposed areas of the UK, with wind speeds on average only greater in western Scotland. The strongest winds are associated with the passage of deep depressions close to or across the British Isles. The frequency and strength of depressions is greatest in the winter half of the year and this is when mean speeds and gusts are strongest. (Met office)

The range of directions between south and north-west accounts for the majority of occasions and the strongest winds nearly always blow from this range of directions with a predominant SW direction.

Late winter and spring time tends to have a maximum of winds from the north east, due to the build up of high pressure over Scandinavia at this time of year. Periods of very light or calm winds with no preferred direction are usually about 15% of the total time and can be compared with a typical inland station in central England that would have light winds for around 25% of the time.

Due to their inner city location, the Howell Road and the Bus Station site are both well protected by adjacent 4-5 storey buildings from prevailing easterly and south-westerly winds and driving rain. The Clifton Hill site is more exposed due to the open green space serving as a driving range to the East/North-East. During late winter and spring the site will be more exposed to wind and driving rain. Under future climate scenarios an increase in rain fall and storm severity is expected for the winter months. Thus there is a higher climate change related risk for the Clifton Hill site with regards to an increase in storm intensity.

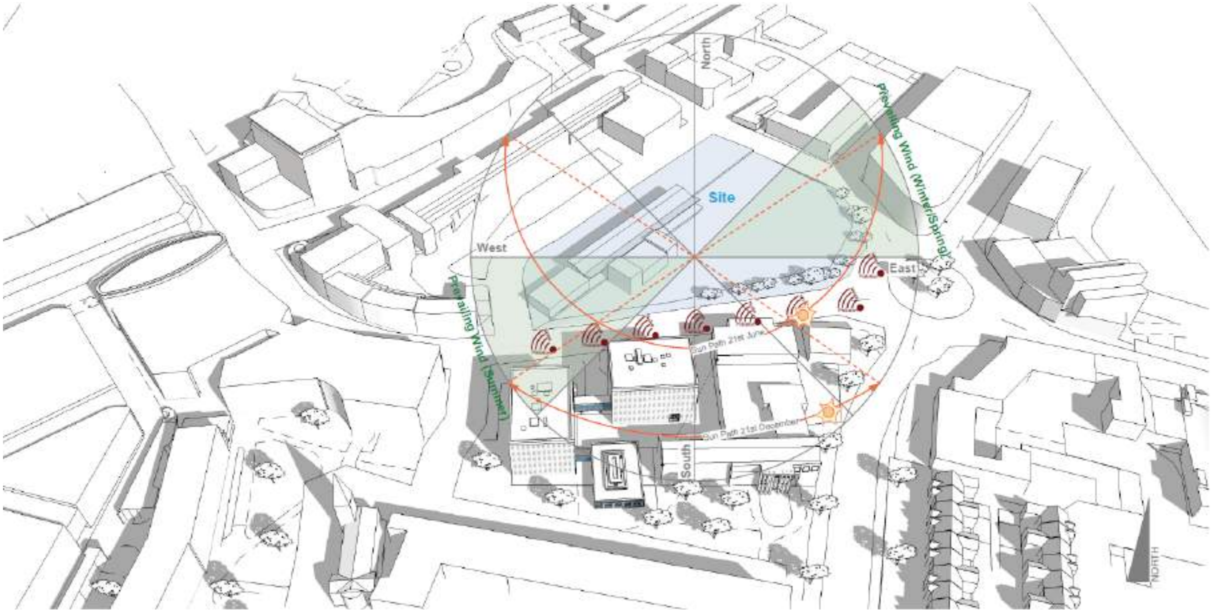


Figure 15: Overview of the Bus Station site

3.1.6 Landscaping

A well considered integrated landscape design can help moderate the microclimate to address issues of overheating. Generally green spaces can provide a cooling effect from shading and evaporation. Plant selection and rainwater attenuation are key elements to ensure green spaces retain their capacity to provide a cooling effect during longer periods of drought.

A permaculture landscape option appraisal based on E. Toensmayer's 'Multiple Functions Chart' has been prepared to evaluate different design alternatives and a copy has been included in Appendix 3. The following are the main findings from this exercise:

External Spaces

Clifton Hill offers the opportunity to create landscaped external spaces for the use of occupants as a future climate change adaption strategy. Research on swimming pool users has found that as long as people remain in the water they will still feel comfortable even at increased temperatures and humidity conditions. However, when resting outside the pool areas the conditions would typically be conceived as too hot/humid. An outside area could be positioned so that building users can easily leave the building for resting and cooling in the event of higher internal temperatures without abandoning the building. This area could also be used for galas where guests could make use of it for cooling and in between events. Howell Road and the Bus Station site do not offer this opportunity due to site constraints.

Water on site

Attenuation ponds, swales and underground tanks could be implemented as part of the drainage strategy. For the Clifton Hill site, an extended pond near the building could provide cooling from evaporation and it could also reflect heat and light into the main pool area. Howell Road and the Bus Station site do not offer this opportunity due to site constraints. A green roof system could be implemented for rain water attenuation and also to reduce the risk of overheating. Research by Exeter University prepared for the 'Exeter, Extra Care project' under the D4FC first phase suggested that internal temperatures can be reduced by moderating the external climate through planting and green roofs.

Planting

Deciduous planting around the south and west of the building could reduce temperatures in the summer but drought proof species would need to be selected that also will not reduce daylight into the building during all seasons.

The Clifton Hill site, being a former landfill site, offers an opportunity for the implementation of a bioremediation strategy. Bioremediation consists of mitigating pollutant concentrations in contaminated soils, water, or air, with plants able to contain, degrade, or eliminate metals, pesticides, solvents, explosives, crude oil and its derivatives, and various other contaminants from the media that contain them. It is considered a clean, cost-effective and non-environmentally disruptive technology, as opposed to mechanical cleanup methods such as soil excavation or pumping polluted groundwater.

Contaminated land, currently unusable, could be reclaimed for more extensive landscaping (like e.g. deep routed trees, ponds/water features) which would open up further opportunities to address climate change issues in future years.

3.2 Building Adaptation Options

This section describes the Climate Change Adaptation methodology used by the team to investigate the building physics of the design during the design process.

One generic pool design was modelled using IES dynamic and PHPP modelling to make best use of modelling resources and to allow the design team to investigate and analyse a range of potential overheating reduction strategies. This generic pool design follows the same accommodation requirements as the proposed individual designs and is therefore representative for these options. Various orientations, glazing ratios, ventilation strategies (single sided, cross ventilation, mechanically controlled), orientations with regards to solar gains, shading scenarios and passive cooling techniques (like ground cooling) have been modelled for the main pool area and the dry sports area because these two zones represent the two ‘extremes’ in terms of humidity levels and temperature requirements.

The key areas assessed were:

- Building Orientation
- Single sided ventilation vs. cross flow ventilation
- Construction strategies – heavy weight, medium weight, light weight
- Intelligent ventilation control – windows closing when external air temperature is hotter than inside
- Solar shading strategies
- Zoning to reduce internal gains and minimise energy losses
- The role mechanical ventilation heat recovery (MVHR) can play to support passive ventilation strategies in a mixed mode approach
- The role of MVHR coupled with ground cooling

3.3 Comfort in the Main Pool Area

3.3.1 Thermal Comfort Requirements for the Main Pool Area

Thermal comfort is dependent on a range of factors as previously discussed. For a pool building the main factors determining the level of comfort are high temperatures paired with high relative humidity.

With its high humidity levels swimming pools fall outside the general categories listed in ASHRAE standard 55 or BS EN 15251. Comfort levels have therefore been calculated using the PPD and PMV method described in BS EN 7730.

An average relative humidity of 55% is typical for standard pools in the UK. Research by the German Passivhaus Institute has shown that energy losses from evaporation in a well insulated pool building can account for almost half of the energy demand and increasing the humidity can reduce evaporation from the pool water considerably and with it reduce latent heat losses and water demand. However, increasing the relative humidity will affect user comfort and also might affect the building fabric. For example, in a swimming pool environment even stainless steels start corroding when exposed to humidity levels higher than 65% RH for a longer period of time. To protect the building fabric 65% RH has been identified as the maximum allowable RH and has been analysed for its impact on user comfort.

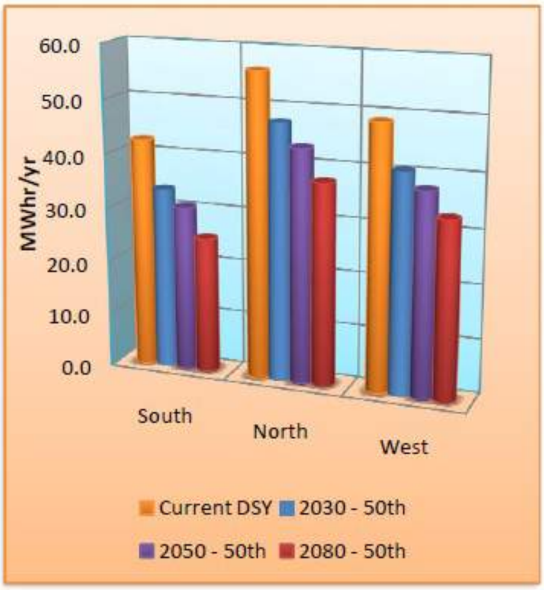
The PPD analysis shows that generally a wet person will find a relative humidity of 100% at a temperature of 32°C comfortable. However, for a dry person and even when resting (i.e. a low degree of activity) acceptable humidity levels drop for temperatures above 30°C.For a dry bather the RH would need to be controlled at 10% to still achieve a PMV of +1.

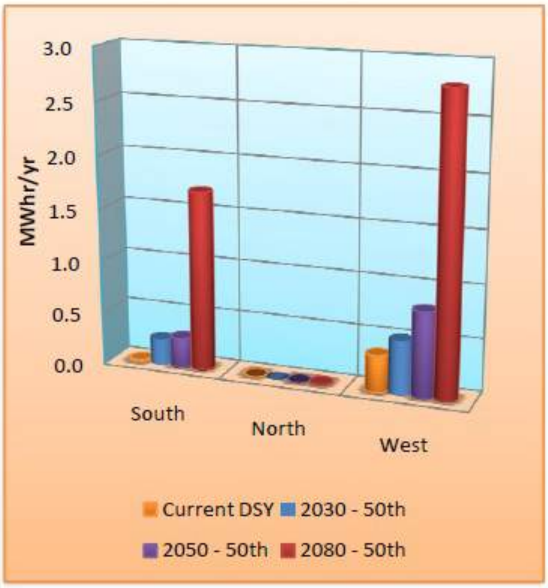
The optimum comfort is therefore very much dependant on how the space is used. If the pool area is used purely as a sport facility and bathers can be expected to spend only short periods of time resting outside the pool then high levels of RH are acceptable.

If humidity levels are to be further increased to reduce the energy and water demand then it appears even more sensible to zone the building on the basis of use and temperature requirements. By zoning the building into wet areas dedicated for swimming and areas where dry persons can rest, high levels of thermal comfort could be achieved without compromising the low energy strategy. However, careful consideration will need to be given to overheating due to increased solar gains under future climate scenarios.

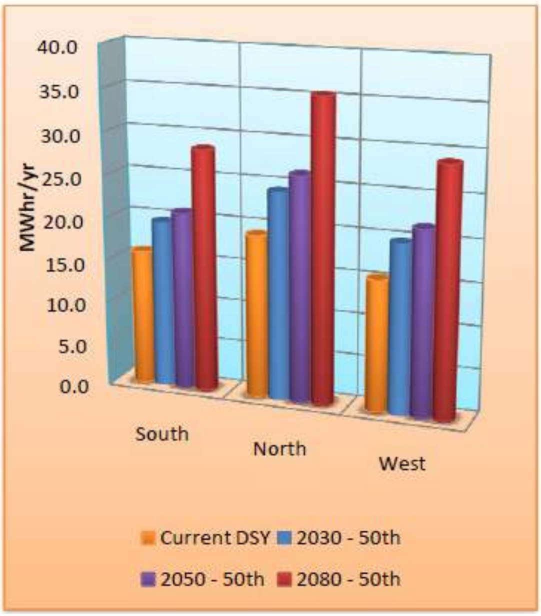
3.3.2 Solar Orientation of the Main Pool Area

The thermal modelling of the main pool hall showed that orientating the pool with glazing facing south has a significant effect on the heat load throughout the year (see Figure 16).





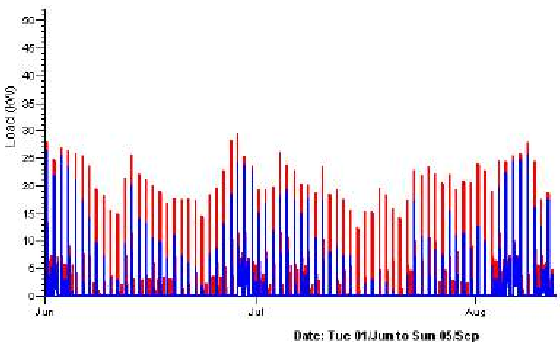
Facing south the heating load is 42 MWh/yr and facing north it is 56 MWh/yr. This is a difference of 16 MWh. Moving into future climates significant heating savings can still be found with a south facing orientation. Figure 17 shows that the optimum orientation for cooling is north with a resultant zero cooling load. However, the cooling load when facing south is negligible in the current day climate and even into a 2050 scenario is minimal. At 2080 facing south presents a cooling load of 1.7 MWh but even this is relatively small compared to the heating savings of 16MWh obtained with this orientation. The results in Figure 18 show that the dehumidification loads for south and west orientations are approximately 3 MWh/yr lower than for a north orientation. It was expected that there should be no difference in heat gain to the space when controlling to 29°C whether it be from solar or a heating system, hence humidity control should not change either.



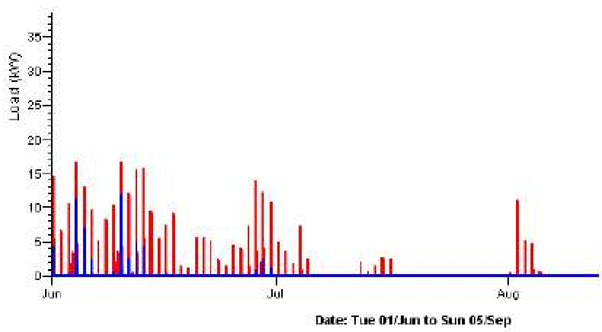
It can also be seen from Figure 18 that dehumidification loads will increase moving into future climate change scenarios. The south facing scenario shows the dehumidification load at 15.9 MWhr/yr for the current design summer year and increasing to 28.4 MWhr/yr in a 2080 scenario. The main reason for this is the increased moisture content available in warmer air temperatures when compared to the current design summer year thus increasing energy dehumidification loads.

3.3.3 Additional Shading to Glazed Areas

As an alternative, the base case design was simulated with the inclusion of a 1 metre overhang to the predominant glazing on the main pool hall. The 3 different orientations were simulated with this overhang. The results show that including the overhang actually increases the heat load, more so than decreasing the cooling load. During the current design summer year this increase in heating load is an additional 16 MWh / yr whilst the cooling load increase is negligible. Upon further investigation it was found that there was still a significant heat load during the summer months (see figures 19 and 20).



Red line represents with overhang, blue line represents without.



Red line represents with overhang, blue line represents without.

The addition of the overhang whilst providing shading in the summer to reduce cooling also reduces the level of solar gain which was assisting the heating loads. This also has a knock on effect of increasing the dehumidification load. The results show that including an overhang has a detrimental effect on the energy requirements for the building. There is still a heating requirement during the summer months which is due to the high temperature requirement within the pool space of maintaining 30°C all year round. Any solar gain that can contribute to this provided the optimum is found with cooling loads will reduce this heat requirement.

3.3.4 Comparison of Passivhaus with a Building Regulation 2010 Compliant Design

It could be shown that reducing the building fabric thermal properties from Passivhaus to 2010 thermal targets almost doubles the heating load. During the current DSY the change is from 49 MWh / yr to 89MWh / yr. In addition the 2010 simulation does not take account the weakness in thermal bridging and the higher infiltration rates as will be expected with this type of construction. The difference in cooling between the two is insignificant and there is a slight increase in dehumidification load.

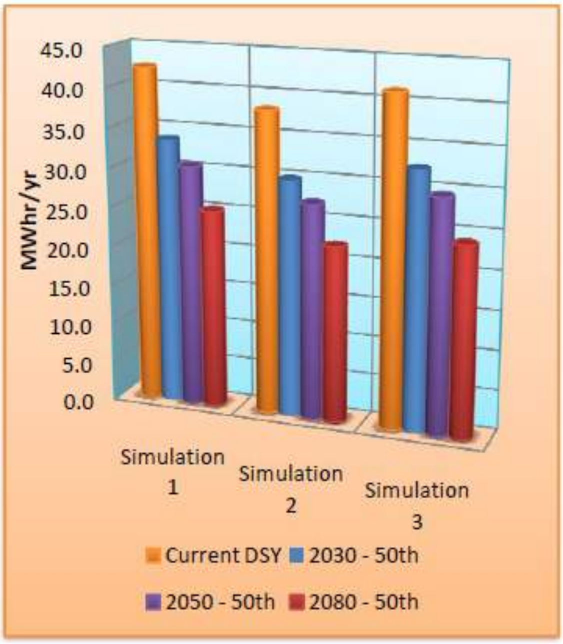
The Passivhaus fabric approach together with minimising thermal bridging is an important factor when designing for high heat loads in swimming pool buildings more so than for most other building types. It was found for both approaches including the glazing overhang that cooling was not a factor.

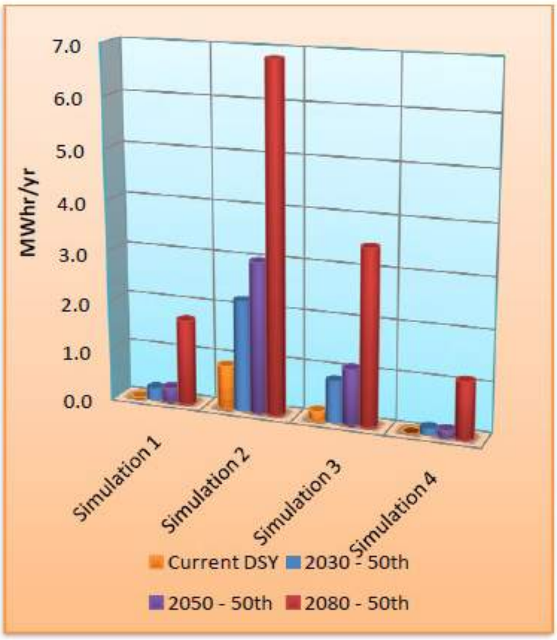
3.3.5 Increased Glazing to South Facing Facades

To maximise daylight levels and optimise beneficial solar gains the team decided to increase the area of south facing glazing. This was done to further investigate the limits of south facing glazing for a Passivhaus pool under current and future UK climate conditions. It was decided to assess the impact of doubling the glazing area on the south facing vertical facade would have on the building into future climates. The following scenarios were assessed:

- Simulation 1: The base case design facing south without overhangs on the vertical glazing
- Simulation 2: Doubling the south facing glazing without overhangs
- Simulation 3: Doubling the south facing glazing and including 0.5 overhangs.
- Simulation 4: As 3 but using the ventilation system in summer bypass mode without heat recovery

Increasing the glazing without the use of an overhang (simulation 2) will reduce the heat load further by approximately 3-4 MWhr/yr across the climate change scenarios. However it will also increase the cooling load by 3 MWhr/yr in 2050 and by 5 MWhr/yr in 2080. In 2080 this negates the heating savings made.





Including an overhang to compensate for the increased glazing area (simulation 3) negates this net reduction in heat load shown in simulation 2. It also reduces cooling loads throughout the climate change scenarios but it is not significant enough when compared to the heating load. Therefore the optimum is to double the glazing areas and not include overhangs. It can be seen for simulation 4 that using the ventilation system in summer bypass mode can assist with reducing cooling loads by between 1-2.5 MWhr/yr which can compensate for the effect of having no overhang. Therefore if increased glazing areas are required for increased daylight levels and further interaction with external spaces, the overall impact on the energy load of the building is minimal.

3.3.6 Conclusion

Results indicate that selecting a site and window design that enables south facing orientation would allow for an optimum balance of heating and cooling requirements for current and also future climate scenarios. If at the same time the relative humidity is to settle around 65% in the pool hall this can offer dehumidification energy savings which would result in lower air change rates, lower fan power, lower energy loads on evaporative cooling/ dehumidification systems and also generate considerable water savings. However, it is important that the optimum Relative Humidity (RH) is realised for both users' comfort and to protect the fabric of the building. Thermal bridge free detailing will further reduce the condensation risk and help protect the building fabric. The Passivhaus pool, the team visited in Bamberg, Germany had RH levels set to 65%RH and control was achieved with 1.5 air changes per hour (with 30% recirculation).

The results therefore indicate that the optimum design strategy for current and future climate scenarios for the main hall is:

- South facing orientation
- 65% RH
- Close control of RH

This will result in the following benefits under current and future climate scenarios:

- Lower heat loads
- Lower dehumidification loads
- Minimum risk of overheating

Furthermore it could be shown that shading devices such as overhangs will actually increase the heat load more than decreasing the cooling load.

3.4 Dry Sports Area

3.4.1 Thermal Comfort for the Dry Sports Area

Guidance from the CIBSE recommends indoor summer temperatures of 14-16°C for dry sport facilities. Even under current climate conditions this is hardly achievable without active cooling systems.

Adaptive comfort standards like BS EN 15251 suggest that dependant on external temperatures considerably higher internal temperatures are acceptable if a building is naturally ventilated. However, the adaptive comfort as calculated by BS EN 15251 or ASHRAE 55 does not take into account humidity. For a building with varying and at times very high occupancy and humidity levels like sports facilities this approach is highly questionable.

Therefore the project team decided that thermal comfort criteria are to be analysed using the PMV and PPD method described in BS EN 7730. When assessed using the PPD method temperatures of 20°C will still be accepted as comfortable by 90% of the users and 80% of users will still feel comfortable at 24°C.

Comfort Range according to	CIBSE Guidance			BS EN 7730			ASHRAE Standard 55			ADS (Adaptive Comfort Standard)					
Predicted Mean Vote	-0.21	-0.08	0.09	0.17	0.3	0.43	0.57	0.7	0.83	0.97	1.1	1.24	1.38	1.52	1.66
Percentage People Dissatisfied	6	5.2	5	5.6	6.9	9	11.8	15.4	19.8	25	30.9	37.5	44.7	52.1	59.8
Ambient Temperature	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28

Figure 23: Comparison of commonly used standards for thermal comfort when applied to typical sports hall conditions.

The frequency of overheating was assessed against various commonly used thermal comfort standards including CIBSE guidance, BS EN7730, ASHRAE Standard 55 and ASHRAE adaptive comfort standard. Figure 23 shows the frequency of overheating (i.e. exceeding a set temperature) for the dry sports area under current and future climate data (Base Case). The temperature range and colours along the x-axis reflect these various thermal comfort standards:

- Dark green = CIBSE guidance (95% user satisfaction)
- Light green = BS EN 7730 (90% user satisfaction)
- Yellow = ASHRAE standard (80% user satisfaction)
- Orange = Adaptive comfort range

Figure 24: Frequency of exceeding a set temperature (x axis) in % (y axis) for the base case scenario

The base case design allowed for a Passivhaus compliant fabric design, high thermal mass, high level west facing glazing and natural ventilation via opening windows.

Whilst under the current data the building will only exceed BS EN 7730 requirements (light green: 90% user satisfaction) for less than 5% of usable hours, in 2050 this is likely to be in excess of 20% and by then even the more relaxed ASHRAE standard (yellow: 80% user satisfaction) will be exceeded >5% of the time.

3.4.2 Zoning

Leisure facilities, as is the nature of this project, have to provide various comfort zones within one envelope. To maintain optimum comfort in one building with the least possible energy demand will require zoning and careful consideration with regards to layout. Current design standards in the UK typically do not take into account this level of zoning and changing areas are often directly connected to pool areas and reception areas, affecting comfort and at the same time increasing the energy demand for heating, cooling, humidity control and ventilation. In terms of thermal performance, compartment walls and floors should be treated in a similar way as external walls, i.e. they should be designed as thermal boundaries.

Additional internal heat gains from the pool area through the compartment wall can significantly increase the risk of overheating. Applying additional insulation to the compartment wall and floor between these areas will reduce the risk of overheating. When compared to the base case (blue line) this strategy will reduce the frequency of overheating by ~2-4%.

3.4.3 Thermal Mass

Whilst the lightweight approach (light blue line) will still comply with ASHRAE standard 55 in terms of overheating (i.e. 80% user satisfaction) it will regularly exceed this temperature range under future climate scenarios. It is therefore advisable to include mass into the building structure and to aim for at least an intermediate form of construction (orange line).

Figure 26: Base case design compared to intermediate (option 3) and lightweight construction (option 4)

The heavy weight (dark blue line, base case) construction outperforms both the intermediate and lightweight approach and would reduce the frequency of overheating by 3-10% depending on the chosen comfort standard.

3.4.4 Orientation and Shading

Effective external shading (grey line) or a north orientation (purple line) of the dry sports area will reduce the risk of overheating without affecting the overall heating demand.

Figure 27: Base case design with north facing orientation

An optimum orientation for this type of leisure facility would be a north facing dry sports area to minimise detrimental solar gains to this temperature zone. When compared to the base case (blue line) this strategy will reduce the frequency of overheating by ~2-4%.

3.4.5 Ground Cooling

If an earth tube system would be installed to pre-heat/pre-cool the supply air to the dry sports area then this would successfully reduce the risk of overheating in that temperatures throughout the year could be kept within the comfort range described by BS EN 7730 (90% user satisfaction) when modelled under current climate conditions (see green line in diagram below). Even for future climate scenarios internal temperatures can be maintained within the ASHRAE comfort range (80% user satisfaction).

Figure 28: Base case design with ground cooling

For these comfort zones this strategy could reduce the frequency of overheating by 12-15%.

It is beneficial to fit this system with a bypass because otherwise the system preheats the supply air when external temperatures are below ground temperature the ideal temperature range (maximum satisfaction i.e. 95%) as recommended by the CIBSE of 14-17°C will be exceeded more frequently than the base case. If a bypass were to be installed that closes off the earth tube if cooling is required and when external temperatures are below ground temperatures, this could alleviate this problem.

3.5 Comfort – Conclusions

- Leisure facilities provide a range of different comfort zones within one envelope. To maintain optimum comfort in every part of such a building with the least possible energy demand will require zoning and careful consideration with regards to layout. Current design standards in the UK typically do not take into account this level of zoning and changing areas are often directly connected to pool areas and reception areas, affecting comfort and at the same time increasing the energy demand for heating, cooling, humidity control and ventilation. Compartment walls and floors should be treated in a similar way as external walls, i.e. they should be designed as thermal boundaries.
- The dry sports area will be most vulnerable to overheating because of its relatively low temperature requirements of ideally 14-16 °C and high internal gains from users. The overheating analysis in this report has therefore focused on the dry sports area and the following observations relate to this area. Because of its low internal temperature requirements, and high internal heat gains the ideal temperature range of 14-16°C as recommended by CIBSE is unlikely to be

maintainable with a natural ventilation strategy. Even the comfort range as per BS EN 7730 (90% user satisfaction) can only be achieved if detrimental solar gains are successfully minimized.

- Additional internal heat gains from the pool area through the compartment wall can significantly increase the risk of overheating. Applying additional insulation to the compartment wall and floor between these areas will reduce the risk of overheating.
- Whilst for the dry sports area the lightweight approach will still comply with ASHRAE standard 55 in terms of overheating (i.e. 80% user satisfaction) it will regularly exceed this temperature range under future climate scenarios. It is therefore advisable to include mass into the building structure and to aim for at least an intermediate form of construction. The heavy weight construction outperforms both the intermediate and lightweight approach.
- Effective external shading or a north orientation of the dry sports area will reduce the risk of overheating without affecting the overall heating demand. An optimum orientation for this type of leisure facility would be a south facing pool area with >30% glazing to wall ratio and a north facing dry sports area minimizing detrimental solar gains to this temperature zone.
- If an earth tube system was to be installed to pre-heat/pre-cool the supply air to the dry sports area then this would successfully reduce the risk of overheating. Temperatures throughout the year could be kept within the comfort range described by BS EN 7730 (90% user satisfaction) when modelled under current climate conditions. Even for future climate scenarios internal temperatures can be maintained within the ASHRAE comfort range (80% user satisfaction). However, because the system preheats the supply air when external temperatures are below ground temperature, the ideal temperature range of 14-16 °C, as recommended by CIBSE, and within maximum satisfaction levels of 95%, will be exceeded more frequently than the base case. If a bypass was to be installed that closes off the earth tube if cooling is required and when external temperatures are below ground temperatures, this could alleviate this problem.

3.6 Water

The total water demand of a swimming pool building is a combination of water used for water treatment (refilling and backwashing of filters), evaporation from pool water and water used for hygiene (showers, toilets). It is dependent on various factors: the strategy of water treatment and filtration will influence the amount of water used for backwashing, the ventilation strategy and internal humidity levels will affect the evaporation rate and the number of bathers and use patterns define how much water will be required for refilling of pool water, showers and toilets.

Good practice guidance from Sports England and the PWTAG (Pool Water Treatment Advisory Group) recommends minimum requirements for water treatment, refilling, humidity levels and ventilation rates. BS 6465 describes a method to estimate the required WC, urinal and shower provisions. Combining this information with expected levels of occupancy allows the minimum required overall water consumption for a certain number of users to be estimated.

Under this project the following water saving measures to reduce the water demand were investigated:

- Increased internal humidity to reduce evaporation rates
- Reuse of water for backwashing
- Recouping of water and latent heat from exhaust air via post MVHR heat pump systems
- Use of water saving appliances for showers toilets etc.
- Use of water saving filtration techniques
- Rainwater harvesting

Using the above methodology the average water consumption of a standard pool building was established as a base case scenario and to estimate potential water savings from the various proposed adaptation strategies. Results are listed in table 1 below. The calculations are based on the following assumptions:

- Visitors are assumed to be 50% male and 50% female.
- One visit to facilities per visit to a swimming pool is assumed.
- Two showers per visitor are assumed. One 'one-push' shower pre-swimming, and one 'two-push' shower post-swimming (one shower of 30 seconds (push control), 8 litre/minute flow rate; one shower of one minute (two pushes).
- The same ratio of WC to urinal uses is assumed as the ratio for provision in BS 6465 (i.e. one WC use to five urinal uses for men).
- The amount of evaporated water from a water surfaces depends on the temperature in the water and in the air, and the humidity and velocity of the air above the surface. Calculations were based on 30 degree air temperature, 29 degree water temperature and a velocity of 0.5m/s
- For refilling of pool water guidance from the PWTAG was followed
- For backwashing 10% of pool water per week was allowed for in accordance with good practice guidance

	Base Case (water use cbm/year)	**Proposed Water Saving Strategy**	**Resulting Water Use** (water use cbm/year)
Evaporation	1,451	Increase relative humidity to 64%	599
Backwashing	9,157	Provision of tanks and reuse of excess pool water for backwashing	0
Refilling/dilution of pool water	8,419		8,419
Showers	3,368	Use of low water use appliances	2,526
WC/Urinals	1,193	Provision of tanks and reuse of excess pool water for WC/urinals	0
Calculated annual water use	**23,588**		**11,544**

Table 1: Comparison of annual water use for a standard swimming pool and the proposed pool

This analysis indicates that if all of the recommended water saving strategies are implemented then the water consumption can be reduced by 50%.

3.7 Summary of Site Selection Findings

The client decided that the Bus Station site is to be further progressed. Whilst potential impacts from climate change were not key to making this decision, of all three sites the bus station site offered an optimum orientation to manage beneficial solar gains, provide shading in summer and to allow for the development of a successful natural ventilation strategy. The dry sports area could be orientated to the north, facing a newly created open place. The wet areas will be south facing and act as a buffer. A staggered roof with high level clerestory windows will provide a stack effect and cross ventilation to the dry sports area. Planted areas along the south elevation will contribute to reducing surface water runoff and provide some shading. Building adaptation strategies have been analysed focusing on the Bus Station site.

3.8 Summary of Building Adaptation Appropriate Options

The following is an overview of the adaptation options that were identified by the design team as most appropriate and most effective for this project. Strategies have been categorised into comfort, water, construction and landscape related items. An additional section lists management and people adaptations strategies.

3.8.1 Building Adaptation – Comfort

Figure 29 below visualises the key strategies to maintain thermal comfort in a warming climate as a result of the thermal modelling carried out for this project.

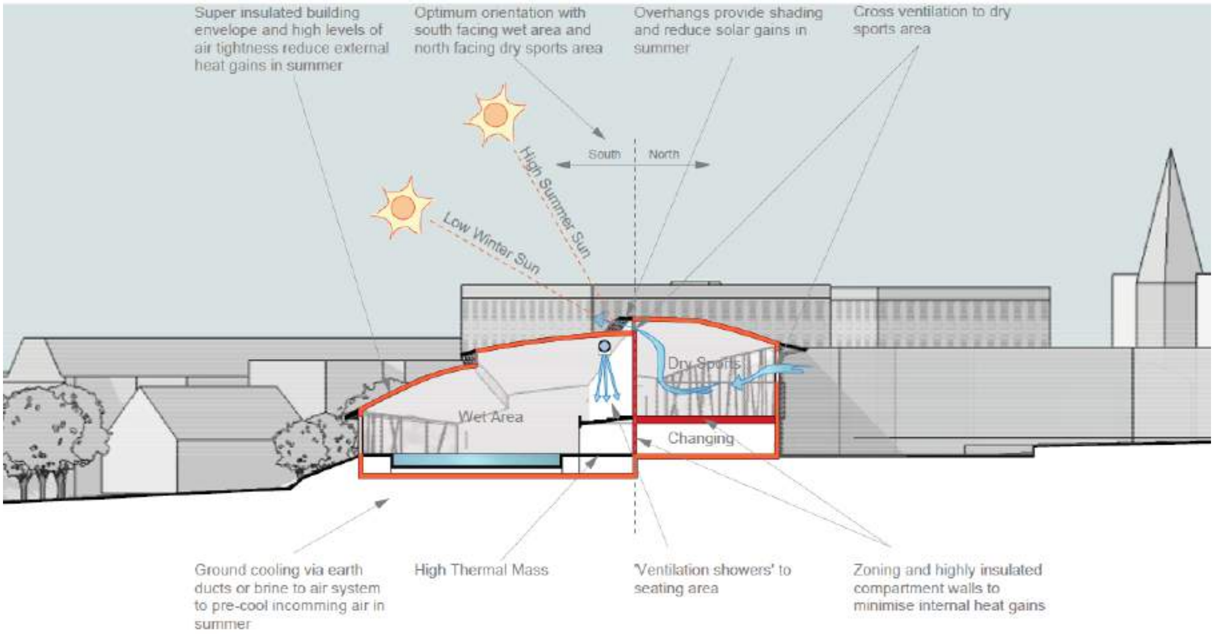


Figure 29: Building Adaptation for thermal comfort

3.8.2 Building Adaptation – Water

Figure 30 describes water management opportunities that address potential water shortages and flooding issues due to changes in rainfall patterns.

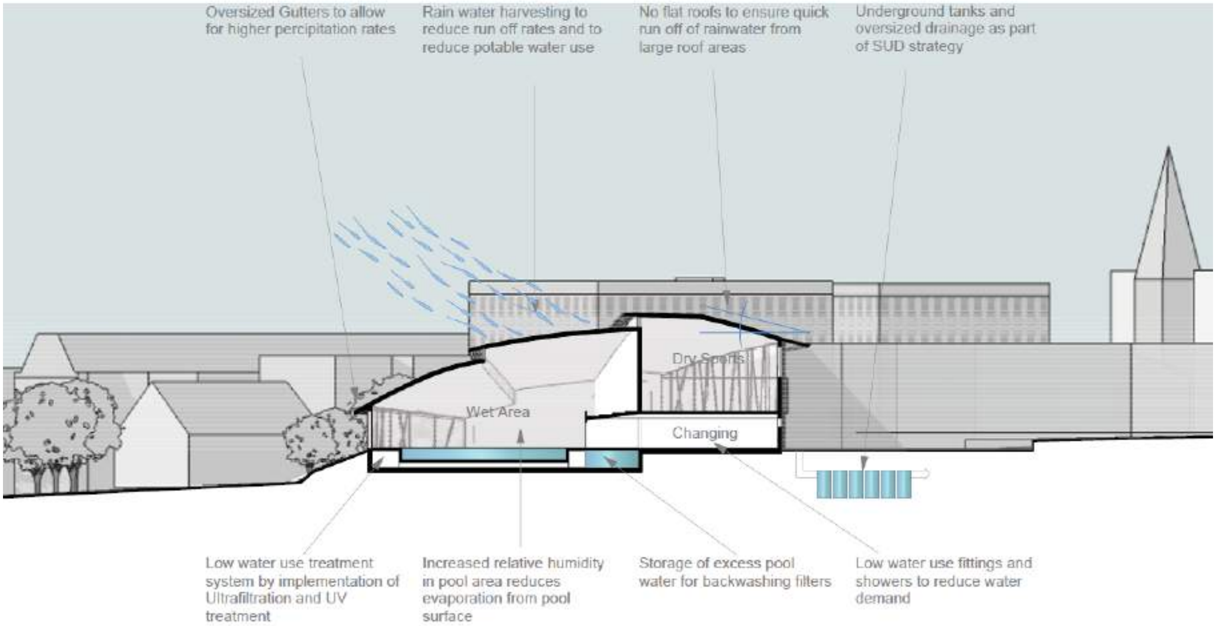


Figure 30: Building Adaptation for water management

3.8.3 Building Adaptation – Construction

Figure 31 shows opportunities with regards to construction to address potential impact from climate change on the structural stability, fabric detailing and material selection for the swim4Exeter project. As mentioned earlier in this report, the stage of this project did not allow for an in-depth analysis or further development of construction details and specifications and this item is included for completion. It is to be understood as a recommendation for further investigation during the next stages of this project and to flag up some of the opportunities that this project offers to minimise construction related risk from changes in future climate.

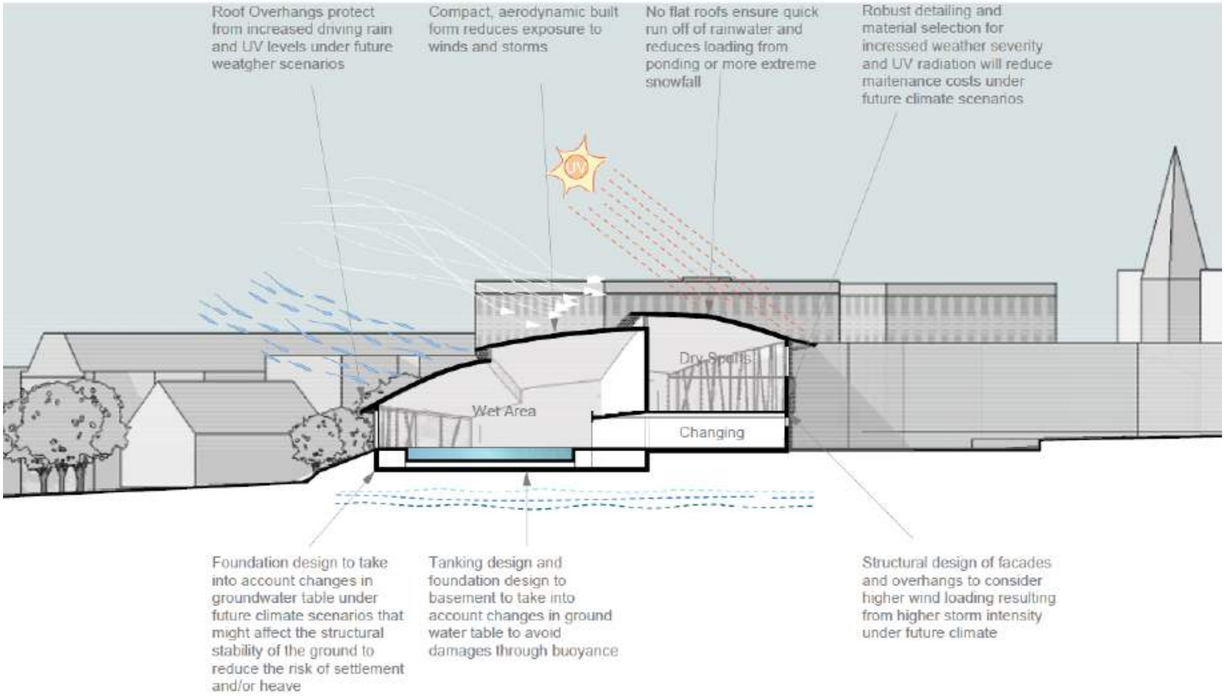


Figure 31: Building Adaptation for construction

3.8.4 Landscape Opportunities

Although the site is located in a city centre location and the space available for landscaping is very restricted, a green belt along the south west boundary offers the opportunity to influence the microclimate, provide additional shading and filtration and to influence the drought/flood cycle through appropriate landscaping. The following graphic visualises the opportunities that are to be implemented within this project.

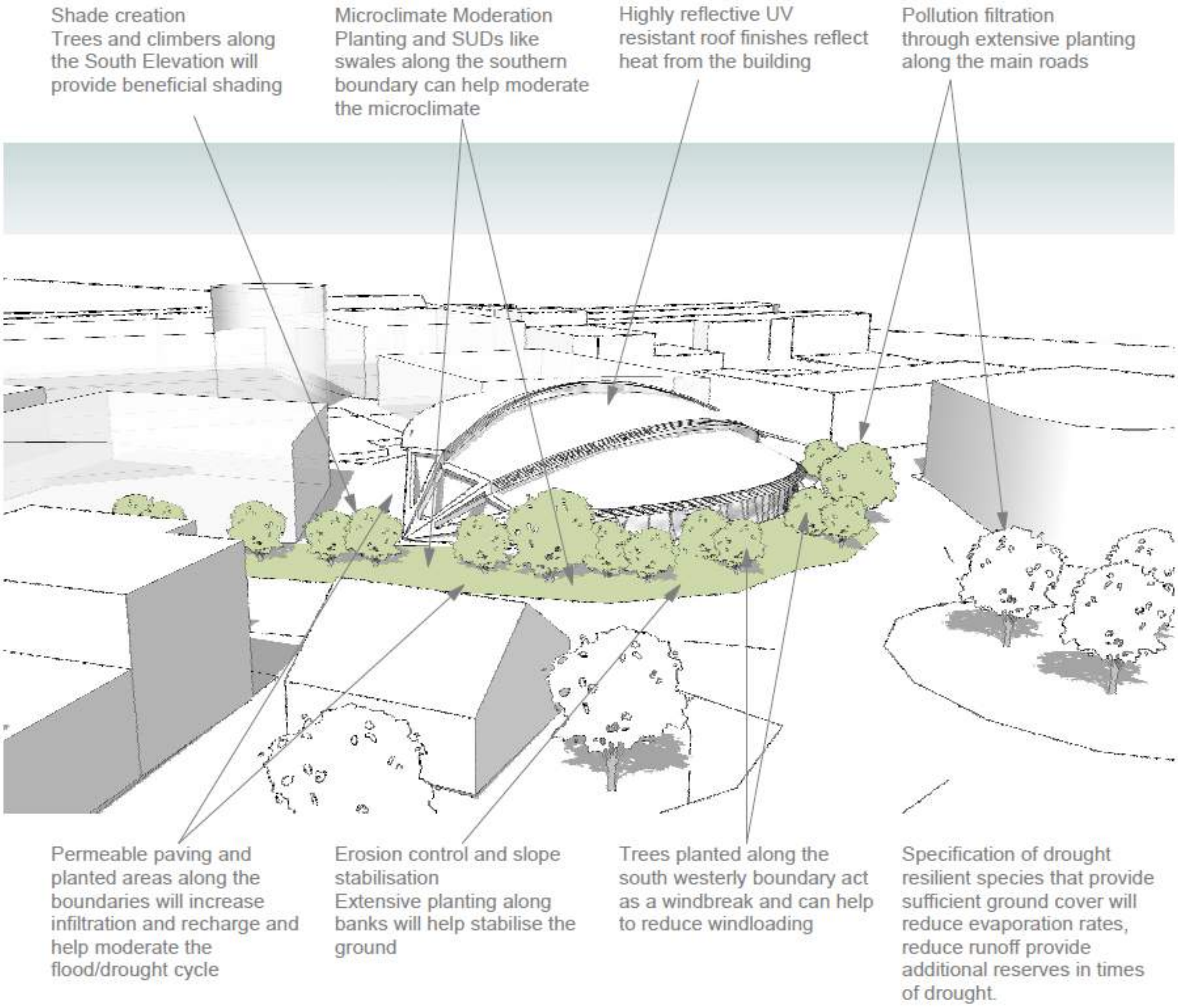


Figure 32: Landscape opportunities

3.9 Adaptation Option Appraisal and cost analysis

Following the identification of suitable adaptation strategies a cost analysis was carried out for this project by the design team to:

- Establish the costs associated with the various climate adaptation strategies recommended by the design team.
- Establish the cumulative costs for a ‘base case’ swimming pool, built to 2010 Building Regulation requirements, for heating, cooling and additional future investments required to maintain adequate comfort conditions under future weather scenarios over the lifetime of the building.
- Establish the cumulative costs for a swimming pool building, including the adaptation strategies detailed in this report, for heating, cooling and additional future investments required to maintain adequate comfort conditions under future weather scenarios over the lifetime of the building.
- Compare the two sets of cumulative costs to demonstrate to the client the long term benefits of the climate change mitigation and adaptation strategies

Passivhaus Design Strategy

Whilst in the UK typically the Passivhaus methodology is seen as a way to reduce the heating demand, the same principles have proven to be successful in addressing issues of overheating in warmer countries. Today there are numerous examples from Mediterranean countries and also tropical countries where the Passivhaus methodology was used in building projects to reduce the cooling demand and protect buildings from overheating (e.g. Austrian Embassy in Jakarta).

The thermal modelling results carried out for the Swim4Exeter project indicated that the same measures that help to reduce heat losses in winter, are also successful in reducing issues of overheating in summer as long as a successful ventilation and night cooling strategy can be implemented. This is consistence with Gale & Snowden's findings on the D4FC round 1 Extra Care for Exeter project and publications from the Passivhaus institute. High levels of insulation, controlled ventilation, high levels of airtightness and thermal bridge free construction reduce the heat transfer through the building fabric and in summer create a thermal lag. The insulation thicknesses of Passivhaus constructions typically achieve a thermal lag in excess of 8-12 hours and heat gains through the building fabric become negligible. As a result a Passivhaus maintains a comfortably cool environment for longer, even under extreme weather conditions, when compared to a standard building. Because of this night cooling and also the use of ground heat exchangers have proven to be very successful in these types of buildings.

The proposed Passivhaus construction has been included in the table below as a key climate change adaptation strategy. The costs indicated below include the upgrade from a standard specification to the levels required to meet the Passivhaus standard.

The following strategies have been approved by the client to be included from the outset. The schedule details the adaptation strategy, its potential with regards to climate change adaptation and related costs.

Thermal Comfort Strategies			Costs
	General description	**Climate Change Adaptation Potential**	
Super Insulation / Thermal Bridge Free Construction	This involves insulating fabric elements such as walls, roof, and ground floors beyond that of Part L of the building regulations. Uvalues between 0.1 – 0.14 W/m^2/k. The use of triple glazing with Uvalues in the region of 0.7–0.1 W/m^2/k	In warming climates a number of passive strategies working together will be required to reduce overheating. Thermal modelling on this project found that this approach compared to standard building envelope reduced overheating in future climates. This is backed up by in field studies of buildings in warmer climates.	£550,000.00
Cross and Stack Flow Ventilation	Ensuring buildings are designed with adequate ventilation strategies beyond simply single sided ventilation. Windows which can open either side of a space can take advantage of the natural affects of wind pressure in buildings which provides a natural driving force via positive and negative pressures on the opposite facades. Openings at high levels for example via ventilation chimney stacks or roof lights can enhance the cross flow affect via using additional driving forces such as buoyancy and temperature differential between the high and low level openings.	The dry sports area and admin area has been designed with cross flow ventilation on ground floors with window openings either side. On the first floor openings have been provided at high level via roof light openings. These provide stack and cross flow ventilation. In warming climates robust and adequate ventilation strategies will be an essential requirement to ensure buildings do not overheat when using passive measures. Thermal modelling on this project found that for these areas designing with cross flow ventilation was the most significant strategy at reducing overheating when compared to single sided ventilation design.	cost neutral
Night Cooling	This involves purging the heat that has built up during the day via opening windows at night. Night cooling is particular effective if mass is incorporated into the building envelope. Unlike the domestic situation heat gains are predominantly during day from solar gain and in-use activities between 7am and 10pm. During unoccupied hours this heat can be purged.	Research carried out on case study of passively ventilated buildings around the world in hotter climates than the UK has found night cooling to be an essential element at reducing the effects of overheating. Thermal modelling on this project also concluded this. Would need to be part of the building design at the outset. The building is currently designed for night cooling to take place via restricted night ventilators and high level openings. This can also be backed up via the MVHR system.	cost neutral
Intelligent Ventilation Control	Passive ventilation strategies rely on external air to help cool the building. If external air temperatures are hotter than inside than this can increase the levels of internal overheating. Rather than cool the building down. Intelligent ventilation control involves ensuring that openings are closed to minimum fresh air levels under this scenario.	In future climate change scenarios there will be increased incidents of hotter external air temperatures than inside.	cost neutral

Thermal Comfort Strategies			**Costs**
	General description	**Climate Change Adaptation Potential**	
Intelligent Ventilation Control Continued	This could be done manually via a simple temperature warning system or automatically via temperature sensors, BMS system and actuated opening control. A mixed mode approach could be adopted whereby the MVHR system is enabled for minimum fresh air volumes and if coupled to ground cooling system would further reduce the effects of overheating.	A MVHR system has already been included in the scheme and this provides an ideal strategy to enable this system when windows close. Coupled with ground cooling or other such cooling elements such as exhaust air heat pump or dessicant wheel will enhance this strategy further.	
Daylight Design and Daylight Dimming	Ensuring good daylight design in internal spaces helps to reduce lighting loads, associated energy consumption and internal gains which increase overheating. The optimum has to be designed when sizing, selecting glazing types and the shape of windows to ensure good daylight levels internally, reducing heat loss in winter, and for the dry sports area minimising solar gains during the summer. It can also be beneficial in the whole building energy analysis to optimise solar gain in winter.	Reducing internal gains will be a key strategy in ensuring buildings can be passively designed to adapt to future climate change scenarios. Reductions in internal gains can help reduce the reliance on energy intensive air conditioning equipment. And adopt more passive measures.	cost neutral
	Reducing internal loads such as from lighting can have a significant impact on overheating levels.	A simple strategy using current technology is to ensure lighting systems are designed to switch off when not required provided adequate daylight levels are being met.	
	Lighting systems linked into daylight dimming will ensure that lights are switched off when not required.	The scheme has been thermally modelled for optimum window design and daylight levels to ensure this strategy can be realised. Daylight dimming from thermal modelling has also been highlighted as key strategy.	
	Future innovations in low energy lighting technologies such as LED lighting systems will reduce lighting loads further in future climate change scenarios.		
Reduction of Internal Gains	As well as utilising advances in low energy equipment other methods at reducing internal gains can be employed. This could include removing some equipment and people entirely form the building to reduce overheating. Equipment: 'Cloud' based computing systems ensures that offices do not require server equipment in the building. This moves the server to a dedicated building which can be designed in a different manner to cope with this gain.	Internal layout allows for effective zoning and high performance compartment walls can be included. Site restrictions will make it unlikely that external sports areas will be available.	cost neutral

	The main internal heat source for the dry sport area is represented by the pool area. This space is operated at 31 ° C throughout the year. Effective zoning and high thermal performance compartment walls can help to considerably reduce internal gains.	Thermal modelling of this project indicated that introducing insulation to compartment walls will considerably reduce the frequency of overheating in the main pool area.	£20,000.00
Thermal Comfort Strategies			**Costs**
	General description	**Climate Change Adaptation Potential**	
Heavyweight Construction vs Lightweight	One strategy is to investigate the optimum with regards to the construction and its associated mass. Heavyweight buildings with exposed mass such as the walls, floors and ceilings can absorb the heat build up during the day and then release it again at night when night cooling strategies can be implemented. For mass to work effectively ventilation strategies have to be realised. Lightweight constructions can still benefit from night cooling but may require additional measures such as solar shading and enhanced daytime ventilation control to limit daytime overheating.	Understanding the effects of construction type are important in future climate change scenarios because different passive ventilation and control strategies will be required to mitigate the effects of overheating. In addition different passive measures such as solar shading may be required depending on the construction type. The current scheme is a predominantly solid construction. Floors are anticipated to be in parts false floors to allow services distribution as too are the ceilings. This effectively can turn it to a middleweight building. Additional mass can be incorporated if required by introducing 3 layers of plasterboard at ceiling or a phase change material board instead of the 3 layers. Mass would have to be incorporated at the outset as it would be difficult to retrofit at a later date.	G&S previous Passivhaus projects have indicated that a heavyweight solution with external wall insulation results in cost savings of approximately 5% when compared to light weight construction.
Solar Shading, Glazing Blinds	Solar gain to the dry sports area can be controlled via various means – external shading devices, overhangs and reveals, internal blinds, solar shading glazing, the use of strategically located trees, solar control glazing Overhangs are fixed to the building facade above windows to reduce high level south facing solar gain. Recessing windows in the facade can introduce a level of overhang too the glazing. Strategically located trees – these can be located on eastern or western facades to mitigate solar gain in the morning or afternoon. During winter periods with minimum foliage the winter sun can contribute beneficial solar gain.	The control of solar gain through passive measures such as insulation and shading in the windows or external devices is to be considered a key adaptation strategy for future climate change scenarios (this is only relevant for the dry sports area and admin area).	Overhangs and window recesses have been allowed for at initial design stage to provide a degree of shading. No additional costs for this item are anticipated.
Landscape and planting effects	The local topography shading from other buildings, shading from plants, site exposure, local cooling effects from green and blue landscapes, reduction of hard landscape areas adjacent the building can all contribute to reducing the effects of overheating on the buildings.	In order to reduce heat island effects of buildings green and blue landscapes will play an increasing role in changing climates A permaculture landscape design proposed as part of the climate change adaptation strategy includes edible plants, shrubs and trees.	cost neutral

	In addition externally landscaped spaces can provide cooler pleasant spaces for workers to relax and keep cool in.	Research carried out from the previous ExeterCare4Exeter D4FC project concluded that external green spaces can reduce local external air temperatures by 3°C and have a positive impact in the adjacent building lowering internal temperatures by 1.5°C. This research also found that a green roof can also have a cooling effect to its local vicinity.	
Thermal Comfort Strategies			**Costs**
	General description	**Climate Change Adaptation Potential**	
Mechanical Ventilation with Heat Recovery (MVHR) Constant Volume	Ducted fresh air supply and extract system incorporating high efficiency plate heat exchanger or thermal wheel. Thus reducing heating loads associated with fresh air in winter. Constant volume system means that fresh air loads are constant throughout the building when in use throughout the day. In some instances rooms such as meeting rooms may be unoccupied.	As a MVHR system is to be implemented at the outset the MVHR system can be controlled in changing climates to supplement the natural ventilation system to operate in a mixed mode approach. It can help provide secure night cooling and provide minimum fresh air volumes when external air temperatures are hotter than inside. MVHR systems can be adapted in future climate change scenarios to include additional technology such as ground pipe / earth tube systems and desiccant cooling wheels. Additional temperature sensors and controls can be added to enable more sophisticated mixed mode cooling control.	Inc. in PH costs
Mechanical Ventilation with Heat Recovery (MVHR) Variable Volume	As above - ducted fresh air supply and extract system incorporating high efficiency plate heat exchanger or thermal wheel. Variable air volume systems ramp fan speeds up and down to suit the number of occupants in the building. Control is via PIR / CO_2 sensors linked to dampers for each space. Fan speeds ramp up and down on differential pressure control.	Generally as above	Inc. in PH costs
MVHR Plate Heat Exchangers	Typically an air to air metal heat exchanger. Types: Cross flow heat exchanger – up to 60% efficient; Counter current heat exchanger – up to 95% efficient (small units)	For summer control heat exchanger is bypassed so that outgoing heat is not transferred to the incoming air stream unless linked into a desiccant cooling wheel system as described below.	Inc. in PH costs
Ground Brine to Pipe Heat Exchangers	Consists of a ground pipe system 40-50 mm in diameter laid in the ground which is connected to heater/cooling wet battery in the incoming supply air duct. As with earth tube can pre-heat in winter and pre-cool in summer. The brine solution is pumped around the pipe in the ground and the through the heat exchanger in the duct. Simple temperature control parameter in winter and summer switched the pump on. Thus is it only uses energy when required.	Ground piped heat exchangers can be retrofitted in the future easier than earth tubes as they are smaller and easier to install. Provided external ground space is considered at the outset ground pipes can be installed without too much ground disruption using for example a vermeer pipe trenching machine. To be considered a viable adaptation strategy.	£29,000.00

Water Management			Costs
	General description	**Climate Change Adaptation Potential**	
High performance building envelope (Passivhaus standard) allows increased relative humidity reducing evaporation rates.	Thermal bridge free, super insulated building envelope with high performance windows and doors allows the building to operate at increased humidity rates all year round. This will reduce evaporation from pool water.	Effective measure to reduce water consumption and to address seasonal water shortages under future weather scenarios	incl in PH costs
Low water use time-flow-controlled showers and appliances	Low water use showers and WCs are effective means to reduce water consumptions. If showers are fitted with a push button operated time flow control water use could be further reduced	Effective measure to reduce water consumption and to address seasonal water shortages under future weather scenarios	cost neutral
Inclusion of oversized gutters and drainage to allow for increased annual rainfall under future weather scenarios	Oversizing drainage provisions will allow for increased rainfall under future weather scenarios	effective in addressing increased rainfall under future weather scenarios	assumed cost neutral
Inclusion of pool cover	A flexible pool cover allows for the pool to be covered when the building is not in use reducing water loss via evaporation.	Effective measure to reduce water consumption and to address seasonal water shortages under future weather scenarios	£45,000.00
Reduce pool water level over night	Reducing pool water level below the line of the edge drain over night when the building is not in use and effectively reducing filtration losses can reduce evaporation and drainage losses.	Effective measure to reduce water consumption and to address seasonal water shortages under future weather scenarios	cost neutral
Water harvesting for back washing filters	Introducing tanks for storing excess water for back washing will help to retain latent heat and reduce water demand	Effective measure to reduce water consumption and to address seasonal water shortages under future weather scenarios	£8,000.00

Many of the adaptation measures did not add extra capital costs and in some cases made the scheme simpler. The following points provide further explanation of the associated additional capital costs:

- Incorporating the Passivhaus requirements of extra insulation, thermal bridge free design and air tightness and the MVHR system was approximately 5% cost increase when compared to 2010 building regulations envelope base case. It was also found that the Passivhaus design saved £60,000 a year in heating energy alone.
- The heavyweight design was found to be 2-5% cheaper to build. On a £12M build cost when compared to a lightweight construction method this equates to £300K to £600K. Whilst the lightweight was slightly quicker to build its material costs were higher. In addition, for a light weight construction, more elements and costs were associated with the thermal, acoustic and moisture protection requirements. For the life cycle costing exercise, both the standard case and the adapted building were considered of high mass construction.
- The ground cooling system was included in this scheme for the dry side only.
- Movable floors are still being discussed as a potential adaptation option and also to add more flexibility to the use of the main pool. In terms of water savings a similar effect can be achieved by pool covers. Because of the lower capital investment pool covers have been allowed for.
- Water saving filtration techniques have been excluded from the lifecycle costing exercise. More detailed design information and specialist input will be required to identify additional costs and benefits. This will be looked at with the project progressing.

The total additional capital costs for the thermal comfort adaptation measures to be adopted at the outset of the project are £599,000. These costs include £550,000 for external fabric improvements to meet Passivhaus standard, £20,000 for thermally separating the dry sports area from the pool areas and £29,000 for a ground piped heat exchanger system.

The total additional capital costs for the water adaptation measures to be adopted at the outset of the project are £45,000 for pool covers. Water saving filtration techniques are to be further investigated at a later stage but have not been included at this stage.

3.9.1 Costs Associated with a Typical Swimming Pool Facility

It was found that an extra £599,000 was required for thermal comfort adaptation strategies over and above a swimming pool building built to 2010 Building Regulations. This equates to an increase in built cost of approximately 5.5%. However this design whilst meeting Building Regulations will not be as thermally comfortable as the adapted design and in 2030 will require a full air conditioning system. Air conditioning will also incur associated running costs for the remaining duration of the building.

3.9.2 Cost Benefit Analysis

The graph in Figure 33 shows the cumulative costs for swimming pool building, built to 2010 Building Regulation requirements, for heating, cooling and additional future investments required to maintain adequate comfort conditions under future weather scenarios over the lifetime of the building. All costs have been discounted at 5% to represent present value. A conservative annual increase in fuel costs of 4% has been allowed for and a reduction of heating demand of 30% from 2050 to 2080 has been included. In 2030 an air conditioning system will need to be installed to maintain acceptable internal temperatures that again will need to be upgraded in 2050.

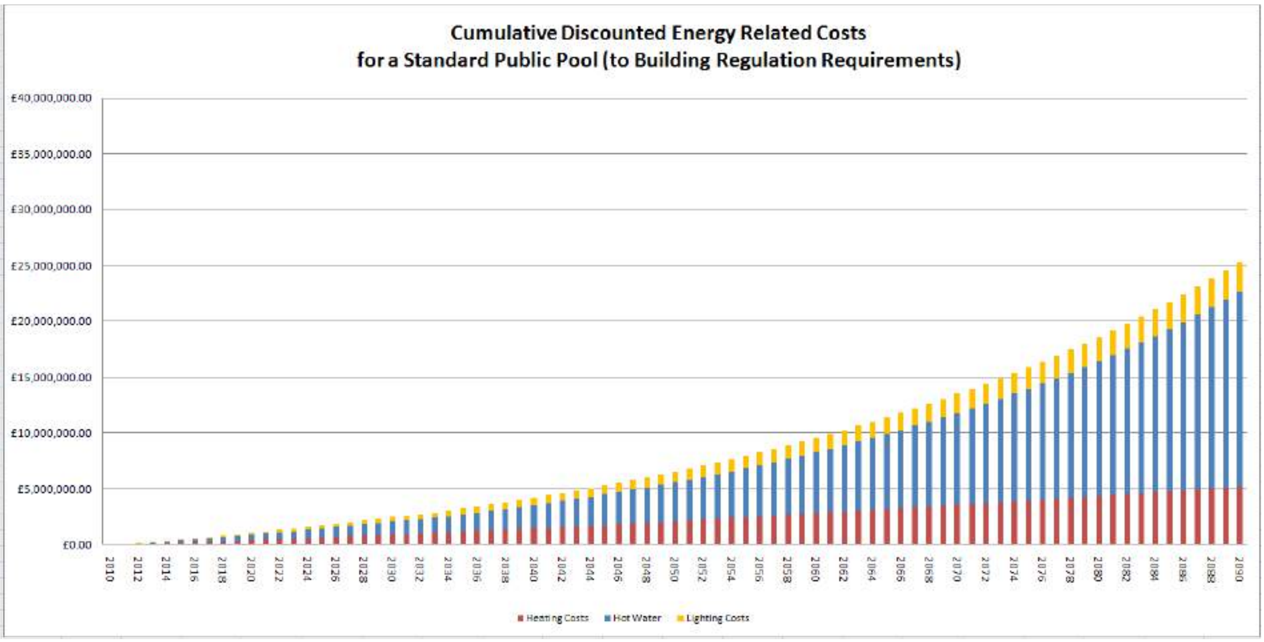


Figure 33: Cumulative Costs for Swimming Pool Building, Built to 2010 Building Regulation Requirements

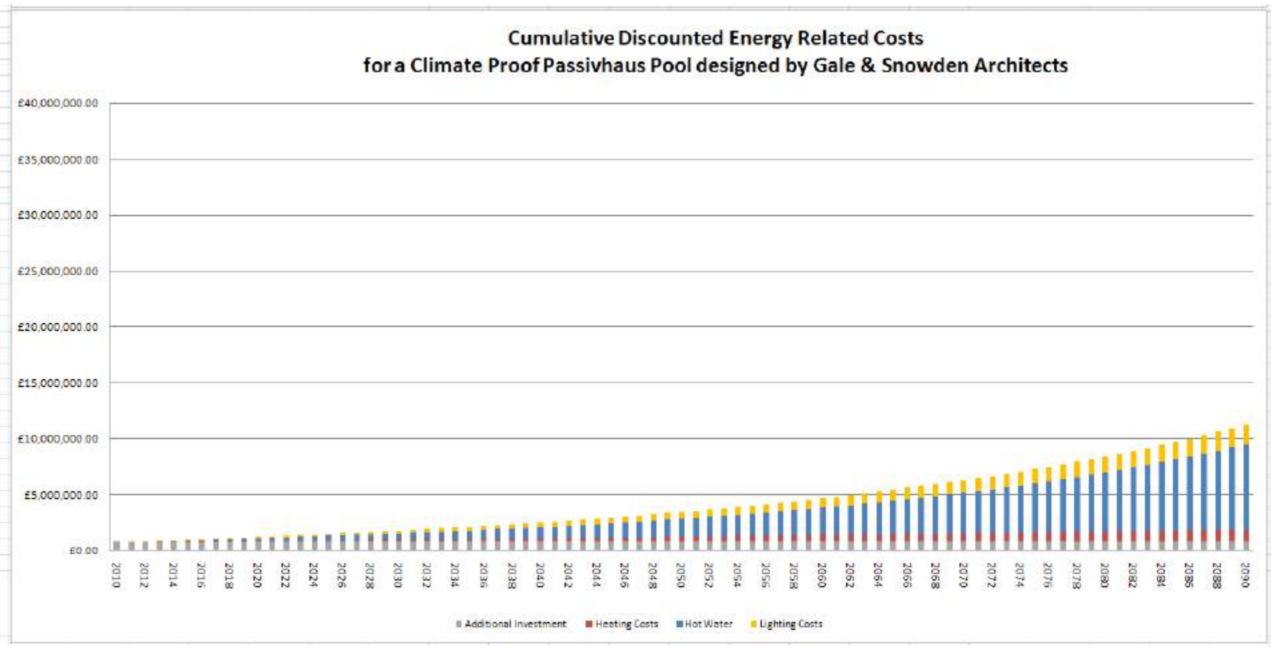


Figure 34: Cumulative Costs for Swimming Pool Building, Including the Adaptation Strategies Detailed in This Report

The graph in Figure 34 shows the cumulative costs for swimming pool building, including the adaptation strategies detailed in this report, for heating, cooling and additional future investments required to maintain adequate comfort conditions under future weather scenarios over the lifetime of the building.

All costs have been discounted at 5% to represent present value. A conservative annual increase in fuel costs of 4% has been allowed for and a reduction of heating demand of 30% from 2050 to 2080 has been included.

The building is to be constructed to Passivhaus standard, high mass solid construction, optimised cross-flow ventilation strategy and integrated landscape design.

This graph shows that over the lifetime of the building the net present value of the cumulative energy costs are approximately £11M compared to £25M for the swimming pool built to 2010 Building Regulation Standards. This illustrates that it is also cost effective to design to mitigate climate change from the outset.

3.9.3 Additional Benefits

In addition these measures will extend the useful life of the building and enable the pool sports facility to be operable and open to the public even under more extreme external temperature conditions. And droughts.

By maintaining comfortable conditions and warranting sufficient water supply, a municipal pool can play an important part to assist people in adapting to future climate scenarios as an opportunity to cool down and refresh during heat waves and hot summers. This strategy is well used in eg Mediterranean countries where a pool forms part of any modern large scale housing project.

However, considering a standard pool building of this size consumes as much water as 750 households and operating a pool during droughts will only be viable if the water consumptions can be reduced significantly. The measures proposed with this report will help reduce the water demand by 50% making which will help to reduce the impact on future water provision during periods of water shortage.

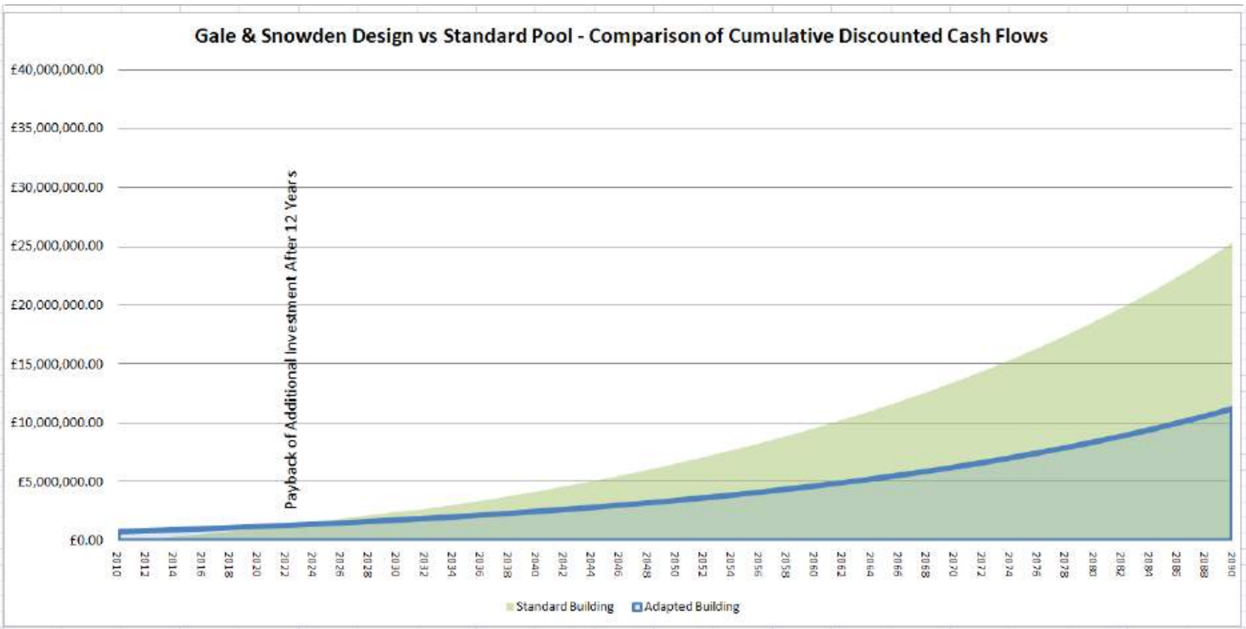


Figure 35: Comparison of Cumulative Costs for a Standard Pool (Green) Building and the Proposed Pool (Blue)

Figure 35 is an overlay of Figure 33 and Figure 34. The comparison of the cumulative discounted cash flows for both options shows that after 12 years the additional energy costs of the standard build will exceed the additional investments related to the adaptation strategies detailed in this report.

3.10 Timescales and Triggers for Implementation

When developing an adaptation strategy for the Swim4Exeter project the design team focussed on strategies that could be implemented with the initial design at no extra costs such as optimum solar orientation, cross ventilation, compact building form and thermal mass, or strategies, that provided both, an energy or water saving effect that at the same time helped mitigate impacts from climate change.

The Passivhaus design principles for example proposed for this project will reduce the energy demand and carbon emissions by up to 60%. The energy savings will be considerably higher than the cost of the investment and therefore are already economically viable in today's climate. The proposed ground cooling system will pre-cool the incoming air in summer and at the same time can be used to pre-heat the air in winter, again reducing the heating demand. At the same these measures were found to be successful in reducing heat gains in summer and to help maintain thermal comfort until 2080.

For a swimming pool building it was found that even some of the water saving features will considerably reduce the energy demand making them already economically viable. Research by the

German Passivhaus Institute has shown that energy losses from evaporation in a well insulated pool building can account for almost half of the energy demand. Increasing the relative humidity, installing pool covers and reducing the water level at night can all considerably reduce evaporation from the pool water and with it reduce latent heat losses and water demand. It can be shown that the energy savings from implementing these strategies again exceed the investment cost thus making them economically viable independent from climate change.

A chlorine free, water saving, ultra violet filtration system will allow to reduce ventilation rates and to increase the relative humidity, again reducing the heating energy and water demand.

The life cycle costing analysis showed that the additional investment for these measures can be recovered within a payback period of 12 years which is well within the life expectancy of all the critical components of the design.

Nevertheless it should be noted that future maintenance cycles offer additional opportunities to mitigate impacts related to climate change. For example instead of replacing the windows after 30 years with a like for like product, a glazing system with an increased U value and reduced g value could be specified. This system would allow reduced heat losses from the building whilst providing better protection from increased thermal gains. Changes in radiation due to climate change can thus be balanced out to a certain extent. Similarly roof covers and external finishes can be replaced at the end of their useful life with materials that have a better UV resistance.

4.0 Learning from Work on This Contract

4.1 Summary of the Teams Approach to the Adaptation Design Work

When the project was awarded funding from the TSB under the D4FC programme the project was still at work stage AB and no designs had been developed. The team had the chance to develop the climate change adaptation strategy alongside with the design of the building. Instead of checking and making recommendations for adapting an already progressed design, where most of the important decisions had already been made, this approach allowed for maximum flexibility.

The team built on their experience from their 'Extra Care for Exeter' project that received funding in the first round of D4FC projects. Again, an invaluable resource proved to be the 'study tour' at the beginning of the project to visit exemplary buildings in more extreme climates that could be representative to a future UK climate. Strategies that were found successful for the extra care project were transferred and validated for the swimming pool project. Methodologies like the risk assessment process were fine tuned and further developed and aspects like for example the lack of guidance on overheating criteria were investigated in more depth. A better understanding of the strengths and limitations of the different assessment and modelling (IES and PHPP) tools used to simulate summertime performance gained from the Extra Care project allowed for a more efficient use of these tools and analysis of the results. Please also refer to section 4.4.1 and 4.4.2 below for a more detailed analysis of these tools, their strengths and weaknesses.

The requirement to mitigate climate change related risks became part of the client's brief and a key performance indicator of the design.

4.2 The project team

Exeter City Council was the client and project leader for the TSB funded work on this project. Gale & Snowden were the technical project leaders. Their in-house integrated design team includes the following disciplines: Permaculture Designers, Architects, Landscape Designers, Passivhaus Designers, Building Physicists, Species Specialist, Mechanical & Energy Engineers. This team was already fully experienced in designing passive low energy buildings having been following this design approach for 20 years.

The client (ECC) brought to the CCA project:

- An enthusiasm and engagement in the CCA project work and design development
- Participation in the workshops and design input
- Commitment to implement the findings wherever possible
- Commitment to delivering low energy and low carbon buildings
- They also brought an appropriate level of staff to all CCA meetings to make decisions for the design team to implement CCA measures as the design was ongoing

The architectural designers and passivhaus designers brought to the design the following:

- Experience of designing and building both passivhaus and naturally ventilated passive and low energy buildings
- Healthy building design principles

- Ensuring any low energy and passive overheating strategies were developed in an aesthetic manner to create a low energy and comfortable building that will be a pleasure to be in
- An integrated landscape and permaculture design approach which links the building and external spaces together as part of the design process
- In depth knowledge of plants, species and landscape design to assess how climate change may impact on the landscape and planting strategy
- Experience of monitoring low energy buildings after they have been built and handed over to the end users

The building physicists, passivhaus designers and mechanical engineers brought to the project:

- Experience of thermal modelling and the PHPP and designing for summertime overheating in a wide range of both commercial and domestic buildings
- Linking outputs from thermal simulations into the design process to help inform key CCA design decisions at early stages
- Using both IES and PHPP in conjunction to provide a robust analysis methodology into assessing overheating in building designs
- Investigating active strategies such as the MVHR system that could link in with passive strategies and the early temperature warning system
- Experience of designing low energy mechanical systems in buildings and in this instance developing the CCA strategy of relocating heating plant outside the flats
- Experience of designing passivhaus mechanical systems such as the MVHR
- Experience of designing and implementing ground cooling systems

In addition to this the following disciplines also contributed to the project: Academic Institution (Exeter University), Civils Engineer & Structural Engineer, Quantity Surveyor and Project Manager.

Exeter University provided the following:

- In depth knowledge with regard to the future weather files and UKCP09 data
- Thermal modelling experience to assess in house thermal outputs
- Development of a methodology to simulate the impact of evaporation on humidity and energy use in IES

The quantity surveyor participated in the CCA process by providing capital costs and life cycle costs against CCA measures. As the CCA research commenced at early RIBA stages A/B it was possible with cost input to design many CCA strategies into the building with little extra costs. It was also possible to highlight potential savings that CCA strategies would eventually lead to.

Bringing the CCA element in at early stages clearly defined the high aspirations for the project everybody was engaged in and set the tone for the working brief and agenda for the team and the rest of the design development that was to follow

4.3 The initial project plan

The initial project plan was based on the team's experience from the first round of D4FC projects and in hindsight set out a successful route for the delivery of this project. Some minor impacts due to team members not being available caused some slippage. However all of these minor delays were recovered in the early parts of the next quarter. To address this issue, regular additional status meetings were introduced early on in the project to catch up on progress and to ensure important milestones are met in accordance with programme.

The site selection was delayed because of the political implications and the council's internal decision making mechanism. However, this did not cause delays to the project as the design team had already decided to analyse a generic model representative for all three sites to analyse potential impacts and opportunities. In the end this proved beneficial as it allowed the team to fine tune the model without site restrictions to form the ideal solution, before applying it to a specific site with its inherent drawbacks.

4.4 Review of resources and tools

4.4.1 IES Thermal Modelling Software

The IES software is a useful design tool at assessing the thermal performance and comfort conditions of building design for a wide range of thermal and passive strategies:

Details as follows:

1. Calculation engine: Apache
2. Calculation engine (version): v6.0
3. Interface to calculation engine: IES Virtual Environment

The thermal modelling software tools utilised to assess the buildings' thermal performance include:

1. Calculation engine (version): v6.0
2. Interface to calculation engine: IES Virtual Environment
3. Model tool: ModelIT Building Modeller
4. Thermal tool: Apache Thermal Calculation and Simulation
5. Solar analysis tool: Suncast Solar Shading Analysis
6. Wind & air movement tool: Macroflo: Multi-zone Air Movement
7. CFD tool Microflo: Computation Fluid Dynamics

Outputs:

- Advanced dynamic thermal simulation at sub-hourly time steps for better computation of building components
- Assess solar gain on surfaces, surface temperatures and radiant exchanges
- Extensive range of results variables for buildings and systems
- Building and room-level annual, monthly, hourly, and sub-hourly analysis
- Assess passive performance, thermal mass, and temperature distribution
- Link results from ApacheHVAC, MacroFlo, Suncast&RadianceIES and use as integral thermal simulation inputs
- Export results to MicroFlo as boundary conditions for detailed CFD analysis

Strengths:

- It is a powerful design tool at assessing the thermal performance and comfort conditions of building designs for a wide range of thermal and passive strategies.
- Can assess mechanical active strategies as well as passive
- Can assess energy performance as well as overheating
- Can be used as a concept design tool as well as compliance checking
- Can be used as a whole building approach analysis and can also be zoned to investigate individual spaces in more detail
- Is industry recognised software which has been developed in conjunction with industry guidelines such as those produced by CIBSE.

Weaknesses:

- Wide range of user experience inputs required so relies heavily on user competence when assessing future climate change overheating.
- There is currently no clear industry guidance and methodology on using dynamic simulation software when assessing future climate change impact on building design.
- Can be sometimes cumbersome to use as a concept design tool for inexperienced users
- It is difficult to assess the impact some simple adaptation changes have when simulating dynamically - for example when including solar shading with windows also opening automatically when temperature conditions dictate. Adding solar shading also changes the way windows open automatically when dynamically simulating as the internal temperature conditions will change with the lower solar gain. This can prove difficult to compare the full impact of some measures.
- The IES software is unable to analyse the impact of latent heat and therefore it is difficult to fully analyse the benefit of green roofs. Further research is required to develop methodologies to assess the role plants can play at producing cooling effects inside and around buildings

4.4.2 Passivhaus Planning Package PHPP

Details:

- Simulation is based on calculations of monthly energy balances. Overheating and cooling load calculations are based on daily intervals.
- It is a one zone model and each temperature zone has to be analysed as a separate assessment
- It takes into account internal casual gains and solar gains
- It allows to assess achievable ventilation rates, taking into account building design, window design, user behaviour, weather conditions and controls
- It takes into account building orientation and properties of the materials used including mass
- It utilises local weather data

Outputs:

- calculates energy balances (including U-value calculation)
- specifying and designing building envelope components
- designing the comfort ventilation system
- determining the heating load
- determining the cooling load
- determining primary energy demand

- determining the frequency of exceeding a set temperature
- design the heating and hot water supply

Strengths:
- simulation tool developed through empirical research and monitoring results of completed Passive Houses (commercial and residential) over the last 20 years
- simplified model which pairs reliable results with justifiable effort for data acquisition
- has proven track record of reliably predicting the average energy demand and summer performance of a low energy building for both commercial and domestic projects including dwellings, offices, schools and sport facilities.

- The PHPP includes a reliable tool to help designers assess achievable ventilation rates

Limitations:
- only suitable/reliable for low energy buildings with an annual heat demand of less than <40kWh/sqm year and an airtighness<1ac/hr
- summer comfort calculation allows to determine the general performance of a given building design. It is not suitable to assess individual 'critical' rooms within a building.
- According to research from the PHI (PHI PB 41, 2012) the calculation method used in the PHPP is limited to where the expected peak heat load is below 50 W/sqm. High temporary peaks beyond this level cannot be reflected by the calculation method.
- For high ventilation rates i.e. above 3 ac/h the PHPP tends to overestimate the frequency of overheating
- currently no future climate data files are available for the PHPP but it is understood that a research project at Cardiff University has been set up with the aim to generate this data
- the majority of papers/research are only available in German

4.4.3 Architects Tools / Other Software

In addition to thermal modelling and building physics software other tools used include:
- Vectorworks
- Sketchup – 3d visualisation tool
- Therm (thermal bridging analysis)
- Powerpoint for presentations and dissemination

Vectorworks and Sketchup were useful at initial design stages to help form the massing and shape of the building for the cross flow ventilated design. Sketch up also provides details of the sun path and shading analysis for a range of design concepts. The Sketchup visualisation software was found to be an important tool to help the client understand visually the impacts on the design various CCA strategies were having. Other tools such as PHPP and IES were found to be limited at providing 3d visualisations of CCA designs to present to the client. Sketchup as with any 3d visualisation tool helps to present CCA ideas visually to the client.

4.4.4 Prometheus Weather Files

The Prometheus weather files[62] generated by Exeter University have proven to be a useful tool as part of the thermal modelling process.

Strengths:

- Very easy to access from the Prometheus website and download for the location concerned
- In easily accessible format to incorporate into the IES software
- They are free which would encourage designs teams to use them in modelling software
- Are backed up with support by Exeter University

Limitations:

- File extension names could be made clearer as it is easy to use the wrong weather files in IES when simulating. At the time of writing this has now been made clearer by Exeter University.
- Although future years and high and medium emissions scenarios have been narrowed down from 3000 weather years, it is felt there are still too many for design teams to choose from. Choices for particular scenarios become subjective for design teams and building types. It would be helpful to either narrow down the weather files or provide guidance from industry as to which weather files are appropriate for particular building types.
- The Prometheus weather files include both wind speed and wind direction which is consistent with the rest of the weather signal. However, the climate change signal of these variables is much more uncertain with very little change currently expected in the winter and a very small negative change in the summer. Also there is little evidence to suggest that the future weather patterns will be fundamentally different to those which are currently experienced so the wind field provided within the weather file is likely to be fit for purpose. The natural variability is more likely to dominate over any climate change signal so the analysis of wind used within the models is robust given current knowledge of future climates. Better knowledge of future weather patterns would be of benefit. Limitations in predicting future wind speeds in changing UK climates and rain patterns to be made clear to design teams at the outset especially if designing natural ventilation strategies in buildings in warmer climates. Future wind patterns are part based on past UK historical records; considering there have not been many days above 30^0C in the past in the UK, caution is to be exercised when assuming a business as usual approach. This is more a limitation of availability of robust wind data rather than the Prometheus files.

4.5 What worked well?

- Having funding to carry out the D4FC research in the first place. The team have learnt an enormous amount with regard to passive design and climate change adaptation which will help inform designs for many years to come
- It allowed the design team to explore a whole range of new design ideas which have not all been incorporated as part of this work but would help inform future designs for years to come. This would not have been possible without the D4FC contract
- The designers and D4FC team working together at a very early stage of the design as this fundamentally steered the design in the right direction
- Integrated design approach at early concept stages – having the full team engaged at these stages in D4FC strategies
- The use of thermal modelling software at early stages helped inform decisions based around building physics rather than it being based on assumptions
- The combination of using both PHPP and IES flagged up strengths and weaknesses in both approaches and initiated an invaluable discussion on key elements like for example achievable ventilation rates and thus effectiveness of thermal mass and the inherent risk of overestimating or ignoring their potential to control internal temperatures

- Research into case study buildings and technologies and strategies that have been found to work in warmer climates other than the UK
- Visiting the Passivhaus swimming pool in warmer climates helped inform key design decisions during the design process
- Full client engagement in D4FC workshops throughout the design
- Having access to the Prometheus weather files which were used for summertime overheating modelling and Exeter University providing support in this area
- Separate D4FC workshops to design team meetings which helped focus the design team and client

4.6 What did not work well?

- Some of the available weather data into changing climates such as wind speed and driving rain and rainfall patterns was limited and not in a useful format for designers to work. More research is required in this area as to how wind speeds and rain patterns will change in the future.
- Lack of clear industry guidance into overheating criteria or a generally accepted approach to evaluating the impact on thermal comfort. Today there is clear guidance on assessing the energy demand of buildings and despite some differences in some of the assessments methods buildings within the same category are directly comparable. Research has been carried out to confirm actual energy demand and to review the existing models with the result that some assessment methods like the PHPP already today consistently achieve remarkable compliance with the design aspirations. To assess the summertime performance there is still no generally accepted methodology that leads to reliable results and only very limited research on built projects has been carried out.

On the whole the D4FC work was found to be a positive experience for the design team and it had a genuine and positive impact on the design and there is little that did not work well.

4.7 The most effective ways of influencing the client

- To fully engage the client in the process at the outset and involvement in all D4FC workshops and to contribute with design ideas and adaptation strategies
- To clearly present ideas and climate change risks with a range of visualisation tools such as the climate risk radar, Sketchup and power point
- To provide lifecycle cost analysis of D4FC strategies to be adopted
- To design adaptation measures passively into the building at little to no extra cost. It was found that if climate change is thought about at the outset of the design process and it is used to help influence the design, this building if designed robustly and correctly in the first place requires very little in the way of mitigation strategies to address impacts from future climate.

4.8 Recommended Resources

- Fully integrated design team approach with all design team members including engineers involved at early concept stages
- All design team members having the required level of competency, experience and proven track record
- Thermal modelling tools such as IES, PHPP
- 3d visualization tools to present climate change adaptation concepts

- Looking abroad – Analysing design strategies in countries that experience a similar climate to what can be expected to affect the UK in the future helps to show new paths.
- Including climate change considerations at feasibility study stage of a project helps to minimise potential adaptation costs and maximises the potential to increase the life expectancy of a building
- The methodology used on this project (i.e. climate risk assessment - site assessment - impact assessment) is applicable to any larger residential or commercial development.

5.0 Extending Adaptation to other Buildings

5.1 How can this strategy be applied to other projects and what are the limitations

The project had a strong focus on thermal comfort because of the design stage (RIBA work stage AB), which meant that no construction details were developed, but also because of the nature of the building, being a mixed leisure facility with three very different but equally demanding comfort zones. On the one hand, the wet areas have high humidity and high temperature requirements whilst the dry sports area has a relatively low internal temperature requirement. At the same time these areas have to react to peak loads from large user groups creating quite unpredictable and at times very high additional internal loads. The combination of all these factors makes these types of buildings unique when it comes to thermal comfort and this in itself is likely to limit the application to other projects.

Nevertheless, the general key stages that the team applied to develop a climate change adaptation strategy can generally be applied to any project, including: 1. Analysis of a building's exposure to climate change in a qualitative and quantitative way (e.g. Climate Risk Radar); 2. Identification of key risk areas and suitable future weather data; 3. Application of building physics and dynamic modelling to analyse the suitability of various options paired with a lifecycle costing analysis. Gale & Snowden successfully used this methodology on three D4FC projects and since then also implemented it in parts on other projects within the practice.

With regards to specific design strategies the following key recommendations identified in this report can be transferred to other building projects in the UK:

5.1.1 Looking abroad

A key recommendation for all design teams working in this field would be to look at countries that already experience a more extreme climate when compared to the UK. The team found that one of the most valuable resources for developing a climate change adaptation strategy was to look abroad and visit buildings that today have to perform under a climate that quite likely will not be dissimilar to what we might experience in the UK in the future. The team was able to experience these likely weather conditions for themselves rather than relying on simulations. In these climates, buildings and their users already have to cope with the higher temperatures, increased rainfall and more extreme weather conditions than are expected for the UK. The team was able to analyse local building designs and discuss their merits and the performance of these buildings directly with their users. Naturally, these countries have a long tradition of developing materials, detailing and cooling strategies to cope with the more extreme climatic conditions and represent a most valuable pool of information for the UK. This was found to be very helpful when it comes to overheating and increased temperatures under future weather scenarios. Not unsurprising there are however only very few habitable regions that experience more extreme rainfall and storm events than currently experienced in the South West of the UK.

5.1.2 Overheating

Whilst leisure facilities (the nature of this project) are unique in that they contain various comfort zones in one building, the majority of overheating strategies detailed herein such as insulation, mass, shading control, ground cooling, and ventilation are equally applicable to a wide range of commercial and residential buildings to limit overheating. Each building type however would have to be assessed for their vulnerability to climate change in its own right. The fundamental differences between different building types need to be taken into account when carrying out thermal simulations. Typically there are different activity and clothing levels, different internal gains, different comfort temperatures and occupancy patterns and control. For example a typical office will operate during the hours of 9 and 5. Overheating criteria are typically based on the loss of productivity. The predominantly heat gains will be during the day and will switch off at night. In an office with high mass, night cooling can commence to purge the daily heat gains. A dwelling on the other hand might have the same internal gain 24 hours a day and with this scenario night cooling would not be as effective as it is for an office which has no nightly gains and can be purged at night because it is not occupied.

The strategy of zoning is applicable to all building types with different temperature/comfort zones. Removing internal heat gains is applicable to all building types. In offices for example IT equipment such as printers and servers could be moved to cooler parts of the building on Northern façades away from people and could have localised extract to remove equipment gains during hotter periods.

5.1.3 Green Spaces / Healthy Buildings / Heat Stress Awareness

The green spaces and landscaping strategy and healthy building design strategy can be applied to any type of building design within the UK. It has been found that buildings and landscapes that are pleasant places to be in whether in the leisure or work environment or at home can have a positive impact on the health and well being of an individual.

In the work environment raising awareness of the issues and effects of heat stress will also help individuals cope. Relaxed attitudes during heat waves to dress codes, working patterns providing external green spaces to cool down in and cold water drinking stations are all strategies applicable to any building type.

5.1.4 MVHR and Ground Cooling

Thermal modelling has found ground cooling to be a viable strategy at reducing overheating in future climates for this scheme. However, for buildings that require fire compartmentation such as large scale dwellings, costs associated with this approach are significant. In addition limited space externally and competition with other ground services, a ground pipe array might not be a viable option for other schemes. For buildings other than apartments and flats which do not have extensive zoning and fire compartmentation for example large open space office buildings, schools etc ground cooling linked into MVHR systems could be considered a viable solution for dealing with overheating in changing climates. This is provided it can be simplified and that there is sufficient ground area. Of the 2 systems available, ground air ducts and ground pipe systems, the conclusions drawn from this analysis were that the pipe system would be the better option for the following reasons:

- It requires less ground space
- There would be no issues of air contamination from bacteria developing in the underground ducts as the piped system is hydraulically separated from the supply air.
- The pump distributing ‘coolth’ or heat from the ground only enables when external conditions are not favourable. For example below 5^0C and above 22^0C. A ground duct system pulls air through the duct 365 days of the year even when not required to do so. This results in an oversized fan to overcome the added pressure drop and increased energy costs.

5.2 Which buildings across the UK might be suitable for similar recommendations

Any mixed leisure facility across the UK could in principle benefit from the recommendations made in this report. To what extent and whether the individual strategy is successful both in terms of finances but also comfort levels will need to be assessed on an individual basis.

Despite the unique character of mixed use leisure buildings when it comes to thermal comfort, quite similar issues can be found in school buildings although to a lesser extent as the temperature differences are less extreme. Nevertheless, in the same way as leisure centres, schools have to cater for various comfort and activity zones, i.e. classrooms, offices, kitchens, sports halls etc. Quite often these different uses have to be accommodated in a single building and high peak internal loads from occupants need to be managed to avoid conflicts with the more vulnerable and demanding spaces. It is likely that some form of temperature zoning, even if only by grouping and locating the individual spaces according to their temperature requirements and use patterns is likely to help mitigate issues with overheating of the more vulnerable areas.

5.2 Resources Tools and Materials Developed

The main resources and tools that were developed:

- A thermal modelling methodology for assessing climate change impact on building designs at concept design stages
- A PHPP methodology for assessing climate change impact on building design at concept and design stages
- A methodology to run PHPP and IES tools in parallel so that they complement each other at concept and design stages as a design tool. This method also provides a means for comparing the results of one against the other.
- A methodology for thermally simulating the impact of evaporation from water surfaces on humidity and energy demand
- A risk assessment methodology that visualises potential risks from climate change using a climate risk radar. It was found this tool was very helpful in communicating climate change related risks to clients and others involved in the project
- A full understanding of climate change and its impact on building designs and appropriate passive climate change adaptation strategies that can be used to limit its effects
- A better understanding of the role green spaces and plants can play to mitigate impacts from climate change

5.3 Further Needs

- Further research into actual summertime performance and user behaviour in the UK. Monitoring studies from the Passivhaus Institute eg is suggesting that windows are not opened as widely or as often as generally expected in thermal simulations in the UK. No comparable studies on a representative scale are currently available in the UK.
- Clear guidance on overheating criteria, assessment methodology and input parameters for different building types and users

- Research into how people are likely to adapt to climate change in the UK. Will they become more tolerant to hotter climates?
- Further development of future rain files and accuracy
- Further development of future wind speeds especially if designing for natural ventilation design
- Development of probabilistic weather files for the PHPP

Appendix 1

Outline Brief

Existing Site Plans:

- The Central Bus Station
- Clifton Hill
- Howell Road

Proposed Sketch Design Drawings

- The Central Bus Station
- Clifton Hill
- Howell Road

Passivhaus Pool Bamberg – Site Visit Report

Adaptation Options Appraisal

Appendix 2

Climate Change Risk Radar and Assessment

UKCP09 data subsets

Appendix 3

IES Thermal Modelling Assessment Report

PHPP Pre-Assessment Report

Exeter University Study: Accounting for Heat Losses from Swimming Pools in Thermal Models

Permaculture Landscape Design Options

Adaptation Options Appraisal

Cost Analysis and Life Cycle Costs Report