Technology Strategy Board, Design For Future Climate

Climate Adaptive Neighbourhoods (CAN)

Final Report, April 2013

by Baca Architects with

JBA, UEA, UoWE, Sweett Group, Lanpro, Serruys Property

Client Reference: 13183-86165

ARCHITECTS
baca

Prepared by
Name Robert Barker
Position Director
Signature

Approved on behalf of Baca Architects by
Name Richard Coutts
Position Director
Date 4th April 2013
Signature

Revision A, 30 July 2013

Statement of use: This report describes the work to be done on the CAN ref. 13183-86165 project.

Dissemination status: Final report

Keywords: Adaptation, Flood Resilience, Floodproof, Climate Change, and Residential

Contractor: Baca Architects Ltd

Innovation Platform Leader: Julie Meikle

Publishing Organisation:
Technology Strategy Board
Block A1
North Star House
North Star Avenue
Swindon
SN2 1UE

Disclaimer

This report is for information only. The authors take no responsibility for the subsequent use of this information, nor for any errors or omissions it may contain. Professional advice should be sought when considering any development, particularly where flood risk may be present.

ARCHITECTS
baca
Unit 1, 199 Long Lane
London SE1 4PN
+ 44 (0) 20 7397 5620
mail@baca.uk.com
www.baca.uk.com

Contents

CONTENTS

APPENDICES

Executive Summary

The Climate Adaptive Neighbourhoods (CAN) project is one of 50 projects funded by the Technology Strategy Board as part of the Design for Future Climate Programme. The aim of the Design for Future Climate Program is 'to help develop innovative ideas to make our buildings fit for the future'. This involves the identification of and, ideally implementation of, adaptation measures to manage future climate on real building projects in the UK.

The CAN project, has advanced the design of an existing innovative masterplan for floodproof housing on a prominent regeneration site in Norwich; to create a holistic design that simultaneously addresses a range of climate issues for East Anglia.

Section 1 - Building Profile

The study site comprises a block of 72 new homes and approximately 2,000 sq ft retail and restaurant space, set to the north of the master plan, along the edge of the River Wensum. This block is part of the first phase of the redevelopment of a major brownfield site on outskirts of Norwich City Centre, which encompasses 670 homes and 25,000 sq ft of commercial space. This block was used to study the effects of future climate risks in detail, to explore adaptation options which could be applied over the life-time of the building, and to identify what lessons could be applied to other buildings within the master plan or other developments.

Section 2 - Climate Risks

The future climate risks were assessed using a range of tools, including the weather generator and flood flows modelling, based on two of the IPCC economic development scenarios: 2030s high and 2080s medium. The assessments showed a general trend towards increased temperatures, more frequent and intense heat waves and drought, increased intensity and duration of rain storms and higher flood levels. The uncertainty of the predictions was shown to increase over time, with the 2080s showing a wider range of possible climatic conditions. For instance mean temperatures were shown to increase by 14% to 28% in the 2030s (from 9.4°C to between 10.7°C and 12.1°C), and by 22% to 48% in the 2080s (from 9.4°C to between 11.5°C and 14.0°C). This variability was even more pronounced for:

> the wettest days, which were shown could decrease by as much as -33% or could increase by as much as +128%,
>
> for extreme flood levels which were shown could decrease by 21cm or increase by upto 100cm (when considering combined effects of rain and sea level rise),
>
> and for 30 year drought events which were shown could increase by 38 days (apx 100% increase).

The median predictions showed a more gradual change in climate, with mean temperatures rising from 9.4°C to 12.6°C and mean precipitation falling from 630m to 622mm. More severe events such as hottest day, coldest night, wettest day, number of dry spells, and number of days above 30°C were all shown to increase. The mean prediction for flood levels was an increase of approximately 0.3m. When increased river levels from sea level rise was considered this was shown to possibly increase to approximately 0.7m[1].

The main climate risks to life and property were considered to be associated with water and comfort. These were river flooding, surface water flooding, drought, and overheating; and their associated construction issues. To provide a robust and adaptable building design no matter which of the future climate predictions occurred, the 90th percentile scenario was used to inform the choice of adaptation measures and the timeline for implementation. Should a less dramatic change in the future climate occur then the adaptation measures could be implemented later or possibly never.

Section 3 - Adaptation Strategy

A range of adaptation options was explored and tested using various methods of simulation modelling and expert advice. The simulation modelling allowed a number of options to be discarded and the priority items to be identified. The preferred options were selected on multiple preferences and prioritised based on practicality of installation and cost effectiveness over time.

A passive house scheme was intentionally not explored, on the basis that the base scheme (as well as most building developments) are not designed to passive house and are unlikely to be so in the near future. The intention was that the CAN project would be applicable to as many new developments as possible that are built to building regulations standards as well as Code for Sustainable Homes Levels 3 and 4.

The base building design was found to be well suited to cope with the future climate. The main improvements to the building design were related to tackling more extreme temperature increases and increased flood levels, were they to occur. It was found that a single measure could not, sensibly, be used to tackle each of the main climate risks. For instance air conditioning could be used on its own to tackle overheating but would increase the overall energy use, thereby increasing emissions; or raising all of the buildings several metres above the ground may prevent risk of river flooding but would be extremely expensive and unnecessary (like designing a house to the same fire standards as a hotel). In all cases a number of design measures were thought to be required, particularly to tackle more extreme climate risks.

It was found that more extreme future flood risk could be managed without changing the base building design and that flood resistance and resilience measures could potentially be phased over time to respond to rising flood levels, rather than installed from day one[2]. Sufficient space and levels were identified to incorporate Sustainable Drainage Systems (SuDS) to tackle future surface water flood risk. Greywater recycling was found to be more cost effective than rainwater harvesting to maintain water use savings as the occurrence of drought events increased. It was found that overheating could be managed with passive measures, unless more extreme temperature changes were to occur. It was also identified that after only slight modification to the base building design, all of the passive measures could be retrofitted, with the exception of the thermal mass of the superstructure, which would need to be incorporated from the start.

Where possible it was sought to identify adaptation measures that could reduced more than one risk simultaneously, thereby improving the cost effectiveness of the solution. One of the most positive findings of the work was the potential that flood-risk management measures could improve cooling opportunities within neighbourhoods and buildings and provide space for rainwater harvesting.

- The proximity to water presents opportunities for cooling either directly from the water or indirectly from the reduced temperatures surrounding the water.
- The flood void created by raising buildings above the ground level provided a potential source for passive ventilation and cooling (equivalent to a labyrinth and stack cooling system).
- The heavy masonry construction required to provide flood resistance or resilience at the ground floor, provided thermal mass that helped to reduce the overheating risk.
- The possibility to use the flood void to provide large volumes of rainwater harvesting warrants more detailed research, particularly in areas of water stress.

---

[1] This was considered a precautionary increase in river levels and not a simulation of tidal interactions as this type of modelling does not exist as far upstream as the site).

[2] Implementation would have to be linked to changes in typical river levels or predictions as major flood events are too infrequent to measure over the life of the building; further more there would still be residual risk from a 1 in 1000 year flood event)

Executive Summary (continued)

The CAN solution was to provide an integrated suit of measures to provide a balance of flood resilience, overheating reduction and water saving. Whilst the most cost effective measures based on their benefit to reducing risk were found to be: flood resistance measures (based on NPV in 2037), swales (based on CAPEX), labyrinth and stack ventilation (based on NPV in 2058), and water saving devices (based on CAPEX); each of these measures had a limit to the benefit that they could provide. Therefore, the initial measures were chosen to be raised construction, swales, additional trees and water saving devices. This was largely consistent with the base scheme design.

The base scheme design for a raised deck within the courtyard of the building was found to be unnecessary to managing any climate risk and therefore could be omitted. Therefore, the changes to the base building to manage the future climate risks were found to only increase the capital cost by 0.3%. If the raised deck was excluded from this cost comparison then the capital cost was found to increase by 1.4%.

Findings from the work led to suggestions to change the two storey houses to three storey townhouses, with car parking at the ground floor. In this situation the additional costs associated with the garages would be balanced (at least in part) by the reduced cost of providing flood resistance and resilience.

The adaptation measures selected were broken down into initial measures, and first and second retrofit measures. These are shown in the adjacent summary table. This was also expressed through a possible timeline for the implementation / retrofitting of adaptation measures. However, in preference to relying on climate projections and possible dates it was suggested that a number of thresholds could be identified to act as triggers for retrofitting improvements. The most relevant

Neighbourhood scale	Building scale	Detail scale
Increase planting of trees to the south and west facades of buildings to provide future shading once mature	Buildings raised marginally to reduce cost of resistance measures required	Thermal mass to main building fabric
Create surface level SuDS formed from extensive ground swales along the edges of buildings	Provision for labyrinth / stack cooling within service risers	Reduced door widths at ground level to enable retrofitting of door guards
	Communal grey water recycling	Service void brought to face of the units to allow change to stack ventilation in the future or to install HVAC system.
		In-situ concrete slab to ground floor (in preference to beam and block) to provide flood resistance

Recommended key changes over base scheme

Measure	Initial (day 1)	Retrofit 1	Retrofit 2
Comfort	Heavy weight construction (masonry) Deck access shading	Add system for labyrinth Add balconies on the south side of the building, overlooking the street	Install HVAC system
Water – river flooding	Raise building and car-parking height to min 2.7m (note: mostly above this level anyway) In-situ concrete slab to ground floor Resistant lower walls	Install flood resistance measures (door guards etc)	Install flood resilience measures
Water – surface water flooding	Install ground level swales	Extend swales	Replace paving with permeable paving
Water – drought	Install water saving devices Install greywater recycling system	Install rain water harvesting system	None required
Construction	Heavy weight construction (masonry)	Install flood resistance measures (door guards etc)	Install flood resilience measures

Summary of adaptation measures

to this study would be annual outside temperatures, tidal water level changes (influence of sea level rise), mean annual precipitation, peak annual precipitation.

Section 4 - Learning from the work

This project examined both structural and design issues for residential buildings, with the aim: ‘to determine the best ‘adaptation’ measures to make this development safe from flooding, those that are compatible with and will reduce other climate risks and the time at which they should be implemented’. The project was divided into four stages, set out below.

The project was developed through regular workshops with various team members. There were approximately two workshops per work stage. A steering group was created to review the project, which included NHBC, the Environment Agency, University of East Anglia, Aviva, Building Research Establishment and the Homes and Communities Agency.

A large number of tools were required to carry out the research. The most useful of these were the public documentation (such as information from the Environment Agency), past research work (by the team and other papers), modelling software such as IES and ISIS-TuFlows, supported by future climate data from a number of sources (EA, Weather Generator and Prometheus).

The impact on successful planning consent and the capital cost of the adaptation measures were the client’s main concerns. The best way to influence the client in their decision-making has been to identify their concerns as part of the project decision-making process, such as the MCA and Cost Analysis. This has enabled decisions to be made on the basis of cost and saleability as well as lifetime issues.

The success of this project was dependent on the multi disciplinary background of the team with a mix of specialists from both industry and academia. This approach should be applied more widely to other projects to bridge the gap between theory and practice. Employing a methodology that analysed strategies at the neighbourhood, building and detail level enabled a more rigorous understanding of the impacts throughout the scales and therefore avoided concerns regarding implementation (such as building regulations) that can effect research work.

Section 5 - Extending adaptation to other buildings

Parts of the CAN solution are transferable to both new build schemes and existing developments in areas of flood risk from rivers, the sea, surface water and ground water. The aspects of water saving, surface water management and overheating are applicable to all new build residential schemes in the UK.

One of the key findings within this research is the potential beneficial relationship between overheating and flooding resilience strategies. Many of the sites currently at risk of flooding throughout the UK are also predicted to experience significant increases in average and peak temperatures. Interspersing blue and green space throughout development can help make space for water as well as provide natural cooling.

Throughout the UK, more than 2.4 million homes are already at risk from flooding and this number is set to rise. Whilst this building project is for a new development the consideration of retrofitting improvements will apply to many existing buildings. Identifying what can be done in an incremental fashion to tackle flood risk could apply to many building in the UK, particularly those in coastal or tidal locations where increases in sea level can be monitored and therefore flood risk/levels more accurately revised over time.

Many measures including incremental adaptation would be relevant to redevelopment work. Where raising a new building entirely above the future predicted flood level may tackle the flood risk but result in a poor relationship with a neighbouring property this may be aesthetically unacceptable.

Many of the recommendations of this study apply to taller buildings; however, the elements that focussed on avoiding flood risk from elevation and building in resilience, particularly at the detail level apply.

An opportunity currently exists in this instance to create a Local Development Order to deliver the CAN Project findings. A Local Development Order could be devised to deliver the CAN Project tool kit findings and subject to local issues could be applied across large areas of the UK considered likely to be affected by climate change over the timeline.

1

SECTION 1 > Building Profile

SECTION 1 > Building Profile

The building project

The CAN project is based on an existing development proposal for just over 100 new homes and approximately 2,000 sq ft retail and restaurant space. This forms part of the first phase of a wider masterplan for the redevelopment of a major brownfield site on outskirts of Norwich City Centre (Figure 1.1), which encompasses 670 homes and 25,000 sq ft commercial space.

The masterplan is referred to as the Deal Ground and May Gurney Development. A summary of the development plans is included in Appendix 1.

The larger development

The Deal Ground and May Gurney sites cover an area of 19 hectares. The Deal Ground site is situated between two rivers, the River Wensum and River Yare. The May Gurney site is bordered by two branches of the River Yare. The site is understood to be at risk of flooding. Though there is no recent history of flooding, this is a clear consideration.

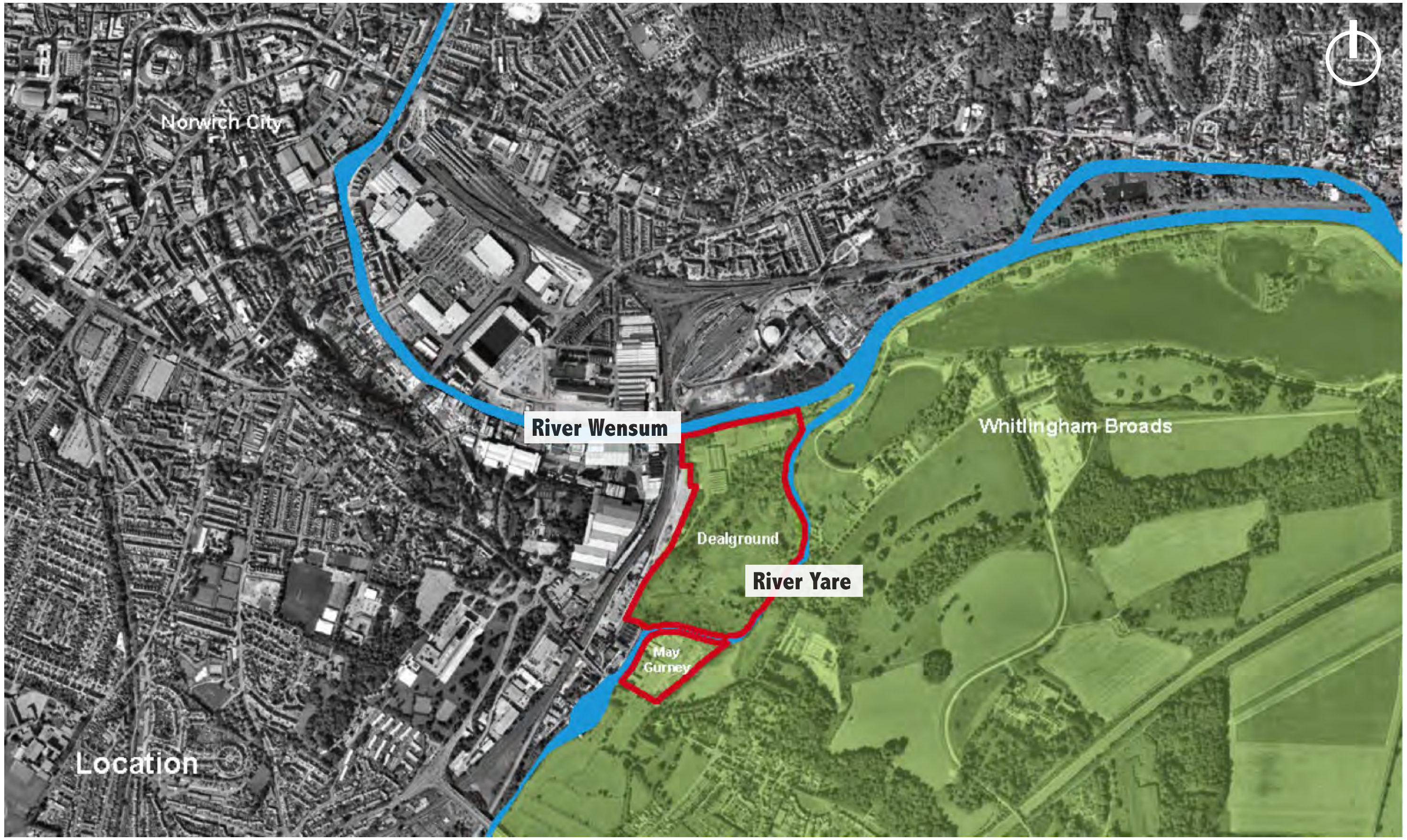


Figure 1.1, Location Plan

The larger development (shown in Figures 1.2 and 1.3) adopts a landscape led masterplan, with a non-defensive approach to flood-risk management, letting floodwater onto the site in a predetermined manner, to make space for water (policy advocated by Defra); providing a sustainable transport approach which includes a pedestrian and cycle main through fare, reduced car parking and neighbourhood car club. It has ecology green infrastructure at the heart of the development using SUDS and extending the county wildlife site into the development.

Location

The study site for the CAN project is located towards the north of the Deal Ground, bordered by the River Wensum to the north, as shown in Figures 1.2 and 1.3. The site is previously developed land (brownfield), with some contamination (including gas).

The study site lies partly in flood zone 3 and partly in flood zone 2, as described on the following pages.

Figure 1.2, The study site

Figure 1.3, Outline Planning Masterplan

SECTION 1 > Building Profile

The building proposal

The study site comprises a block development of approximately 70 residential units and 1,210 sq ft retail and restaurant use, arranged around a courtyard as shown in Figure 1.4. The residential units include apartments, located above duplexes and town houses.

Typical plans for these units have been included in Appendix 1. The courtyard is used for car parking with additional car parking along the street. The original proposal was create an amenity deck, raised above the courtyard. However the massing of the development, the layout and the deck have all been reviewed as part of this work. The construction method has also been reviewed as part of the research.

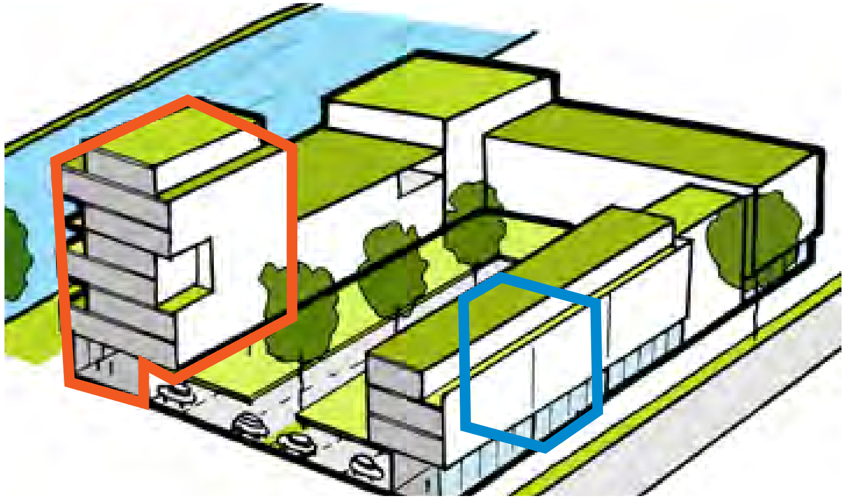


Figure 1.4, Development block (source Atelier PRO)

Key

🟦 **Commercial**

🟧 **Residential**

▢ **Mixed-use design (duplexes and flats)**

▢ **Townhouse**

Flood risk

The Environment Agency flood map (Figure 1.5a) indicates that the study site lies within Flood Zone 2 and Flood Zone 3. This is desscribed as medium and high probability of flooding.

Two dimensional flood modelling was carried out to determine the future extent of flood risk as indicated in Appendix 1. Previous modelling work was used to determine the extent of a 1 in 100 year flood including an allowance of 20% increase in river flows to account for climate change (CC) as indicated in Figures 1.5b and 1.5c.

The buildings are elevated above the 1 in 100+CC and a further precautionary 300mm as required by the Environment Agency. The 1 in 100 year flood level is taken from the centre of the site and is actually higher than the predicted flood levels for much of planned development area of the site.

The ground floor of all of the buildings is designed to be flood resilient upto the 1 in 1000 year flood level. This is a precautionary 'belt and braces' requirement, above and beyond the requirements of insurance companies and the requirements set in many other parts of the country.

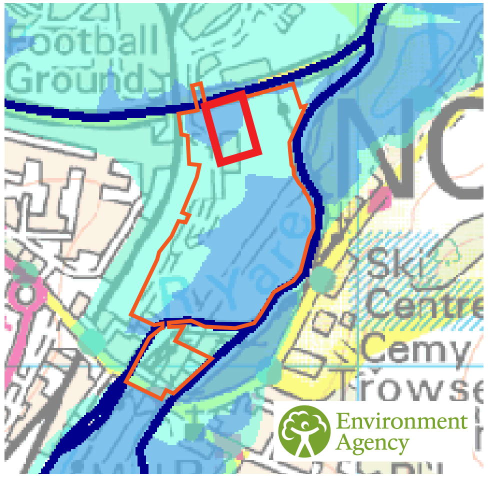


Fig 1.5a, Environment Agency flood risk map (source: Environment Agency website)

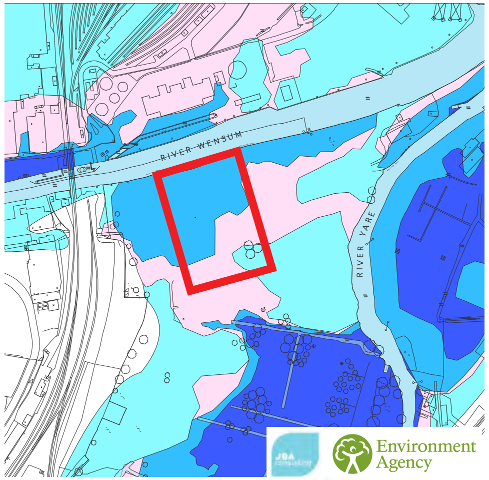


Fig 1.5b, Flood Zones to the site(source: JBA consulting based on EA guidance, Flood Zone 2 - EA)

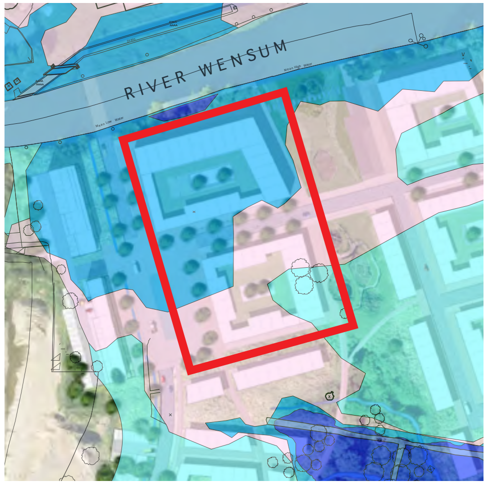


Fig 1.5c, Flood Zones in relation to the study site (source: JBA consulting based on EA guidance, Flood Zone 2 - EA)

Key

☐ Flood Zone 1 (Low Probability)
Areas with less than 1 in 1000 year (0.1%) probability of flooding.

🟦 Flood Zone 2 (Medium Probability)
Areas with between 1 in 1000 year (0.1%) and 1 in 100* year (1%) probability of flooding.
* 1 in 200 year (0.5%) probability of flooding from the sea

🟦 Flood Zone 3 (High Probability)
Areas with greater than 1 in 100* year (1%) probability of flooding.
* 1 in 200 year (0.5%) probability of flooding from the sea

☐ Flood Zone 1
🟦 Flood Zone 2
🟦 Flood Zone 3a
🟦 Flood Zone 3b
🟪 1:100 + CC*
*Climate Change assessment based on 2006 predictions

The geology is made ground, alluvium, silt and clay with peat. The groundwater is between 1 and 2 m below ground level. Most of the existing site is covered by tarmac or concrete, partially draining directly into the river. A SUDS system has been planned to manage peak run off rates with an allowance of 30% increase in rates based on 2006 guidelines on the effects of climate change.

The wider neighbourhood

To the north of the block lies the River Wensum (which becomes the River Yare downstream of the site). The river is influenced by the tides and flows out to the North Sea at Great Yaremouth.

To the east lies a low lying park area which is designed to allow periodic flooding (Figure 1.6).

The main access road lies to the south and the ramped access to a new bridge over the river lies to the west. A public square and bus stop lies to the south west.

An equipped play area is provided to the south east of the site with other local play areas within the courtyard and along the river side.

A communal Gas CHP is located in one of the adjacent blocks. The base scheme includes a raised amenity deck for flatted residents above car parking as shown in Figure 1.7.

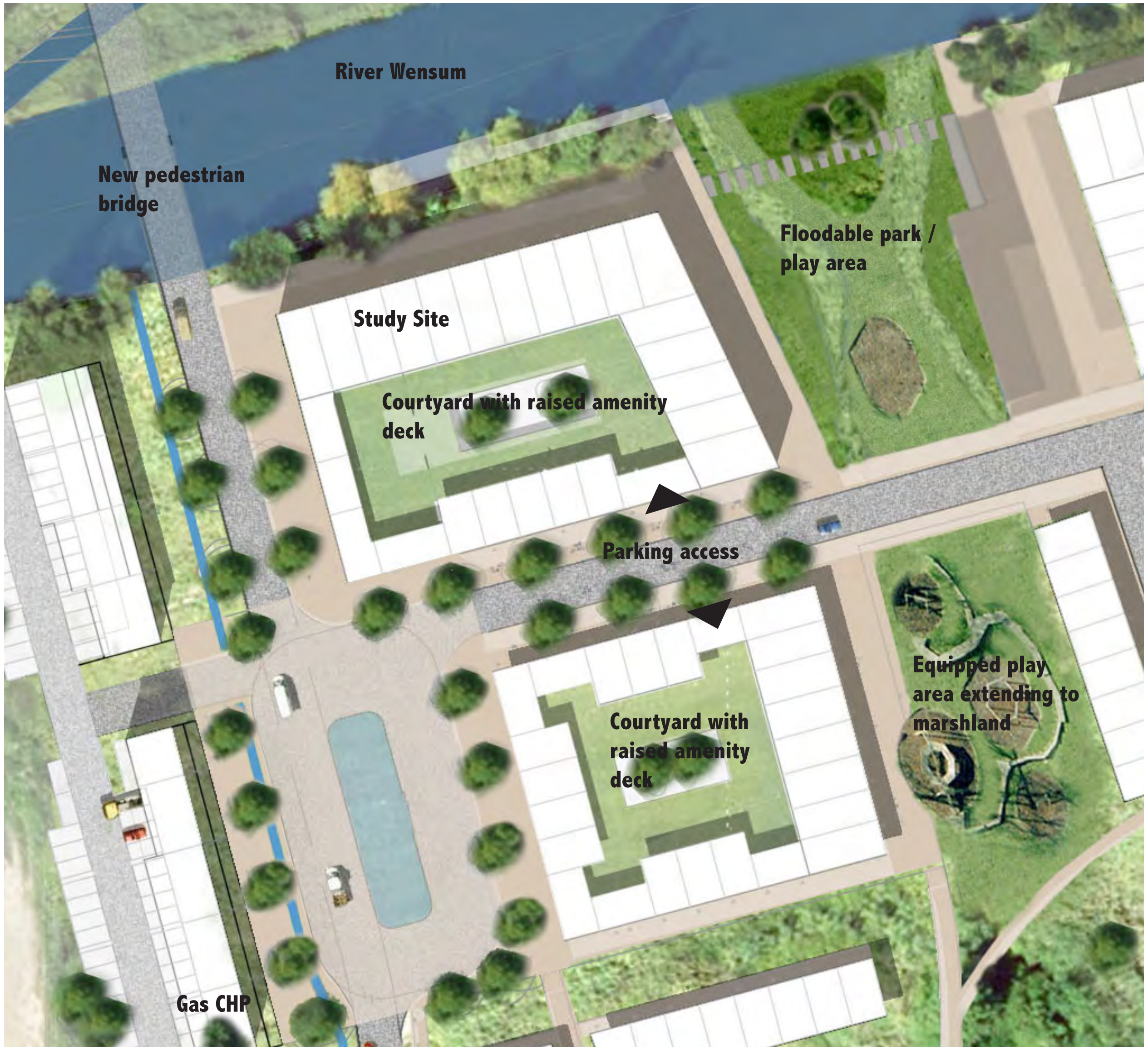
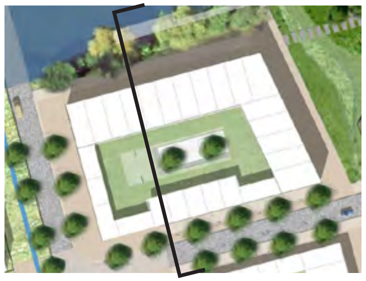


Figure 1.6, Surrounding neighbourhood

Energy and sustainability

The planning design uses a district gas Combined Heat and Power (CHP) system. The scheme is designed to Code Level 3 & 4, increasing to Code Level 5 with future phases and adopting many of the LifE principles (Defra innovation fund SLD2318) for sustainable development in flood risk areas. The minimum development requirements are set out in the building regulations Part L and the local authority requires a minimum 10% renewable energy provision. An average thermal performance criterion has been established for the development and included in Appendix 1.



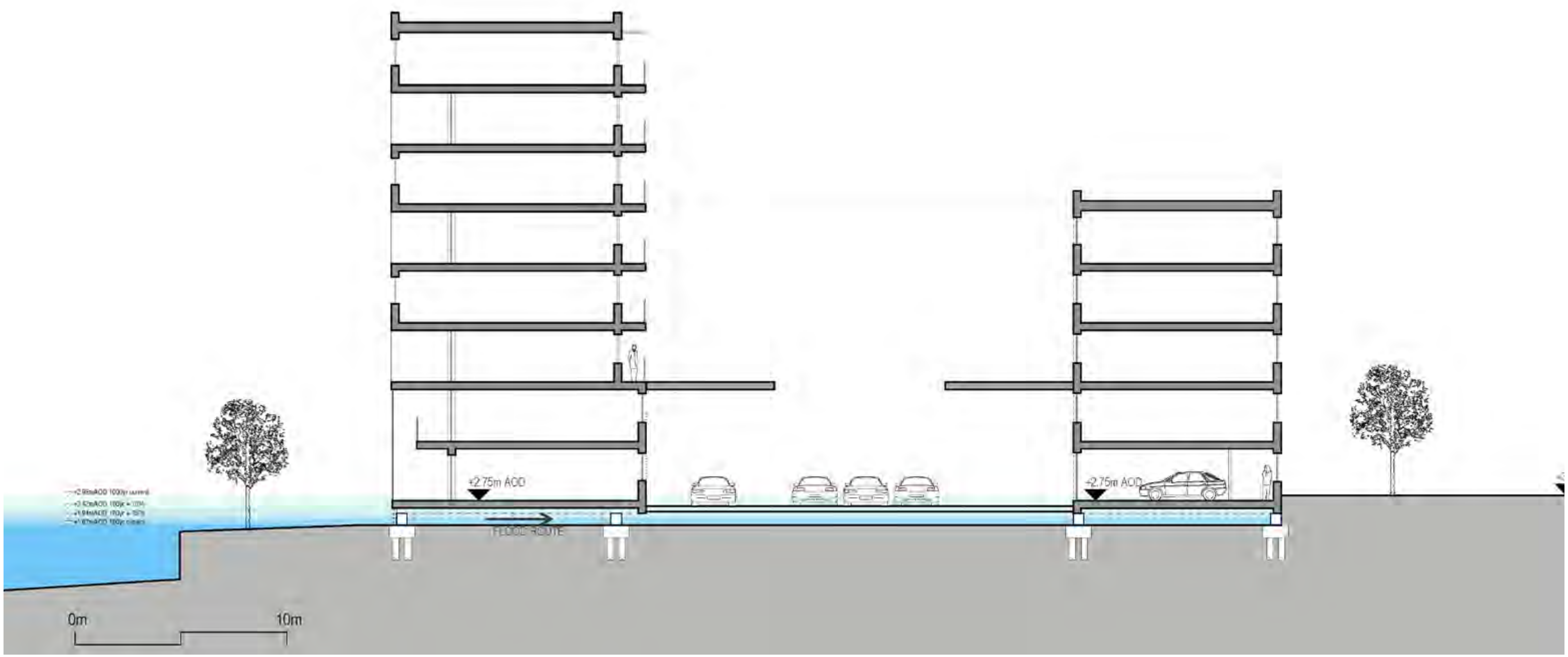


Figure 1.7, Section through the block

2

SECTION 2 > Climate Change Risks

Assessment of future climate

To assess the potential climate risks to the site climate data was generated using the Weather Generator (WG) modelling software and complimented by additional information gathered from a number of sources (see Appendix 2). Modelling of future climate change requires estimation of future levels of emissions of greenhouse gases and other substances. The Weather Generator projections are based on different greenhouse gas emissions based on projected development scenarios. For the purposes of this study it was agreed that projections should be based on the A1 storyline, which describes a future world of very rapid economic growth, and a population that increases from 5.3 billion in 1990 to peak in 2050 at 8.7 billion and then declines to 7.1 billion in 2100.

For the purposes of this investigation the model was run for the following time periods/ scenarios:

2030s High (A1FI): strong economic growth with reliance on fossil fuel energy sources.

2080s Med (A1B): strong economic growth with a mix of fossil fuels and renewable energy sources.

See Appendix 2.1 for more detail on the future climate data.

Three probability assessments were generated, the 10th, 50th and 90th percentile, which can be interpreted as:

- 10th probability level: unlikely to be less than;
- 50th probability level: as likely as not; and,
- 90th probability level: unlikely to be greater than.

The 10th and 90th percentiles are also interpretable as occurring one year in ten. The Weather Generator modelling produced results for a range of 'standard' indices in relation to temperature and precipitation specific for a 5km square area centered approximately on the site. A more detailed report on the future weather predictions, flood risk modelling and development scenarios is included in Appendix 2. A summary of the weather generator results is indicated in Table 2.1.

The Weather Generator data was prepared by UEA and the flood risk data was prepared by JBA Consulting. The overheating modelling was carried out by Baca Architects.

	Control	Scenario high 2030s			Control	Scenario med 2080s		
Climate Variable		Probability level				Probability level		
	Median	10th	50th	90th	Median	10th	50th	90th
Changes in annual mean temperature (°C)	NA	1.3	1.9	2.6	NA	2.1	3.2	4.5
Annual mean temperature (°C)	9.4	10.7	11.3	12.1	9.4	11.5	12.6	14.0
Spring mean temperature (°C)	8.2	9.0	9.7	10.5	8.2	9.5	10.8	12.2
Summer mean temperature (°C)	15.2	16.5	17.3	18.5	15.2	17.2	18.8	20.4
Autumn mean temperature (°C)	10.3	11.7	12.6	13.4	10.3	12.9	14.0	15.4
Winter mean temperature (°C)	3.9	4.9	5.7	6.5	3.9	5.2	6.6	8.1
Summer mean daily maximum (daytime) temperature (°C)	20.0	20.7	22.3	23.7	20.0	22.0	23.8	26.0
Warmest day in summer (°C)	31.8	31.8	34.3	36.2	31.8	33.4	35.6	38.4
Warmest night in summer (°C)	22.5	22.4	23.9	25.1	22.5	23.5	25.3	27.6
Winter mean minimum temperature (°C)	1.0	1.9	2.8	3.7	1.0	2.4	3.8	5.3
Coldest night in winter (°C)	-8.8	-8.3	-7.2	-6.2	-8.6	-8.0	-6.4	-4.7
Changes in annual mean precipitation (%)	NA	-5.8	-0.6	6.8	NA	-10.9	-1.9	6.3
Annual precipitation total (mm)	630.4	593.7	626.4	673.3	634.4	565.2	622.5	674.3
Winter precipitation total (mm)	160.2	158.8	169.0	186.3	160.1	162.9	181.8	209.5
Wettest day in winter (mm)	29.3	26.5	32.8	43.1	28.9	25.9	35.7	53.6
Summer precipitation total (mm)	160.1	118.9	137.2	175.1	156.8	79.4	126.3	171.6
Wettest day in summer (mm)	51.8	35.8	60.8	96.9	51.0	34.3	59.9	115.1
Number of days per year with a maximum temperature exceeding 30°C	0.1	0.4	1.2	3.3	0.1	1.0	4.2	15.4
Number of heatwave events per year	0.0	0.0	0.2	0.8	0.0	0.1	1.0	6.8
Number of heating degree days per year	312.4	284.9	268.5	248.8	312.3	262.8	239.7	210.7
Number of cooling degree days per year	0.8	2.2	4.9	10.5	0.8	4.7	13.0	30.8
Heating degree days per year (°C)	2316.7	1936.8	1761.5	1566.6	2317.8	1796.2	1489.3	1212.8
Cooling degree days per year (°C)	0.9	2.6	5.8	14.6	0.9	4.9	19.1	55.9
Number of rainfall events per year likely to result in flooding (>=25mm)	1.0	0.9	1.3	2.1	1.0	1.0	1.4	2.1
Number of 10 day dry spell events per yr	6	6	8	9	6	7	9	11
Number of 20 day dry spell events per yr	1	1	1	2	1	1	2	3
Max day dry spell event per 30yr period	40	37	46	67	40	44	59	78

Table 2.1, Weather Generator results

The projected changes to the climate of the site for the 50th percentile projections are summarised below:

Temperature / Comfort

The baseline indicates that the annual mean temperature of the site is 9.4°C.

50th percentile rise in mean temperature of 20% in the medium term (2030s) and 34% in the longer term (2080s), Figures 2.1 and 2.2.

The most significant seasonal rise in temperature is likely in the winter, of 46% and 69% respectively.

The temperature of the warmest day and warmest night in summer is predicted to rise marginally by 12% by the 2080s but there is a possibility it could rise by over 20%.

The temperature of the coldest day in winter is predicted to increase by 26% from -8.6ºC to -6.4ºC (2080s).

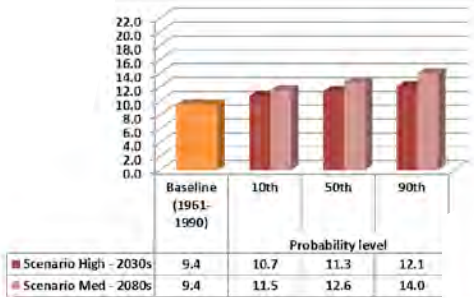
A rise of over 10,000% in the number of days per year with a max temp exceeding 30ºC by the 2080s. In real terms this is a rise from 0.1 days per year to 4.2 days per year, but could be as much as 15.4 days per year. This also corresponds to a rise in the number of heat waves per year (classified as 2 consecutive days in which temperature reaches above 30ºC in the day and does not drop below 15ºC at night).

A rise of almost 4,000% in the number of cooling degree days per year by the 2080s. In real terms this is a rise from 0.8 days per year to 13.0 days per year, but could be as much as 15.4 days per year.

A simple comparison was carried out between the future average annual temperatures in Norwich and the current annual temperatures in other cities to better understand what the future climate might be like; this is shown in Figure 2.3. Through reviewing the 'world climates' information the most comparable city to Norwich in the 50th percentile 2030s is London 2010s and the most comparable city to Norwich in the 50th percentile 2080s is Paris 2010s, albeit that Paris winter temperatures are likely to be colder. This rough comparison helps to understand and visualise both the climate issues and potential solutions.

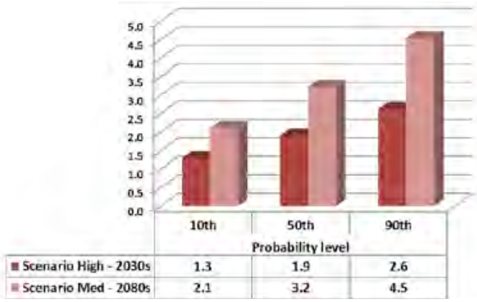
Wind

The University of East Anglia advised that wind is not likely to significantly change in either 2050 or 2080 under the high and medium emissions scenarios respectively.



	Baseline (1961-1990)	10th	50th	90th
		Probability level		
■ Scenario High - 2030s	9.4	10.7	11.3	12.1
■ Scenario Med - 2080s	9.4	11.5	12.6	14.0

Figure 2.1, Future Mean Temperature (ºC)



	10th	50th	90th
	Probability level		
■ Scenario High - 2030s	1.3	1.9	2.6
■ Scenario Med - 2080s	2.1	3.2	4.5

Figure 2.2, Change in Mean Temperature (ºC)

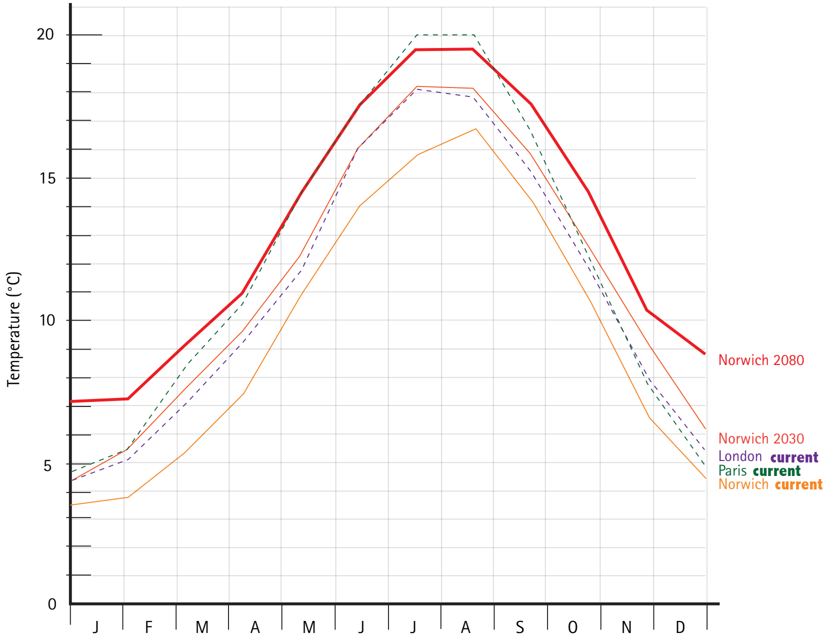


Figure 2.3, Future temperatures comparison with other cities (sources: WG temperature changes and http://www.world-climates.com/)

Rain / Water

Annual precipitation is relatively sTable, falling by -1% and -2% respectively but could fall by as much as -11% by the 2080s.

Winter precipitation is predicted to rise by 5% in the medium term (2030s) and 14% in the longer term (2080s). The prediction for the wettest day is much more varied from a decrease of 10% to an increase of 85% (2080s). There is even greater statistical uncertainty for the summer precipitation and wettest day in summer with a percentage variance of almost 60% (-49% to +9%) and 160% (-33% to +126%) respectively. These results are plotted in Figure 2.4.

The number of drought occurrences is likely to increase. The number of 10 day dry spells is predicted to rise from 6 per year to 8 per year in the medium term (2030s) and 9 per year in the longer term (2080s). The number of 20 day dry spells is predicted to rise from 1 per year to 2 per year in the longer term (2080s).

The model also indicated a rise in the number of rainfall events per year likely to result in flooding. However, more detailed flood risk assessment work was carried out for the site as indicated below.

Shortfalls in the data or processing tools

The Weather Generator cannot determine future wind and therefore also driving rain. This could have been an issue, requiring two data sources, however, the University of East Anglia, reported the following feedback from UKCP09:

- Central estimates of change (in wind speeds) are small in all cases (< 0.2 ms-1).
- Projected changes in winter wind speed are approximately symmetrical around near-zero change.
- In the summer, it is slightly skewed towards negative in the UK and slightly positive in Scotland under the Medium emission scenario for the 2050s.

Accordingly, as current evidence suggests that future changes in wind are likely to be minimal there is no need to make changes in design and adaptation for future climate beyond those that are currently required as part of good design. As such, the recommendation would be to continue on the basis of current design standards.

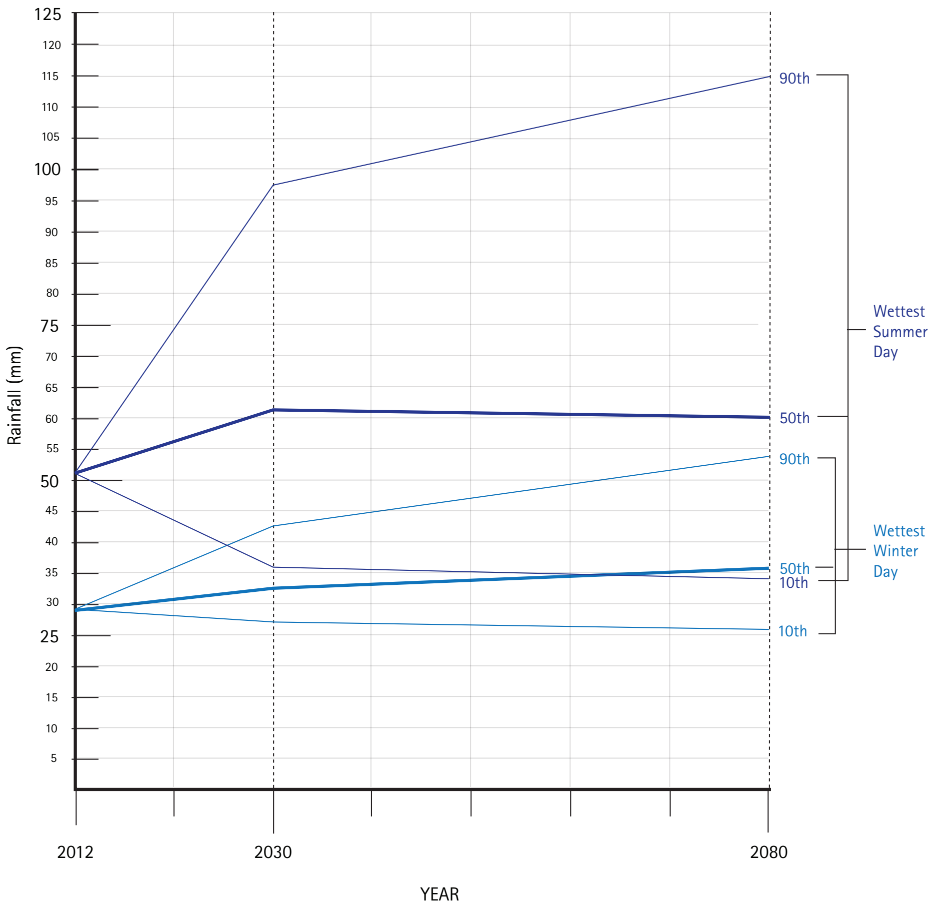


Figure 2.4: Predicted Rainfall

Climate risks to the building project

The results of the Weather Generator model identified projections for temperature and precipitation. To assess the risks secondary assessment of the data was required. This was carried out in four ways:

- Expert review of the data to identify potential risks.
- Analysis of exceedances of thresholds or accumulations/deficits of the Weather Generator (WG) data (Appendix 2.1).
- Analysis of the internal temperatures and exceedence of thresholds of a typical unit using Integrated Environmental Solutions (IES) modelling (Appendix 3.4, Overheating)
- Analysis of the flood levels, depths and velocities using the ISIS-TUFLOW (ISIS) hydraulic modelling software (Appendix 2.2).

It should be noted that the weather generator model uses 'traditional' building stock for assessment of heating and cooling degree days and this information is not applicable to a new building, which is designed to different thermal standards. Therefore it was necessary to create a bespoke model using IES to model the impact of future temperature on internal temperatures. Because building regulations are set on a regular basis it would be useful if future climate impact data could be generated for a range of typical building types or if the indices within such models as the WG could be updated to incorporate these factors.

The expert review enabled risks to ground conditions to be ruled out. This is due to the prevailing soil type (which lacks any clay) and the associated foundation design required. It was also possible to rule out driving wind and rain as an issue on the basis that wind speeds were not identified to increase. Therefore, the results from these assessments identified that the main climate risks to the building project were:

- Flood risk (tidal influence, river flooding and surface water flooding)
- Drought
- Overheating

These relate to 'Designing for Water' and 'Designing for Comfort'. In addition these risks have a bearing on some of the 'Designing for Construction' issues identified in the D4FC Opportunities for adaptation in the built environment though the emphasis has been on the architectural design and planning. This is more relevant to the stage of the project, level of detail available and the technical expertise available at this stage of the project.

The risks are explained in more detail below.

SECTION 2 > Climate Change Risks

Flood risk

Due to the known flood-risk to the site a more detailed assessment of the future flood-risk was required to determine the main risks and therefore the priority for this study.

As the site is already at risk of flooding increased peak rainfall is likely to have the most significant impact on the development. This could result in increased risk of surface water flooding and increased risk of river flooding. A further consideration is the tidal influence on the rivers and whether sea level rise will affect the future river flows or ground water. The future weather predictions (using regional data) were used to update the flood risk assessment for the site using the ISIS-TUFLOW hydraulic modelling software. This was based on data for the future river flows upstream and downstream of the site, provided by the Environment Agency, East Anglia division, itself based on UKCP09 data for the region. More details are included in Appendix 2.

Fluvial Flood Risk

The magnitude and frequency of river flooding are expected to increase in the future. The Environment Agency published a new Climate Change Advice Note (CCAN) in 2011 which is based on a study investigating changes in peak river flows; this work was completed by the Centre for Ecology and Hydrology. The CCAN quotes possible changes in peak river flows compared with a baseline period of 1961-90. A range of possible changes is given to illustrate the uncertainty in both future emissions of greenhouse gases and the scientific understanding of the impacts of global warming on extreme rainfall and river flows. The change factors are derived for a flood return period of 50 years but are expected to remain relatively constant with increasing return period.

For the Anglian region, the total potential change in peak river flows for the 2080s ranges between -5% (lower estimate) and +70% (upper estimate), with the central change factor being +25%.

These changes in flows were used to model the impact on future river levels at the site.

The wide range between the upper and lower end estimates indicates that there is a large amount of uncertainty over the impacts of climate change on flood flows in Anglian Region. This may be partly due to the conflicting effects of the impact of higher temperatures on the development of large soil moisture deficits over the summer period and the potential for more extreme rainfall. The range stated also represents the uncertainty produced by the range of projected outcomes and emission scenarios, which are, SRA1B, SRA2 and SRB1.

Using the central percentage increase for 2080 of 25% for the 100-year flood, we find that the peak water levels increase by between 0.27m and 0.32m across the site. This is similar to the Defra 2006 guidance, assumed increase of 0.27m.

Tidal Flood Risk

The fluvial flood risk estimates above contain no allowance for increased sea levels. The existing model was used to assess the sensitivity to increasing water level from sea level rise. The water level at the downstream (D/s) boundary of the model was increased by 0.5m for three modelled flows (the present day 100-year flow as well as an increase of 25% and 70%), and the peak modelled water levels are provided in Table 2.2 and Table 2.3.

Since the commencement of the project emerging guidance produced by the Environment Agency suggests that mean levels at the mouth of the Yare will rise 0.57m (compared with the 1961-90 baseline) by the 2080s. This rise in water levels is likely to be lower at the site, due to its distance from the coast (some 45km away). The rise in water levels is also likely to be reduced during large fluvial flood events, which can last several days, and where tides will rise and fall during each day.

Due to the difficulty of assessing the impact of sea level rise with the current models the median probability flood levels for the 100-year event in 2080 are likely to be inbetween the +25% flow and the +25% +0.5m D/s boundary; ie an increase of between +0.32m and +0.72m on the current 100-year flood levels. This wide margin of uncertainty relates to the uncertainty of the interaction with the tides. For the purpose of the study the worse case future prediction of +70% flows +0.5m D/s boundary have been used to guide the adaptation approach.

The model results show that the main source of flood risk is fluvial, from the Rivers Wensum and Yare. At the confluence, these rivers have a combined catchment area of over 1,100km^2. They river levels are tidally influenced at the site, but fluvial effects dominate the flood levels. The possible climate risk from the combined effects of future fluvial flows and tidal influence adjacent to the building are indicated in Figures 2.6 to 2.8, Peak Water Levels.

Climate change scenario	Peak Water Level (metres Above Ordnance Datum)		
	YART2_4859u	YART2_4123u	WENT1_481u
100yr present day flow (base)	1.81	1.68	1.62
100yr present day flow (equivalent to 10th percentile) + 0.5m D/s	2.11	2.05	2.02
100yr +25% flow (equivalent to 50th percentile) + 0.5m D/s	2.38	2.35	2.34
100yr +70% flows (equivalent to 90th percentile)+ 0.5m D/s	2.79	2.69	2.68

Table 2.2, Peak water level extracted from hydraulic models

Climate change scenario	Indicative impact on peak water levels
100yr present day flow (10th percentile)	0.00 m
100yr + 25% flows (50th percentile)	+0.27m to +0.32m
100yr + 70% flows (90th percentile)	+0.72 to +0.80m

Table 2.3, Indicative impact of increased flows on peak 100-year water levels excluding an allowance for sea level rise

Climate change scenario	Indicative impact on peak water levels
100yr present day flow + 0.5m D/s Boundary	0.30 m to 0.40 m
100yr + 25% flows + 0.5m D/s Boundary	0.57 m to 0.72 m
100yr + 70% flows + 0.5m D/s Boundary	0.98 m to 1.06 m

Table 2.3, Indicative impact of increased flows + raised downstream boundary on peak 100-year water levels

Figure 2.6 indicates the flood depths across the site with a 1 in 100 year event based on the 10th percentile prediction + 0.5m increase in downstream water levels as an allowance for sea level rise.

Figure 2.7 indicates the flood depths across the site with a 1 in 100 year event based on the 90th percentile prediction + 0.5m increase in downstream water levels as an allowance for sea level rise.

Figure 2.8 indicates the flood depths across the site with a 1 in 100 year event based on the 50th percentile prediction + 0.5m increase in downstream water levels as an allowance for sea level rise.

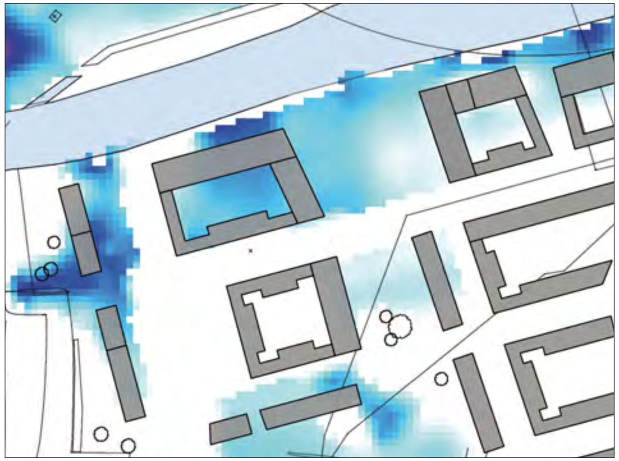


Figure 2.6, 2080s flood depths during 1 in 100 year + no change in flows(equivalent to 10th Percentile) + 0.5m increase in water levels.

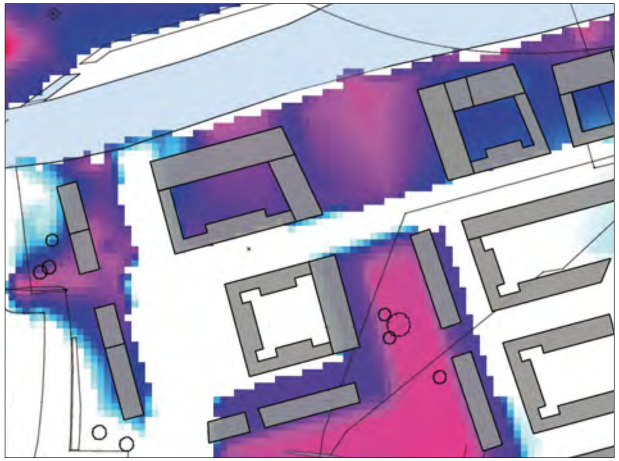


Figure 2.7, 2080s flood depths during a 1 in 100 year flood and incorporating a 70% increase in river flows (90th percentile) + 0.5m increase in water levels.

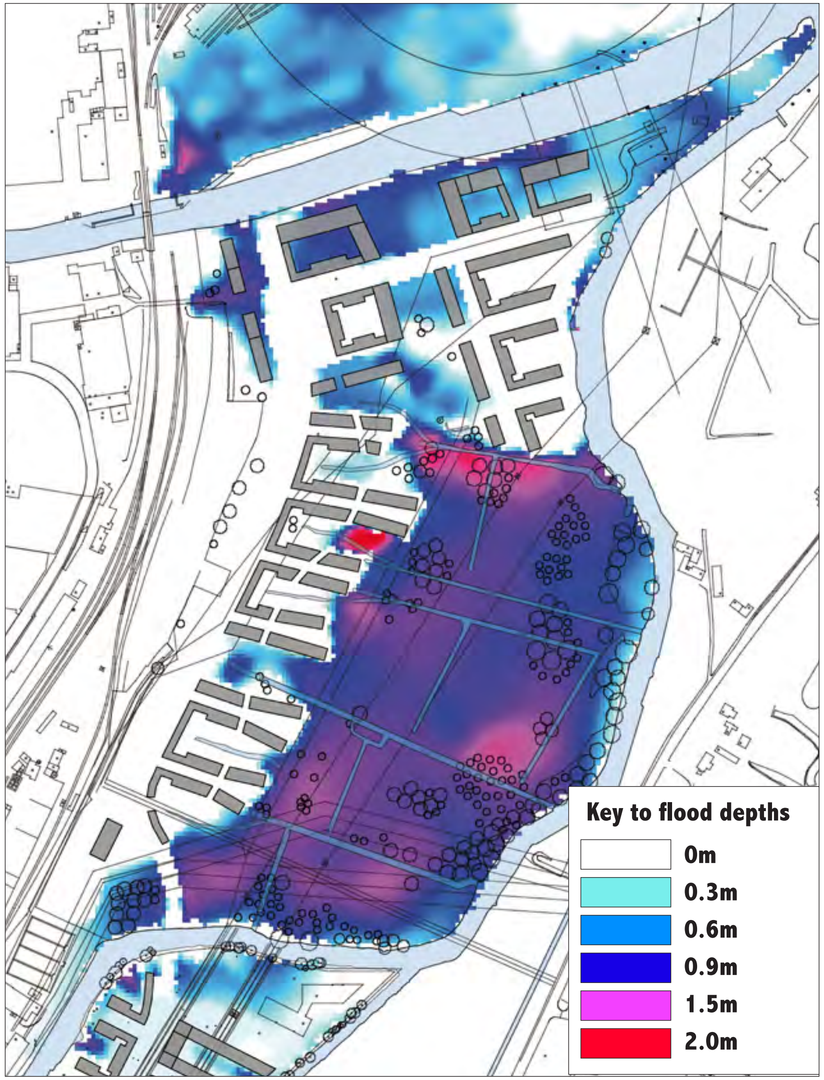


Figure 2.8, 2080s flood depths during 1 in 100 year +25% flows (equivalent to 50th percentile) + 0.5m increase in water levels.

Figure 2.9 plots the range of predictions for the Wensum Node, nearest to the site. This shows a variety of possible future flood levels for 2080s of between 1.62m and 2.68m, corresponding to an increase of between 0 metres and upto 1 metre.

The median between the 25% increase in flows and 25% + 0.5m D/s boundary is approximately 2.00m for the Wensum node is similar to the previous guidance of 2.03m (for the whole site), given by the Environment Agency, which was used to inform the planning design. Furthermore, the 2.34m flood level of 25% + 0.5m D/s boundary is less than the floor levels set for the planning proposal of 2.4m. However, the increase in water levels that could result from the 90th percentile possibility were used to develop a climate adaptive design, ie one that could be adapted to meet these increased water levels were they to occur.

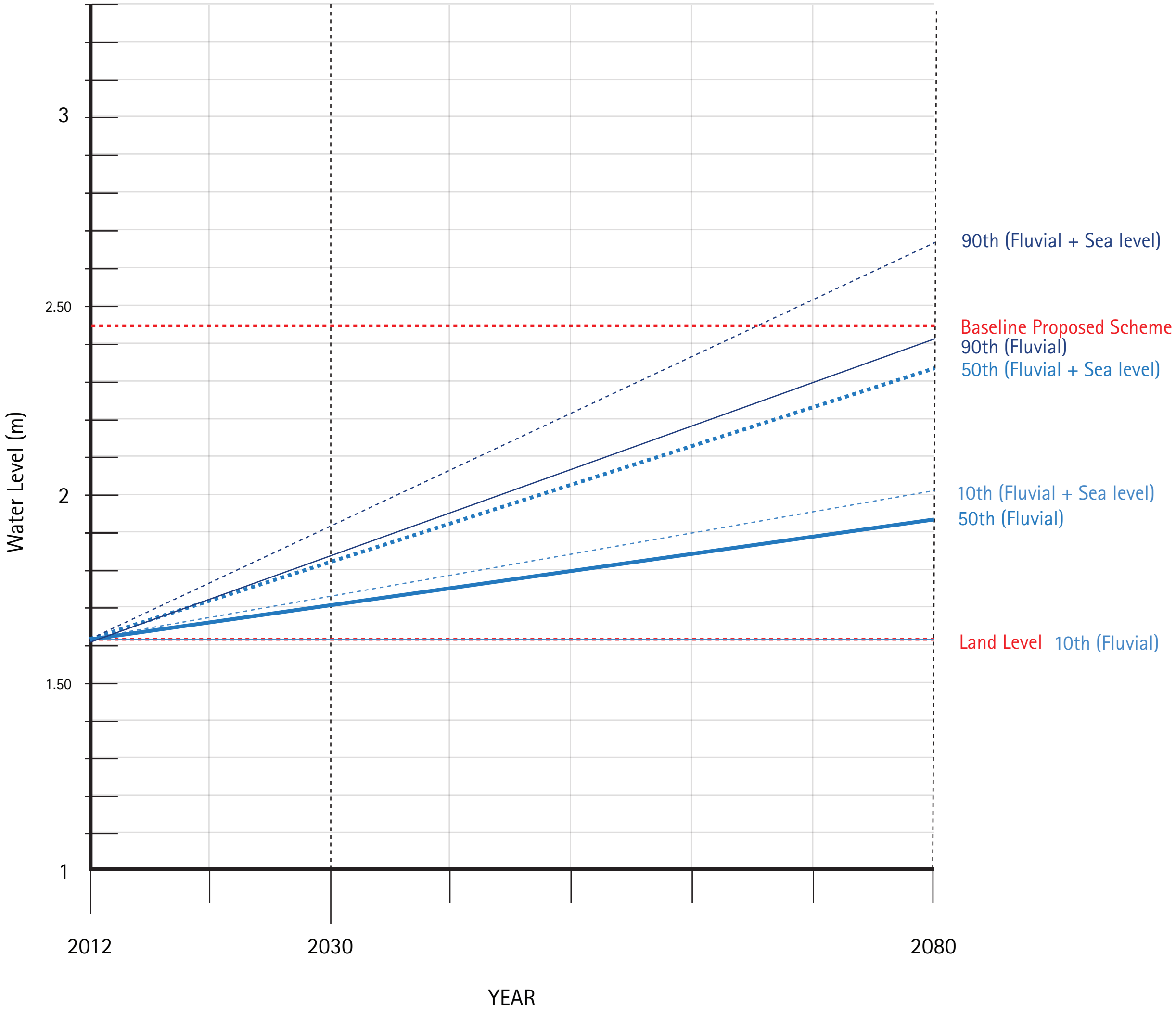


Figure 2.9, Predicted Peak Water Levels For 1 in 100 Year Event Wensum Node

Surface Water (sometimes referred to as Pluvial) Flood Risk

The WG data indicated a rise in both the peak winter and summer rainfall. This percentage increase in rainfall was used to identify the increase in the rainfall attenuation (storage) requirements for the 1 in 100 year rainstorm event as indicated in Figure 1.20.

The current building project design has been designed to provide a SUDS scheme that incorporates an allowance of 30% increase in rainfall. The Figure above shows that this is ‘more likely than not’ to be sufficient to cope with the future rainfall. If however, the peak rainfall events do exceed this allowance then the building project would need to be adapted to provide sufficient capacity. This information was used to assess the potential future requirement for surface water storage on site and to identify how the building project could be adapted to provide sufficient capacity over the lifetime of the development.

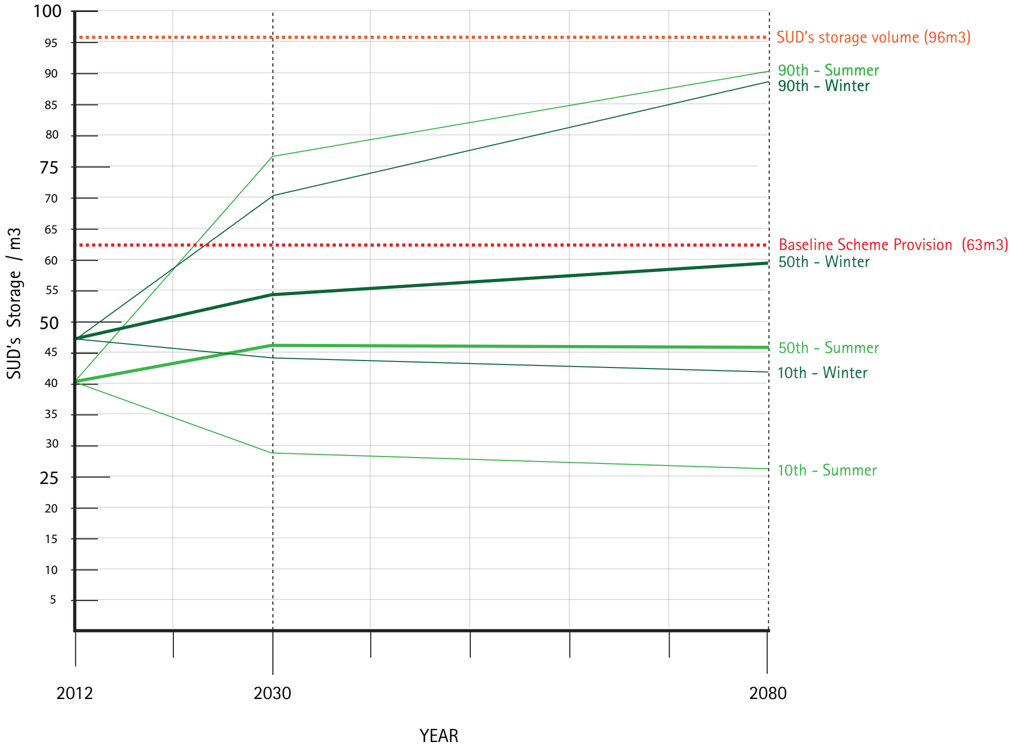


Figure 2.10, Future SUDS storage requirement

Drought

The WG data was analysed to determine the number of drought occurrences of 10 and 20 or more consecutive days without rain per year. It was also used to determine the peak number of days drought that may occur in a 30 year period, ie in a 1 in 30 year event. The results are indicated in Figure 2.11. This graph shows a gradual rise in the number of droughts of 10 and 20 days and above and a potential steep rise in the number of days drought that could occur during a 1 in 30 year event, from 40 days in the base case to between 44 days and 78 days in the 2080s (10th to 90th percentile respectively).

In 2007 the Environment Agency identified East Anglia as an area of 'Serious' water stress (source: the 'Future Water The Government's water strategy for England' Defra 2008). Local Planning Policy requires that all new development be designed to provide the equivalent of Code For Sustainable Homes Level 4 for water – this means that all new development should use no more than 105 litres of water per person per day. In England, the average person uses about 150 litres of water a day, according to the Future Water strategy. The Building Regulations set out a requirement to restrict water use to 125 litres per person per day (l/p/d) (Source: Approved Document G: Sanitation, hot water safety and water efficiency, 2010 edition). Therefore, to achieve the current standards the use of water needs to be reduced by 45 l/p/d from a typical usage to meet the current requirements. Because the future climate does not show a fall in the mean annual rainfall the climate risk is based on drought events. Therefore, to ensure that the building project adapts in the future so that it continues to provide the water saving of 45 l/p/d the choice of water saving measures needs to take into account the change in the drought conditions.

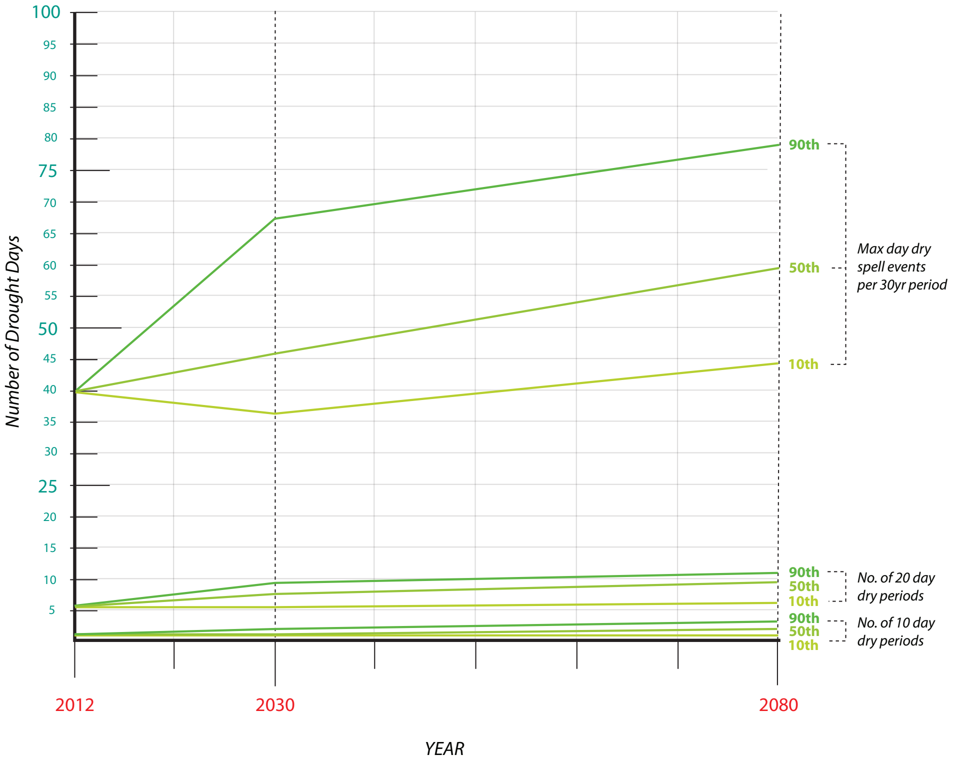


Figure 2.11, Predicted number of consecutive days of droughts

Overheating

The change in average mean temperature and peak temperature are indicated in Figure 2.12. This shows a general increase in mean and peak temperatures from the current day to the 2080s in the 10th, 50th and 90th percentile.

Figures 2.13 and 2.14 shows how the heating and cooling requirement could change over a range of possible climate scenarios for a base building, formed from concrete frame and slab with lightweight infill construction. The Figure shows that the space heating will continue to be the predominant energy requirement, but that the need for cooling will rise in the future. Whilst the Figure indicates that the total energy demand is likely to drop as a result of rising temperatures this must be considered against the energy source used to provide the cooling and the impact on global carbon emissions. Electricity used to provide 1kW of active cooling would result in higher carbon emissions than gas used to provide 1kW of heating.

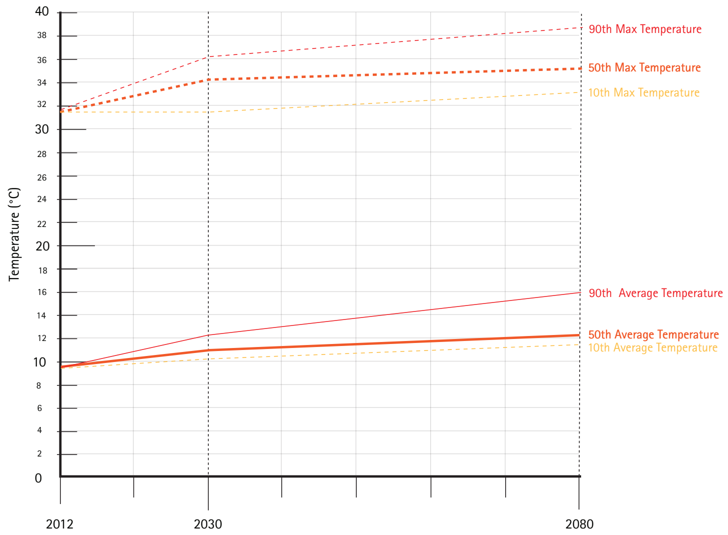


Figure 2.12, Predicted average and peak annual temperatures

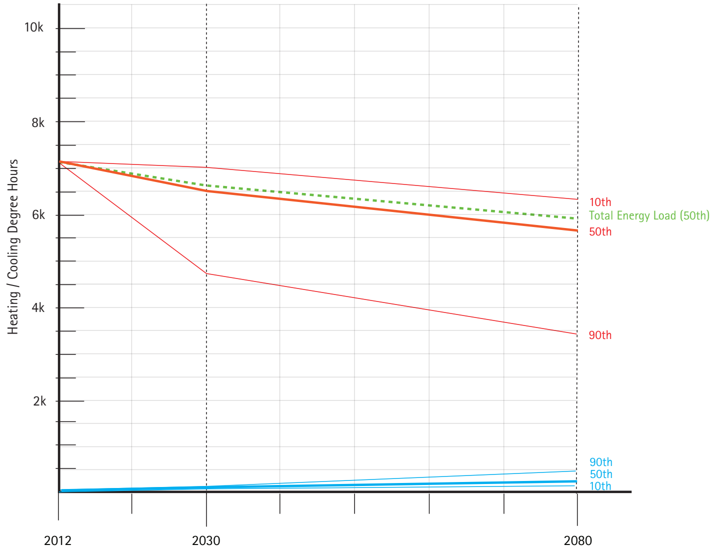
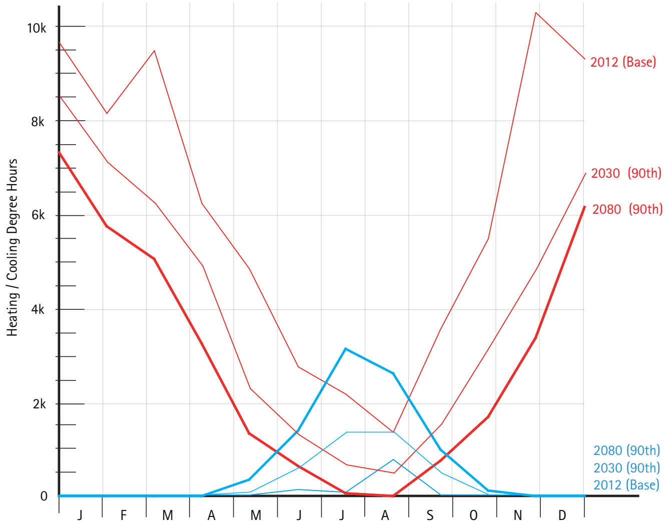


Figure 2.13, Predicted heating and cooling need for base scheme

Figure 2.14, Predicted heating and cooling need for base scheme and throughout the year



To assess if the current and possible future temperatures might result in overheating a dynamic thermal model of the building was set up to assess the internal temperatures of a typical flat under current and future climate conditions. This was initially calibrated for a contemporary high-rise modern building construction to form a base scheme. This included concrete frame and floor slabs, lightweight steel outer walls with render or brick slip cladding. Occupancy profiles were calibrated and inputted within the model to simulate the generic inhabitation of a domestic setting. The model was then tested to identify if the internal temperatures would rise above 28ºC for more than 1% of the occupied hours.

The results of the thermal modelling of the base scheme against future climate projections are indicated in Figure 2.15. This shows that with the 10th to 60th percentile projections for temperature increases the building project should not be affected by overheating. However, if the temperature were to rise above in line with the 90th percentile projection for future temperatures then overheating could be an issue within approximately 30 years. To make the building adapTable to the full range of possible future temperatures identified then it would be required to consider different cooling measures both passive and active to identify if any changes would be needed to the initial design and construction of the building and landscaping.

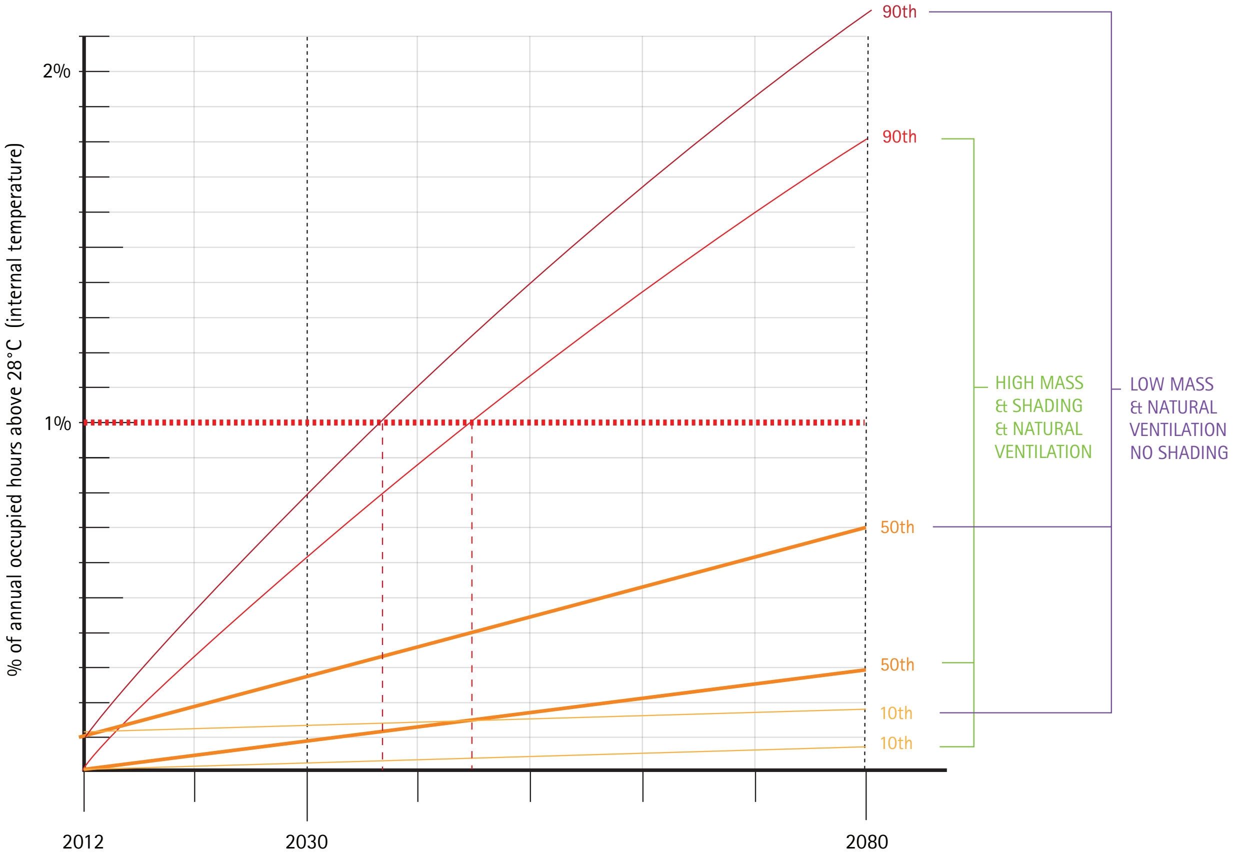


Figure 2.15, Predicted Risk Of Overheating For Base Scheme (Base Scheme: Concrete frame and slab with lightweight infill construction)

SECTION 2 > Climate Change Risks

Summary of key climate risks

Based on the future weather predictions and the future flood-risk assessment, the most significant effects of these were identified as:

- WATER – River flooding (effected by increased peak river flows and sea level rise)
- WATER – Surface water flooding (effected by increased peak rainfall)
- WATER – Drought (effected by rising number of consecutive days without rain)
- COMFORT – Overheating (effected by summer peak temperatures)

Due to the lack of wind and therefore driving rain data, as well as the low likelihood of this changing, and as the requirement for piles limiting the below ground issues, 'Construction' issues were not seen as a key issue.

WATER – River flooding (effected by increased peak river flows and sea level rise) http://www.climatechangeandyourhome.org.uk/live/flooding_and_ground_water_intro.aspx

WATER – Surface water flooding (effected by increased peak rainfall) http://www.bgs.ac.uk/anthropocene/Future.html

To develop a robust adaptation strategy for the building project, it was decided to identify solutions to cope with the 90th percentile future climate projection. This would provide a more robust solution should the predictions be too optimistic or if high growth (A1FI) and reliance on fossil fuel energy sources continue. The solutions could then be worked back to identify the requirements for the construction of the new building and a timeline / thresholds when different adaptation measures could be installed.

WATER – Drought (effected by rising number of consecutive days without rain)
http://serc.carleton.edu/eslabs/drought/index.html

COMFORT – Overheating (effected by summer peak temperatures)
source: www.nbcnews.com

3

SECTION 3 > Adaptation Strategy

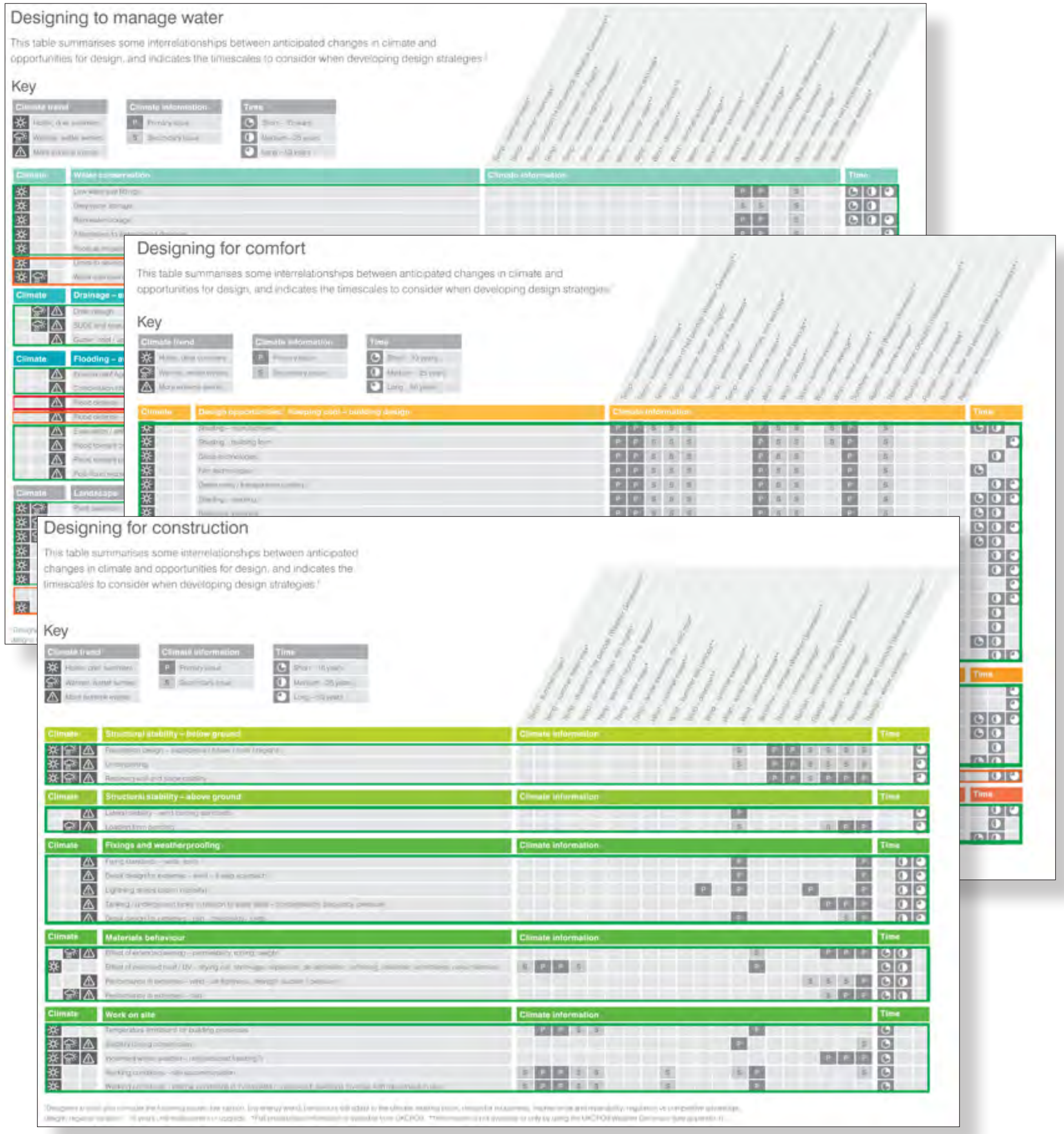
Methodology

To identify the adaptation strategy for the building project it was important to identify the adaptation measures that were relevant or applicable to the project and to determine their effectiveness. They were therefore identified through a number of different means and in several stages, as outlined below.

1. Review of 'opportunities for design' to adapt to future climate, set out in the Design for Future Climate report produced by TSB
2. Appraisal of adaptation options to rule out any that would be inappropriate for the site and scheme and to identify viable options
3. Multi Criteria Assessment (MCA) and SWOT analysis to identify preferred options
4. Detailed testing through modelling and design to assess effectiveness of options and further viability
5. Cost appraisals and Cost Benefit Analysis to refine preferred options and identify timeline for implementation of measures to inform the Adaptation Strategy.

1. Review of 'opportunities for design'

The three Tables produced by the TSB (figure 3.1) set out various 'opportunities for design' to respond to three climate trends, hotter drier summers, warmer wetter winters and more extreme events. The Tables are to be used to identify primary and secondary measures and there appropriate time frame. A high level review of the 'opportunities for design' based on a simple traffic light system is included in Appendix 3.1. This highlighted the 'opportunities for design' as Green – Relevant; Orange – Possibly relevant, needing further consideration; Red – Not relevant or it has already been considered in the design prior to this stage in the construction process.



Designing to manage water

This table summarises some interrelationships between anticipated changes in climate and opportunities for design, and indicates the timescales to consider when developing design strategies

Key

Designing for comfort

This table summarises some interrelationships between anticipated changes in climate and opportunities for design, and indicates the timescales to consider when developing design strategies

Key

Designing for construction

This table summarises some interrelationships between anticipated changes in climate and opportunities for design, and indicates the timescales to consider when developing design strategies

Key

Figure 3.1, TSB tables

2. Appraisal of adaptation options

A long list of adaptation options was compiled from the TSB Tables and others to consider which may work and also to rule out those that won't work or work well together. Through this process 18 adaptation measures were selected to be considered or implemented in the project and to be further scrutinised. Three viable options were established for each measure at a:

- neighbourhood scale
- building scale or
- detail scale

This established approximately 90 different options to choose from for the study. All 90 options/measures were researched and presented in a summary data sheet for review by the team and steering group. Table 3.1 indicates the range of options explored. Some cells in the table are blacked out as there were no adaptation / design measures relevant to that section.

		Neighbourhood scale			Building scale			Detail scale		
ADAPTATION APPROACH	**Future climate issues**	**Op 1**	**Op 2**	**Op 3**	**Op 1**	**Op 2**	**Op 3**	**Op 1**	**Op 2**	**Op 3**
WATER										
Foul Drainage (below ground+fittings)	Impact of future water levels, depths on drainage system, location of fittings and choice of systems.Flexibility Note: back flow drains and sealed covers (given)	Pipes located under roads (as convention)	Secondary pipes located under soft landscaping to enable replacement/ improvement	All pipes located under soft landscaping to enable replacement/ improvement (greater space take)	Waste fittings on ground floor, above 100 level & incorporating back flow drains (WC, AAV stub stacks etc)	Waste fittings elevated/ able to be raised in future (WC, AAV stub stacks etc)	Transfer to non water closets?	Conventional plastic drainage in pea gravel with flexible connections	Concrete encased plastic piping with flexible connections (to withstand future water loads during flood)	Clay pipe systems to withstand future water loads during flood
Rainwater harvesting	Need for rainwater harvesting and the potential to increase provision in the future				Communal system located below ground in the courtyard (need for pipes, pumps, treatment etc)	Communal system located at high level (New York style+need for pipes, pumps, treatment etc)	Individual RW systems located on terraces or within flats (space take on flats)	Rainwater harvesting infrastructure WCs only (ability to install at later date?)	Rainwater harvesting infrastructure all water (ability to install at later date?)	Grey water recycling systems, infrastructure to WCs (ability to install at later date?)
SUDS (awaiting options from JBA)	Need to increase SUDs provision to reduce future run off rates and deal with extreme downpours	Pumped drainage and below ground storage (option to expand / change rates)	Gravity fed natural systems with top up storage where required (min required)	Wide, shallow gravity fed natural systems (more space take)	Ground level measures (such as swales, prob on street side)	Podium level rainwater storage	Intensive green roofs (sufficient to control all run off)	Flat roofs, parapets and conventional rain water goods	Pitched roofs, parapets / set in RWPs (for security)	Pitched roofs and external guttering / RWPs
Resilience and conveyance	Need to provide resilience (water in) above design flood level (100+CC)	Floors above 100+20% CC+0.3m. Flow paths beneath building/ courtyards. Risk level is exceeded.	Floors above 100+20% CC+0.3m. Create flow paths between buildings by removing 10% of grd flr units.	Raise all floor levels (apx 0.6m) to above 100+70% CC+0.3m flood level and create flows beneath slab.	Change ground floor units to less vulnerable uses, such as restaurant or retail where in flow paths.	Remove potential obstructions to flood flows such as patio walls between houses.	Create flow paths through dedicated resistant areas, such as stairwells to flats or entrance halls/garages to houses	See construction section below		
Resistance and debris	Need to consider resistance (keeping water out) in some areas	No part of the buildings are designed to be resistant. They will flood if a flood in excess of 100+20% CC occurs.	Bin areas+services designed to be resistant. Flood storage reduced if a flood above 100+20% CC occurs	All ground floor units, building designed to be resistant. Flood storage reduced if a flood above 100+20% CC occurs	Buildings are not designed to be resistant now but option to retrofit improvements in the future.	All ground floor units designed to be resistant to 0.6m water depth by raising windows, solid walls, solid doors, flood guards etc.	Entrance halls, WC areas are designed to be resistant to 0.6m water inundation (1000 yr level) with solid walls, doors, flood guards etc.	See construction section below		
Flood refuge and recovery (access and egress)	Provision of access and egress during an extreme (1 in 1000) event. Note EA requires only an area that one can be rescued from.	Safe refuge at first floor with recovery by helicopter or boat (as currently designed)	Temp access (such as balconies that fold down to make a temporary escape)	High level permanant access through the site, such as a podium deck	Access through another room at first floor or above	Access over a balcony or terrace at first floor or above	Dedicated access at first floor or above (potential loss of floor space)			
Pools and ponds	Option to provide ponds and pools to aid natural cooling through evaporation	Located within courtyard	Located on south side of buildings	Located on north side of buildings						
COMFORT										
Shading/cooling	Passive cooling measures such as building orientation, and scale	Change building massing / urban plan to allow more sunlight into courtyard	Change building massing / urban plan to provide greater shading in future (but less solar gain now)	Additional tree planting to south and west of building to increase shading (linked to plant growth)	External louvres or shutters	Internal / interstitial blinds or shutters	Glass films			
Plant selection	Planting native plants to potentially aid cooling /shading and improve soil stability	Trees and planting on the streets	Trees and planting in the courtyard	Planting to individual terraces						
Cooling (typically passive)	Night time cooling. Issues of noise pollution.				Stack cooling to building, using stairwells. Additional ducting to flats not adjacent to stairs	Night cooling ventilation to individual units, with dedicated high level windows, shutters etc	Mechanical ventilation/cooling systems such as ducted air/heat recovery system			
Thermal mass	Ability to change proportion of exposed thermal mass				Conventional floor and wall finishes (such as wood or carpet and plasterboard) with possibility to replace/remove in future	Upgrade floor and ceiling finishes to stone/tiling and say painted concrete respectively	Building designed to be able receive additional dense (nom 50mm) finishes overlaid to increase thermal mass (similar to adding drylining)	See relationship with insulation		
Heating systems and services	Heating and electrical systems throughout design	Communal plant (CHP, fuel etc) at ground floor	Communal plant above ground floor	Plant inside each unit (such as individual boilers)	Conventional radiators (limited potential for cooling, would need additional system).	Underfloor heating (with potential to add cooling to system)	Ducted air system with possible heat exchange and future cooling			
Building Insulation	Type and location of insulation with respect to resilience, cooling etc				External to walls or frame	Within the cavity or frame	Internal to walls or frame	PIR, EPS (ie oil based products)	Mineral/rock wool, recylced plastic	Natural products (cellulose, wool, straw, etc)
CONSTRUCTION										
Foundation design	Soil conditions dictate that piles are best option but can they be adapted to work with the future flood levels and flows				See relationship with convevance			Friction piles, stub columns, ground beams	Piles + ground beams set back and slab cantilevered to edge of building	Deep trench footings
Resilient materials - SLAB	Effect of (future) extended wetting and water pressure							In-situ concrete slab with insulation above/below slab	Timber joists and boarding	Precast hollow core concrete planks or beam and block
Resilient materials - WALLS	Effect of (future) extended wetting and water pressure							Brick and block, cavity masonry wall construction	Timber frame and insulated timber infill. Brick, timber, render or metal panel finish	Steel or concrete frame with steel stud infill and render/ single brick skin (mass house builder approach)
Resilient materials - FINISHES	Effect of (future) extended wetting, cost of replacement							Carpet / soft flooring	Timber / board flooring	Stone / tiled / solid floors
Threshold joints (windows, doors)	Impact of debris, water logging and water pressure on external doors and windows				As shown - full height glazed doors (no protection)	narrow glazed doors and raised windows	narrow solid doors and glazing above flood level	Aluminium frames	Timber frames	UPVC frames

Table 3.1, Table of options

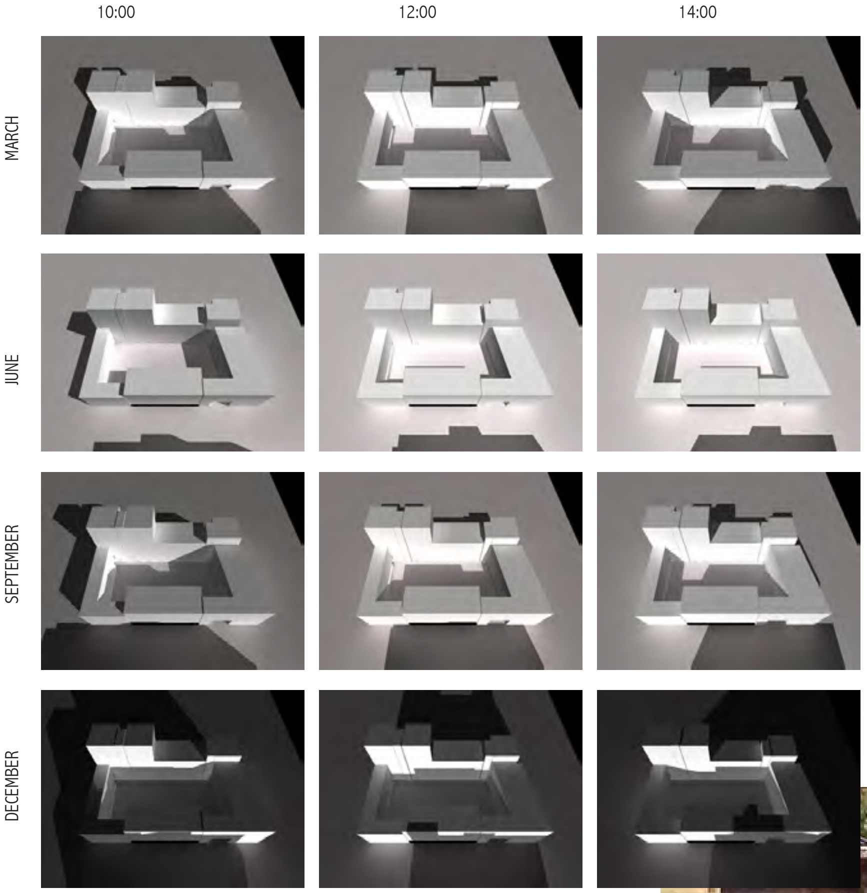
Some of the options considered are illustrated in the photos opposite (figure 3.2) and described in more detail in Appendix 3.2.

3. Multi Criteria Assessment (MCA) procedure

A MCA was carried out to identify which of the 90 options would be most appropriate for the building against a number of criteria (shown in table 3.2), including flexibility to respond to future climate conditions (particularly related to water - increased flood levels, peak rainfall and drought). This was a means of further refining the options for detailed testing, to avoid unnecessary and abortive work during the detailed assessment or sole reliance on past experience.

Using median weightings and the completed score sheet, the preferred options are shown in the table 3.3.

Figure 3.2, Photogrpahs of some of the options considered.
A. Swales
B. Rainwater attenuation tanks / also used as river flood storage
C. Door guard
D. External louvres
F. Internal greywater recyling system
G. Sun studies for massing variations
H. Permeable paving



G

Criteria	Description	Score
Capital Cost	Affordability, Saleability, Profit	1
Lifetime Cost	Lifetime affordability	4
Adaptability / flexibility	Ability to defer increased costs, Ability to adapt to change as it happens	3
Durability	Ease of maintenance, Feeling of quality	6
Flood risk reduction	Non damage impacts, Peace of mind, Insurability/saleability	2
Environmental Benefits	Cooling, light, community spirit, views…	7
Environmental Impacts	Carbon reduction benefits, habitat protection…	5

Table 3.2, Weightings Table

H

The MCA and sensitivity testing resulted in 18 ‘preferred’ adaptation options, shown in table 3.3. A SWOT analysis of the preferred options was carried out and is set out in Appendix 3.3. In particular this identified areas of Weakness and Threat of the adaptation options, which helped to identify areas for additional ‘detailed’ testing.

	Neighbourhood	Building	Detail
Foul Drainage	Option 3 All pipes located under soft landscaping to enable replacement/ improvement (greater space take)	Option 2 Waste fittings elevated/ able to be raised in future (WC, AAV stub stacks etc)	Option 3 Clay pipe systems to withstand future water loads during flood
Rainwater harvesting / Grey water recycling	N/A	Option 2 Communal system located at high level (New York style+need for pipes, pumps, treatment etc) DB(3)	Option 3 Grey water recycling systems, infrastructure to WCs (ability to install at later date?) SB(2)
SuDS	Option 3 Wide, shallow gravity fed natural systems (more space take)	Option 1 Ground level measures (such as swales, prob on street side) SB(2)	Option 3 Pitched roofs and external guttering / RWPs
Resilience and conveyance	Option 3 Raise all floor levels (apx 0.6m) to above 100+70% CC+0.3m flood level and create flows beneath slab. DB(1)	Option 2 Remove potential obstructions to flood flows such as patio walls between houses. DB(3) SB(3)	N/A
Resistance and debris	Option 2 Bin areas+services designed to be resistant. Flood storage reduced if a flood above 100+20% CC occurs DB(1)	Option 1 Buildings are not designed to be resistant now but option to retrofit improvements in the future. OB(3)	N/A
Flood refuge and recovery (access and egress)	Option 2 Temp access (such as balconies that fold down to make a temporary escape) OB(3)	Option 1 Access through another room at first floor or above SB(2)	N/A
Pools and ponds	Option 2 Located on south side of buildings	N/A	N/A
Shading/cooling	Option3 Additional tree planting to south and west of building to increase shading (linked to plant growth)	Option 3 Glass films	N/A
Plant selection	Option 2 Trees and planting in the courtyard DB(1)	N/A	N/A
Passive ventilation	N/A	Option 2 Night cooling ventilation to individual units, with dedicated high level windows, shutters etc	N/A
Thermal mass	N/A	Option 2 Upgrade floor and ceiling finishes to stone/tiling and say painted concrete respectively DB(1)	N/A
Active systems and services	Option 1 Communal plant (CHP, fuel etc) at ground floor	Option 2 or 3 Underfloor or ducted system DB(3) OB(2) SB(3)	N/A
Building Insulation	N/A	Option 1 or 3 External or Internal DB(2) OB(1) SB(1)	Option 2 Mineral/rock wool, recycled plastic OB(1) SB(3)
Foundation design	N/A	N/A	Option 3 Deep trench footings
Resilient Materials SLAB	N/A	N/A	Option 1 In-situ concrete slab with insulation above/below slab SB(2)
Resilient materials - WALLS	N/A	N/A	Option 1 Brick and block, cavity masonry wall construction SB(2)
Resilient materials - FINISHES	N/A	N/A	Option 3 Stone / tiled / solid floors DB(1) SB(2)
Threshold joints (windows, doors)	N/A	Option 1 As shown - full height glazed doors (no protection) SB(3)	Option 1 Aluminium frames SB(2)

Table 3.3, Preferred options, after MCA and sensitivity testing

4. Detailed testing

The high level nature of the MCA and SWOT analysis meant that some design options required more detailed assessment to determine there effectiveness, viability and cost benefit. The detailed testing and cost assessment were carried out simultaneously so that each could inform the other in decision making. These were based on the main climate risks to the building project:

- river flooding
- surface water flooding
- drought and
- overheating

The results of the detailed testing are included in Appendix 3.4.

Water - River flooding

To assess the effectiveness of the design options to combat flooding the ISIS-TUFLOWS model used for the initial assessment of flood levels was re-run with different design options in place. The design options tested included the following:

- Floodplain conveyance – creating areas for water to flow through the site and building
- Flood avoidance - raising the ground floor of the building on stilts
- Flood avoidance – raising the land level and thus the building
- Flood resistance – making the building impervious to water, to prevent water from entering the building during a flood (also called dryproofing and water exclusion strategy)

These options were then considered on the basis of their appropriateness at different flood depths, their effect on the flood levels, and their cost efficacy.

Water - Surface water flooding

To identify the most appropriate means to attenuate rainwater the existing drainage run off calculations (which were produced using Micro Drainage modelling software) were updated to reflect the 90th percentile projections for rainfall. This provided a volumetric calculation for the size of attenuation required at a controlled run off rate, designed to emulate the existing conditions. The previous assessment had identified ground level SUDS options, such as swales or permeable paving as preferred design option to below ground storage, infiltration basins or green roofs. Therefore options for the location of the swales and the capacity that they could deliver were reviewed.

Water - Drought

To identify the most effective water saving options to deliver the necessary water saving (apx 45 l/p/d over standard water use) over the lifetime of the development, design options were reviewed for water saving potential and cost effectiveness. The three options considered were:

- Water saving devices
- Rainwater harvesting (at different levels)
- Grey water recycling

Comfort - overheating

To assess the effectiveness of the design options to combat overheating the ISIS-TUFLOWS model used for the initial assessment of flood levels was re-run with different design options in place. The options tested included the following:

- Thermal mass – heavy weight construction, light weight construction, surface finishes
- Natural Ventilation – small windows, large windows, night purge window, labyrinth & stack cooling system (either with or without mechanical ventilation)
- Shading - Glazing films, Louvres, Projecting access deck or balcony
- Active Cooling – Heating, Ventilation and Cooling System (HVAC)

SECTION 3 > Adaptation Strategy

Results

Following the first three phases of assessment the preferred options were pulled together in table 3.3 set out according to three scales of development, and the three categories identified previously by the TSB.

The results of the detailed testing, which focussed on specific measures relating to river flooding, drought, SuDS, and overheating are described in the following pages and in more detail in Appendices 3.4 and 3.5.

Water - River flooding

The model results showed that sea level rise would not dramatically increase the flood levels (even using a precautionary estimate that does not take into account low tides) see Appendix 3. The range of increased flood levels demonstrate that the finished floor level given by the EA of 2.4m AOD should be sufficient to cope with an increase of almost 70% river flows or 25% increased river flows and sea level rise for the 2080s.

The results of the simulation modelling indicated that flood levels are not significantly affected by changes in the building design. Even land raising showed only minimal and localised increases in water levels, suggesting that some additional land raising could also be considered, such as secondary access roads .

The overriding consideration was found to be the potential future flood level. Therefore the uncertainty over what this may be in the future requires a well-considered approach. The difficulty with peak events is that a flood with a certain flow rate could occur tomorrow but it may be some years before one can identify what the return period may be. Climate change makes this even more difficult.

Because building design measures (including site changes) were shown to have little effect on the flood levels the optimum solution would need to be based on elevation above potential flood levels, cost and acceptability. The uncertainty of the future possible flood level makes it difficult to determine the level to raise the building by. The cost of raising the building higher than the level set for the base scheme could significantly increase the capital cost of the construction. Additionally it may be difficult for the developer to accept the need to increase the building above the median projected flood level, particularly as a 1 in 100 year flood may not even occur during the lifetime of the development.

Yet, resilience measures are always likely to be unacceptable to householders who would rather not be flooded at all, therefore raising and resistance measures are preferred. Resilience measures may still provide a benefit should water levels exceed the threshold at which water is excluded, such as for a more extreme event than a 1 in 100 year flood.

A range of resilience measures was considered based on guidance on their maximum effectiveness against flooding to determine a strategy that could enable the building to be adapted to future flood levels. Some of the level raising scenarios explored are indicated in figure 3.3 and retrofit resistance measures indicated in figure 3.4.

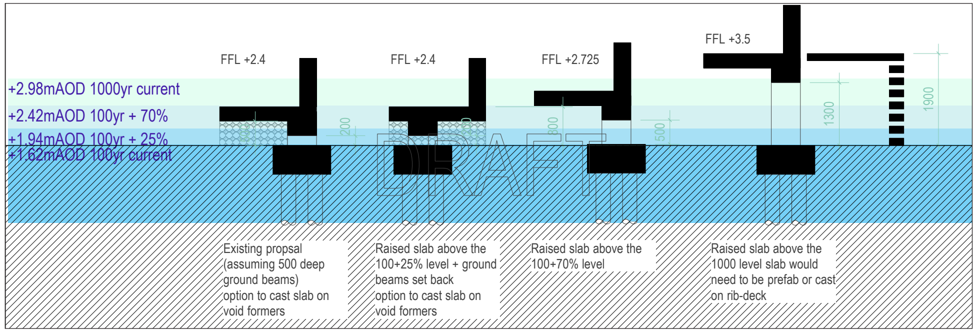


Figure 3.3, Level raising

Figure 3.4, Flood resistance measures

The cost analysis showed that raising the building and the associated parking, services and all the additional landscaping was more expensvie per metre of flood protection than resilience or resistance measures, particularly when NPV values were considered. Howevver, it should be noted that above certain depths of water inundation some of the measures become unsuitable and therefore raising is still likely to be a sensible solution. It is also most likely to be the safest solution as it does not rely on protection measures.

The costs were found to vary quite dramatically for different depths of flood water, with all three measures becoming cheaper for deeper levels of water protection.

The most effective approach to manage the worst predicted future scenario was found to be to raise the whole development above the 1 in 100 year event + 70% river flows + 0.5m. This would provide a balanced approach with the higher cost raising providing greater safety over the life time of the development and the retrofit resistance or resilience measures providing flexibility to improve the standard of protection if further future flood levels changed. Arguably the amount of raising could be reduced but the protection for a 1 in 1000 year event would need to be resilience and not resistance.

For other parts of the development where smaller buildings are proposed and pile foundations may not be necessary the cost benefit of raising the building may be less and this may not be the most appropriate solution. Therefore greater reliance on resistance or resilience measures may be appropriate.

To cope with flood levels in the event of a 1 in 1000 year flood resistance measures were seen as a more acceptable solution than further raising the building and carparking, which could create a greater distance to the ground level and may have planning implications.

CAN solution

The CAN adaptive solution was to:

1. raise the buildings and car park above the 1 in 100 year +70% increased river flows and +0.5m to allow for sea level rise (figure 3.3)
2. provide flood resistance measures for the first 0.3m above floor level to provide protection from the 1 in 1000 year flood were it to occur.

For other parts of the site it would be more cost effective to set the floor levels above 2.4m AOD (equivalent to the 1 in 100 year + 70% increased river flows and the 1 in 100 year +25% increased river flows and +0.5m to allow for sea level rise) in accordance with the existing guidance.

Should future predictions worsen and peak water levels greater than the 90th percentile + sea level rise be considered possible then the flood resistance measures could be increased in height and/or flood resilience measures added.

Other changes required included:

- ground floor doors and windows less than 0.6m above FFL to be changed to aluminium frames
- high quality seals provided around all openings and doorways
- no door widths greater than 1.2m on the ground floor to allow fitting of standard door guards
- hard surfaces on the ground floor, as a precautionary measure should the resistance measures fail
- Electrics fed down from the first floor and all sockets located 0.6m above FFL, as a precautionary measure should the resistance measures fail

The raised ground floor and car parking provided opportunities for cooling and rainwater harvesting.

Water - Drought

The WG data identified that drought events would become more frequent and longer lasting in the future. It identified that the frequency and duration could double by the 2080s. To provide the water saving to meet current planning requirements the occurrence of drought needed to be considered. It was identified that without additional treatment either rainwater harvesting or grey water recycling could only be used for flushing WCs and irrigation, only offering a maximum potential water saving of up to 24 l/p/d. This water saving could be met by either rainwater harvesting or grey water recycling alone.

The uncertainty of the frequency and duration of droughts made it difficult to identify the appropriate capacity of rainwater harvesting (see table 3.4) therefore the preferred solution is a combination of water saving devices with communal grey water recycling, which would continue to provide water saving regardless of the future climate. This approach would still enable a rainwater harvesting system to be added at a later date.

Costs

The cost of low flush fittings was found to be by far the most cost effective, costing less than £500 / litre saved / person / day. The cost to install greywater recycling was in the order of £4,500 / litre saved / person / day and rain water harvesting in the order of £7,500 / litre saved / person / day.

The cost of grey water treatment was found to be higher than for rainwater harvesting, however, the size of the tank required is a lot smaller and therefore the associated works would be cheaper. When NPV values were considered for retrofitting rainwater harvesting the cost was between £3,100 and £4,200 / litre saved / person / day - making rainwater harvesting a potential future adaptation solution to further reduce potable water consumption.

The opportunity to harvest rainwater in the flood void beneath the building was also considered and could provide cost savings. However, it was identified that there may be technical issues related to using the flood void, with regards to emptying it when needed to store flood water and waterproofing it to prevent water loss at all other times. There may also be clean up and extensive repair requirements after it is flooded that would need to be considered. This approach has been used for below ground SuDS storage and so would be interesting to consider for other flood voids but would require further research, such as partial construction and physical testing within a water simulation tank (flume).

Number of Inhabitants	Litre saving	Water required each day	Number of days without rain	Size of tank required to nearest m3	Number of days without rain	Size of tank required to nearest m3
157	15 l/p/d	2355 litres	10	24 m3	20	48 m3
157	18 l/p/d	2826 litres	10	28 m3	20	56 m3
157	20 l/p/d	3140 litres	10	32 m3	20	64 m3
157	24 l/p/d	3768 litres	10	38 m3	20	76 m3

Table 3.4, Rainwater harvesting calculations

CAN solution

The preferred solution is to use water saving measures to reduce the water consumption with rainwater harvesting linked with the flood storage area below the car park. This should create sufficient capacity to cope with future drought conditions from day one but without any additional cost for excavation in the future. However, this would increase the maintenance cost of the flood storage area. This approach would still enable the grey water recycling system to be added at a later date. There are potential technical issues related to using the flood void and what might happen to it after it is flooded that would need to be considered. This is likely to require further research, such as partial construction and physical testing within a water simulation tank (flume).

Therefore the developer preference is to use a dedicated grey water recycling system that will deliver the necessary water saving and should continue to do so regardless of the future climate. This approach would still enable a rain water harvesting system to be added at a later date.

Water – SuDS

The base scheme is required to provide 63m3 of storage for rainwater attenuation. This was based on current run off rate calculations + 30% increase to allow for climate change. The WG model showed that storage volume should be sufficient to cope with increased rainfall through to the 2080s for the 50th percentile projection but in the 90th percentile predictions that additional storage could be required by 2022. By 2080 this storage requirement could be 90m3 for this building alone.

Due to the cost of each system, swales were identified as the preferred option, though below ground storage would also be relatively cost effective. Swales are low maintenance, resilient to periodic flooding, and cheap to construct. Typically they would be relatively small, and discharge into a SuDS pond. It was also considered that ground level swales and ponds could help to reduce the ambient air temperature around the buildings and may help to provide some cooling benefit.

Due to the potential for flooding this would only be possible in some parts of the site. Therefore the main consideration with regard to using swales was the area required. Based on 0.5m depth shallow swales (figure 3.5), that would enable a gravity discharge system, and using three areas on the site a total storage capacity of 95m3 was identified. This could diminish over time without regular maintenance therefore further capacity was identified in the pavements.

CAN solution

Therefore the CAN adaptation strategy was to install swales on two areas (shown as Areas A and B in Figure 3.6), before retrofitting a further swale in 2022 or later if required. An alternative or addition to a further swale would be to install permeable paving below the main street, when it was scheduled for relaying (table 3.5).

Water Storage Area	Volume/m3
Swales	96.85
Under Pavement	50.6

Table 3.5, SuDS storage area

Figure 3.5, Ground level swales

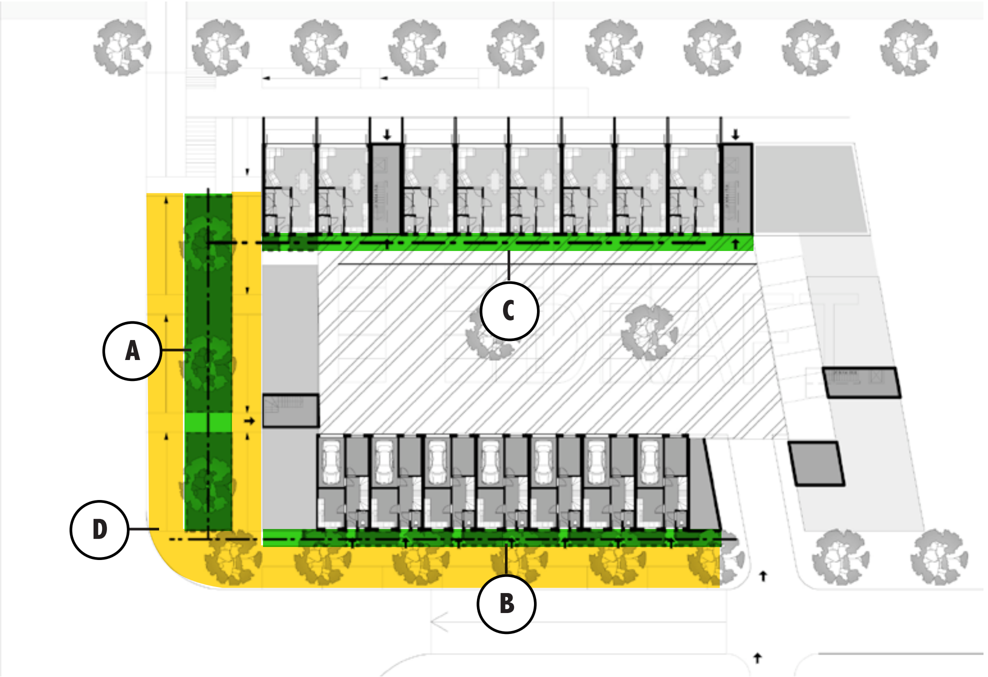


Figure 3.6, Possible areas for ground level SuDS

Comfort - overheating

The IES modelling showed that the risk of overheating would increase in the future. However, it showed that the specific unit studied, would not suffer from overheating by the 2080s with the 50th percentile predictions, and based on a typical 'developer' construction used as the base scheme. When the 90th percentile predictions were considered it showed that overheating could become an issue as early as 2040, ie less than 30 years after the building is completed.

The results found that no single passive technology could meet the cooling need required and that even if the most effective passive measures were combined that they still require additional cooling from active measures by 2058 (Figure 3.7).

If no passive measures are incorporated and the temperature rise is towards the higher predictions then the need for cooling would rise and if no passive measures added then the energy demand for active cooling could be significant (particularly assuming that they are powered by electricity). With concern by some scientists that feedback mechanisms will result in more significant warming (such as Turn down the heat: Why a 4°C Warmer World Must be Avoided, World Bank 2012) it was considered appropriate to base the adaptation strategy on the 90th percentile and linking choices to temperature increases not time.

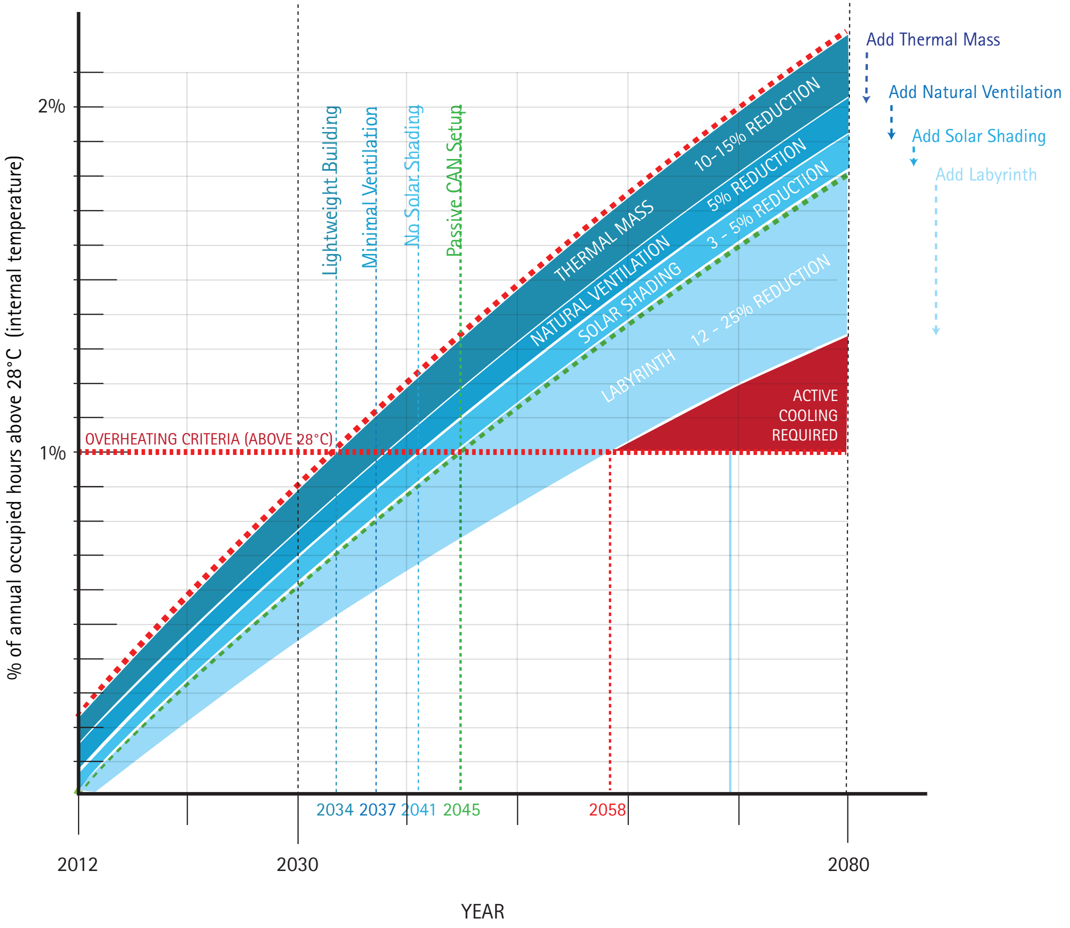


Figure 3.7: Incremental Effect Of Cooling Strategies On Base Scheme (For 90th Percentile Future Climate)

To make a comparison of the cost efficacy of different options the cooling benefit as assessed above was compared with the cost of installation either the capital expenditure (Capex) for options which needed to be installed from day one, the Net Present Values (NPV) for those that could be retrofitted or a combination of Capex + NPV for those that needed some provision to be installed from day one to allow retrofitting in the future. The retrofit date for the NPV calculation was taken from the optimum latest date when the measure may be required, assuming that passive measures would be preferred over active, to create the most robust long-term adaptation solution.

An option such as labyrinth/stack cooling, which was found to be very effective, was calculated to have a high capex cost of £320,000 and therefore high cost per % reduction in POE of £12,800. This was despite the labyrinth being created by the flood void and the service riser to each adapted to form the stack. When considered as a retrofit in 2058 the discounted cost makes the labyrinth system far more appealing, reducing the cost per % reduction in POE to apx £1,400.

The thermal mass of the building was the only item that could not readily be retrofit and whilst it resulted in a high cost per % reduction in POE of apx £8,700 it would be more cost effective than all of the other measures explored if installed from day one with the exception of planting more trees.

Therefore from a cost per efficacy the options could be prioritised as:

1. Tree planting
2. Thermal mass to the construction
3. Labyrinth retrofit system
4. Louvres / shading, closely followed by
5. Active cooling system

The addition of high-level windows for night cooling was not found to be as cost effective as other measures, even when retrofitted. Glazing films were not found to be cost effective at all, this is likely to be due to their poor demonstrable benefit.

CAN solution

The CAN adaptive solution was to use passive cooling technologies before incorporating active cooling if and when required.

Because the thermal mass to the fabric of the building could only be introduced from day one this would be introduced as a change to the base building. The deck access would remain on the southside of the building, providing cooling to the units below. The doors onto the balconies overlooking the river would provide good natural ventilation, which would not need to be improved.

The labyrinth/stack cooling would be the first measure to be added potentially in 2041 and 2045 for the units to the south and north sides respectively. Mechanical ventilation may help to improve the effectiveness of this system.

For the units with a south facing aspect onto the street solar shading would be added in the future potentially as early as 2041 or delayed by 13 years by the use of the labyrinth cooling.

Additional solar control could then be added with louvres to the glass or interstitial blinds when the glazing units were due to be replaced (typically every 10 years) to postpone the need for active cooling.

If once these technologies had been implemented the temperature continued to rise then an active cooling system would be required. This would be added to the labyrinth/stack ventilation system to reduce the complexity for the user, space occupied and improve the efficiency.

5. Cost appraisals and cost analysis

A cost plan for the entire base building scheme was developed by Sweett Group, using information from the current planning scheme, but with a specific focus on the items that were to be compared with the design options identified. This then enabled the cost change from the base scheme to be considered as either a fixed amount or a percentage change.

This provided an assessment of the capital cost of different options. Where there was likely to be ongoing maintenance costs and depreciation a net present value (NPV) was calculated to determine their cost efficacy. This was used to assess the options studied in detail and to finally compile a preferred list of options and an adaptation strategy for options that were to be added later.

The relative efficacy of key adaptation measures was calculated based upon:

- the cost per meter of flood protection gained
- the cost per % of improvement to overheating
- the cost per litre of water saved

Naturally some measures can only be incorporated at 'day one' and these costs are therefore presented on the basis of what is likely to be experienced now (first quarter 2013). Other costs are future adaptation costs and these have been presented on a net present value (NPV) basis, dependent upon their year of implementation. All costs are exclusive of VAT and professional / other fees.

It was therefore possible to select flood, comfort and water saving measures from a menu of possible solutions having different levels of cost effectiveness.

A more detailed summary of the cost assessment and appraisal is included in Appendix 3.5.

Costs

The costs for each preferred measure to be considered were calculated by Sweett Group. These were then refined following further design work and are indicated in the cost change over base scheme in table 3.7.

The modelling work enabled some measures to be further refined or ruled out in preference for others (for instance building raising cancelled the need for resilience measures such that resistance measures could be used).

Following this work it was then possible to collectively consider which measures could be omitted and / or retrofitted.

Comparison

The changes to the base building to manage the future climate risks were found to only increase the capital cost by 0.3% as indicated in Table 3.8. However, this included a saving for the removal of the raised deck, which was found to be unnecessary. If the raised deck was excluded from this cost comparison then the capital cost was found to increase by 1.4%. The main cost increase was the enhancement of the building fabric from lightweight to heavyweight construction.

The cost of retrofitting the cooling measures, including labybrinth / stack ventilation, louvres and windows for night cooling would add a further £57,000 Net Present Value to the build. Therefore, the total cost increase could be 3.1%.

Item	Type	Scale	Measure	Cost change over base scheme	Notes from initial Sweett Group cost assessment	Adjustment following review	Final adjustment	Notes regarding review
1.1	Foul Drainage	Neighbourhood	Pipe location	-£9,000.00	Cost saving for shallow drainage with short sectionunder hard standing paved area (crossing courtyard)	£0.00	-£9,000.00	Keep in
1.2	Foul Drainage	Building	Elevated waste+backflow	£0.00	no cost change as required in base scheme	£0.00	£0.00	no cost change as required in base scheme
1.3	Foul Drainage	Detail	Clay pipes	£18,000.00	Increase based on extra cost for clay fittings and labourfor installation.	-£18,000.00	£0.00	omitted, not required
2.1	Water reduction	Neighbourhood	N/A	£0.00	N/A	£0.00	£0.00	N/A
2.2	Water reduction	Building	Rainwater harvesting	£122,000.00	Communal system	-£122,000.00	£0.00	omitted, not required at start
2.3	Water reduction	Detail	Grey water	£88,000.00	Communal system	-£88,000.00	£0.00	no cost change as required in base scheme to achiee Code Level 4
3.1	SUDS	Neighbourhood	suds	£49,000.00	Increased cost for 1,096m2 SUD area @ £36/m2	-£32,000.00	£17,000.00	less cost of tanked system already allowed for
3.2	SUDS	Building	street swales	£5,000.00	Increased cost assumed channels with say 300mm depth, approx 200m @ £30/m (£5/m excavation, £20/m for channel plus prelims and OH&P)	-£5,000.00	£0.00	retrofit item, no capital cost
3.3	SUDS	Detail	pitched roof	£21,000.00	Cost dependent on flat roof finish. Base model flat roof assumes a single ply membrane sheet finish with rainwater goods, insulation. Pitched roof rate £150/m2	-£21,000.00	£0.00	retrofit item, no capital cost
4.1	Resilience & Conveyance	Neighbourhood	raised floors	£175,000.00	Increased cost to raise all floors 600mm extending pile lengths and caps above ground and associated ground works. Flood preventative measures from Base Model omitted in adjustment calculation	-£95,000.00	£80,000.00	no cost change as level of raising kept same as base scheme. Add £80k for further 300mm raising
4.2	Resilience & Conveyance	Building	openings in walls	£4,000.00	Works to create water flow to patio walls between ground floor flats	-£4,000.00	£0.00	omitted, not required as modelling showed it made no difference to conveyance
4.3	Resilience & Conveyance	Detail	N/A	£0.00	£78,500 required in base scheme for raised electrics, tiles, resilient plasterboard, plastic doors.	-£78,500.00	-£78,500.00	Required in base scheme. Not required due to raising by further 300mm
5.1	Resistance measures	Neighbourhood	To bin areas and cores	£35,000.00	Bin areas and services flood resistant - comprising concrete barrier upstand and door seals comparison with external work package value £5,000 for bins/ recycling, £1,000/ unit for Ground floor 18 nr units, plus £5,000 for entrance halls protection.	-£35,000.00	£0.00	no cost change as required in base scheme
5.2	Resistance measures	Building	Ground level improvements	£78,000.00	Changes to slab, walls, door seals, guards	-£78,000.00	£0.00	no cost change as required in base scheme
5.3	Resistance measures	Detail	N/A	£0.00	Considered above	£0.00	£0.00	N/A
6.1	Flood Refuge	Neighbourhood	N/A	£60,000.00	Access- fold down balconies to first floor units	-£60,000.00	£0.00	omitted, not required in final scheme as flood risk mitigated by other measures
6.2	Flood Refuge	Building	N/A	£5,000.00	Access through another room at first floor to balcony	-£5,000.00	£0.00	omitted, not required in final scheme
6.3	Flood Refuge	Detail	N/A	£0.00	Refuge at first floor, part of base scheme	£0.00	£0.00	no cost change as required in base scheme
7.1	Pools & Ponds	Neighbourhood	Assumed 2 Nr pool ponds	£14,000.00	Increase for 2 Nr ponds - assumed two pools at 10m x 10m, 2 metre depth, say; £20/m3 excavation & prep, £10/m2 membrane and £5/m2 planting	£0.00	£14,000.00	Included but probably could be omitted due to proximity of river
7.2	Pools & Ponds	Building	N/A	£0.00	N/A	£0.00	£0.00	N/A
7.3	Pools & Ponds	Detail	N/A	£0.00	N/A	£0.00	£0.00	N/A
8.1	Shading	Neighbourhood	Additional trees	£9,500.00	Increase for additional assumed 10 Nr new trees	£0.00	£9,500.00	Included
8.2	Shading	Building	Raised deck	£0.00	Raised amenity deck, allowed in base scheme	-£125,000.00	-£125,000.00	Raised deck omitted as not required / not effective, external access and balconies retained
8.3	Shading	Detail	Glass films / louvres	£98,000.00	Increase to flats and houses only, £35/m2 extra over to 50% of windows	-£98,000.00	£0.00	Omitted from capital works. NPV - £8,700 for louvres, £6,800 for film
9.1	Plant Selection	Neighbourhood	N/A	£0.00	Not costed	£0.00	£0.00	Not costed
9.2	Plant Selection	Building	N/A	£0.00	Not costed	£0.00	£0.00	Not costed
9.3	Plant Selection	Detail	N/A	£0.00	Not costed	£0.00	£0.00	Not costed
10.1	Cooling	Neighbourhood	Building massing	£0.00	No cost implication as building massing just shifted and heights the same overall	£0.00	£0.00	Measure not found to be significant as just moved heat gain from one unit to another. Only appropriate in mixed use scheme or in relation to adjacent buildings
10.2	Cooling	Building	Labyrinth cooling	£320,000.00	Stacks, pipes, all works to the roof, fans, inlets, outlets etc.	-£320,000.00	£0.00	Using a private sector discount rate of 5% the net present value of the work in 2058 is £34k. Cost not included as may not be required
10.3	Cooling	Detail	Night cooling	£57,000.00	Increase to flats and houses only, £650 x 70 nr units	-£57,000.00	£0.00	£14,000 NPV, not included as may not be required
11.1	Thermal Mass	Neighbourhood	N/A	£0.00	N/A	£0.00	£0.00	N/A
11.2	Thermal Mass	Building	Construction	£130,000.00	Block and insulated rendered wall construction	£0.00	£130,000.00	Kept in
11.3	Thermal Mass	Detail	Finishes	£45,000.00	Increase £25/m2 to 1st floor flats and houses ceilings, including uplift for integrating services into concrete finish ceilings. Additional £10/m2 for floor finishes	-£45,000.00	£0.00	omitted in preference to heavy building construction
12.1	Mechanical Heating / Cooling	Neighbourhood	Communal CHP plant	£57,542.00	Modified CHP system to include cooling	-£57,542.00	£0.00	omitted in preference of passive cooling measures.
12.2	Mechanical Heating / Cooling	Building	HVAC	£197,500.00	HVAC system to individual units. Note: unnacceptable carbon emissions. Therefore only of arithmetic interest	-£197,500.00	£0.00	£197,500 NPV to retrofit HVAC systems
12.3	Mechanical Heating / Cooling	Detail	N/A	£0.00	N/A	£0.00	£0.00	N/A
13.1	Insulation	Neighbourhood	N/A	£0.00	N/A	£0.00	£0.00	N/A
13.2	Insulation	Building	Insulation on outside of blockwork	£209,000.00	Increase for additional changing to blockwork walls in lieu of Metsec and also adding in Rockwool on framing	-£209,000.00	£0.00	omitted, included with thermal mass above
13.3	Insulation	Detail	N/A	£0.00	included above	£0.00	£0.00	omitted
14.1	Foundation Design	Neighbourhood	N/A	£0.00	Foundation design fixed by ground conditions and no change required as a result of Climate Changes	£0.00	£0.00	N/A
14.2	Foundation Design	Building	N/A	£0.00	as above	£0.00	£0.00	N/A
14.3	Foundation Design	Detail	N/A	£0.00	as above	£0.00	£0.00	N/A
15.1	Resilient Materials - Slab	Neighbourhood	N/A	£0.00	N/A	£0.00	£0.00	retrofit item, no capital cost
15.2	Resilient Materials - Slab	Building	N/A	£0.00	N/A	£0.00	£0.00	retrofit item, no capital cost
15.3	Resilient Materials - Slab	Detail	Precast slabs	£45,550.00	Programme/ prelims time savings off set by pre cast fabrication, craneage costs and screeding over trades	-£45,550.00	£0.00	omitted, no benefit identified / not required
16.1	Resilient Materials - Walls	Neighbourhood	N/A	£0.00	N/A	£0.00	£0.00	N/A
16.2	Resilient Materials - Walls	Building	N/A	£0.00	N/A	£0.00	£0.00	N/A
16.3	Resilient Materials - Walls	Detail	Brick and block cavity	£150,000.00	Brick and block traditional cavity wall construction	-£150,000.00	£0.00	included with 11.2, thermal mass above
17.1	Resilient Materials - Walls	Neighbourhood	N/A	£0.00	N/A	£0.00	£0.00	N/A
17.2	Resilient Materials - Walls	Building	N/A	£0.00	N/A	£0.00	£0.00	N/A
17.3	Resilient Materials - Walls	Detail	Stone / tiled floors	£143,000.00	Cost increase £15/m2 to lay stone/ tilling	-£143,000.00	£0.00	omitted, not required due to raised floors
18.1	Threshold Joints	Neighbourhood	N/A	£0.00		£0.00	£0.00	N/A
18.2	Threshold Joints	Building	Narrow doors at ground	-£28,000.00	Cost saving for full height glazed doors changed to narrow doors and solid wall where low level glazing omitted	£0.00	-£28,000.00	Kept in final scheme but note some loss of quality/light
18.3	Threshold Joints	Detail	Aluminium frames instead of UPVC	£24,000.00	Cost increase for aluminium, average EO £500/ door over UPVC allowance	£0.00	£24,000.00	omitted, not required
	Total						**£34,000.00**	

Table 3.7, capital cost changes over base scheme of adaptation measures

Cost Pathways

The cost efficacy of specific measures is illustrated in table 3.9. Some of the initial costs from table 3.7 were discounted through the NPV technique.

In the areas of adaptation it can be seen that the lowest cost pathways through the focus areas of flood protection, comfort and water saving comprise the following (continued overleaf):

Flood protection:

- Initial raising – more expensive on a cost per meter basis to build at day one than any of the other measures
- Dry proof (resistant construction) – the cost efficacy for either 0.3 or 0.6m raise is broadly the same and outperforms all the other protection measures in the study
- Wet proof (resilient construction) – cost efficacy is lower than dry proof construction, producing higher cost per meter of protection.

Broadly speaking therefore it seems most sensible to maximise the benefit delivered through dry proof construction when considering capital costs.

Attention is drawn to the fact that the basket of measures within the dry proof technique includes those implemented at day one (such as in-situ concrete slab to the ground floor and traditional brick / block walls) and items that are future retrofitted such as door seals and flood guards, the cost of which has been discounted through the NPV

Buildings:	**Cost per sqm**	**Capital cost of base scheme**	**Capital cost of CAN scheme**	**% change**
Flats & Duplexes 64 Nr- 4 to 8 storey (55% of total)	795	£6,390,000	£6,460,125	1.10%
Townhouses 6 Nr- up to 4 storey (30% of total)	139	£1,120,000	£1,158,250	3.42%
GROUND only- (to 3 storey building) Ground level Retail Units/ Commercial shell and core (8% of total)	24	£190,000	£200,200	5.37%
GROUND only- (to 5 storey building) Ground level Restaurant- shell and core (7% of total)	44	£355,000	£363,925	2.51%
Recycling/ Waste- single storey	4	£30,000	£30,000	0.00%
CHP Plant and room (site wide)	85	£685,000	£685,000	0.00%
Marketing suite/ office fit out	3	£25,000	£25,000	0.00%
Sub Total Buildings	1,095	£8,795,000	£8,922,500	1.45%
External Works				
External Works and landscaping (including external deck)	27	£216,000	£131,500	-39.12%
Utilities/ External Services	19	£150,000	£141,000.00	-6.00%
Site Wide Below Ground drainage	10	£78,000	£78,000	0.00%
Marketing/ temporary advertising signage	1	£5,000	£5,000	0.00%
Sub Total Ext Works	56	£449,000	£355,500	-20.82%
Main Contractor Site and Works Preliminaries	92	£739,520	£739,520	0.00%
OH&P	75	£599,011	£599,011	0.00%
Sub Total Preliminaries	167	£1,338,531	£1,338,531	0.00%
Risk allowances	62	£499,176	£499,176	0.00%
Rounding		£3,293	£3,293	0.00%
Total	**1380**	**£11,085,000**	**£11,119,000**	**0.31%**
With deck added back into total		£11,085,000	£11,244,000	1.43%
With deck added back into total + NPV cost of retrofitting the cooling measures, including labybrinth / stack ventilation, louvres and windows for night cooling		£11,085,000	£11,425,700	3.07%

Notes:
Capital cost of CAN scheme is based on cost change from 'CAN comparison' worksheet added into the appropriate section.

Table 3.8, capital cost changes over base scheme

technique discussed above. Clearly the benefit of the basket of measures is diminished if one of the future retrofit items is not carried out, a risk that appears if the work becomes the responsibility of individual householders or subsequent landlords who do not fully commit to the design solution for the building.

Comfort:

- Tree planting at day one – relatively cost effective and therefore implemented at construction
- Labyrinth retrofit – becomes a cost effective measure when looked at on a net present value basis
- Other comfort measures – horizontal louvres are the most cost effective retrofit, followed by mechanical cooling (based on in dwelling VRF) and finally high level shutters. Mechanical cooling will incur operational costs in use for electricity consumption and repairs / servicing, none of which are included in this assessment

Water:

- Water saving devices – a highly cost effective measure even at day one costs, being consistent with published third party findings
- Grey water recycling – this measure has operational issues associated with it that require careful consideration. The costs are based on a communal system and as such the benefits of the water saved need to be accounted for proportionally across all dwellings. The water recycled displaces mains water. Mains water is metered per dwelling and tenants pay for what they use, unlike grey water. It is possible therefore for some tenants to benefit disproportionally from the use of grey water to the detriment of others

  System use needs be controlled by restricting liquids that can be disposed into certain sinks and basins as these will enter the grey water system, with potentially adverse consequences
- Rainwater harvesting – the costs for the retrofitting of the rainwater tanks has been discounted to a net present value consistent with other retrofit measures. It can be seen that higher levels of water saving become progressively cheaper to achieve. In implementation it will be necessary to determine how the savings benefit of displaced mains water is allocated across the tenancies in a similar way to the grey water system.

Table 3.9, cost efficacy of specific measures

WATER > RIVER FLOODING	STRATEGY	**COSTS**	Flood level protection (in m)	cost per metre of flood protection	Comment
RAISED CONSTRUCTION	Raised construction	£255,000	0.9	£283,333	Total for 0.9m raised structure, parking etc
	Raised construction	£175,000	0.6	£291,667	Total for 0.6m raised structure, parking etc
	Raised construction	£105,000	0.3	£350,000	Total for 0.3m raised structure, parking etc
RESILIENT CONSTRUCTION	Resilient to 0.6m	£98,000	0.6	£163,333	NPV cost in 2037 for 0.6m flood resilience
	Resilient to 0.3m	£78,000	0.3	£260,000	NPV cost in 2037 for 0.3m flood resilience
RESISTANT CONSTRUCTION	Resistant to 0.6m	£70,550	0.6	£117,583	NPV cost to upgrade in 2037 for 0.6m flood resistance. Note that the wall construction is CAPEX cost
	Resistant to 0.3m	£50,550	0.3	£168,500	NPV cost in 2037 for 0.3m flood resistence. Note that the wall construction is CAPEX cost

WATER > SURFACE WATER FLOODING			attenuation	cost per volume of attenuation	Comment
SuDS	swales	N/A	N/A	£45	CAPEX cost (from JBA)
SuDS	pervious paving	N/A	N/A	£130	CAPEX cost (from JBA)
SuDS	green roofs	N/A	N/A	£140	CAPEX cost (from JBA)

WATER > DROUGHT			water saved / person / day (in litres)	cost per litre saved	Comment
WATER SAVING DEVICES	Low flush fittings	£5,040	22	£229	Initial installation of low flush fittings
GREY WATER RECYLING		£88,000	20	£4,400	Initial installation of grey water recycling
RAINWATER HARVEST	BUILDING	£113,000	15	£7,533	Initial installation of communal rainwater system
	BUILDING	£63,000	15	£4,200	NPV retro 2031 cost 48m^3 tank
	BUILDING	£67,000	18	£3,722	NPV retro 2031 cost 56m^3 tank
	BUILDING	£70,000	20	£3,500	NPV retro 2031 cost 64^3 tank
	BUILDING	£75,000	24	£3,125	NPV retro 2031 cost 76m^3 tank

COMFORT > OVERHEATING			Overheat Reduction (in %)	cost per % improvement	Comment
SHADING	Trees	£9,500	3.0%	£3,167	
	Horizontal louvres	£8,700	2.0%	£4,350	NPV of retrofitting louvres in 2050. If required sooner then the cost would increase
	Deck access / balcony		4.0%	£0	Not calculated as part of the initial design
	Glass film	£6,800	0.3%	£22,667	NPV of retrofit of films in 2050
VENTILATION	Labyrinth / stack ventilation (day 1)	£320,000	25.0%	£12,800	CAPEX cost of installing
	Labyrinth / stack ventilation (retrofit)	£34,000	25.0%	£1,360	NPV of retrofitting chimney stacks, fans, inlets and outlets etc in 2058 using a private sector discount rate of 5% the net present value of the work
	Night cooling high windows	£14,000	2.0%	£7,000	NPV of retrofitting H/L shutters in 2045
ACTIVE COOLING	HVAC (capital cost)	£195,000	40.0%	£4,875	Assumes retro fit of 12kW per dwelling system in 2045. Price is NPV value of the work in 2045
	HVAC (+10 years running)	£197,500	40.0%	£4,938	Includes the NPV of capex and running costs for 10 years from 2045. No abatement for gas has been taken. No allowance for running costs but would increase cost versus a passive measure
THERMAL MASS	Construction	£110,000	15.0%	£7,333	CAPEX cost of heavy weight construction, less the solid masonry for the flood resistance

The integrated CAN solution

When tested, the base scheme was found to provide a reasonably robust solution to climate change. Many of the measures previously developed in response to the site and to manage the flood-risk resulted in a building project that is more resilient to future weather. For instance the deck access provided natural shading, the orientation meant that solar gain was diminished, landscaping and riverside setting were believed to reduce ambient temperatures and the combination of land works, pile construction, cellular storage and flood resilience were found to manage the future flood risk. However, there were a number of key changes that were identified. These are described in table 3.6.

Neighbourhood scale	Building scale	Detail scale
Increase planting of trees to the south and west facades of buildings to provide future shading once mature	Buildings raised marginally to reduce cost of resistance measures required	Thermal mass to main building fabric
Create surface level SuDS formed from extensive ground swales along the edges of buildings	Provision for labyrinth / stack cooling within service risers	Reduced door widths at ground level to enable retrofitting of door guards
	Communal grey water recycling	Service void brought to face of the units to allow change to stack ventilation in the future or to install HVAC system.
		In-situ concrete slab to ground floor (in preference to beam and block) to provide flood resistance

Table 3.6, recommended key changes over base scheme

How the measures may be integrated

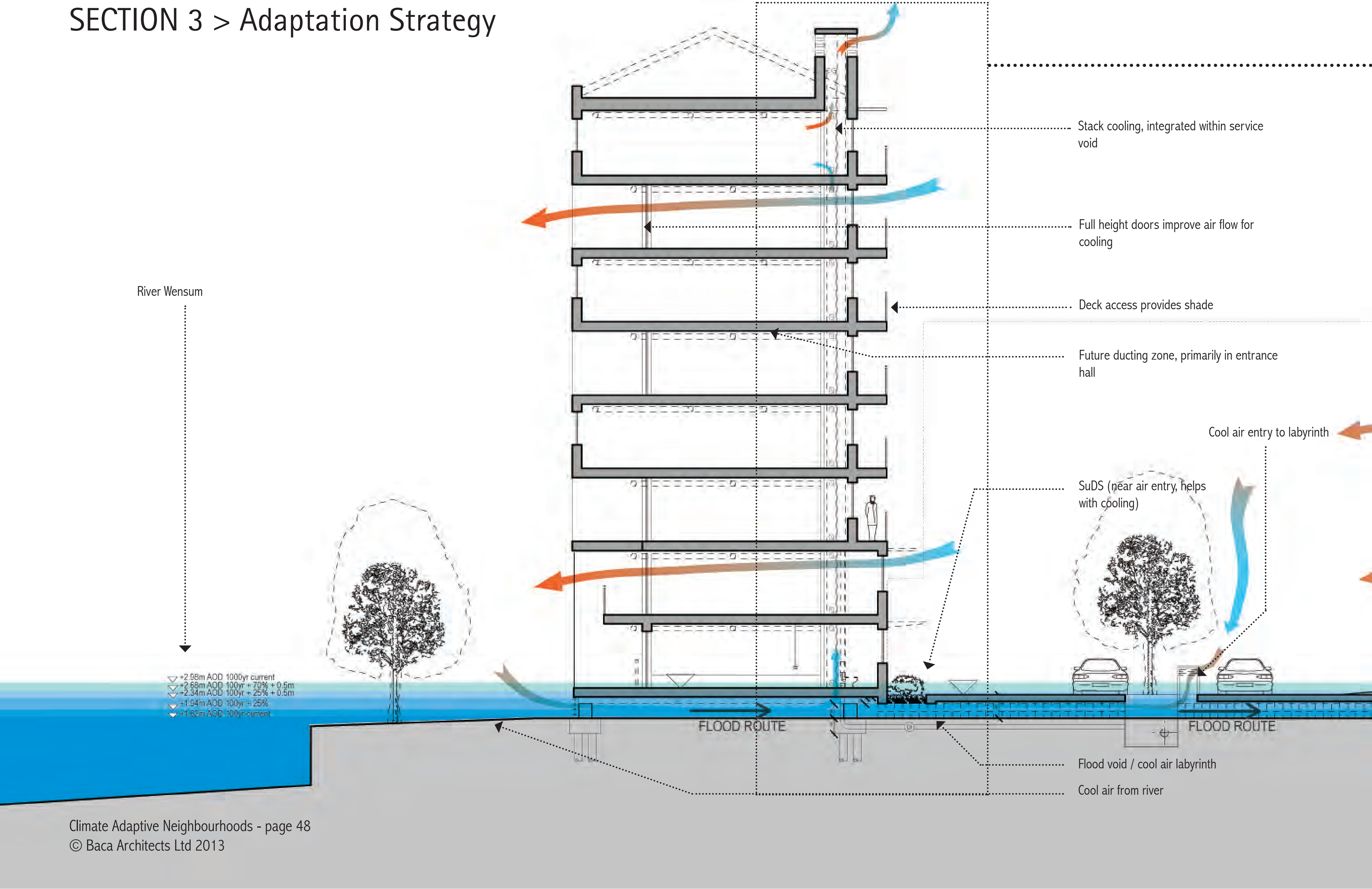
One of the most positive findings of this work is the potential that flood-risk management measures can improve the cooling opportunities within neighbourhoods and buildings and potentially to provide space for rainwater harvesting. The proximity to water presents opportunities for cooling either directly from the water or indirectly from the reduced temperatures surrounding the water. Whilst in this case heat exchange was ruled out on the basis of cost and impact on the water temperature the benefit resulting from raising the building to reduce the floodrisk was that a labyrinth cooling system could become economically viable on a residential project. This may not be possible for other buildings on the site, which are only two storeys and do need to be raised off the ground floor. However, stack cooling (high level ventilation / purge) or earth tubes may be a possible solution. The integrated measures are illustrated in Figures 3.8 and 3.9.

The heavy masonry construction required to provide flood resistance or resilience at the ground floor, provided thermal mass that helped to reduce the overheating risk. The benefit from this would be even more clear-cut for other buildings on the site, which are only two stories and one floor of which would need to be masonry.

The possibility to use the flood void for rainwater harvesting would be appealing and warrant future investigation. This type of system is easier to work with SuDS storage than it would be for river flooding where contamination risk and liability may lead to a separate rainwater system, therefore nullifying the potential benefit of integration.

The integrated CAN solution provided a balance of flood resilience, overheating reduction and water saving.

SECTION 3 > Adaptation Strategy



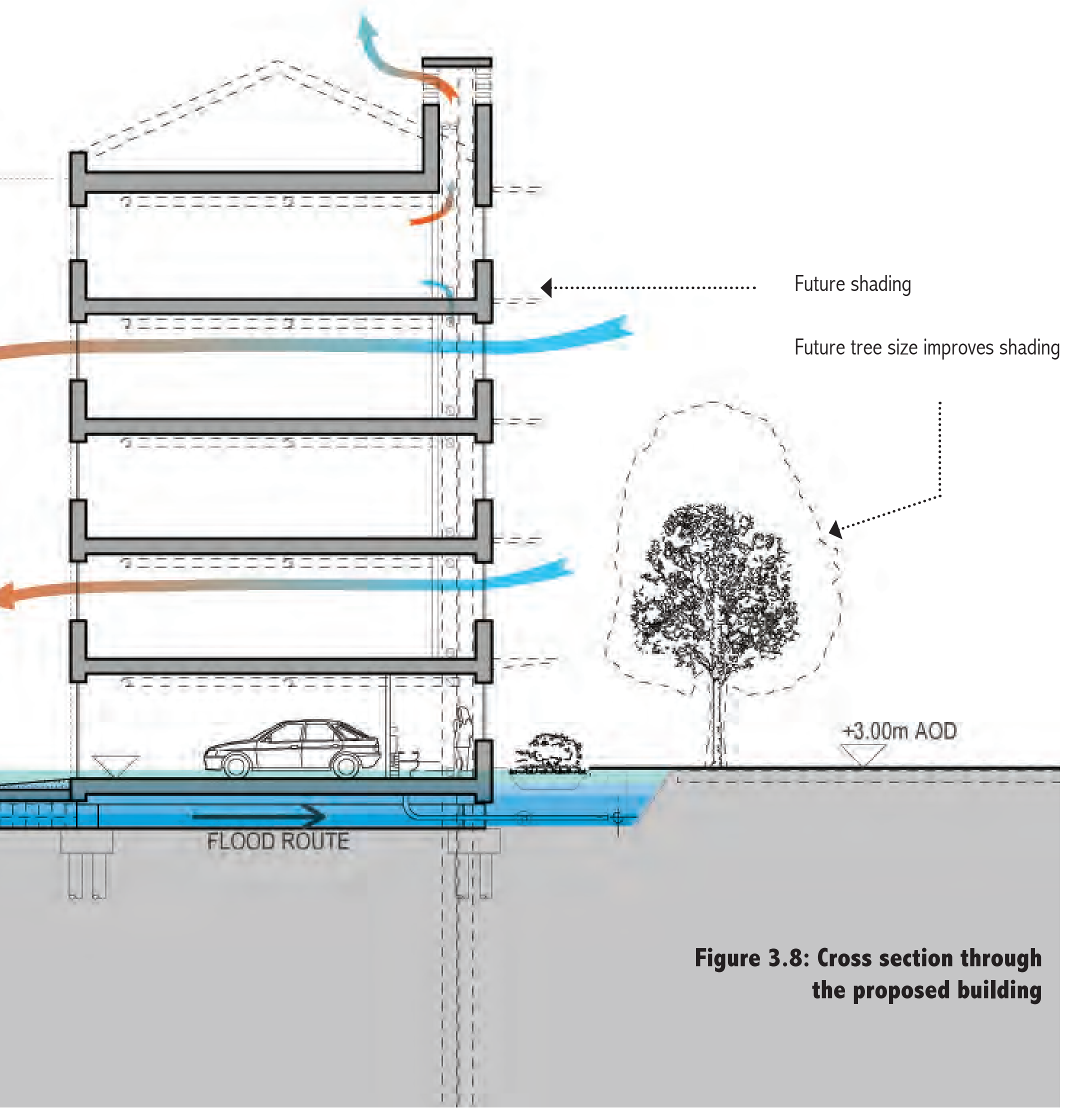


Figure 3.8: Cross section through the proposed building

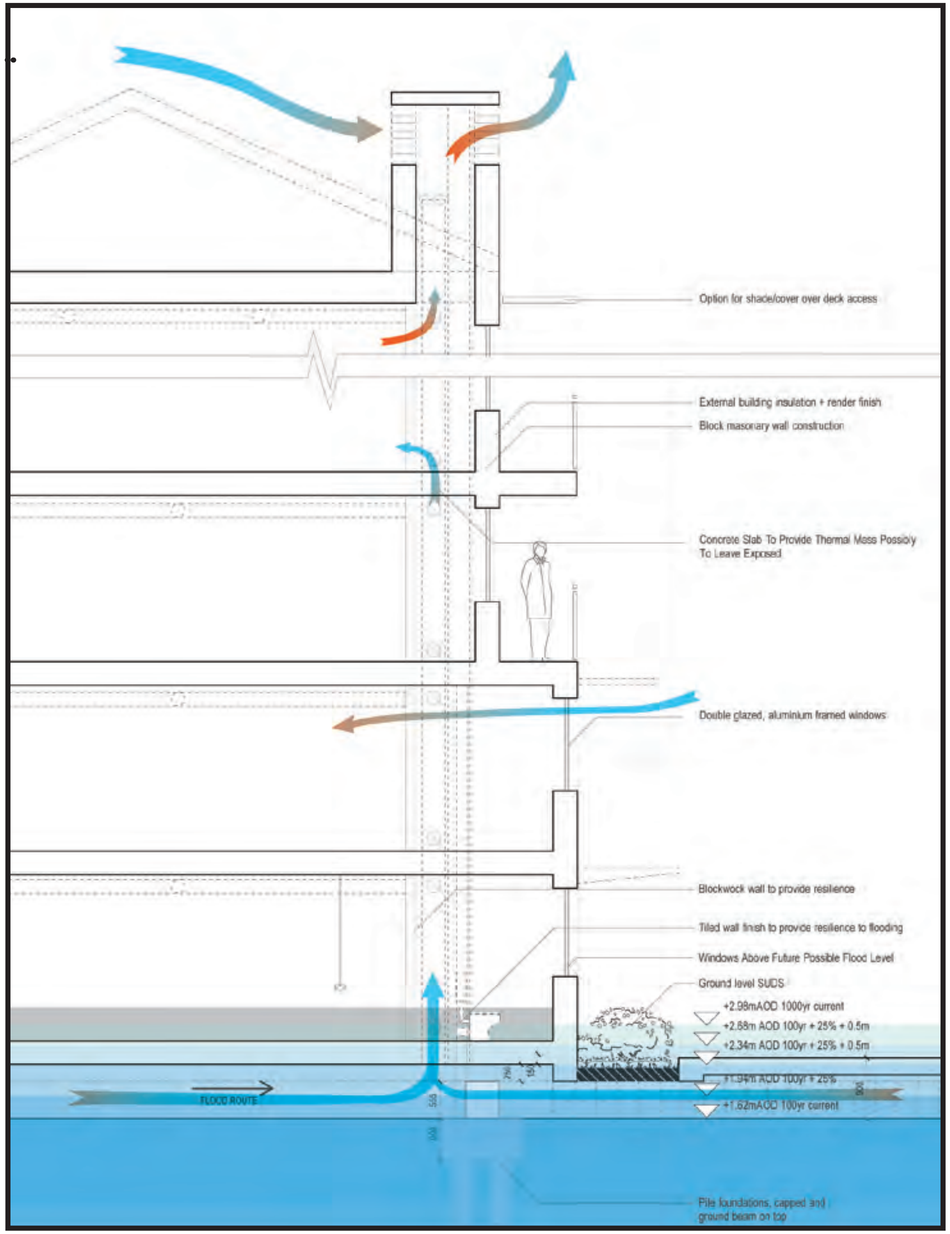


Figure 3.9: Cross section detail

Timeline for adaptation

The adaptation measures have been summarised in table 3.7 with each adaptation strategy (as defined by TSB) incorporating a list of initial measures, and first and second retrofit measures.

A possible timeline for the implementation / retrofitting of adaptation measures is shown in figure 3.11. This has been developed with consideration of several issues:

1. Identification of earliest time when adaptation measure may be required, based on 90th percentile probability.
2. Latest time when adaptation measure is likely to be required (all outside the time scope of the project / lifetime of the building).
3. Regular maintenance periods (typically 20 years).

This timeline provides the triggers for investment but should be revised/refined with revisions to future climate assessments.

However, in preference to relying on climate projections and possible dates a number of thresholds could be identified to act as triggers for retrofitting improvements. The most relevant to this study would be annual outside temperatures, tidal water level changes (influence of sea level rise), mean annual precipitation, peak annual precipitation.

All of these measures in table 3.6 have been recommended to the client. The client has expressed support for including these measures in the detailed scheme design as it develops. However, the client is only likely to carry out the capital works and the long-term management of much of the building stock will be with individual management companies, freeholders and resident social landlords.

Measure	Initial (day 1)	Retrofit 1	Retrofit 2
Comfort	Heavy weight construction (masonry) Deck access shading	Add system for labyrinth Add balconies on the south side of the building, overlooking the street	Install HVAC system
Water – river flooding	Raise building and car-parking height to min 2.7m (note: mostly above this level anyway) In-situ concrete slab to ground floor Resistant lower walls	Install flood resistance measures (door guards etc)	Install flood resilience measures
Water – surface water flooding	Install ground level swales	Extend swales	Replace paving with permeable paving
Water – drought	Install water saving devices Install greywater recycling system	Install rain water harvesting system	None required
Construction	Heavy weight construction (masonry)	Install flood resistance measures (door guards etc)	Install flood resilience measures

Table 3.7, Summary of adaptation measures

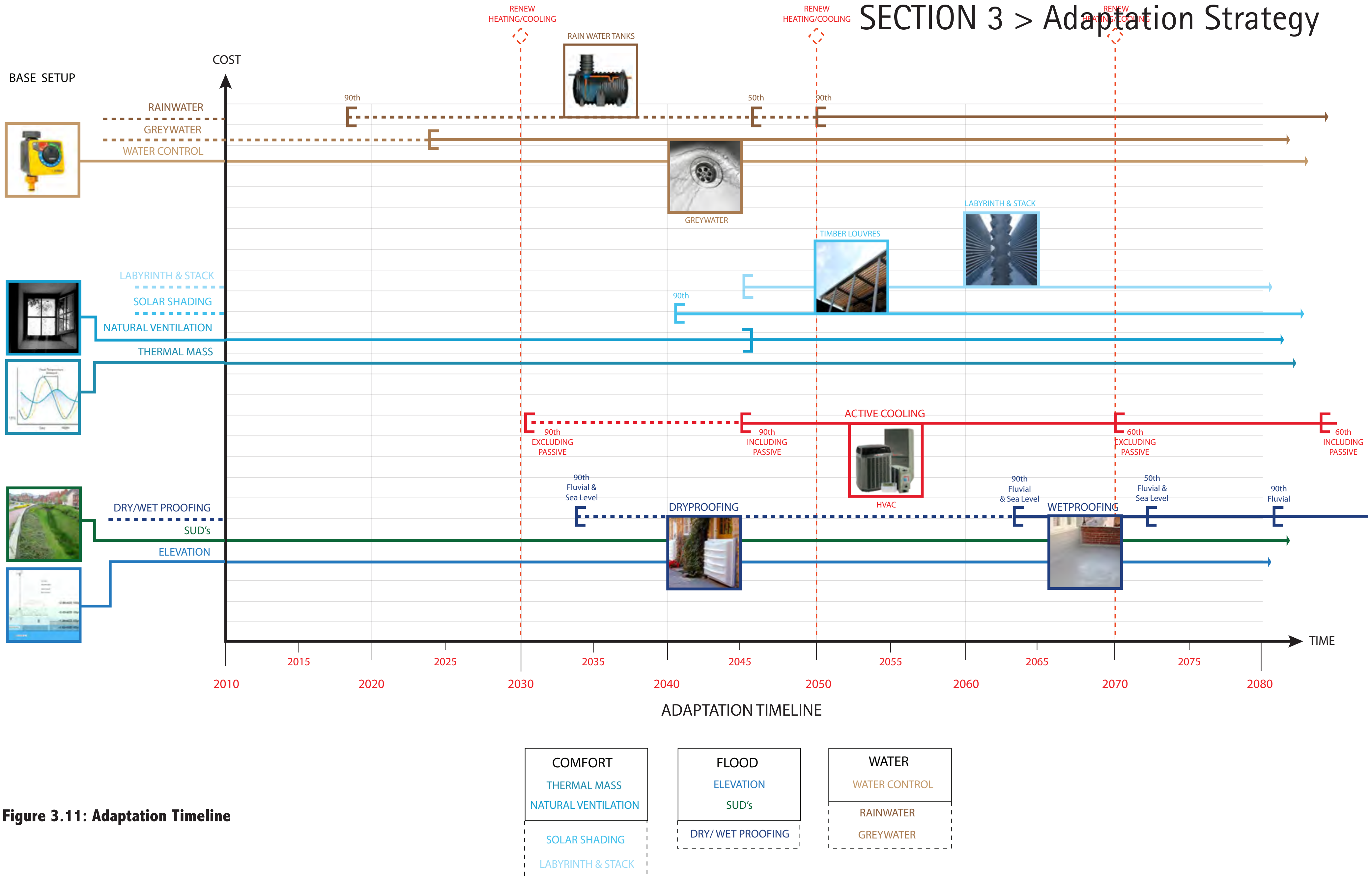


Figure 3.11: Adaptation Timeline

4

SECTION 4 > Learning From Work On This Contract

SECTION 4 > Learning From Work on this contract

A summary of your approach to the adaptation design work

This project examined both structural and design issues for residential buildings, with the aim: 'to determine the best 'adaptation' measures to make this development safe from flooding, those that are compatible with and will reduce other climate risks and the time at which they should be implemented'. The project was divided into four stages, set out below.

1. Stage 1, Climate risk assessment: Climate risk analysis was carried out using computer simulation of future climate and flood-risk, to quantify these risks, using query tools and 2D modelling, where appropriate. This stage included an initial assessment of adaptation options as given by the TSB.
2. Stage 2, Appraisal of adaptation measures Appraisal was carried out in a sequential manner. A long-list of options, was sequentially refined to create a short list of options using Expert review, Multi Criteria Assessment and SWOT analysis, across three sections:
   - Neighbourhood (the layout and orientation of the buildings and the external works),
   - Building (the internal layout and uses of rooms in the building),
   - Detail (the materials and construction details).
3. Stage 3, Detailed design and appraisal of possible solutions: Detailed appraisal, using drawings, computer simulation and expert advice including an external review by an expert steering group. Cost Benefit Analysis of preferred measures over traditional design (to current building regulations) and potential impacts.
4. Stage 4, Reporting and dissemination: The results were presented in this illustrated technical report.

Who was involved in the work and what they brought to the project

The project was developed through regular workshops with various team members. There were approximately two workshops per work stage. A steering group was created to review the project, which included NHBC, the Environment Agency, Building Research Establishment and the Homes and Communities Agency.

The adaptation design work was carried out in a logical and sequential manner, supported by regular sense checking and sensitivity analysis.

The steering group comprised of the following people

National House-Building Council (NHBC)

NHBC (National House-Building Council) is the leading warranty and insurance provider and standards setter for UK house-building for new and newly converted homes.

George Fordyce, was the Head of Engineering Policy for the NHBC until 2013

The Environment Agency (EA)

UK government agency concerned mainly with rivers, flooding, and pollution.

Aaron Dixey, is a Senior Advisor - Development and Flood Risk and based in East Anglia

The Building Research Establishment (BRE)

The Building Research Establishment (BRE) is a former UK government establishment (but now a private organisation) that carries out research, consultancy and testing for the construction and built environment sectors in the United Kingdom.

Dr Stephen Garvin, is Construction Director of BRE Scotland and specialist in flood risk

Homes and Communities Agency (HCA)

The national housing and regeneration delivery agency for England, enabling local authorities and communities to meet the ambition they have for their areas.

Jane Briginshaw is the Head of Design and Sustainability

SECTION 4 > Learning From Work on this contract

Who was involved in the work and what they brought to the project

The project team for the TSB project incorporated several key members of the building project team: client, architect, planning consultant, architect, quantity surveyor and flood risk engineer. Specialist climate advice, soil expertise and flood risk insurance/financing advice was provided by the University of East Anglia and the University of the West of England.

Baca Architects

Baca led the project and all design outputs.

Robert Barker, led the project. Robert developed the project plan, appraisal options, led on the full range of design solutions, project management and the report writing. Robert, was lead author of the LifE project and World Bank for Baca. Robert's work on the defra funded LifE project (RIBA president's research award 2009), which demonstrated how to combine zero carbon design with ecological flood mitigation.

Richard Coutts, carried out the Quality Assurance.

Robert Pattison, worked on planning and initial design options.

Roger Ashman, carried out assessment of material and detail technological options, and worked on the water saving strategy. Roger also carried out technical drawings.

Ed Barsley joined the project in work stage 3. Ed carried out the IES modelling, bringing an added level of detail and accuracy to the work (not originally planned). Ed worked on the development of the cooling strategy.

JBA Consulting

Andrew Collier. led the flood risk assessment work and other engineering input.

Duncan Faulkner and Colin Riggs, carried out the hydrological modelling of potential flood levels. They provided advice on modelling and techniques to simulate the building design options.

Stephen Farrer, provided input into SuDS options and materials.

University of East Anglia

Benedict Binns, was the point of contact for the team.

Dr Colin Harpham, who developed the Weather Generator, undertook the Weather Generator outputs and analysis.

Anthony Footitt, put together the climate risk report and initial response to queries.

Dr Martin Ingham, provided advice on the cooling strategy, review of relevant research and examination of the WG data to develop high level guidance on the cooling demand.

University of West of England

Jessica Lamond led the Multi Criteria Assessment and provided guidance from an Insurance and Finance perspective.

Sweett Group

Simon Harris, led the cost evaluation and cost benefit analysis. In addition Simon provided personal experience of energy systems, which aided constructive discussion on both heating and cooling systems.

Rishi Rai, prepared the detailed cost assessment work and attention to detail.

Lanpro

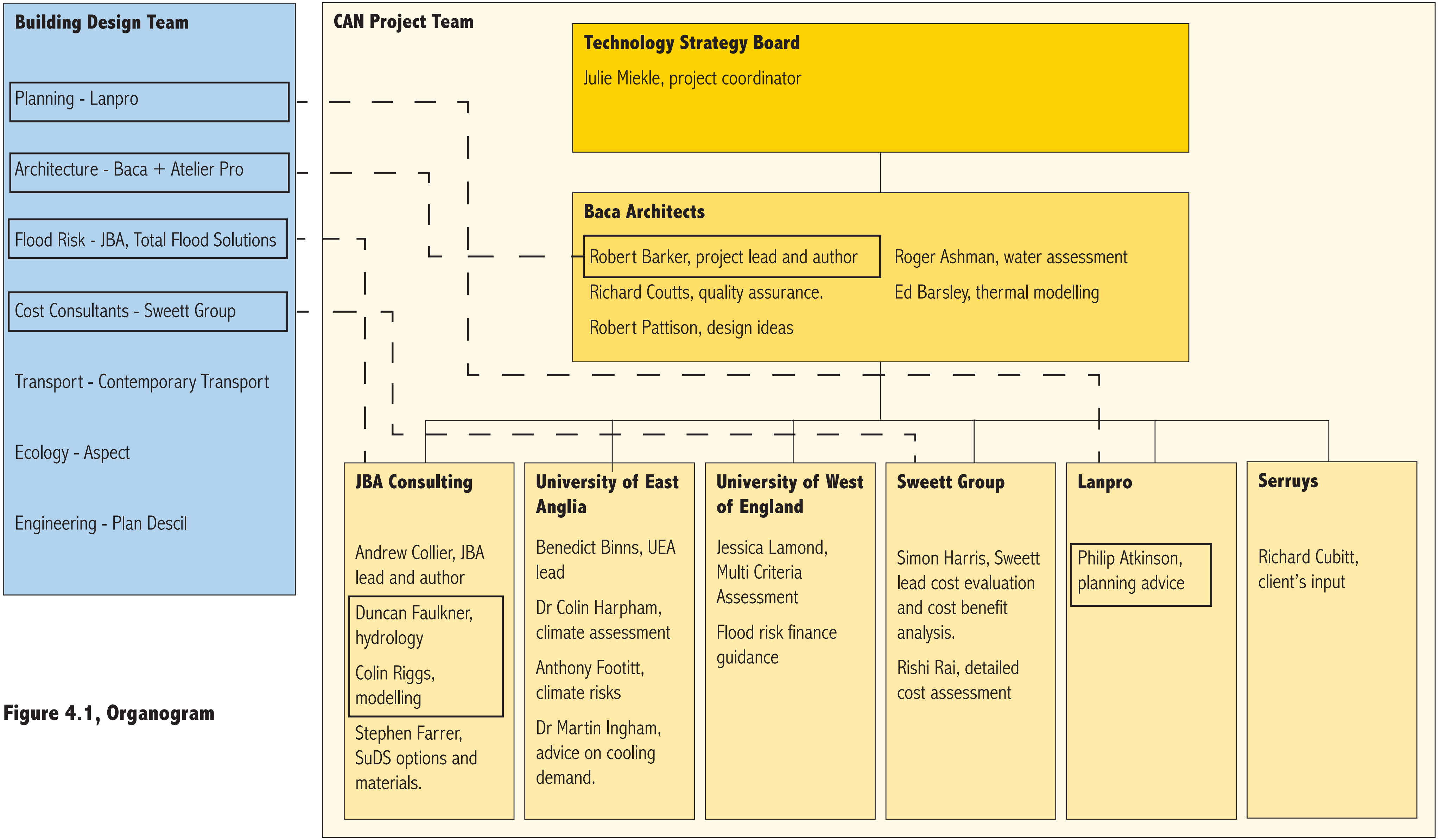
Philip Atkinson, provided input on planning advice on the adaptation measures considered and planning perspective mechanisms to deliver the solution.

Serruys

Richard Cubitt, provided the client's input on design and decision making.

Biopics of key team members are provided in Appendix 4.

An orgonagram of the team in relationship to the Building Design Team is given in figure 4.1.



Building Design Team

Planning - Lanpro

Architecture - Baca + Atelier Pro

Flood Risk - JBA, Total Flood Solutions

Cost Consultants - Sweett Group

Transport - Contemporary Transport

Ecology - Aspect

Engineering - Plan Descil

CAN Project Team

Technology Strategy Board

Julie Miekle, project coordinator

Baca Architects

Robert Barker, project lead and author

Richard Coutts, quality assurance.

Robert Pattison, design ideas

Roger Ashman, water assessment

Ed Barsley, thermal modelling

JBA Consulting

Andrew Collier, JBA lead and author

Duncan Faulkner, hydrology

Colin Riggs, modelling

Stephen Farrer, SuDS options and materials.

University of East Anglia

Benedict Binns, UEA lead

Dr Colin Harpham, climate assessment

Anthony Footitt, climate risks

Dr Martin Ingham, advice on cooling demand.

University of West of England

Jessica Lamond, Multi Criteria Assessment

Flood risk finance guidance

Sweett Group

Simon Harris, Sweett lead cost evaluation and cost benefit analysis.

Rishi Rai, detailed cost assessment

Lanpro

Philip Atkinson, planning advice

Serruys

Richard Cubitt, client's input

Figure 4.1, Organogram

SECTION 4 > Learning From Work on this contract

The initial project plan and how this changed through the course of the project.

The initial project plan was carried out with only minor variation during the course of the project. The plan proved to be well structured and considered and very beneficial to the development of the adaptation strategy. The main change to the plan was the addition of IES modelling into Stage 3. The IES modelling was required because their was a limited amount of accuarate information on passive cooling measures for new buildings and therefore we needed to carry out modelling to test various options accurately and to complete this section of the work.

Whilst there have been many studies into existing housing stock there is not the same level of information for buildings built to modern regulations. This may be in part because the regulations change and therefore information becomes obsolete (although it was also difficult to find information on old building regulation standards). The team were directed to various studies but none of the information was appropriate. This clearly indicated to the team the need for some simple guidance for new buildings and perhap rules of thumb that could apply to all housebuilders.

List the resources and tools you used and review their strengths and limitations

The key resources and tools used were:

- Weather Generator Project
- Prometheus
- ISIS-TuFlows modelling
- Geographic Information System (GIS)
- CAD: Vectorworks and Cinema 4D modelling
- IES modelling
- Online information
- Magazines and journals
- Suppliers information
- Approved documents (interpretation of Building Regulations)
- National Guidance, such as EA, Defra and CLG publications (which included Rain Water Harvesting guidance, Flood Risk guidance...)
- Planning Policy
- Past research papers

The strengths and limitations are discussed below

Weather Generator Project

- Provides industry standard predictions for future climate
- Model can be run on site centred locations
- Large amounts of data allow multiple assessments of criteria
- Project partner advised that it takes a long time to make assessments and therefore is expensive to carry out assessment work
- Is not easily exportable to industry standard software used by construction professionals, such as IES

Prometheus

- Provides industry standard predictions for future climate
- Readily and freely (subject to terms of use) available data for many key cities - it is based on previous assessment work carried out using the Weather Generator Project. Therefore it is quickly usable.
- The files are in the Energy Plus format (.epw) and as a comma separated file making it compatible with industry standard software, such as IES, and excel. This information was used instead of the Weather Generator Data for the thermal modelling because it was readily available.
- The data is available from previous climate model runs and therefore may not be specific to the exact site location being reviewed. However, for the purposes of climate studies and given the variability of prediction there is a good likelihood it may be close enough.
- Use of prometheus data for Norwich demonstrated the results to be very similar to the WG data.

ISIS-TuFlows modelling (also see Appendix 4 for a more detailed assessment of hydraulic modelling)

- Provides a good level of assessment of flood levels, depths and hazard, particularly to a wider area and master plans.
- Is not able to carry out detailed assessment of flows through buildings and building blocks.
- Integrated with and outputs to GIS software for assessment and visualisation
- Not compatible with industry standard CAD

Quantum GIS

- Shareware GIS software
- Compatible with most operating systems including PC, Apple Macintosh and Linux making it more transferable
- Good for querries and assessment of large GIS files and volumes of data
- Limited drawing capability and limited compatability with CAD. Relies on GIS ready CAD such as Vectorworks Landmark (as used for this project)
- Limited dynamic assessment capability - such as volumetric studies
- Not as powerful as industry standard GIS software such as ArcView or MapInfo
- Not always stable

CAD (Cinema 4D modelling)

- Used to carry out block modelling and simple sunlight studies to determine the amount of sunlight on parts of the site
- Not designed for thermal modelling

IES modelling

- Provides the possibility to explore a large number of variables
- Large number of assessment methods and data outputs
- Not always robust, can be sensitive to input data and stop working unexpectedly if data is input in wrong order
- Does not easily import architectural computer models from other software

Online information

- Wide range of material available
- Access to papers, suppliers info, statutory guidance etc
- Quick to obtain information
- Not likely to be comprehensive as it relies on data input onto the web
- Searches controlled by software such as Google that work with algorithms that prioritise popular information and not always the most relevant to the query
- Sometimes questionable authenticity

Magazines and journals

- Similarly to past researh papers this can provide access to many different materials
- Relies upon access to the journals and awareness of the potential source of information. In this project case that was based on individual team members
- Raises awareness of past projects and their outputs
- Typically less detailed than research or publication papers

Suppliers information

- Often detailed and well illustrated material
- Tends to be provided by more industry standard products rather than by emerging products, potentially limiting the available technologies
- Often tried and tested technologies and information
- Questionable reliability

Approved documents (interpretation of Building Regulations) and other National Guidance, Planning Policy etc.

- A lot of research work is published as guidance
- Often well researched and typically clearly presented
- Limited availability of new or emerging ideas and technologies
- Fundamental to current acceptability of proposals and therefore to inital building project proposal

Past research papers

- Potential for access to copious research
- Limited information available specific to the research work carried out (as advised by the project partners)
- More readily accessible to University partners as commercial access must be paid for

SECTION 4 > Learning From Work on this contract

Describe what worked well and what worked badly in your approach, and the methodology you recommend others to use.

One of the key factors that lead to the success of this project was the multi disciplinary background of the team that was assembled to conduct the research. The project engaged with specialists from both industry and academia to deliver a piece of research that is both rigorous and commercially applicable. This approach should be applied more widely to other projects to bridge the gap between theory and practice. Employing a methodology that analysed strategies at the neighbourhood, building and detail level enabled a rigorous understanding of the impacts throughout the scales and therefore avoided concerns regarding implementation (such as being prevented by building regulations) that can effect / be a criticism of research work.

Conducting a cost analysis of the various strategies provided an effective mechanism to evaluate the overall performance of each strategy.

Applying this to other projects would help build up in depth database of various systems, materials and their next present values.

The methodology adopted within this research project provides a strategic framework for understanding the impacts strategies and materials have on a wide range of scales.

Decision-making processes by the client on implementing recommendations and what were the best ways to influence them?

The client's main prerogatives have been

1. Planning consent, which has still not been determined
2. Capital cost, to be kept to a minimum (in particular due to the extensive upfront costs)
3. Saleability, reducing flood-risk to ensure that the properties sell is particularly important

As the scheme has been extensively consulted upon and concerns raised by Environment Agency, in particular, addressed it is hoped that the scheme will be granted planning and the results of the CAN project are unlikely to effect this.

The concern regarding capital cost has been the main priority. Having met the local authority and EA requirements the client is not keen to see any increase in cost as this would have to be deducted from the profit (which is part of the fixed economic agreement with the council) or renegotiated with the council to reduce the contributions and therefore putting planning consent at risk. The client could see the merits in omitting the first floor raised amenity deck, which provided no demonstrable benefit to the adaptation strategy.

The saleability has mostly informed the decision-making for the client with regard to questions of the location and aspect of units, build quality, perceived luxury of appliances (promptly ruling out dry waste toilets) and service charges and point of sale, such as energy and heating/cooling systems and SuDS. The issue of maintenance for a future Resident Social Landlords, which will inevitably be a significant purchaser, was raised. This brought the question of durability and adaptability into the decision framework.

The best way to influence the client in their decision-making has been to identify their concerns as part of the project decision-making process, such as the MCA and Cost Analysis. This has enabled decisions to be made on the basis of cost and saleability as well as lifetime issues.

List the resources you recommend others to use

- Prometheus climate data. This is because it is readily and cost effectively available. It is also well integrated with modelling software.
- Integrated Environmental Solutions (IES) dynamic thermal analysis. This is a powerful tool with multiple variables to allow different testing. A lof of inforamtion has been built into the softwarer to allow testing of numerous cooling approaches and simulation of cooling effects. It does require training and moredetailed knowleged of the software. It is also possible to output many different results and graphs (although the relevance of some of these may be low for a given project). The integration with architectural and engineering CAD packages appears to be limited and it required a dedicated model to be built within IES. The numerous variables can make the package unstable.
- Environment Agency Data. This is regularly updated and the information available within their standard flood products gives a good indication of flood extents and regularity of flooding, and to some extent of the likely flood depths, when combined with topographical mapping.
- Geographic Information System (GIS). GIS is a powerful tool that allows detailed information to be reviewed using specific enquiries such as for flood maps. There is also a lot of free national data available that can be useful for initial assessments and masterplanning.
- Online information (such as CIRIA, CLG, Defra, RIBA Sustainability Hub etc). Online information from more reliable sources, such as CIRIA, CLG, Defra or RIBA has typically been well researched and backed by other research.
- National Guidance, such as EA, Defra and CLG publications (which included Rain Water Harvesting guidance, Flood Risk guidance...). Often this information is available online and the points above are relevant. These organisations have produced a lot of useful guidance that can go someway to informaing decisions, particularly with regard to flood risk but often with some consideration of climate change.

How the Climate Change Adaptation (CCA) study team and Building Design Team worked together

The building design has been at RIBA stage C throughout the duration of the CCA study. The building design was submitted for outline planning approval in 2011, however, due to the complexity of the scheme it was not determined until 2013. In reality this meant that the Building Design Team were only working on providing limited supplementary planning information during the CCA study. It also meant that the Building Design Team was reduced to a few key members during this period. This included Serruys Property, Lanpro, Baca Architects and light and noise consultants in particular. Therefore the CCA team developed work often independently of the Building Design Team but with the benefit that the key members of the Building Design Team were also part of the CCA team.

Instead of the CCA study work being incorporated into the client decision-making for the outline planning application the results will effect the client decision-making for the next stage of the project which will be RIBA stage D, and the detailed planning application. The results should provide an excellent springboard for the detailed planning design and further work, potentially accelerating the decision making and confidence in the detailed application of the results.

Additional commentary

From a developers perspective it is useful to examine the benefits in terms of property market value from adopting alternative options at initial build stage and for owners to consider the potential of later retrofit of options to enhance the market value of their property.

5

SECTION 5 > Extending Adaptation To Other Buildings

SECTION 5 > Extending Adaptation To Other Buildings

How this strategy, recommendations and analyses might be applied to other buildings and building projects.

The adaptation strategies within the Climate Adaptive Neighbourhood project could be applied to a number of other building projects particularly residential projects or those in area of potential flood risk. This means that the potential audience for this work is significant.

This strategy could be applied to other projects through a similar process of analysis and assessment or through more standardised toolkits, which could be developed regionally based on localised climate risks. The flood-risk aspects which are often more site specific could be developed based on potential flood levels and characteristics of rivers. In the LifE project, guidance was based upon location within river catchments, this again could be useful.

Many climate adaptation measures may be retrofitted, therefore, a recommendation to prioritise design and structural interventions could be appropriate.

Limitations of applying this strategy to other buildings

This project took a holistic view to adaptation and resilience, amalgamating principles from the neighbourhood to the building scale. When individual strategies are applied in isolation it may limited their effectiveness.

There are three particular limitations of applying the adaptation strategy to other buildings:

- Site specific
- Building specific
- Capacity for adaptation within existing buildings

Site specific issues

Whilst all projects are site specific, flood risk issues are particularly site specific. This may be in part due to the accuracy of data available. Flood levels are often gauged very close to a site (three on this site alone) and water levels are accurate to cm. Climate data from the WG on the other hand is measured over 5km squares. However, flood depths, velocities and durations are particularly site specific, varying across individual sites and more broadly across wider areas.

However the principles outlined would generally apply to other sites with similar flood risk conditions, such as in low flowing middle catchment locations (particularly in the South and East of England where most development is focussed).

Building specific issues

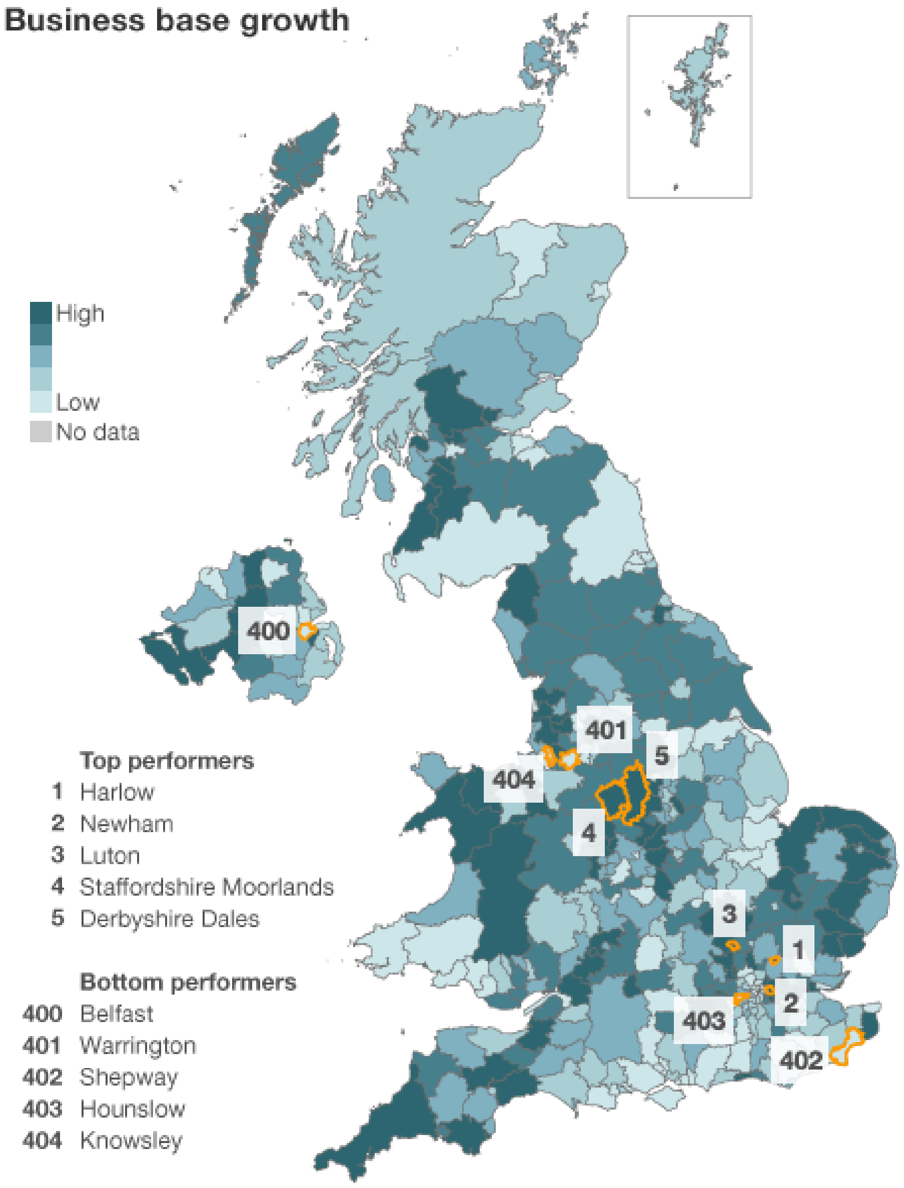
Non-residential buildings often have specific environmental requirements, such as minimum and maximum working temperatures or ventilation requirements. Equally occupational habits vary considerably by building type and control over internal temperatures may be more difficult. Buildings with deeper floor plans may struggle to achieve sufficient ventilation rates through passive means alone. Commercial buildings may also have higher internal temperature gains and less option for openable facades. There can also be security issues when applying strategies of nighttime purge ventilation, which are less difficult in residential buildings.

Capacity for adaptation within existing buildings

The adaptation strategy for this project enabled the opportunity to design in measures that allowed the retrofit of environmental improvements in the future. This meant that decisions about the structure and the fabric of the building were made to support the sustainability of it. This decision making process is unlikely to have occurred in most existing buildings and therefore the adaptation measures may be different, particularly structural decisions such as flood resistance (dry proofing) and possibly forms of solar shading, and ground conditions, such as foundation choices and SuDS measures.

Buildings across the UK that might be suitable for similar recommendations

There are a number of findings from this research project that may be applicable to other buildings in the UK. Whilst this building project is for a new development the consideration of retrofitting improvements will apply to many existing buildings. There are two main outputs from this research, combating flooding and overheating. These are discussed below:



Business base growth (Source: BBC, 2012)

Flooding

Throughout the UK, more than 2.4 million homes are already at risk from flooding. The Environment Agency has predicted that if the national approach to flood risk management is not altered, there could be an additional 350,000 properties classified as 'at risk' by 2035 (EA, 2009). Previous government targets aimed to deliver 60% of new housing on brownfield land, much of which is in higher flood risk areas (LifE project 2009).

After the 2007 floods, which saw extensive and previously unpredicted surface water flooding, the number of homes at risk from flooding was revised to 5.2 million, which accounts for 1 in 6 of all homes in the UK (source: Defra).

Climate change is likely to result in these numbers rising further, through more extensive and frequent flooding.

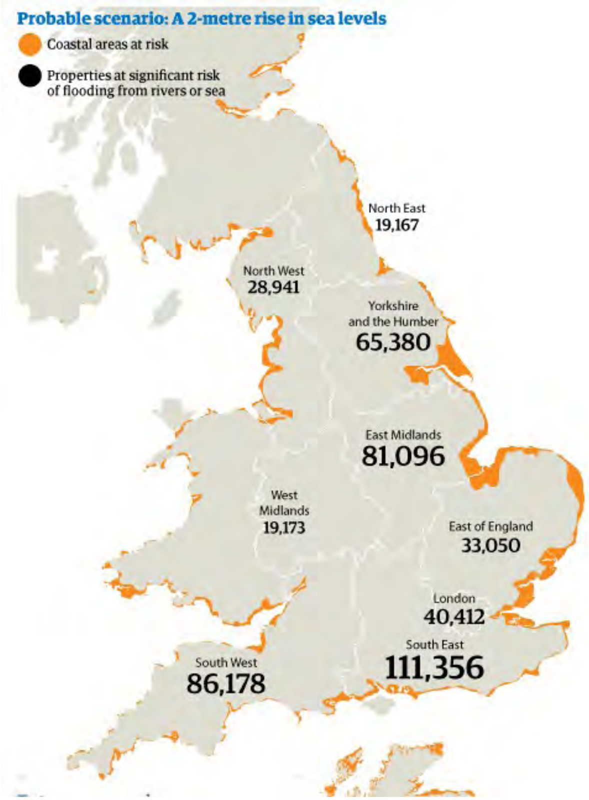
Some argue to locate new development out of floodplains. However, this is failing to address several key issues:

1. the role buildings in the wider rainwater catchment plan,
2. surface water flooding,
3. existing properties (such as much of London),
4. and redevelopment and clean up of Brownfield land.

Identifying what can be done in an incremental fashion to tackle flood risk could apply to many building in the UK, particularly those in coastal or tidal locations where increases in sea level can be monitored and therefore flood risk/levels more accurately revised. One in 25 homes in England and Wales is at risk of coastal flooding, and this is expected to increase with a changing climate and rising sea levels (source: EA 2013).

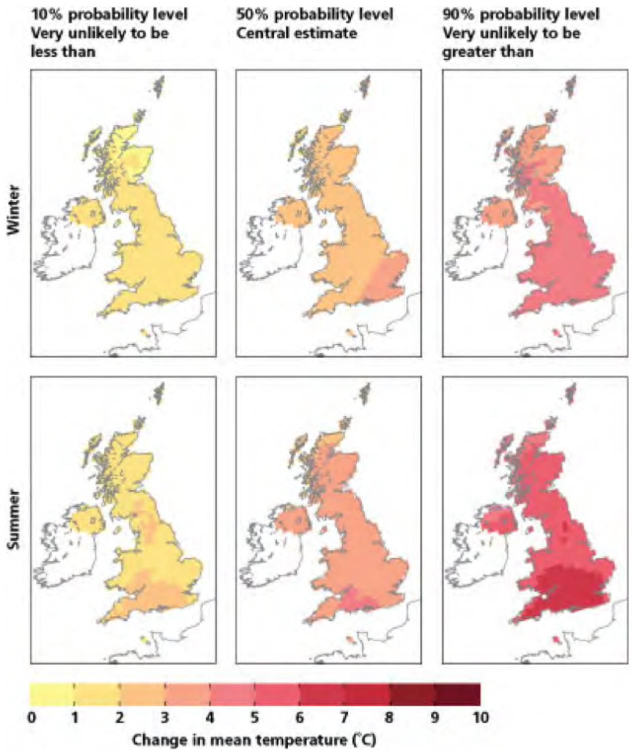
Areas at Risk
(Source: EA, 2010)

Many of the recommendations of this study apply to taller buildings; however, the elements that focussed on avoiding flood risk from elevation and building in resilience, particularly at the detail level apply. In particular development in the Thames Gateway, low lying areas in Bristol, Lincolnshire and other areas may benefit from considering the approaches outlined.



2m Sea Level Rise
(Source: EA, 2010)

Appendix 5 > Extending Adaptation To Other Buildings



**Business base growth
(Source: UKCIP, 2009)**

Overheating

The results from UEA analysis on existing building stock showed the increase in cooling load under future climate conditions to be minimal. New build properties however, built to contemporary construction standards were shown to be at much higher risk of overheating.

'The National Housing and Planning Advice Unit (a non-departmental public body) has said that the recession has increased the requirement for house building (e.g. to make up for the fall off in construction rates). It has advised that up to 290,500 additional homes may be needed in each year to 2031, although this requirement is not uniform across the regions.' (source: www.parliament.uk). It is therefore crucial that relevant adaptation strategies for resilience to future climate conditions outlined in this report are embedded within all future housing proposals.

Overlaps

One of the key findings within this research is the potential beneficial relationship between overheating and flooding resilience strategies. Many of the sites currently at risk of flooding throughout the UK are also predicted to experience significant increases in average and peak temperatures. Interspersing blue and green space throughout development can help make space for water as well as provide natural cooling.

Identification of water saving devices that do not take up space for water or become a potential risk during a flood is also crucial. Zero carbon development over 3 storeys in height, requires the use of all roof space for solar PVs, unless large-scale wind was available (LifE project, 2009). This in turn informed the preference for ground level SuDS over green or brown roofs (which are far less successful when covered in PVs). This reinforces the applicability of integrated design to all buildings.

There are approximately 100,000 new homes constructed each year in the UK (and calls to increase this to 300,000 by the Future Homes Commission). Every single home would benefit from the incremental approach to providing cooling outlined in this study. Furthermore flood resilience guidance to supply electrics from the 1st floor to the ground could be made mandatory as it should not increase cost but could save money if a flood occurred.

Other than residential buildings

For non-residential buildings where cooling demand is higher the use of labyrinth and stack cooling systems is particularly applicable.

Resources, tools and materials you developed through this contract for providing future adaptation services

There are a number of resources developed through this contract that would be beneficial for future adaption services. These are:

- Timeline for adaptation measures
- The multi-criteria assessment approach to options
- Cost benefit Tables
- Incremental cooling strategy developed
- Matrix of strategies at various scales

Each or any of these resources could be used as the basis for the development of more generic tools that could be used regionally and possibly nationally.

The cost benefit tables identified a mechanism for measuring benefit to a range of issues, flooding (river and surface water), overheating, and drought, (and incorporating depreciation) which would be applicable to other adaptation projects.

The matrix of strategies at different design scales could be expanded to provide a look up table for projects at different stages but under themes or topics. This could be used as reference for council planning and building control departments, dealing with outline applications, detailed applications and building regulation applications. This could also be applied to the existing TSB tables to simplify the decision making process.

Further needs you have in order to provide adaptation services

There were several elements identified in the project that would have been helpful in developing the adaptation solution and would be helpful for future adaptation services.

We would like to see development of simple climate assessment tools. Considering the wide availability of the UKCP09 data, we were surprised that it was so difficult to identify the impact of climate change on a new residential building designed to building regulations. There seems to be a presumption in the climate research field that buildings are either traditional stock or that new building are to be designed to passiv haus standard. As the bulk of the construction industry is unlikely to move to passiv haus in the immediate future this demonstrates a lack of opportunity to influence the mass house builders. A simple assessment tool such as using degree days and base temperatures or linked to building regulations standards or SAP would be beneficial.

Within our own organisation we need to expand our in house assessment capabilities, with regard to climate assessment and simulation modelling. The transferability of data to a range of formats would help with integration into different computer modelling packages and potentially BIM software.

In the longer term, there is a need for industry standard CAD software and BIM to be able to utilise climate assessment and thermal modelling inputs as part of the standard service, to enable more accurate and adaptable design to be carried out from simple feasibility studies through to detailed design.

There is a lack of test information of flood resilient construction. This tends to be for existing building stock or for buildings abroad. Better testing of materials being specified today needs to be considered to make assessments of their effectiveness in the future.

How can the findings of the CAN project be delivered using existing legislation?

Local authorities have the power under the Planning and Compulsory Purchase Act 2004 (as amended by the Planning Act 2008) to make Local Development Orders to simplify the normal planning process and to remove controls over specific forms of development. To-date Local Development Orders have been used relatively infrequently. An opportunity currently exists in this instance to create a Local Development Order to deliver the CAN Project findings. This is explained in more detail in Appendix 5.

It is suggested that a Local Development Order is the vehicle to deliver the CAN Project findings within the Deal Ground (and May Gurney) site(s).

The Local Development Order for the Deal Ground

A draft LDO could be area wide (and could be City-wide) and would allow for the following CAN Project tool kit works to be undertaken without the need for specific planning permission:

- Ventilation and cooling systems where external works are required;
- Rainwater harvestings and grey water recycling systems;
- Fixing solar shading to the external surfaces of buildings;
- Erection of solar chimneys at sufficient height to create temperature differences;
- Changes to final site levels along escape routes;
- Fixing of air conditioning plant and machinery to external surfaces of buildings; and
- Other ventilation and cooling systems.

The draft LDO could comprise the Order and the Statement of Reasons. The Statement of Reasons would need to contain the following documents:

- Description of development to be permitted (the CAN Project tool kit);
- Justification for the Order (the CAN Project findings and simplifying the adaptability of buildings to climate change);
- Statement of policies supporting the proposals (including emerging Policy R10, the National Planning Policy Framework and the CAN Project findings as material considerations);
- Timescale for the Order (i.e. the period the Order will run having regard to the CAN Project timeline and further options for renewal/extension should climate change not occur as predicted);
- Monitoring i.e. notification procedures for developer/householders;
- Statement outlining the legal advice received;
- Description of risk assessment i.e. how has residential amenity been considered in the implementation of the CAN Project measures; and
- Statement of reasons for conditions applied and any legal agreement.

Once prepared the draft Order would go out to public consultation before being adopted by Norwich City (and South Norfolk Council in the case of the May Gurney site) before being submitted to the Secretary of State for final approval.

Rolling out the CAN project findings throughout the UK

There is potentially no limit to the size of the area covered by the Local Development Order proposed in this instance for the Deal Ground. The only restriction on the size of the area covered being that Local Development Orders cannot be used to deliver forms of development that would otherwise require an Environmental Impact Assessment.

As such it is suggested that a Local Development Order could be devised to deliver the CAN Project tool kit findings (subject to design coding) across large areas of the UK considered likely to be affected by climate change over the timeline.

There could of course be exceptions to implementation built into the draft Order i.e. where formal Conservation Areas, Listed Buildings, high value landscape interests exist, etc which could be controlled by the conditions and/or legal agreement attached to the Order and design coding. This approach would ensure that the CAN Project tool kit could be rolled out through a simplified planning system as acceptable forms of development.

Appendix 5 > Extending Adaptation To Other Buildings

6

References

Association of British Insurers (2008a) Revised statement of principles on the provision of flood insurance, London: ABI

Association of British Insurers (2008b) Climate Adaptation. Guidance on Insurance Issues for New Developments, London: ABI

Association of British Insurers (2008a) Revised statement of principles on the provision of flood insurance, London:ABI

Association of British Insurers (2008b) Climate Adaptation. Guidance on Insurance Issues for New Developments, London:ABIBin, O., Crawford, T. W., Kruse, J. B. & Landry, C. E. 2008. Viewscapes and flood hazard: coastal housing market response to amenities and risk. Land Economics, 84, 434-448.

Baca Architects and BRE (2009) Long-term Initiatives for Flood Risk Environments

Baca Architects and BRE (2009) LifE Handbook

Communities and Local Government (2006) Planning Policy Statement PPS25: Development and Flood Risk

Communities and Local Government (2007) Improving the flood performance of new buildings

Communities and Local Government (2012) The National Planning Policy Framework

http://www.bbc.co.uk/news/magazine-12606943

http://www.hse.gov.uk/temperature/thermal/factors.htm

http://www.natural-building.co.uk/comfort.html

Kenney, S., Pottinger, G., Plimmer, F. & Yasmin, P. (2006) Flood risk and property, impacts on commercial and residential stakeholder's strategies. College of Estate Management

Lamond, J., Proverbs, D. and Hammond, F. (2009) Accessibility of flood risk insurance in the UK - confusion, competition and complacency. Journal of Risk Research, 12(5), pp. 825-840.

Lamond, J., Proverbs, D. and Hammond, F. (2010) The impact of flooding on the price of residential property: a transactional analysis for the UK. Housing Studies, 25(3), pp.335-356.

UEA (2012) TSB Design for Future Climate: Adapting Buildings, Draft Stage 1 Report

Wikipedia

http://tlc.howstuffworks.com/

Improving the flood resistance of your home, CIRIA_Advice_sheet_4

Gulf Coast Community Design Studio, http://gccds.org/

http://www.metoffice.gov.uk/climate/uk/ee/print.html

Approved Document G (Sanitation, Hot Water Safety and Water Efficiency)

WATER CALCUALTOR

Approved Document H (Drainage and waste disposal)

Approved Document L (Conservation of fuel and power)

Environment Agency (2010) Harvesting rainwater for domestic uses: an information guide

Environment Agency (2011) Greywater for domestic users: an information guide

DEFRA (2008) Future Water: The Government's water strategy for England

Lamond, J. 2011. Financial implications of flooding and the risk of flooding on households. In: LAMOND, J. E., PROVERBS, D. G., BOOTH, C. A. & HAMMOND, F. N. (eds.) Flood hazards, impacts and responses for the built environment. New York: Taylor CRC press.

Lamond, J., Proverbs, D. & Hammond, F. 2009 Flooding and Property Values. In: BROWN, S. (ed.) Findings in Built and Rural Environments (FiBRE). LONDON: Royal Institution of Chartered Surveyors.

Leishman, C., Aspinall, P., Munro, M. & Warren, F. J. 2004. Preferences, quality and choice in new-build housing. York: Joseph Rowntree Foundation.

Sirmans, G. S., Macpherson, D. A. & Zietz, E. N. 2005. The composition of hedonic pricing models. Journal of Real Estate Literature, 13, 3-43.

RIBA, Barker (2010) - Sustainability Hub: Water - Water Conservation, Rainwater Catchment, Building Placement, Flood Resilience, Flood Resistance, SUDS

RIBA, Baker (2010) - Sustainability Hub Baker: Ventilation - Night ventilation of thermal mass, Stack Ventilation

http://www.susdrain.org

Product research - not listed in full references