Executive Summary

1. Building profile

The Central Library, National Media Museum (NMM) and Pictureville Cinema occupy 3 buildings erected in the late 60s in the centre of Bradford.

An extensive remodelling of the facade of the museum took place in the 90’s alongside the transformation of the existing theatre to house Pictureville Cinema.

The museum is currently housed in the northern end of Prince's House, a lower standard 60s block under multiple long term leases. The proposal is to refurbish the library building, construct a new purpose built gallery space and link these two elements with the rest of the museum with a generous high glazed street.

Current uses include galleries, archives, cinema and IMAX screen, education rooms, cafe, reception, shop and officers for a team of 80 staff.

These buildings were subject of The Lightwave Strategic Masterplan that aimed to provide a centre of excellence for both traditional literacy and media literacy in the heart of Bradford.

In February 2011 an initial options appraisal for the Lightwave Project was completed by Bauman Lyons Architects. The brief was to review the use of space in Bradford’s cultural quarter and identify partnership opportunities between the National Media Museum, Bradford City Council (Bradford Library), the University of Bradford and other partners.

Other than being the first step in delivering the strategic Lightwave vision the relocation of the museums offices is considered necessary as:

- The current energy use in the existing spaces is extremely high and is not only costing a significant amount of money per year but is at odds with the museums’ aspiration to drive down its carbon footprint. The current energy costs are £43,000 per year. As a bench mark conditioned space of average efficiency for this volume of space should cost in the region of £18,000. The mechanical and electrical installations and fabric of the building are therefore in need of substantial improvement even to bring them up to an average standard let alone to current regulations.
The existing offices are leased in Prince’s House. The lease is due for review in 2014 and renewal will entail a commitment for a minimum of 10 years.

The existing offices are in a poor state of repair and pose health and safety issues that need to be urgently addressed. If the museum is to stay in these offices considerable capital investment would need to be made to bring the spaces up to standard. This upgrade may then trigger an upward rent review.

The existing offices are located in various separate spaces in the building resulting in poor (53%) net to gross usage and poor interaction between the teams. The net space is 744sqm and gross 1403sqm.

National Museum of Science and Industry (NMSI) TARGETS - An EPC target of C was set for National Media Museum, which at the time was E.

Government and local authority targets.

The UK government has committed the country to cut its carbon emissions by 80% by 2050. (http://www.theguardian.com/politics/2008/oct/16/greenpolitics-edmiliband)

The objectives of the relocation are therefore to:

- Reduce energy costs and carbon footprint. As far as economically practical and consider the payback that capital investment would have in reducing the year on year cost.
- Provide con-joined space which is conducive to interaction between teams within the museum and has a far higher net to gross efficiency.
- Provide space that is up to modern office standards thus negating the existing health and safety issues.
- Negotiate more favourable rent terms with Bradford City Council in lieu of the capital investment that would be necessary to facilitate the move.
- Make the first move in delivering the master plan which is the adopted strategy for the museum.

The NMM subsequently appointed Bauman Lyons Architects, Arup engineers and Rex Proctor - Quantity Surveyors in July 2011 to further develop the Lightwave Project through Future Expansion Option Study.

The role of this study was to examine how the relocation could be planned, provide costs and model the energy saving that might result. In parallel to this exercise relocating the offices to alternative accommodation in Bradford or beyond was explored as well as the capital costs for refurbishing the current office space in Prince’s House.
Our feasibility study considered the specifics of moving the NMMs office accommodation to levels 7 & 8 of the library building as part of a phased implementation of the full Lightwave scheme. The library services on these floors are to be relocated on to lower floors of the building as part of the consolidation of the library. The scope of work was the equivalent of a RIBA stage C work stage.

This Option Appraisal run concurrent to the CCAS study.

2. **Risk of exposure of the building to future climate**

The main area of concern for the complex of buildings is the overheating of the currently mechanically ventilated office space on the top floors of the tower block as we implement natural ventilation to reduce carbon emissions. These are expected to need adaptation interventions. Other internal areas of the building will also be influenced by raised external temperatures but the fact that they are predominantly comfort cooled (to protect the exhibits) means that the solutions against overheating are relatively straightforward.

3. **Adaptation strategy over its lifetime to improve resistance and resilience to climate change to extend the commercial viability**

**Aims of the Strategy**

Our strategy is to incorporate incremental adaptations aligned with maintenance cycles to various elements of the elevations and to services to secure natural ventilation solution for up to 2080 to prevent overheating whilst reducing the carbon omissions and running costs of the building working with the environmental controls preferences expressed by the current building users.

Our priorities are:

- Target maximum 1% of hours over occupation hours to exceed 28° C
- To reduce, and if possible eliminate, dependence on mechanical solutions
- To facilitate passive solutions with simple mechanical user centred controls and determine their limits
- To enable a floor by floor approach to adaptations and to differentiate between solutions for different orientations.
- To investigate whether current trend towards increased insulation will create greater problems with overheating in the future.
• To investigate whether current building management systems are used to the
benefit of optimising energy use and user comfort

• To illustrate the commercial benefits of implementing the adaptation strategy

• To consider organizational structures and user behaviour as an ‘adaptation’ in
itself to be considered in addition to fabric adaptations.

Assumptions underpinning the data used in developing the strategy

In addition to the data on future weather and climate predictions (described in 2.2
above) we have incorporated a number of assumptions based on other predicted
trends that will impact on overheating and user preferences:

• Trend for increased occupancy levels in managed office space
• Increase in the use of IT
• Improvements in energy use of IT
• Technological improvements in glass
• Increase in energy costs
• Increase in extreme weather events
• Preference for greater individual control over the environmental comfort
  expressed by current users and simpler controls.

It was our intention for the main focus of the strategy to be the organizational
structure as our previous CCAS study at Church View, Doncaster, revealed that
buildings can be successfully adapted to climate change and that the payback
period of such an adaptation was commercially viable. However the study also
highlighted another adaptation that was required for a successful adaptation
strategy: the need for creating organizational capacity and structures for decision
making within large organizations to enable such strategies to be developed.

As we completed the first stage of this study, it became even more apparent that
it was the structure of the NMM organization that was the biggest barrier to
Adaptation Strategy. In our Interim Report 2 we requested that TSB agrees for
the focus of the study to shift from the modelling of fabric and WLCC to allow us
to develop a Manual for Climate Change Adaptation so that they can then
develop CCAS Strategies. This request was turned down and we were asked to
deliver modelling and WLCC. We were not, therefore able to deliver Management
before Fabric with the focus on management as originally intended.
Adoption strategy

Adoption strategy applies to floor 7 and floor 8 of a 9 storey 1960’s building constructed as concrete frame with cast concrete and coated, single glazed infill spandrels to south and north elevations and Portland Stone facing to east and west gables.

The floors plates are approximately 800sqm with all office fenestration located on the south and north elevations.

Existing 8th floor plan

Proposed layouts for floors 7 and 8

Stage 00: Existing building

Building interior is to be fit out to new tenants needs.

Stage 01: Remove windows

Building is scaffolded. Existing windows and spandrel panels are removed.

Stage 02: Insert new facade

New composite panels installed on south and north facades (see composite panel details in appendix 3.13). The main feature of the composite panel are low g-value glass, hopper window with actuators enabling night purging. This retrofit will reduce
solar gain of the windows, allow natural ventilation and allow the building to be cooled at night.

**Stage 03: Operable roof lights**

Openable roof lights installed above the central stairs between floors 7 and 8 linked to the BMS to provide ventilation during the day and night purge.

**Stage 04: Facade Removed**

Composite panels are removed including the high level spandrel panel to strip the facade back to the frame.

**Stage 05: Install new facade**

New composite facade 13 (see appendix 13.13 for details). It differs from composite facade 14 in having a greater area of opening area to allow increased ventilation and better user comfort control. Below window there is an adjustable grill provided to allow further natural ventilation control when the windows are closed. Like in composite 14 hopper windows are provided for night purging. All windows are inward opening to allow for a manually adjustable louver system to run externally. This design allows view out, reduced solar gain and enables windows to be fully opened on warm, wet days for natural ventilation.

**Stage 06: Install ceiling fans**

Sweep ceiling fans installed on both floors. The fans do not lower the temperature but the air movement creates a cooling effect that can be perceived as up to 2deg.C temperature reduction. It’s a very effective and low cost method of providing localised relief to overheating.

**Stage 07: Maintenance of the facade**

Maintenance of the facade can extend its effective overheating control beyond 2080 and the available weather data. Windows can be cleaned from the inside and the louvers can be maintained from the cleaning cradle already available from the construction stage.
Summary of key drivers

We modelled 19 adaptations all together and there were many permutations of possible strategies.

The key drivers that shaped the final, optimum strategy were:

- The effectiveness of the adaptation to reduce overheating
- The effectiveness of the adaptation to reduce running costs
- Other benefits such as carbon omissions reduction.
- The longevity of the effectiveness of the adaptation.
- The adaptability of the solution to different orientations
- The level of environmental control offered to individual users
- The low tech nature of controls required and the robustness of the design
- The compatibility of the adaptations with other user requirements such as daylight and views.
- The ability to incorporate the adaptation into the maintenance cycles.
- The maintenance cycles required for the adaptations themselves
- The desire to develop a solution that can be universally applied
- Aesthetically acceptable design.
- The affordability of the capital costs
- The payback period for the investment

The calculated whole life cycle costs indicated overall saving or £1,140,000 in the 70 year cycle equivalent of £16,300 saving per annum.

4. Adaptation strategy over its lifetime to improve resistance and resilience to climate change to extend the commercial viability

The strategy will be implemented in three construction phases with 7 adaptation stages:

Phase 1: 2015
2015 for stages 1, 2, 3: composite panels 14 and roof lights

Phase 2: 2054
2054 for stages 4, 5: remove existing and install enhanced composite facade

Phase 3: 2055-2080+
Stage 6: install ceiling fans
A composite solution offers best way of reducing overheating to the four main office areas since it offers natural ventilation and significant reduction in solar gain. This adaptation can offer an acceptable, naturally ventilated working environment up to 2054 when combined with additional roof windows. Upgraded composite panels and ceiling fans are required from 2054/2055 respectively and this solution appears to suffice till 2080 and maybe beyond. Ceiling fans are required from 2054/2055 respectively and this solution appears to suffice till 2080 and maybe beyond.

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

This adaptation strategy could apply to all spaces on a floor by floor basis as well as to whole buildings, which are experiencing, or will experience in the future, problems with overheating.

The strategy is likely to be most successful in buildings that are ‘inherently sustainable’ and have the following features:

- High ceilings
- High thermal mass
- Shallow floor plates
- Potential for increasing natural ventilation
- Good daylight penetration
- Orientation

There are many buildings in the country that still have considerable life expectancy and have good passive design elements built in already: mass, high ceilings, narrow depths, good daylight and potential for natural ventilation, which represent excellent potential for achieving low carbon adaptation strategy. This applies especially to 60’s buildings that have ribbon window designs. The large window area, although good for daylight and natural ventilation, make this
building typology especially vulnerable to overheating - the biggest climate change risk for buildings.

The floor by floor approach could be applied to various areas of a wide range of buildings, from housing and education to offices, areas of retail and industrial, even in buildings which cannot be adapted in their entirety. Also it is possible to adapt selectively only those elevations most adversely effected.
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3 - Adaptation strategy over its lifetime to improve resistance and resilience to climate change to extend the commercial viability

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1.2 - Bradford Lightwave Project
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1.4 - The Design Stage and CCAS
1.5 - Specific features or aspect which will affect resilience to climate change

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4.6 - Decision making process by the client on implementing the recommendations and what were the best ways of influencing them.

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10. Modelling Part 1 Conclusions
11. Modelling Part 2 Introduction
12. Combining Adaptations
13. Adaptation Timeline
14. Composite Details
15. ACT Comparisons
16. Whole Life Costs
17. Materials

Appendix 4

CVs
Section 1: Building profile

1.1 Location
The National Media Museum, Pictureville and The Central Library are a major cultural venue located in the centre of Bradford in Yorkshire. They form a key component within the Alsop Masterplan and help to define the city centres cultural offering. The buildings overlook the centre of town been situated just to the south of it in a raised position. (see also Appendix 1)

An online version of the Alsop masterplan can be found here:
1.2 Bradford Lightwave Project

In response to the Alsop Masterplan the National Media Museum (NMM) undertook a expansion strategy feasibility study - named Lightwave. The aims of the Lightwave project are to preserve, sustain and develop, through timely investment, this key cultural complex so that it can continue to play a role in Bradford’s development. The Lightwave project’s output was a series of recommendations that called for refurbishment of the library building, construction of a new purpose built gallery space at the rear (south side of the building) and to link these two elements with the rest of the museum with a generous high glazed street. The overall project will be around 23,000m². The recommendations suggest a phased implementation of work owing to the complex nature of building work and a desire to keep facilities open.
The Lightwave project proposals are confidential and not in the public domain, for further information surrounding the proposals please contact the Museum.

In February 2011 an initial options appraisal for the Lightwave Project was completed by Bauman Lyons Architects. The brief was to review the use of space in Bradford’s cultural quarter and identify partnership opportunities between the National Media Museum, Bradford City Council (Bradford Library), the University of Bradford and other partners.

The core brief was for a facility which:

- Preserves and sustains the role of the NMM as a prime UK attraction for Bradford through gallery and activity spaces
- Delivers a modern cutting edge City Centre Library
- Extends the unique media training offer of the University of Bradford while building on partnerships with Bradford College and media producers.
- The options appraisal identified two possible schemes both with a budget in the region of £30m plus fit out costs.
- The partners are very committed to this project and this stage will be a first important step to the delivery of the master brief.

**Principles and Objectives of this Project**

The museum currently has 1400 sqm (882sqm net) of offices located in Prince’s House- a 60’s building adjacent to the Museum building fronting Little Horton Lane.

Other than being the first step in delivering the strategic Lightwave vision the relocation of the museums offices is considered necessary as:

- The current energy use in the existing spaces is extremely high and is not only costing a significant amount of money per year but is at odds with the museums’ aspiration to drive down its carbon footprint. The current energy costs are £43,000 per year. As a benchmark conditioned space of average efficiency for this volume of space should cost in the region of £18,000. The mechanical and electrical installations and fabric of the building are therefore in need of substantial improvement even to bring them up to an average standard let alone to current regulations.

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capital investment would need to be made to bring the spaces up to standard. This upgrade may then trigger an upward rent review.

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- National Museum of Science and Industry (NMSI) TARGETS - An EPC target of C was set for National Media Museum, which at the time was E.

- Government and local authority targets. The UK government has committed the country to cut its carbon emissions by 80% by 2050. (http://www.theguardian.com/politics/2008/oct/16/greenpolitics-edmiliband)

- Reduce energy costs and carbon footprint. As far as economically practical and consider the payback that capital investment would have in reducing the year on year cost.

- Provide con-joined space which is conducive to interaction between teams within the museum and has a far higher net to gross efficiency.

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Our feasibility study considered the specifics of moving the NMMs office accommodation to levels 7 & 8 of the library building as part of a phased implementation of the full Lightwave scheme. The library services on these floors
are to be relocated on to lower floors of the building as part of the consolidation of the library. The scope of work was the equivalent of a RIBA stage C work stage. This Option Appraisal run concurrent to the CCAS study.

1.3 Building Description

The Central Library, National Media Museum and Pictureville Cinema occupy 3 buildings erected in the late 60s. An extensive remodelling of the facade of the museum took place in the 90’s alongside the transformation of the existing theatre to house Pictureville Cinema.

The library building is of high specification, been clad in portland stone with marble finishes internally. Despite not been liked by many people in Bradford it is somewhat of a landmark on the skyline and there are discussions about listing it.

The National Media Museum is currently housed (with the exception of the Pictureville Cinema which is attached to the bottom of the library) in the northern end of Prince’s House, a lower specification 1960s block under multiple long term leases that will be due for renewal in the next 5 years.

Context Diagram
1.4 The Design Stage and CCAS

This Climate Change Adaptation Study (CCAS) is focused on the office accommodation within the museum building at Princes House and the proposed relocation of these offices to floors 7 and 8 or the adjacent library building. The offices are to be open plan and connected internally by a new void created in the floor plate between the levels. The Museum is keen to embrace new working patterns and envisages an environment of hot desking within departments and large informal break out areas. This CCAS study forms part of the current design stage to evaluate relocation options for the Lightwave project. The design team is the same for both projects and we are reporting to a working group within the client organization.

The CCAS work is informing the strategy for Lightwave Project in terms of future expansion options and is helping to bold up the case for utilisation of the Library building. The findings of the CCAS are communicated not only to our client NMM, but also to The City of Bradford who are the owners of the library building.

The design team members are from the same firms, BLA and Arup for the main project and the CCAS but different people from each organization are involved in each. Furthermore there are additional skills provided for CCAS that are not required for the main project such as BSM, behaviour change management and thermal modelling. Cost consultants are different for each project - the CCAS study's cost consultant is Bernard Williams Associates (BWA).
A larger set of plans and additional information can be found in Appendix 01
1.5 Specific features or aspect which will affect resilience to climate change

The key aspects that affect resilience to climate change:

- The main museum building is very deep plan; this could be positive in terms of reduced solar gain per square meter, but requirements for air conditioning will continue to increase with climate change and adaptations will make little difference to the overall overheating.

- The Library building is relatively shallow in plan, with a high ceiling, high thermal mass and overprovision of window area. All of these features make the building suitable for adaptation to prevent overheating. The library, however, is a good exemplar of early 60’s architecture and still has many of the original details and fittings. There is some possibility that the building will be listed in which case major adaptation to windows might not be possible.

- The library building has two identical elevations and yet overheating conditions are different for each. It is possible that different adaptation of each elevation will not be acceptable to planning authorities due to visual impact.

- Adaptation to the library elevations is not easily undertaken given their height and the need to scaffold the building, any incremental strategy will have to be designed with these financial and programmatic restrictions in mind.
Section 2: Climate Change Risks

2.1 Design Challenges

Taking the categories laid out in the report “Design for Future Climate” by the TSB, we note that behaviour change and institutional structures, both of which need to be adapted for climate change have not been included in this report. In our view this is the greatest design challenge to adaptation.

The scale of influence that human behaviour has on the operational efficiency of buildings is well understood. A recent European Environment Agency report (Achieving Energy Efficiency through Behaviour Change: What Does it Take?) highlighted a number of potential interventions, with energy reductions up to 20%.

If behaviour change can affect the efficiency with which buildings are run to reduce energy consumption to such a degree then it follows logically that behaviour change can significantly affect the response of the building to climate change. However, this link between behaviour and performance is still made less often in relation to adaptation than it is to climate change mitigation efforts.

Whilst some behaviour change is centred around occupants being able to be comfortable in a warmer internal environment (changes in clothing and fluid intake etc.), Koen Steemers (‘Towards a Research Agenda for Adapting to Climate Change’, Building Research and Information, 31, 2003) identified spatial and control elements that affects the behaviour with which occupants interact with a building. These include office space layout and flexibility and the ability to open windows and control temperature.

Understanding human behaviour can be difficult and changing it even harder. However, amongst behavioural psychologists it is accepted that a significant factor is the ‘social norm’ i.e. ‘what do other people do’. This, in turn, is greatly influenced by the culture and relationships within an organisation.

Hence, to take advantage of often very effective and low-cost behaviour change interventions we must first examine the culture and structure of the institution within which the individual building occupants exist. It is this fundamental approach that is not often taken within the frame of building design.

But considering the categories that have been included within ‘Design for Future Climate’ the building can be assessed as shown in the table below.

The risk assessment is a combination of two factors, the likelihood of an event occurring and the potential impact on the operation of the building. If either of these is very low then the risk will be low.
For example, the potential impact of a reduction in below ground structural stability is could be considerable but the likelihood of occurrence is so low as to result in a low overall risk.

Much of the assessments have been carried out using a qualitative evaluation of the building and its wider surroundings along with anecdotal historical evidence gathered from those that have worked in and around the building.

Once this perception of the current risks is understood, the predicted impacts of climate change can be superimposed to arrive at the risk assessment relating to which adaptations to climate change should be given the highest priority.

<table>
<thead>
<tr>
<th>Adaptation design challenge</th>
<th>Risk assessment</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Designing for comfort</strong></td>
<td></td>
</tr>
<tr>
<td>Keeping cool – Building Design</td>
<td>The space that is likely to house the future office operations of the NMM is a 8th and 9th floors of a block built in the 60's that currently houses a library and offices. The construction of the building is very poor, with single glazed windows with no openings, high air leakage and little or no insulation in the walls. Summertime thermal comfort is acceptable due to cooling systems but a move to natural ventilation to reduce costs and carbon emissions will mean that the building is at real risk of overheating. In addition, reductions in uncontrolled ventilation and improvements in the thermal performance of the building fabric required by building regulations will further increase summertime internal temperatures. This risk is seen as the most important to be addressed within the future office spaces. Other areas of the buildings under the control of the National Media Museum that house exhibitions will continue to be required to be cooled in order to prevent deterioration of exhibits.</td>
</tr>
<tr>
<td>Keeping cool – External Spaces</td>
<td>Due to the fact that the buildings of the study are on an existing site, there are few opportunities to affect this challenge. There are only short distances between the buildings and little in the way of parking infrastructure. There is, feasibly, potential for this aspect to be improved but it is not considered to be the most important issue and was not intended to form a significant proportion of this study.</td>
</tr>
<tr>
<td>Keeping warm at less cost</td>
<td>The future office space has, in its current form, very poor thermal insulation. The improvement of this will be explored, with examinations of the impacts on cost and summertime overheating.</td>
</tr>
<tr>
<td>Adaptation design challenge</td>
<td>Risk assessment</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>----------------</td>
</tr>
<tr>
<td><strong>Designing for construction</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Structural stability - below ground</strong></td>
<td>The building has been in existence for many years with no evidence of any structural instability of a severity that would be affected by climate change.</td>
</tr>
<tr>
<td><strong>Structural stability - above ground</strong></td>
<td>The existing building is very robustly built and does not sit within a local topography that would encourage ponding.</td>
</tr>
<tr>
<td><strong>Fixings and weatherproofing</strong></td>
<td>The existing buildings have withstood extreme weather events in the past so this issue is not thought to be exceptionally severe in this case even when taking into account the effects of climate change. However, changes to the façade will be necessary so this issue should really be considered during the detailed design of any new elements.</td>
</tr>
<tr>
<td><strong>Construction - materials behaviour</strong></td>
<td>Changes to the façade will be necessary so this issue should really be considered during the detailed design of any new elements. There will be few changes to the external materials of the buildings as the project is concentrating on adaptation though organisational change and management principles rather than extensive alterations to buildings.</td>
</tr>
<tr>
<td><strong>Construction - work on site</strong></td>
<td>A significant amount of scaffolding will be necessary for any proposed façade upgrades. This will introduce a degree of vulnerability to high winds on what is a relatively exposed site.</td>
</tr>
<tr>
<td><strong>Designing to manage water</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Water supply/conservation</strong></td>
<td>This building is not more susceptible to this issue than others of its type and, in general, has a low water demand.</td>
</tr>
<tr>
<td><strong>Drainage - external / building related</strong></td>
<td>The site has been in its current form for many years with no significant issues experienced of this type.</td>
</tr>
<tr>
<td><strong>Flood - Avoidance / Resistance / resilience</strong></td>
<td><img src="image" alt="" /> © Environment Agency The EA flood map shows that the building (at the centre of the map and marked as a museum) is not at risk from any flood areas</td>
</tr>
<tr>
<td><strong>Landscape</strong></td>
<td>The complex of buildings has no significant areas of external planting.</td>
</tr>
</tbody>
</table>
In summary, the main area of concern for the complex of buildings is the overheating of the currently mechanically ventilated office space on the top floors of the tower block as we implement natural ventilation to reduce carbon omissions. These are expected to need adaptation interventions. Other internal areas of the building will also be influenced by raised external temperatures but the fact that they are predominantly comfort cooled (to protect the exhibits) means that the solutions against overheating are relatively straightforward.

2.2 Identify Climate Scenarios and Climate Data Used

For our first TSB CCAS study of Church View in Doncaster we used the CIBSE future weather years based on UKCIP02 information (as laid out in TM48\(^1\)). These were chosen as the dataset for the project for a number of reasons but, primarily; they were the most robust and understood dataset available at the time of the project starting.

For this project we have chosen alternative sources based on the UKCP09 weather generators, the Prometheus file set from Exeter University. The main difference between UKCP02 and UKCP09 is an increase in resolution and a move to probabilistic definitions as opposed to significantly updated climate projections.

Underlying these differences in the data output is a fundamental difference in the way the files were created. The CIBSE files relied on a standard offset in temperature across the entire year so, at any time on any day within the files, the external temperature difference between modelling years would be the same.

However, in the case of the Prometheus files, the monthly change in factors is calculated before models within the UK Climate Projections Weather Generator are applied to generate predictions of future daily weather patterns. The differences in these two approaches are highlighted in the graphs below, with a standard offset seen between the years in the CIBSE file (left) and a varying offset seen in the Prometheus file (right).

\(^{1}\) CIBSE TM48 “Use of climate change scenarios for building simulation: the CIBSE future weather years” (2009)
The exact Prometheus files used were as shown in the table.

<table>
<thead>
<tr>
<th>Location:</th>
<th>Leeds</th>
</tr>
</thead>
<tbody>
<tr>
<td>Emissions scenario:</td>
<td>High</td>
</tr>
<tr>
<td>Risk percentile:</td>
<td>90%</td>
</tr>
<tr>
<td>File type:</td>
<td>DSY</td>
</tr>
</tbody>
</table>

The choice of the high emissions scenario was in response to the incredibly slow progress made in reducing emissions to date, the complete lack of any meaningful progress on the international political stage and the very high projected emissions savings that will be needed in order to reduce potential future temperature rises.

To compound this pessimistic view of the potential to reduce emissions in the future, recent evidence seems to suggest that the effects of climate change are being seen much quicker than previously expected by most models. As a response, the 90th percentile dataset was chosen. This represents the climate projections that are very unlikely to be exceeded. The 90% represents the mathematical confidence.

The file type used was the Design Summer Year, the most common choice for the overheating analysis as it reflects a common ‘warm’ year as opposed to an average.

Appendix 2.1 figure 2.1 contains a graph showing the differences in weather data used for the Summer period modelled 15th April - 16th October.

Design builder chooses 1st April 30th September to look at overheating but this was altered to accommodate an unusually warm period in the weather data that fell just outside this range in early October. During this period 6 month period the average temperature for 2012 was 13.1°C, in 2050 it was 17.7°C and in 2080 it was 20.5°C.

This appendices also shows frequency data comparisons between, Dew point temperature [fig 2.3] Dry bulb temperature [fig 2.4] Relative humidity comparison [fig 2.5] and wind speed [fig 2.6] that are all taken over the standard summer period from 1st April to the end of September.
2.3 Modelling & Design Methodology

2.3.1 Design Principals

The Central Library Building offers a very flexible space that is readily adaptable. At an early stage of design ventilation rules of thumb [2.5x height for single sided vent 5xheight for cross ventilation] were used to assess the viability of a natural ventilation strategy. The floor plate is 14m deep but owing to a large floor to soffit height of 3.2m natural ventilation was identified as a possible workable strategy, this was to be provided as a combination of single and cross ventilation solutions.

Great views from the building drove a desire to place open plan offices around the perimeter spaces to the South and the North. Cellular spaces were either placed centrally or to the ends of the building to make for more efficient servicing and circulation. We proposed creating a generous new stair between floor plates in the middle of the plan to avoid having to go out one set of access up the public stairs and back in to the offices. This stair was placed in such a way to allow a small area of roof on the 9th floor to be opened up allowing natural light to penetrate deep into the building.

2.3.2 Modelling Methodology

Thermal modelling for the project was undertaken in two main stages of work. The first of these (hence referred to as "part 1 modelling") compared the performance of individual adaptations with a base case scenario. The second stage of modelling (part 2 modelling) then makes adaptation proposals that are concurrent, taking into account lifecycles of products and increases in temperature.

The base case model takes the building as it stands and removes the cooling system. In reality this is not a realistic refurbishment approach for renovating the building, since it creates a glass box with no means of cooling, but it enables us to test the effectiveness of each adaptation relative to each other from a situation whereby no modifications have been made.
The table below summarises the properties of the building fabric as defined in the base case model. Detailed assumptions including wall build ups and assumptions where build ups are not known can be found in appendix 3.6

<table>
<thead>
<tr>
<th>Building Element</th>
<th>U Value W/m².K</th>
<th>G Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Roof</td>
<td>0.173</td>
<td>-</td>
</tr>
<tr>
<td>Internal Floor Construction</td>
<td>2.065</td>
<td>-</td>
</tr>
<tr>
<td>External Wall Construction</td>
<td>1.059</td>
<td>-</td>
</tr>
<tr>
<td>External High Level Spandrel Panel</td>
<td>1.124</td>
<td>-</td>
</tr>
<tr>
<td>External Low Level Spandrel Panel</td>
<td>0.860</td>
<td>-</td>
</tr>
<tr>
<td>Internal Partitions</td>
<td>1.471</td>
<td>-</td>
</tr>
<tr>
<td>Window Construction</td>
<td>5.801</td>
<td>0.828</td>
</tr>
<tr>
<td>Rooflight Construction</td>
<td>1.200</td>
<td>0.500</td>
</tr>
</tbody>
</table>
Overheating analysis was calculated in the four main office spaces only. These areas are highlighted in red on the diagrams below. Overheating hours are an average of the overheating in these four spaces. These spaces were chosen because they are the conditions in which most people will be working and they do not have any additional cooling that can be found in some areas more central to the plan.

The graph on the next page shows the total number of hours over 28 degree Celsius as a result of each individual adaptation. The graph shows overheating for today's climate and the climates for 2050 and 2080.

All the thermal modelling was undertaken in Design Builder. This modelling package was chosen by Bauman Lyons because it was felt to offer the most appropriate level of complexity and accessibility for designers.

Modelling for the trombe wall adaptation was terminated owing to the increased risk to planning been deemed unacceptable.
Graph showing effectiveness of individual adaptations in 3 separate years
From the preceding graph the following observations can be made:

- Solutions that naturally ventilate the office spaces perform significantly better than those that don't.

- After natural ventilation solutions adaptations that reduce solar gain perform next best, with the exception of Adaptation 07 Infill Panels.

- Adaptation 07 reduces solar gain but also reduces the buildings capacity to lose heat thus negatively effecting its placing.

- All the mal-adaptations [17,18,19] behaved as expected resulting is a building that overheats more.

- The introduction of ceiling fans was not as effected as expected this is in part because the building overheats to such an extent that a 2°C raise in temperature comfort threshold does not make any significant impact. It is expected that when used in combination with other adaptations, when the building is overheating less, that sweep fans will be able to significantly contribute to peoples comfort.

Once completed the part 1 modelling options were then costed. Their effectiveness of each adaptation and its costs were then tabled in order to form a consensus amongst the design team as to which adaptations offered good value for money. A summary table showing this can be found on the next page along with a detailed version in appendix 3.9.
<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Effectiveness</th>
<th>Cost</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>01</td>
<td>Building Regulations</td>
<td>***</td>
<td>X X X X</td>
<td>😞</td>
</tr>
<tr>
<td>02</td>
<td>Phase Changing Internal Partitions</td>
<td>*</td>
<td>X X</td>
<td>😞</td>
</tr>
<tr>
<td>03</td>
<td>Trombe Wall to South Elevation</td>
<td>-</td>
<td>X X X X</td>
<td>😞</td>
</tr>
<tr>
<td>04</td>
<td>Improved GValue</td>
<td>***</td>
<td>X X</td>
<td>🌼</td>
</tr>
<tr>
<td>05</td>
<td>External Louvres</td>
<td>**</td>
<td>X X X</td>
<td>😞</td>
</tr>
<tr>
<td>06</td>
<td>Solar Control Blinds</td>
<td>*</td>
<td>X X</td>
<td>😞</td>
</tr>
<tr>
<td>07</td>
<td>Infill Panels</td>
<td>X</td>
<td>X X X</td>
<td>😞</td>
</tr>
<tr>
<td>08</td>
<td>External Shutters</td>
<td>**</td>
<td>X X X</td>
<td>😞</td>
</tr>
<tr>
<td>09</td>
<td>Night Purge</td>
<td>*****</td>
<td>X X</td>
<td>🌼</td>
</tr>
<tr>
<td>10</td>
<td>Openable Roof Lights</td>
<td>*****</td>
<td>X</td>
<td>🌼</td>
</tr>
<tr>
<td>11</td>
<td>Replace all Windows</td>
<td>*****</td>
<td>X X X</td>
<td>😞</td>
</tr>
<tr>
<td>12</td>
<td>Composite Solution 12</td>
<td>*****</td>
<td>X X X</td>
<td>😞</td>
</tr>
<tr>
<td>13</td>
<td>Composite Solution 13</td>
<td>*****</td>
<td>X X X</td>
<td>🌼</td>
</tr>
<tr>
<td>14</td>
<td>Composite Solution 14</td>
<td>*****</td>
<td>X X X</td>
<td>🌼</td>
</tr>
<tr>
<td>15</td>
<td>Ceiling Fans</td>
<td>**</td>
<td>X X X</td>
<td>🌼</td>
</tr>
<tr>
<td>16</td>
<td>Reduce Occupancy Density</td>
<td>*</td>
<td>-</td>
<td>🌼</td>
</tr>
<tr>
<td>17</td>
<td>Raised Access Floors</td>
<td>X</td>
<td>X X X</td>
<td>😞</td>
</tr>
<tr>
<td>18</td>
<td>Super Insulate</td>
<td>X X X X</td>
<td>X X X</td>
<td>😞</td>
</tr>
<tr>
<td>19</td>
<td>Increase Occupancy Density</td>
<td>X X</td>
<td>-</td>
<td>😞</td>
</tr>
</tbody>
</table>

Adaptation effectiveness table. A detailed version can be found in appendix 3.9
With the most effective adaptations identified in part 1, part 2 modelling then looked combining adaptations in a sequence to form a project development strategy for improvements. Using 2012 weather data it is possible to create a comfortable environment using a single adaptation but by 2050 further adaptations are needed - See table below.

<table>
<thead>
<tr>
<th>Adaptation</th>
<th>2012</th>
<th>2050</th>
<th>2080</th>
</tr>
</thead>
<tbody>
<tr>
<td>00 Base Case</td>
<td>580h</td>
<td>1071.75h</td>
<td>1194h</td>
</tr>
<tr>
<td>01 Building Regulations</td>
<td>101.5h</td>
<td>397h</td>
<td>723.25h</td>
</tr>
<tr>
<td>02 Phase Changing Internal Partitions</td>
<td>540h</td>
<td>1044.5h</td>
<td>1178.75h</td>
</tr>
<tr>
<td>03 Trombe Wall to South Elevation</td>
<td>X</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>04 Improved GValue</td>
<td>72.75h</td>
<td>736.25h</td>
<td>976.75h</td>
</tr>
<tr>
<td>05 External Louvres</td>
<td>367.25h</td>
<td>952.25h</td>
<td>1126.75h</td>
</tr>
<tr>
<td>06 Solar Control Blinds</td>
<td>565h</td>
<td>1063h</td>
<td>1192.75h</td>
</tr>
<tr>
<td>07 Infill Panels</td>
<td>573.5h</td>
<td>1087.25h</td>
<td>1225h</td>
</tr>
<tr>
<td>08 External Shutters</td>
<td>291h</td>
<td>897.25h</td>
<td>1099.5h</td>
</tr>
<tr>
<td>09 Night Purge</td>
<td>0.75h</td>
<td>314h</td>
<td>593.5h</td>
</tr>
<tr>
<td>10 Openable Roof Lights</td>
<td>23h</td>
<td>247.25h</td>
<td>591.5h</td>
</tr>
<tr>
<td>11 Replace all Windows</td>
<td>23.5h</td>
<td>266h</td>
<td>632.75h</td>
</tr>
<tr>
<td>12 Composite Solution 12</td>
<td>0h</td>
<td>28.5h</td>
<td>183.25h</td>
</tr>
<tr>
<td>13 Composite Solution 13</td>
<td>0h</td>
<td>27.75h</td>
<td>176.5h</td>
</tr>
<tr>
<td>14 Composite Solution 14</td>
<td>0h</td>
<td>36.25h</td>
<td>229.25h</td>
</tr>
<tr>
<td>15 Ceiling Fans</td>
<td>274.75h</td>
<td>842h</td>
<td>992.25h</td>
</tr>
<tr>
<td>16 Reduce Occupancy Density</td>
<td>532.25h</td>
<td>1036.5h</td>
<td>1163.25h</td>
</tr>
<tr>
<td>17 Raised Access Floors</td>
<td>637.25h</td>
<td>1108.75h</td>
<td>1222.75h</td>
</tr>
<tr>
<td>18 Super Insulate</td>
<td>1307h</td>
<td>1368.25h</td>
<td>1374.25h</td>
</tr>
<tr>
<td>19 Increase Occupancy Density</td>
<td>663.25h</td>
<td>1139.75h</td>
<td>1247.5h</td>
</tr>
</tbody>
</table>

Table showing individual adaptations hours exceeding 28 degrees Celsius. 1% overheating constitutes 26 hours.
The table below shows number of hours that key combined adaptations overheat in the years 2012, 2050 and 2080.

<table>
<thead>
<tr>
<th>Year</th>
<th>Composite 14 + Rooflights</th>
<th>Composite 14 + Rooflights + Sweep fans</th>
<th>Composite 13 + Rooflights + Sweep Fans</th>
</tr>
</thead>
<tbody>
<tr>
<td>2012</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2050</td>
<td>21.5</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2080</td>
<td>180</td>
<td>68.25</td>
<td>16</td>
</tr>
</tbody>
</table>

The design team combined the most efficient adaptations to test their effects. Modelling combined adaptations was done in the years 2012, 2050 and 2080 to see how far into the future the combined adaptation was viable. By considering natural product maintenance cycles alongside the overheating data the design team designed the adaptation strategy as outlined in section 3.
2.4 Other features significant to the adaptation strategy developed

2.4.1 Comfort threshold

Modelling only predicts the internal temperatures of the building spaces in future climates. There then exists a need to understand how these temperatures will be perceived by the building occupants.

The traditional approach is to consider temperatures over 25°C to be ‘warm’ and temperatures over 28°C to be ‘hot’ as discussed in CIBSE TM36\(^2\). Typically, if the internal temperature exceeds this threshold for 1% of the occupied hours, a building or room is said to overheat. This is the metric we used in modelling the adaptation strategy in this study.

The simplicity of this metric does however have its problems. Firstly, the single threshold does not adequately take into account the perception of overheating at different times of the year. Whilst 28°C may be considered the boundary of acceptable temperature in the peak of summer, it would likely be considered too high a temperature for, say, the spring or autumn seasons.

Conversely, for studies considering hotter climates than that of the UK, or the predicted future UK climate, the rigidity of a single threshold also has limitations when considering how people perceive overheating. It has been shown that through prolonged periods of hot weather, occupants will tolerate higher internal temperatures through a combination of behavioural, psychological and physiological adaptations.

In order to account for these phenomena, there exists a methodology of calculating a variable comfort temperature threshold with more comprehensive measures of how frequently, how severely and how repeatedly the threshold is exceeded. This is termed the Adaptive Comfort Threshold (ACT).

This methodology is currently under development by the CIBSE Overheating Task Force with a view to it becoming the standard in the future. However, at the time of starting this study, no definitive methodology was available that would allow undeniable comparability with future studies.

In addition, previous studies in the Design for Future Climate series have shown that the direction and magnitude of the improvements shown by interventions are similar when the ACT and 28°C methodologies are used.

This, coupled with the current extra difficulty in post-processing modelling results to produce ACT figures lead the more traditional 28°C metric of overheating to be used.

2.4.2. ICT effects

It is clear that the future usages of ICT are set to change massively within the timescales of this study. Recent studies have suggested that, from a hardware point of view, one of the most significant trends is the move to ‘cloud computing’ that requires significantly less computing power to be placed in the same location as the user with desktop PCs being replaced by equipment with much less processing capacity and therefore power consumption and heat rejection.

\(^2\) CIBSE TM36 “Climate change and the indoor environment: impacts and adaptation” (2005)
In addition, the longer term trend will be for local processing capacity to be reduced further and the widespread adoption of ultra-thin client systems with even lower electrical power and cooling requirements.

Whilst these reductions will be offset to some degree by increased usage and more intensive applications such as two way video streaming, it is currently thought that, overall, power consumption will decrease.

We have estimated that the average power consumption of a person’s ICT equipment will reduce from the currently accepted 150W to around 50W. It is unlikely to fall much further due to the inherent maximum efficiencies of screens and ancillary equipment. This is backed up by a study by Fraunhofer that predicted a 100W reduction when the move from a desktop to a thin client system is made.\(^3\)

### 2.4.3 Adaptations not easily measurable with DesignBuilder

There are certain aspects of the thermal behaviour of a building that cannot currently be modelled within conventional thermal modelling tools. Some of these are valid adaptations against increasing temperatures and should not be discounted simply because they cannot be simulated by current software that was developed to address a regulatory framework with a different focus, namely that of carbon reductions.

**Ceiling fans**

DesignBuilder does not take into account any air movement when calculating internal temperatures. The British Standard (15251) on the calculation methodologies relating to thermal comfort quotes a relationship between the airspeed required to offset increased temperatures. An air speed of around 0.6 m/s is sufficient to offset an increase in temperature in the order of 2\(^\circ\). Interestingly, the effectiveness of air movement increases as the temperature increases.\(^4\) For reference, 0.6 m/s equates to only 1.3mph, a breeze that would be barely noticeable and would be unlikely to move papers around on a desk.

**Window Opening Areas**

Whilst it is relatively easy for design builder to auto-size heating and cooling equipment we found no way for the program to auto size window openings. Instead several different percentage openings had to be tested and then evaluated. This was more time consuming than expected.

**Night Purging & Rain**

It is not currently possible to model a natural ventilation solution with windows that close during rain with no backup cooling system. There is a work around, within Design Builder that involves using a mixed mode system that will allow windows to take into account predicted rainfall patterns and close accordingly. There is however no option that will allow a window to be slightly open when raining and fully open when not. Combining this with window profiles that can night purge at one set of

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\(^3\) Weidner et al, “Thin Clients 2011 – Ecological and economic aspects of virtual desktops”, Fraunhofer Institute for Environmental, Safety and Energy Technology UMSICHT, 2011

\(^4\) BS EN 7730 “Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort criteria”
temperatures and open during the day at another set of temperatures proved difficult to simulate.

Human Behaviour

Design builder does not have a function that will allow for human pre-emptive thinking, actions and vagrances - instead relying on data thresholds. For example, it is not possible to model a situation in which someone comes into an office in the morning and opens all the windows knowing that it will be a hot day because the weather forecast has told them. Instead the Design builder relies on a set point temperature over which windows are open and under which they are shut. In addition to this been an issue there is no capacity to model windows half open based on temperature set points, or any profile that takes into account individuals opening windows at different temperatures to suit their personal comfort levels. It is also not possible to model the occasional forgetful element of human behaviour such as not opening natural vents at night for.

Management

There is no way of modelling the failure of management, both human and mechanical in the form of BMS, to optimise the environmental performance of the building. This is the reason why we suggested alternative methodology that included writing of a Manual for Climate Change Adaptations for large organizations. (this recommendation was rejected by TSB)

Effect of water

There is no facility to model the cooling effect of running water, both psychological and real.

Effects of shading by plants

Shading by plants is considered to offer up to 2-3 degrees C of cooling but this cannot be accurately modelled. The only method is to assume a percentage of an open area in a solid shade making this measure only an approximation.
Section 3: Adaptation Strategy

3.1 The adaptation strategy

3.1.1 Overview of the Strategy

Aims of the Strategy

Our strategy is to incorporate incremental adaptations aligned with maintenance cycles to various elements of the elevations and to services to secure natural ventilation solution for up to 2080 to prevent overheating whilst reducing the carbon omissions and running costs of the building working with the environmental controls preferences expressed by the current building users.

Our priorities were to:

- Target maximum 1% of hours over occupation hours to exceed 28°C
- To reduce, and if possible eliminate, dependence on mechanical solutions
- To facilitate passive solutions with simple mechanical user centred controls and determine their limits
- To enable a floor by floor approach to adaptations and to differentiate between solutions for different orientations.
- To investigate whether current trend towards increased insulation will create greater problems with overheating in the future.
- To investigate whether current building management systems are used to the benefit of optimising energy use and user comfort
- To illustrate the commercial benefits of implementing the adaptation strategy
- To consider organizational structures and user behaviour as an ‘adaptation’ in itself to be considered in addition to fabric adaptations.

It was our intention for the main focus of the strategy to be the organizational structure as our previous CCAS study at Church View, Doncaster, revealed that buildings can be successfully adapted to climate change and that the payback period of such an adaptation was commercially viable. However the study also highlighted another adaptation that was required for a successful adaptation strategy: the need for creating organizational capacity and structures for decision making within large organizations to enable such strategies to be developed.

As we completed the first stage of this study, it became even more apparent that it was the structure of the NMM organization that was the biggest barrier to Adaptation Strategy. In our Interim Report 2 we requested that TSB agrees for the focus of the study to shift from the modelling of fabric and WLCC to allow us to develop a Manual for Climate Change Adaptation so that they can then develop CCAS Strategies. This request was turned down and we were asked to
deliver modelling and WLCC. We were not, therefore able to deliver Management before Fabric with the focus on management as originally intended.

Assumptions underpinning the data used in developing the strategy

In addition to the data on future weather and climate predictions (described in 2.2 above) we have incorporated a number of assumptions based on other predicted trends that will impact on overheating and user preferences:

- Trend for increased occupancy levels in managed office space
- Increase in the use of IT
- Improvements in energy use of IT
- Technological improvements in glass
- Increase in energy costs
- Increase in extreme weather events
- Preference for greater individual control over the environmental comfort expressed by current users and simpler controls.

Adoption strategy

Adoption strategy applies to floor 7 and floor 8 of a 9 storey 1960’s building constructed as concrete frame with cast concrete and coated, single glazed infill spandrels to south and north elevations and Portland Stone facing to east and west gables.

The floors plates are approximately 800sqm with all office fenestration located on the south and north elevations.
Location of the Library within the National Museum of Media, central Bradford
7 Stages to the Proposed Adaptation Strategy:

Stage 00: Existing building

Building interior is to be fit out to new tenants needs.

This is triggered by the expiry of existing leases that the museum currently holds and needing a space to move employees to once they run out.
Stage 01 Remove windows

Building is scaffolded. Existing windows, which are in a poor state of repair, need to be replaced and are the first investment trigger. Windows and spandrel panels are removed.
Stage 02: Insert new facade

New composite panels installed on south and north facades (see composite panel 14 details in appendix 3.13). The main feature of the composite panel are low g-value glass, hopper window with actuators enabling night purging. This retrofit will reduce solar gain of the windows, allow natural ventilation and allow the building to be cooled at night.

This adaptation is £176,000 cheaper than composite panel 13 (see appendix 3.9 fig 3.9.0) and along with operable roof lights, as outlined in stage 03, will provide a comfortable building until the windows reach the end of their maintenance cycle in 40 year time (see appendix 3.16)
Stage 03: Operable roof lights

Operable roof lights installed above the central stairs between floors 7 and 8 linked to the BMS to provide ventilation during the day and night purge.

This adaptation has been triggered by a desire to allow natural light deep into the plan; since roof lights are necessary for this design move the cost increase to make them operable to purge heat is relatively small given its effectiveness.
Stage 04: Facade Removed

Composite panels are removed including the high level spandrel panel to strip the facade back to the frame.

This is triggered by the facade coming to the end of its maintenance cycle and the performance of it been reduced owing to increased temperature externally.
Stage 05: Install new facade

New composite facade 13 (see appendix 13.13 for details). It differs from composite facade 14 in having a greater area of opening area to allow increased ventilation and better user comfort control. Below window there is an adjustable grill provided to allow further natural ventilation control when the windows are closed. Like in composite 14 hopper windows are provided for night purging. All windows are inward opening to allow for a manually adjustable louver system to run externally. This design allows view out, reduced solar gain and enables windows to be fully opened on warm, wet days for natural ventilation.

This facade replaced the old facade that will have come to the end of its maintenance cycle. It is more expensive than the previous facade but performs better environmentally.
Stage 06: Install ceiling fans

Sweep ceiling fans installed on both floors. The fans do not lower the temperature but the air movement creates a cooling effect that can be perceived as up to 2deg.C temperature reduction. It’s a very effective and low cost method of providing localised relief to overheating.

Ceiling fans are needed to make the environment comfortable by 2080. They may not be necessary as early as we are proposing to install them but with no weather data between 2050 and 2080 available it was decided to err on the side of caution and install them whilst there is already work happening on site to the facade. This will cause less disruption to the occupants of the building.
**Stage 07: Maintenance of the facade**

Maintenance of the facade can extend its effective overheating control beyond 2080 and the available weather data. Windows can be cleaned from the inside and the louvers can be maintained from the cleaning cradle already available from the construction stage.
Results

The graph below shows the overheating hours of the adaptation strategy. The first phase of works [stages 1-4] is shown by the blue line, with the second phase [stage 05 onwards] been shown in green. The red line shows the implications of adding sweep fans to the building without replacing the windows - this will improve performance but not significantly enough to make the building comfortable in 2080.

A larger version of this graph can be found in appendix 3.12 fig 3.12.2
Summary of Key Factors

There were several key factors that shaped the final adaptation strategy and these have been grouped under three headings below:

Physical nature of existing buildings

- It became apparent from the early stages of the research that the main building where the majority of the museum collection and the staff office are housed was not suitable for non-mechanical adaptation due to the considerable depth of building and the extensive party wall to the west elevation that made it impossible to introduce additional openings. Furthermore the nature of exhibits required permanently conditioned spaces.

- The working conditions for the staff in the existing building were very poor due to air conditioning, inadequate space that was not designed for its purpose, poor adjacencies and lack of privacy. Absenteeism and sick leave were a considerable problem.

- In contrast the central library building that forms part of the museum complex was underutilised, shallow in plan with good amount of open elevations, generous ceiling heights and concrete floors with good thermal mass and adequate load bearing and acoustic properties for an office use.

- The challenges presented by the library in terms of natural ventilation adaptation was that it has large area of glass both to the north and to the south and the south elevation has the added challenge of noise from major traffic on inner ring road.

- The library building was 50 years old and the fenestration and services have not been renewed in this period. A major renovation was required. This created excellent opportunity to integrate CCAS into the refurbishment design.

The needs and preferences of the user group

- It has to be noted that the National Media Museum considers itself to be foremost a visitor facing organization with priorities to attract, entertain and retain visitors. All building related decisions were informed by this requirement and prioritised accordingly.

- In our feasibility study for the client, which was ongoing in parallel with the TSB research, the client team expressed a preference for moving the staff office (for 100 people) from the main museum complex to the two floors in the disused library building as it offered an opportunity for bringing together
currently dispersed team. The library building also offered additional, badly needed space and better working conditions.

- The Building in Use (BUS) survey (see appendix 3.2) that we carried out as part of the TSB study revealed almost the highest level of dissatisfaction with the current staff accommodation out of the 400 buildings that form the benchmark for the survey method.

- The BUS study also clearly highlighted that the staff wanted to have control over their comfort and expressed a preference for simple manual controls such as opening a window. A summary of the BUS survey is on the next page and a full version can be found in appendix 3.2:
Summary of BUS survey findings
The external political and financial imperatives

- Both the design project and the CCAS coincided with dramatic downturn in economy and the austerity policy. Nevertheless the design project was fully supported during the design stage of staff accommodation in the library. The integration of CCAS into the design proposal was considered by the client team to strengthen the case for moving and for funding.

- The Library building, although part of the same complex as the NMM, was in Bradford MDC ownership and although keen for NMM to occupy the free floors, the Council were also looking for a return on the space. The value of the return was in disputed by both parties.

- During the CCAS project there were also, complex management changes taken place within NMM and the larger organisation MMSI that created a great deal of uncertainty within the management and made it difficult to finalise decision. (see appendix 3.1 for the structure of decision making within the organization and the changes that occurred during the project period.)
Summary of key drivers

We modelled 19 adaptations in total and there were many permutations of possible strategies. A summary table of these adaptations can be found below, a more detailed table with descriptions can be found in appendix 3.7.2:

<table>
<thead>
<tr>
<th>No</th>
<th>Title</th>
<th>Type of Adaptation</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>Base Case</td>
<td>-</td>
</tr>
<tr>
<td>01</td>
<td>Building Regulations</td>
<td>Fabric</td>
</tr>
<tr>
<td>02</td>
<td>Phase Changing Internal Partitions</td>
<td>Fabric</td>
</tr>
<tr>
<td>03</td>
<td>Trombe Wall to South Elevation</td>
<td>Fabric</td>
</tr>
<tr>
<td>04</td>
<td>Improved GValue</td>
<td>Solar Gain Reduction</td>
</tr>
<tr>
<td>05</td>
<td>External Louvres</td>
<td>Solar Gain Reduction</td>
</tr>
<tr>
<td>06</td>
<td>Solar Control Blinds</td>
<td>Solar Gain Reduction</td>
</tr>
<tr>
<td>07</td>
<td>Infill Panels</td>
<td>Solar Gain Reduction</td>
</tr>
<tr>
<td>08</td>
<td>External Shutters</td>
<td>Solar Gain Reduction</td>
</tr>
<tr>
<td>09</td>
<td>Night Purge</td>
<td>Ventilation Strategies</td>
</tr>
<tr>
<td>10</td>
<td>Openable Roof Lights</td>
<td>Ventilation Strategies</td>
</tr>
<tr>
<td>11</td>
<td>Replace all Windows</td>
<td>Ventilation Strategies</td>
</tr>
<tr>
<td>12</td>
<td>Composite Solution 12</td>
<td>Composites</td>
</tr>
<tr>
<td>13</td>
<td>Composite Solution 13</td>
<td>Composites</td>
</tr>
<tr>
<td>14</td>
<td>Composite Solution 14</td>
<td>Composites</td>
</tr>
<tr>
<td>15</td>
<td>Ceiling Fans</td>
<td>Comfort</td>
</tr>
<tr>
<td>16</td>
<td>Reduce Occupancy Density</td>
<td>Comfort</td>
</tr>
<tr>
<td>17</td>
<td>Raised Access Floors</td>
<td>Maladaptation</td>
</tr>
<tr>
<td>18</td>
<td>Super Insulate</td>
<td>Maladaptation</td>
</tr>
<tr>
<td>19</td>
<td>Increase Occupancy Density</td>
<td>Maladaptation</td>
</tr>
</tbody>
</table>
The key drivers that shaped the final, optimum strategy were:

- The effectiveness of the adaptation to reduce overheating
- The effectiveness of the adaptation to reduce running costs
- Other benefits such as carbon omissions reduction.
- The longevity of the effectiveness of the adaptation.
- The adaptability of the solution to different orientations
- The level of environmental control offered to individual users
- The low tech nature of controls required and the robustness of the design
- The compatibility of the adaptations with other user requirements such as daylight and views.
- The ability to incorporate the adaptation into the maintenance cycles.
- The maintenance cycles required for the adaptations themselves
- The desire to develop a solution that can be universally applied
- Aesthetically acceptable design.
- The affordability of the capital costs
- The payback period for the investment

3.2 Timescale for our recommendations to implement relevant measures over the lifetime of the building

The strategy will be implemented in three construction phases:
Phase 1: 2015
Stages 1, 2, 3: Composite Solution 14 and Operable Roof Lights

Phase 2: 2054
Stages 4, 5: Remove existing and install enhanced Composite Solution 13

Phase 3: 2055-2080+
Stage 6: Install ceiling fans

Timeline of adaption strategy showing the 7 stages. A large version of this drawing can be found in appendix 3.13.
3.3 Cost benefit analysis and sensitivity analysis of these adaptations measures

3.3.1 Adaptation Strategy / Options / Assumptions

Our Whole Life Cost models (WLC), “in-house” models developed in Excel spreadsheets, set out to calculate the total cost associated with the occupation of the National Media Museum (Administrative Offices only) of the 7th and 8th floors of the facility.

These total cost include: the Initial Capital Cost / Annual Operational Maintenance / Periodic Life Cycle Replacement, they do however exclude any possible extra over disposal costs for any items replaced [e.g. currently assumed disposal of surplus materials after Life cycle replacements do not incur any specific additional costs, over time].

Our preliminary calculations for the WLC exercise determined that only a “Base Case” (defined below) and “Composite Adaptation Strategy” (defined overleaf) are relevant for this report. Detailed models have therefore only been included for these “solutions”.

Furthermore we have only identified costs, in the models, where differences occur as a direct result of the introduction of adaptations, this is for the sake of simplicity and to maintain focus on the adaptations themselves e.g. costs for floor finishes for example, have not been included in either model as they are deemed to be exactly the same in both cases.

We have however included, for information, a table indicating the calculated capital cost of each possible adaptation identified by the project team in Appendix 3.16.

3.3.2 Whole Life Cost (WLC) Models

3.3.2.1 “Base Case” Model which represents what we have calculated would be a “current / conventional” solution to the refurbishment of this space with no allowances for adaptations which may be required to deal with predicted rises in temperature. The Base Case model “simply” assumes that increased cooling demand is met by a combination of increased energy consumption and increased chiller capacity. The model includes as follows:

- no adjustments made to life cycle plan, for planned future adaptation works and only include adjustments in utility consumption / cooling capacity within existing system configuration to cope with increasing "Global" temperatures. It includes the replacement of the external; glazing (like for like (sealed glazing with no venting capability), but meet current buildings regulations) and continued use of full air-conditioning systems;
• assumes full replacement of all air-conditioning services serving the whole building as the whole system is “life expired, by others – the costs associated with the 7&8th floors only are applied on a pro-rata basis to the Base Case model. The new plant / controls would obviously be required to meet current building regulations.

• assumes that the existing sealed external glazing system will require immediate replacement (prior to occupation to avoid disruption shortly after the Museum staff moving in), as the whole system is “life expired”, to the entire tower block, by others, the costs associated with the 7&8th floors only are applied on a pro-rata basis to the Base Case model (including apportioned costs for full external scaffolding). The new glazing would obviously be required to meet current building regulations

• energy consumption data based upon modelled information provided by BLA

• the model assumes that on replacement on its next Life Cycle period building regulations are constant with current as it is difficult to attempt to predict what changes might be enforced in the future.

• assumes no work required / possible to increase roof drainage capacity for possible future rainfall increases [this report only examines part of the whole building and any such works deemed necessary in future could require major works throughout the building and including underground drainage], roof outlet inspections included within normal maintenance regime to keep outlets clear from blockage.]

3.3.2.2. The “Proposed Adaption Strategy” Model which represents the overall cost effect of the project team’s strategy, as outlined in detail above “7 Stages to the Proposed Adaptation Strategy” and also assumes:

• that existing heating and cooling distribution systems are replaced by a natural ventilation led system of mainly LPHW heating and only direct ventilation to proposed central high density areas as required, [created as part of the initial capital expenditure but excluded here as both options deemed to be the same]

• that ceiling mounted electric fans are installed to only approximately 75% of the floor area.

3.3.2.3 The WLC models incorporate: capital cost estimates for proposed adaptations by BWA as well as energy consumption and comparative data as indicated in Section 2.2 above and in Section 4.4 - List of resources and tools and review of their strengths and limitation

3.3.2.4 Detailed “common” WLC modelling assumptions are presented in Appendix 3.16
3.3.3 Expenditure assumptions

A series of “unit rates” for all cost centres has been compiled (see Appendix 3.16), from, BLA adaptation modelling, benchmarked Hard and Soft FM data from BWA internal databases and separate Gas and Electricity consumption assumptions. These are applied to the appropriate area to give the total expenditure, per category, per year in the WLC Models.

Costs such as maintenance and Electricity have also been adjusted, where appropriate, to take account of changes in the scope of service requirement e.g. where mechanical cooling is adjusted, whether increased to cope with rising temperatures or reduced when adaptations are undertaken.

3.3.4 Life Cycle Costs

Information used has been based largely upon the assumptions given in the Bauman Lyons / Arup Bradford Media Museum & Central Library - Feasibility Study (Oct 2009); Bauman Lyons / Arup / Rex Procter & Partners National Media Museum Office Relocation Stage C Design Report (Feb 2011); and BWA’s own cost and information databases. The costs and specification provided have been used as the basis for the projected life cycle costs in each option.

Life cycle periods have been derived from the following sources (Royal Institution of Chartered Surveyors, Building Research Establishment and BWA internal data) to generate a composite model where appropriate; we have also adjusted some periods to suit the individual options and to avoid impractical and plainly uneconomical replacement of assets (deviations have been stated where they apply):

The Life Cycle Models are generated by calculating “cyclical” costs for each predicted life cycle replacement item or element. The cost is based upon the original capital cost with the application of additional percentages to take account of such things as preliminaries, access equipment and out of hours working etc. according to the specific work required – generally the more difficult or disruptive the works the higher the addition (see Appendix 3.16 for detailed information.)
As with all Life Cycle Models, especially in this case where they run to 70 years, are essentially only estimates based upon a set of given parameters. Actual costs over time will obviously depend upon a wide range of variables including: usage, maintenance levels and frequency, actual weather conditions against predictions, actual available specification selection and simply components performance against expectations.

### 3.3.5 Summary

The table below illustrates comparative Whole Life Costs the Base and for the Composite adaptation models indicating the potential for a £16,300/annum (over 70 years) saving for the latter or 16% of the Base Model Costs.

#### NATIONAL MEDIA MUSEUM - WHOLE LIFE MODEL (OPTION SUMMARY)

<table>
<thead>
<tr>
<th>OPTION</th>
<th>HEADLINE DESCRIPTION</th>
<th>INITIAL CAPITAL COSTS</th>
<th>LIFE CYCLE COST TOTAL</th>
<th>FM / OPERATING COST TOTAL</th>
<th>TOTAL COST</th>
<th>VARIANCE</th>
</tr>
</thead>
<tbody>
<tr>
<td>A) BASE MODEL</td>
<td>BASE CASE assumes no adjustments made to life cycle plan, for planned future adaptation works and only includes adjustments in utility consumption to cope with increasing &quot;Global&quot; temperatures. It includes the replacement of the external; glazing (like for like) and replacement of existing VAV air conditioning in full from day one in existing 9th floor plant room</td>
<td>£1,040,000</td>
<td>£1,610,000</td>
<td>£4,512,000</td>
<td>£7,162,000</td>
<td></td>
</tr>
<tr>
<td>B) COMPOSITE ADAPTATION</td>
<td>COMPOSITE SCENARIO assumes adjustments made to life cycle plan, for planned future adaptation works and includes adjustments for increasing &quot;Global&quot; temperatures and an assumption that this will impact upon the occupants of the space in the future. Planned adaptations are “phased in”. Replacement of external cladding as initial expenditure with internal ceiling fans installed in year 55 and operable roof lights for night purge from day 1 and replacement of external glazing system in 2055 to include external louvres</td>
<td>£780,000</td>
<td>£1,830,000</td>
<td>£3,412,000</td>
<td>£6,022,000</td>
<td>-16%</td>
</tr>
</tbody>
</table>

| VARIANCE | £260,000 | £220,000 | £1,100,000 | £1,140,000 | ![Average Annual Equivalent Benefit](image) |

INITIAL CAPITAL COSTS ARE CONSIDERED TO BE EXPENDED DURING INITIAL FITOUT AND PRIOR TO OCCUPATION TO AVOID OCCUPIER DISRUPTION

LIFE CYCLE AND FM/OPERATING COSTS ARE AS CALCULATED FROM DETAILED MODELS, ALL OPTIONS ARE OVER 70 YEARS

NORMAL INFLATION IS EXCLUDED (EXCEPTIONAL INFLATION FOR ENERGY COSTS IS INCLUDED)

IT APPEARS THAT THERE COULD BE AS MUCH AS A 16% REDUCTION IN WHOLE LIFE COSTS, OVER THE 70 YEARS, (INCLUDING INITIAL CAPITAL COSTS) BETWEEN OPTION B (FULL COMPOSITE SOLUTION) TO CLIMATE CHANGES AND OPTION A (BASE MODEL) - WHICH EQUATES TO AN ANNUAL EQUIVALENT SAVING OF SOME £16,300

NB: IT IS IMPORTANT TO NOTE THAT COSTS ARE ONLY INCLUDED IN THIS SUMMARY FOR ELEMENTS WHICH ARE AFFECTED BY ADAPTATIONS AND AS SUCH THEY DO NOT REFLECT THE FULL COST OF FITTING OUT THE SPACE FOR USE.
By far the most significant cost variation, between the two models, is in the FM operating cost sector which is due mainly to the reduction in electricity consumption achieved by the adaptations proposed over the use of full air-conditioning as external temperatures rise.

The charts below illustrate the pattern of expenditure in both models and how it differs.

Base Case: life cycle/maintenance and utility costs combined:

*Highlights peak Life cycle replacement costs for air-conditioning units in 2044 and 2074 and external glazing in 2054 peaking at just over £800,000.*

Composite adaptation solution lifecycle/maintenance and utility costs combined:

*Highlights much lower peak life cycle replacement costs for boilers in 2044 and 2074 and the adaptation solution “13” enhanced external glazing in 2054 peaking in excess of £1,100,000*
**Base case : maintenance and utility costs only chart** above clearly illustrates the growing significance of the cost of electricity in meeting the ever increasing cooling load, accentuated by the predicted above inflation costs of providing electricity in the future.

**Composite adaptation solution maintenance and utility costs only** chart above clearly illustrate the predicted above inflation costs of providing electricity in the future, but unlike in the Base Case the total effect is restricted due to the much lower requirement for electricity following the implementation of the adaptations which use natural ventilation (including ceiling fans) rather than mechanical cooling.

Table of identified adaptations and capital costs of each are in Appendix 3.16.
3.4 Details of which recommendations are being implemented and any barriers

The early findings were presented to senior management team who all seem to be on board with the questions we were asking.

At this stage of the project the greatest influence we had in influencing the Museum was being able to illustrate that they could save significant amount of energy in the future and that the initial capital investment could be offset by savings in the maintenance costs and in the energy savings. It was also apparent that there was great value to the Senior Management Team in the Building in Use Survey we conducted since we had 90% response for the 100 staff so that a very accurate picture emerged about the need to improve the comfort of the team.

The CCAS study influenced the final choice to move the staff to the Library building. In this sense the study was successful in alerting the client to new ways of thinking about climate change,

3.4.1 Options Appraisal

The CCAS contributed to the option appraisal for the NMM that considered the best way of developing the complex of buildings in which the museum is housed. The option chosen by the NMM was to move 100 of their staff team to the two refurbished floors of library building. The decisive factors in the decision was the long term comfort, carbon reductions and financial benefits that the CCAS offered over standard refurbishment approach.

The proposed strategy integrated many of the design opportunities identified on checklist 3 including manufactured shading, glass technologies, secure and bug free night ventilation, enhanced thermal mass, and additional insulation. Conflicts between maximising daylight and overheating and natural ventilation and noise/pollution were resolved through design. Full advantage was taken of the increased ceiling heights by removing suspended ceilings and raised floors and using high window assemblies.

All of our recommendations were accepted but none are as yet implemented due to lack of tenancy agreement for the two floors of the library building.
3.4.2 Key barriers to implementation

We have clustered the key barriers to implementation under 4 headings below:

Existential

- Current denial about potential climate change impact. This is true of individual as well as of institutions. The denial takes form of negation (it will not happen), denialism (protection of institutional interests, political and business, in retaining the status quo) and disavowal (knowing that climate change is happening but inability to come to terms with the need for action)

Management

- Client management structure and decision making does not currently allow for strategic planning for climate change. The structure is complex and estate matters are managed by a number of uncoordinated and disjointed decision making teams (see section 4.f of the report). There is no long term strategy for the estate. Major capital projects are focused on visitor offer. Refurbishment work that could include adaptation is financed from maintenance budgets that are set, and bid for, on an annual basis and are determined by what has happened the year before.

- Client’s priorities are visitors, exhibitions and footfall. Climate change adaptation, or for that matter any improvements to the buildings, are of interest only if the visitor experience can be improved, the visitors numbers increased or cost savings can be demonstrated

- Buildings future is uncertain – council has conflicting views internally on whether the building should be retained. Tenancy agreement has stalled because neither party can fully afford the basic health and safety driven refurbishment currently required to the whole building.

Legislative

- There is a conflict driven by current building regulations between the need to conserve energy and heat through insulation and the benefits of high thermal mass for keeping buildings cool in future climates.

- Planners might not accept variations to elevational treatment between the south and north elevations since the original 60’s building did not make such distinction.

- The legal imperative to improve EPC and the public perception of the museum’s energy performance could lead the museum to prioritise the addition of insulation to achieve shorter term performance gains to the detriment of long term performance
Section 4: Learning from work on this contract

4.1 A summary of our approach to the development of the adaptation design work

4.1.1 The key aims of our adaptation strategy we agreed with the client as:

- Target maximum 1% of hours over occupation hours to exceed 28° C
- To reduce, and if possible eliminate, dependence on mechanical solutions
- To facilitate passive solutions with simple mechanical user centred controls and determine their limits
- To enable a floor by floor approach to adaptations and to differentiate between solutions for different orientations.
- To investigate whether current trend towards increased insulation will create greater problems with overheating in the future.
- To investigate whether current building management systems are used to the benefit of optimising energy use and user comfort
- To consider organizational structures and user behaviour as an ‘adaptation’ in itself to be considered in addition to fabric adaptations.
- To illustrate the commercial benefits of implementing adaptation strategy

4.1.2 Our approach to developing the adaptation strategy

We developed the adaptation in 4 stages of research:

Stage 1: Establishing base information and Data

In this stage we gathered all relevant information to the research questions. There were clustered in 3 broad categories of information:

- Physical:
  building fabric and existing services,

- Operational:
  Client organizational structure; client’s aims and objectives; building user perceptions; use of energy; building management system (BMS)

- Design metrics, tools and future trends in regulations, costs, technical performance: occupation patterns, behaviour change
Weather files; modeling software and the data to be inputted such as future 
energy use by ICT, current and future building regulation requirements, 
technological improvements in glass, fabric and services etc.

We collected this data through desk top research workshops and from existing data 
obtained from the client. The occupancy data was gathered through Building user 
Service (BUS- see appendix 3.2) method of assessment and the information on 
energy performance was obtained from bills available over the last 3 years, from the 
BMS logs and from interviewing the Contract Maintenance provider Honeywell

We also held a workshop with all senior staff to feedback the findings from the BUS 
survey and to explore the capacity of the organization to implement a climate 
change adaptation strategy.

The work on this phase ran in parallel with the main commission to develop option 
appraisal for the expansion of NMM, and the two studies merged into the preferred 
option of moving all 100 members of the staff into 2 floors of the adjacent city 
library to create better conditions for them. It was also confirmed that conditioned gallery space could not be modified in any way due to conditions required by the exhibits.

This allowed us to finalise the brief for the modeling phase.

Stage 2: Options appraisal and design development

In stage 2 we focused on developing adaptation strategy through identifying all possible adaptations and modelling their impact. We considered all options that would encourage natural cross ventilation and maximise the existing potential of thermal mass.

We modelled the following adaptations:

01 Current New Build regulations in current un-refurbished building
02 Phase Changing partitions,
03 Trombe Wall,
04 Improve Glazing G Value,
05 Add External Louvres,
06 Add Solar Control Blinds,
07 Infill 1/3 existing Windows,
08 Add External Shutters,
09 Night Purge,
10 Openable Roof Lights,
11 Openable windows,
12 Composite panel type 1
13 Composite panel type 2
14 Composite panel type 3
15 Ceiling Fans,
16 Reduce Occupancy Levels,
Also maladaptions (adaptation that would increase overheating):
17 Add a raised access floor,
18 Super Insulate,
19 Increase Occupancy Density

Key conclusions from the modelling of individual modifications was that the approach to replace the existing windows with a set of composite panels with variable components adjustable for different orientations and internal conditions would be the most effective strategy.

Stage 3: Climate change adaptation strategy and sensitivity analysis

The modelling carried out in stage 2 allowed us to identify the most effective adaptation strategy in terms of reducing the overheating up to 2080. In stage 3 we focused on establishing the commercial case for implementing the strategy. This consisted of:

- Preparing costs estimates for each adaptation
- Preparing timeline for incremental adaptations to windows to fit in with maintenance cycles to optimise cost benefits.
- Preparing life cycle costs for ‘business as usual’ for 2080 (no adaptation just required maintenance cycles for existing building)
- Preparing life costs for the preferred climate change adaptation based on the timeline.

Assumption about all other variants were kept the same for both cases,

The comparative Life Cycle Costs illustrated that implementing climate change adaptation strategy is commercially beneficial.
Stage 4: Report compilation and dissemination

Whilst working on the final report we presented emerging findings at the TSB conference in May 2012 and future dissemination.

4.2 Who was involved in the design work and what did they bring to the project

Brief details on each of the core team members are set out below. Further information and CVs can be found in appendix 4.

Irena Bauman, Bauman Lyons Architects was the lead consultant and project manager of the research.

Tom Vigar, Bauman Lyons Architects was the project architect researching products, compiling data for modeling, liaising with all other consultants, assisting with developing the methodology and producing the 3D visuals of the adaptation strategy for the final report.

Andy Sheppard, Arup, was the Sustainable Buildings Consultant who contributed to the development of the methodology, identified the climate change risks to the building, developed the metrics, coordinated all the data modelling work and developed the adaptation strategy.

Russel Entwistler, Arup, assisted with modelling in Designer Builder and evaluation of IES and Designer Builder software tools.

Craig Wootton, Arup, carried out the BSM and energy use appraisal.

Amanda Harrison, Arup, carried out review of behaviour and cost of training.

Andrew Hayward, BWA, an associate at Bernard Williams Associates, prepared capital costs and life cycle and whole life costs.

4.3 The initial project plan and how it changed through the course of the project

The initial emphasis of the research was on the adaptation strategy for the main museum complex and the consideration of management and behaviour as a currently ‘missing’ adaptation on Checklist 3.

Early on in the project we perceived that management and behaviour factors are by far the most significant barriers to CCAS in so far that there was no acknowledgement as yet, within the client organization, of the impact of climate
change and the need for adaptation. Furthermore, the organizational structure was such that there was no route through which such a consideration could be introduced into the decision making process.

We proposed to the TSB, at this point, that this body of research will have much greater impact if we are able to shed light on adaptations that are needed to organizations in order for them to be able to engage in adapting to climate change. This has been our intended focus from an outset but we wished to redistribute the resources for remaining phases to develop a 'Manual for Climate Change Adaptation' for large organizations- an illustrated guide to how organizations need to adapt based on this demonstration study.

This proposal was not, however, accepted and we have, therefore, agreed with TSB that in order to fulfil our contract we need to follow the original methodology.

Otherwise the changes arose not so much to the methodology but more to the strategic approach to the CCAS as research evidenced informed the direction of travel

Through early modelling work we identified that the current office spaces in the main museum building were not suitable for climate change adaptation due to the deep plan offices, large areas of party walls that cannot accommodate additional windows, the adjacencies of conditioned spaces which could not be altered without substantial capital investment and the lack of potential for better office layout.

We have, therefore focused our modelling for scenarios on the adjacent 60’s library building which was the favoured relocation site for the offices identified in our concurrent options appraisal for phase one of the Lightwave project.

The modelling indicates that most of the 17 meter deep open plan space could be adapted successful with a very small top up from localized mechanical ventilation and air cooling in the centre of the plan, by developing natural ventilation acoustic grills within the existing external walls and modifying the design of the windows.

This approach proved to be adequate only up to 2050 we have, therefore, altered the strategy to redesign all the windows instead and vary the design to suit the condition of each elevation and room it is serving.

Our initial design approach was to look at a sequential based improvement strategy but facade composite solution found to be more effective.
4.4 List of resources and tools and review of their strengths and limitation

**DesignBuilder versus IES**

DesignBuilder appears to have the capability of being able to model constructions to more detail than IES and in Arups opinion provides better visualisations of the building. There are issues within DesignBuilder, however, which have provide problematic throughout the modelling process although it should be noted that this was our first experience of using the software.

Within the calculation results produced by IES, there is a large volume of data provided to allow a detailed analysis of the calculation to be undertaken. There are also tools within IES which aid in the analysis of the results, such as the ability to show range tests. For the purpose of reviewing the internal temperatures within a room, the range test is able to demonstrate whether the summertime comfort criteria has been achieved by showing the numbers of occupied hours over 28°C. DesignBuilder does not appear to have this function and as such the results file has been extracted from the model and analysed within other software packages.

Profiles within DesignBuilder are also limited depending on which system or gain is looking to be controlled. For example, the heating system can be controlled on a profile to meet the internal temperatures within the occupied hours, with a set-back temperature applied to provide frost protection. This profile, however, cannot be applied to the natural ventilation openings which limits the control of the windows, in particular for night ventilation.

This issue was not truly overcome within the modelling for NMM. The windows are controlled by the internal temperature and are opened fully when the set-point is achieved throughout the course of day and night. In practice it would not be anticipated that the windows would be fully open across the facade at the specified set point. Within IES, there is the ability to control the natural ventilation system on incremental openings and at different set-points across the course of the day which would suit night purge.

We found DesignBuilder easier to use then IES but the interoperability of both software packages with 3D drawings composed by other programs needs to be drastically improved.

**Design builder Limitations:**

We found the following limitations with the Design Builder software:

**Comfort**

DesignBuilder uses the ASHRAE 55-2004 region to determine if a zone is comfortable or not. Times when the combination of zone humidity and operative temperature is outside ASHRAE 55-2004 region are registered as
uncomfortable. The operative temperature of a zone is determined by the
mean of the internal air temperature and radiant temperature. The radiant
temperature is calculated assuming a person is in the centre of a zone with no
weighting for any particular surface.

Taking into account the humidity of a space and the radiant temperature of
objects in it make sense as criteria to judge comfort from. Conditions are
uncomfortable when humidity is very high and the air temperature is lower
than the standard 28 degrees. Conversely when humidity is very low the air
temperature can be degrees higher than 28 [32!] without discomfort been
registered.

Whilst we felt that the considerations Design Builder takes into account whilst
calculating comfort are contributing factors to it, we developed a strong
distrust for the data.

More information can be found here:
http://www.designbuilder.co.uk/programhelp/comfort_analysis.htm

Rain

Design builder is able to recognise when it is raining. Windows can be set to a
schedule when they close when this happens. Unfortunately is only able to
schedule window opening times when a mixed mode ventilation system is
specified and not when an entirely naturally ventilated solution is specified.
Mixed mode ventilation in design builder also places limitations on heating
options.

The primary function of this software is to produce data for the inputs put in by
the user. To this extent the program is focused on achieving the temperature
thresholds that are required of it rather than exploring the performance of
different adaption's, we believe that this could be the reason why no option
exists that will allow natural ventilation and rain to be parametrically linked.

Roof Lights and Rain

Similar limitations apply to roof lights - the model does not recognize that roof
lights must close during rain.

Blinds and louvers don't have dynamic air flows

Two of the composite adaption's that we have modelled have opening
windows/panels and manually adjustable louvers. The louvers are useful to
reduce solar gain but also help to reduce any rain ingress, allowing opening
windows during a downpour. Design builder is not able to simulate the
different effects that the louvers will have on the air flow into and through the
building. It is thus not possible to parametrically link the louver angle and
window opening size. For the purpose of this study we have assumed that the
louvers will reduce the opening area of the window by 50% but this is less
than ideal.

Measuring Temperature

Design builder measures the temperature of a space by averaging the
temperature across a room to a single point. In this building there will likely be
a temperature difference across large spaces that Design Builder will average
out. In reality it is possible that areas next to windows will over heat at certain
times and not get picked up by the model. To overcome this you could divide
a large zone within the building into smaller zones. This was not done in this
instance because it greatly increases the volume of work required to get
information out of the environmental model. The dividing of spaces work
around is also at odds with how other architectural drafting software would
deal with the problem.

Opening times for windows

Design builder assumed that windows are either open or closed and that they
cannot be half opened. In addition to this windows are opened when
temperature gets to a set point - this does not take into account behavioural
patterns such as people opening windows first thing in the morning in
anticipation of a hot day.

Archicad v15

We used Archicad v15 for the initial building model, 2D drawings and 3D model
which was used for illustrative drawings. It was also possible to generate a ‘gbXML’
model to export using a plug-in but this was not used as the basis of the
DesignBuilder model as there were too many discrepancies in the exported data.
This was mainly caused by generating the gbXML from a very detailed CAD model
which was unnecessary for the thermal modelling. It was deemed that it would be
quicker to re-model in DesignBuilder itself rather than attempt to rectify this. This
should be overcome in the future by more awareness of the requirements of thermal
modelling and procedures but further development of cross compatibility is required,
especially for two-way transfer of data. Making this process quicker and easier will
certainly facilitate the collaborative process and ensure that results can have a more
meaningful impact on the design adaption strategy. Using the Industry Foundation
Classes (IFC) format for data exchange was also considered but at the time gbXML
yielded more promising results. However, the IFC protocol is developing strongly and
new releases of ArchiCAD have included more IFC functionality and support.

Prometheus Weather files from University of Exeter versus UKCP02 and 09
For this project we have chosen alternative sources based on the UKCP09 weather generators, the Prometheus file set from Exeter University. The main difference between UKCP02 and UKCP09 is an increase in resolution and a move to probabilistic definitions as opposed to significantly updated climate projections.

Underlying these differences in the data output is a fundamental difference in the way the files were created. The CIBSE files relied on a standard offset in temperature across the entire year so, at any time on any day within the files, the external temperature difference between modelling years would be the same.

However, in the case of the Prometheus files, the monthly change in factors is calculated before models within the UK Climate Projections Weather Generator are applied to generate predictions of future daily weather patterns. This is more accurate data.

**The Adaptive Thermal Comfort, ICT V hours over 28°C**

The adaptive thermal comfort model takes into account that people usually adapt to the temperatures they experience in different seasons thus experiencing a wider range of indoor temperatures as comfortable than specified in standard regulations. It has been most widely applied in naturally ventilated (NV) buildings where a wider temperature range is deemed acceptable. These permit and encourage the use of sustainable passive cooling methods such as natural and mixed mode ventilation, night cooling of buildings, shading of windows and walls, and passive solar systems for winter to regulate temperature within a dynamic range.

Although the techniques and knowledge on how to design buildings to provide effective passive adaption to temperature, in the form of the adaptive model of thermal comfort, are well established, these are as yet not widely adopted because of structural issues in the industry which hinder the diffusion of knowledge and creation of demand. So we continue to use hours over 28°C metric which misrepresents conditions of comfort and exaggerates the number of discomfort hours.

On the basis of the analysis above we would recommend the following tools to be used by others:

- DesignBuilder software - http://www.designbuilder.co.uk/
- ArchiCad software as BIM - http://www.graphisoft.com/archicad/
- CIBSE Guides - https://www.cibseknowledgeportal.co.uk/cibse-guides
- Allowing for tandem working on computer to enable more accurate input and interrogation of assumptions through descussion.
• BUS surveys methodology to gain understanding of user perceptions and comfort in existing buildings - http://www.busmethodology.org.uk/

• Whole Life Cycle Costs as a method to establishing commercial viability

4.5 What worked well and what worked badly and what methodology we recommend for others to use.

What worked well?

• The collaborative work between BLA and Arup- the learning for BLA was considerable since we were, this time, doing our own modelling work with Arup were supporting.

Having the architecture and thermal modelling very closely aligned showed how this approach could benefit projects with a greater emphasis on integrating environmental consideration into design development from an outset, although this would probably be in the form of increased collaboration as opposed to engineers relinquishing the thermal model.

• Using BUS survey at the beginning of the project to gain an understanding of the nature and range of issue affecting comfort perceived and real comfort.

• Holding behaviour change workshop with SMT highlighted that the real barriers to adaptation. These are less to do with costs or technical knowledge of how to do it, but more to do with large organizations not having the structures that allow strategic decisions to be knowledgeably considered.

• Integrating the CCAS into the design options appraisal worked very well since it added a long term perspective to decision making that is usually only informed by short term considerations.

What did not work well?

• Measuring of comfort within Design Builder produced results that were not trusted by the design team and as such needed reprocessing with Microsoft Excel.

• Interoperability of CAD software packages [ArchiCad and Design Builder] proved very difficult to get to work; eventually this resulted in abandoning the idea and rebuilding model from scratch in Design Builder.

• Sizing of windows and % openings took longer than expected because there is no auto generates function and incremental iterative design changes have to be made.

• Difficulties in obtaining data: It was difficult to obtain all the data we needed about energy use because there were no smart meters in the building nor was there any sub metering and some parts of the building were on landlord’s meters. In the year of the study client’s energy went up by £150,000/annum but they did not know why.
Many of the departments were under different directorship and the overall responsibility for services was sub-contracted to Honeywell whose role was to monitor the conditioning of the galleries rather than advise on better use of energy.

- The inaccuracy of data and the likelihood that the commutative effect of inaccurate data can lead to misleading research results. We had the opportunity to do climate change adaptation project in the first round of TSB programme. The two studies were only 18 months apart but even in this short period the omissions scenario shifted from low to high probability.

- Furthermore the comparison between UKCIP P02 weather files and Prometheus weather files highlights the variations in the weather data. We have also found many shortcomings in the modelling software.

- This leads us to believe that whereas the results of long term modelling should be used with caution, the TSB studies should be collated and a design guide should be written that establishes design principles for climate change adaptation so that designer can learn how to think differently.

- The level of engagement by the client was under constant pressure from the ongoing reorganization of staff in search for cost reductions. There was no clear structure for decision making and there was no individual to champion the CCAS.

Recommendations to others

We recommend that examining the needs, priorities and opportunities for an organisation should be standard practice at the start of any project, whether that is related to adaptation or other aspects.

The collaboration of design team, client and change-management specialist should be the way forward. A building project is a huge investment which is occasionally entered into for the wrong reasons or has the wrong scope as organisations have not embraced the possibility of change in other aspects of the way companies operate.

We would also recommend that architects should operate environmental modelling software and have full understanding of the data that is used.

This requires rethinking of the relationship between architects and service engineers with a view to much greater day to day collaboration on design.

4.6 Decision making process by the client on implementing the recommendations and what were the best ways of influencing them.

The decision making process by the client worked reasonably well in the early stages of design work, but deteriorated and fell apart before implementation stage was reached.

The CCAS project was woven into design stage in which we were exploring the options for expansion of the Museum and it was adding value to the decision making. At this stage we had great deal of cooperation from the Director of Development who
was our day to day contact. It was through him that all the data was collated and the workshops with staff arranged.

We also had cooperation from The City Council who owned the City Library which was to be transferred to the NMM.

There was openness in the NMM organization to our questions and we were able to obtain what information existed (although a lot of what we needed did not exist in a useful format.)

The early findings were presented to senior management team and all seem to be on board with the questions we were asking.

At this stage we were able to influence client thinking by being able to illustrate that they could save significant amount of energy in the future and that the initial capital investment could be offset by savings in the maintenance costs and in the energy savings. It was also apparent that there was great value to the Senior Management Team in the Building in Use Survey we conducted to obtain feedback from their staff. We had 90% response for the 100 staff so that a very accurate picture emerged about the need to improve the comfort of the team.

The CCAS study influenced the final choice to move the staff to the Library building. In this sense the study was successful in alerting the client to new ways of thinking about climate change,

However as we continued the research we encountered a number of structural problems within NMSI.

Some of the issues are listed below:

1. **Structure of the organization**
   
   NMM was, at the time of the study one of four museums in an umbrella organization National Museums of Industry and Science (NMSI). The decisions regarding investment into the fabric were split between the two organizations in that NMS had to bid each year to NMSI for maintenance funding. Capital funding did not exist as a pot of money to bid for- it could only be secured through projects route- priorities for projects were set by NMSI not NMM and we had no direct route to NMSI

2. **Organizational priorities**
   
   The priorities for NMM and NMSI were the Collections and The Visitor Experience. The running costs, although of concern, where not on an immediate priority list for the organization. Climate change adaptation did not even feature on planning for the future.

3. **Decision making in the organization**
NMSI Enterprise was the organization within NMSI responsible for all facilities management issues - they were the ones holding the maintenance and project funding. The organizational structure consisted of Chief Operating Officer (located in London), supported by Head of Estates (London) supported by Head of Estates North (York) supported by Project managers in York responsible for Estate Projects of which NMM was one. We had good contact with Head of estates north, but had no access to the layers above where the ultimate decision on funding would be made.

4. Lack of stability within the organization

At the time of our study this structure was undergoing major changes with a number of key appointments pending and some staff acting up on a temporary basis. There was literally no one who could make a final decision about investment and it appeared that due to maternity leave and dates for reorganization this situation was to continue for another 12-18 months.

5. Lack of Strategic Plan for Environmental Sustainability

The organization did not have a plan for reducing energy or improving use of other resource, despite having a sustainability officer.

6. Ownership of decisions

Within NMI we had good access to different departments: Collections, Programme and Visitor Experience. However some of the key operational strands such as cleaning, security, services, catering and ICT were subcontracted out. This seemed to have created a culture of silos with no one being able to take full responsibility for driving through new thinking.

7. Organizational knowledge of Climate Change and sustainability issues

There was very little understanding of energy, sustainability, and climate change issues within the organization. The sustainability officer was appointed as an internal candidate having previously been exhibitions technician at the museum. His main area of activity was to carry out small projects to reduce carbon omissions such as installing LED lighting.

8. BMS

The tools already available to the museum, such as BMS, was only used to control the conditioned spaces rather than to monitor and find savings in energy use - this was symptomatic of lack of optimisation of thinking and planning throughout the organization.

We have not succeeded in implementing the recommendations because the NMSI, (subsequently Science Museum Group- SMG) the decision making organization, was undergoing major restructuring and there was no route available for strategic
decisions. SMG subsequently encountered major financial problems and the investment into expansion of NMM was suspended.
Section: 5  Extending Adaptation to other buildings

5.1 Overview

This adaptation strategy could apply to all spaces on a floor by floor basis as well as to whole buildings, which are experiencing, or will experience in the future, problems with overheating.

The strategy is likely to be most successful in buildings that are ‘inherently sustainable’ and have the following features:

- High ceilings
- High thermal mass
- Shallow floor plates
- Potential for increasing natural ventilation
- Good daylight penetration
- Orientation

There are many buildings in the country that still have considerable life expectancy and have good passive design elements built in already: mass, high ceilings, narrow depths, good daylight and potential for natural ventilation, which represent excellent potential for achieving low carbon adaptation strategy. This applies especially to 60's buildings that have ribbon window designs. The large window area, although good for daylight and natural ventilation, make this building typology especially vulnerable to overheating - the biggest climate change risk for buildings.

The floor by floor approach could be applied to various areas of a wide range of buildings, from housing and education to offices, areas of retail and industrial, even in buildings which cannot be adapted in their entirety. Also it is possible to adapt selectively only those elevations most adversely effected.

5.2 A description of limitations of applying it to other buildings

The proposed adaptation strategy will not work for the following buildings:

- Deep plan that cannot be modified through insertion of courtyards/atria or ventilation stacks.
- Buildings that are hermetically sealed due to any number of requirements such as acoustics, pollution, security or building function.
• Buildings that have low floor to ceiling heights.
• Buildings with low thermal mass or with covered up thermal mass.
• Buildings that require cellular office spaces.
• The strategy may also have limited appeal for buildings where the costs of such a strategy would exceed the costs of additional air conditioning. Contemporary buildings of glass and steel may well fall into this category.

5.3 An analysis of other buildings that may benefit in England?

There is an estimated stock of 566 million m² of commercial buildings in England and Wales. Many of these buildings would benefit from climate change strategy to improve their performance and commercial viability.

Around 60% of the non-domestic buildings in use today will still be in use in 2050 according to The Carbon Trust. Of the £46 billion in the Investment Property Databank (IPD) Office Index, over 90% is more than 10 years old. As such, the building stock, therefore, is highly unlikely to be carbon efficient or comply with current or forthcoming legislation. Over the next five years, 33% of the leases in the UK market will expire. Verdanix estimates the total potential addressable market for the green retrofits to be £14 billion of investment over this period representing in the region of £820 million of annual rental income.

The buildings most likely to benefit from adaptation come in 4 broad categories:

1 Buildings constructed to function without air conditioning but expected to overheat due to rising temperature and increasing internal gains;
2 Buildings constructed with air conditioning necessitated by extensive use of glass;
3 Buildings with air conditioning necessitated by acoustic issues that may change as we move towards electrical transport, pedestrianisation, and changing priorities.
4 Buildings which are inherently low carbon but have mechanical cooling installed for a variety of historic reasons such as:
   • the market expectations of the A grade office specification;
   • the quota of renewable energy required by Planning Departments that inadvertently encourages installation of air source heat pumps whose high capital and running costs are often justified to the client on the grounds that the system can provide both heating and cooling;
   • Legislation (such as Building Regulations) that tolerates air conditioned building and encourages ever increasing insulation and air tightness.
   • Poor design practice arising from inaccurate assumptions and broad-brush approach to modelling practice.
5.4 Resources and tools and materials you developed through this contract for providing future services.

Resources/Tools

- BUS methodology for obtaining user feedback
- Techniques for assisting organizations to develop understanding of environmental priorities and options
- We have developed and understanding, previously available only to engineers, of BSM and their underutilised potential. We can now ask intelligent questions of FM and users.
- We have invested in training all architects in our practice in the use of environmental modelling software DesignBuilder are building our own library of environmental data.
- Services- We have separated services design from building physics and now take responsibility for shaping the environmental performance brief as part of the design stage. Service engineers are engaged purely to design the systems based on environmental brief generated by ourselves.
- The biggest resource is the increased understanding of the intricacies of how modelling works and the effects of design change on overheating. We now incorporate CCAS into our design both on new build and refurbishment projects.
- We have received some new commissions from national utility company who are attempting to meet their carbon omission savings targets but are not managing. We were recommended because of the TSB research. We have learned the discipline of research and are now developing a strong strand of research as part of the practice offer.
- We are also incorporating the adaptation knowledge into design and teaching at the School of Architecture in Sheffield.
5.5 Further needs you have in order to provide adaptation services?

- We need a clearly coordinated industry standard for assessing climate change risks.

- There is a large need for a methodology to be developed for non-modellable adaptations to be evaluated with the same accuracy as those that can be modelled.

- There is a need for the use of BIM to be accelerated as this will help to create a much greater understanding of the issues within the team and contractor.

- We also need the results of all case studies to be widely disseminated with whole life costs data to help make the case for adaptation in preference to additional air cooling/conditioning.

- We need to invest in software and training of all architects in the practice to use environmental modelling software to allow us to get the design right from the outset.

- The RIBA needs to modify the RIBA Work Plan to reflect the different approach to work stages in adoption work and to develop a fee scale.

- There is need to create a number of CCAS demonstrator projects and evaluate their performance over the next decade.

- There is a need to review existing guidance and regulations such as BREEAM, CHS and Building Regulation to reconcile some conflicts, such as view of the sky (CHS) with overheating problems.

- BIM interoperability standards between CAD programmes need to be firmed up to enable efficient fluid working between different packages. AUTO DESK and REVIT (who are market leaders in the UK) are not keen on using open data format standards to enable fluid working with other packages.