TECHNOLOGY STRATEGY BOARD: DESIGN FOR FUTURE CLIMATE: ADAPTING BUILDINGS

Adapting Dragon Junior School for Future Climate

Final report

Revision 2 – 18 February 2014

Submitted to:

The Technology Strategy Board

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Contents

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Funding:

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Period:

- November 2011 – November 2013

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- Ian Caws - Bursar
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List of abbreviations

BREEAM	Building Research Establishment's Environmental Assessment Method
CO_2	Carbon Dioxide
CoP	Coefficient of Performance
CIBSE	The Chartered Institution of Building Services Engineers
DEFRA	The Department for Environment, Food and Rural Affairs
D4FC	Design for Future Climate
DRY	Design Reference Year
DSY	Design Summer Year
GHG	Greenhouse Gas
HTM	Health Technical Memorandum
IPCC	Intergovernmental Panel on Climate Change
kWh	kilowatt-hours
Ofsted	Office for Standards in Education
ppm	parts per million
RH	relative humidity
TRY	Test Reference Year
UKCP09	UK Climate Projections 2009

Executive Summary

This report describes the development and testing of technically-feasible and practical climate change adaptation (CCA) strategies for Dragon Junior School at Oxford, a 2060m^2 school to house 180 children between the ages of 7 to 9 (years three and four). It is designed as a stand-alone school with classrooms, informal learning spaces, library, IT facilities, a school hall and dining area, changing rooms, play and garden spaces. The proposed building is located on the site of the existing school on an existing astro turf site.

Led by Ridge and Partners LLP, this Design for future climate project has been collaborative involving researchers from the Low Carbon Building Group of the Oxford Institute for Sustainable Development, Oxford Brookes University, design team and the client. Key outcomes of the project include the development of skills and innovative design solutions in CCA amongst the design team members, and a knowledge base on costs and valuation of benefits of adaptation measures. The report meets the requirement of the 'Final Report Specification' outlined in Section 7 of the Technology Strategy Board's contract with Ridge and Partners for the project.

Project Client

The Dragon Preparatory School (for 8-13 year olds), together with the Dragon Pre-Preparatory School, Lynams (for 4-7 year olds), is one of the best known schools in the country and numbers amongst its former pupils a very wide range of successful men and women. Currently situated on two sites in leafy North Oxford, its roots lie in progressive educational theory of the late nineteenth century. Founded as the Oxford Preparatory School in 1877 the school was started by a group of Oxford University dons for their own children. Run for many years by the Lynam family, the Dragon reflected their unconventional approach to education which was based on the belief that children should enjoy school and understand the world around them.

The School today reflects its radical roots and has an ethos that hinges on a dynamic balance of relaxed unpretentiousness and academic discipline which has been described as 'robust informality and relaxed rigour'. Children's needs are at the heart of the Dragon and pastoral care is paramount; discipline relies on common sense, kindness and individual responsibility. The joy of learning and the fun of childhood exploration are shared throughout a warm school community where every child is encouraged to try everything and do his or her best.

School life centres on a broad curriculum designed and delivered by a large, very well qualified teaching staff. A huge range of after school activities and clubs extend timetabled subjects and games with every kind of interest and activity. An outstanding sporting school, the Dragon fields strong teams across the board of competition while offering a programme that includes and encourages every level of ability. The extensive Dragon music programme mirrors this in breadth and diversity with orchestras, choirs, bands and performances of every kind.

Boys and girls leave the Dragon, usually at thirteen, to join the finest independent senior schools – a great many with scholarships and awards across the range of academic, cultural and sporting achievement. Former pupils maintain Dragon friendships into adult life and retain a strong affection for the school returning with pleasure for school occasions.

For the past fifty years the Dragon has been a charitable trust dedicated to providing all that is best in education for boarding and day children up to the age of 13. The school is administered by a governing body.

Why the Dragon?

In 2010 Ridge won a competition to design a new building to accommodate 180 children between the ages of 7 to 9 (years three and four). This is intended to place Year 3 students on the same site as the older pupils for the first time grouping them with Year 4. This Junior School is to provide both Year 3 and Year 4 the teaching and independent learning pedagogy of the upper years, whilst integrating them into the heart of the Dragon School site.

Working with Ridge the brief has developed to include providing a music school on the same site adjoining the junior school building, as part of a phased master plan, but this does not form part of this study.

The Dragon is one of the most successful junior schools in the country. It is an Ofsted “Outstanding” school and caters for children between the ages of 4 to 13. The need for a new “Junior School” is to provide new premises for years three and four ie 7 to 9 year olds who currently housed on separate sites. The Governors appointed Ridge and Partners after a competitive interview on the basis of the proposals for a School for the Future. This concept which is based upon adaptability and flexibility encompasses all aspects of the project including curriculum development, carbon management and building fabric design. The client is fully committed to the building concept as it accords with the guiding principles of the School 2009 -2020. As described in the letter of intent, the client is fully committed to participating in this project, viewing it as an excellent opportunity to develop an exemplar scheme future-proofed for a changing climate, and capable of delivering long-term benefits and adding value to the building

The Governors have expressed a desire to achieve a low energy sustainable building which makes use of renewable resources. The project will be subject to the Natural Resource Impact Analysis of the Oxford Local Plan and a BREEAM award of (a minimum of) ‘Very Good’ is targeted. The building project will also be guided by the Schools overarching Guiding Principles 2009-2020 which confirms it’s commitment to reduction of carbon and the “aspiration to achieve carbon neutrality”. The current environmental design strategy indicates an improvement over 2006 Building Regulations CO2 emission rate by 50%.

The Dragon School set a clear aspirational brief with a strong green agenda. The school wishes to use renewable technologies where possible and maintain low levels of operational energy, while providing high levels of internal comfort appropriate for the teaching environments they maintain. These requirements are being quantified through IES thermal modelling and energy assessments feeding into a formal BREEAM assessment.

The principle contacts at the school during the design development have been:

- John Baugh - Headmaster
- Ian Caws - Bursar
- Steve Poyntz - Estates Bursar

Design team meetings and workshops took place with all key stakeholders at regular intervals where brief and design developments were reviewed. During these meetings the Design for Future Climate Change Study was introduced, explained and considered.

What is your building profile?

The gross internal area of the new Dragon School is 2060m^2 and is arranged over two floors. For floor plan layouts please refer to the architectural drawings in section 8 of appendix 1. It is compact in form with learning spaces and the hall forming an L shape which encloses a more free form flexible informal learning space which is the main circulation area and source of light and ventilation to the internal spaces. The library and ICT spaces are at the centre of the building and designed to be flexible and inviting. The central staircase is placed within a large light well which allows daylight into the heart of the school; it is also a route for natural ventilation. The shared spaces such as the Art room, music rooms and upper roof garden will encourage movement between floors in a controlled way. We have imagined the common area as a dynamic, shared space that is stimulating in form and a pleasure to move through. Roof garden, canopy and shading create protection from the sun, shelter from wind and rain and enclosure for outdoor learning and play areas. Play structures and equipment extend into the playground. The concept that the Dragon School are pursuing is that of a School for the Future; this is intended to be a school which is designed to be flexible and adaptable over its lifetime and needs to be designed with change in mind.

What is the risk exposure for your building/s to the projected future climate?

The risk exposure of the building to the projected future climate was assessed using a risk based analysis approach (hazard, exposure and vulnerability) under three risk categories: thermal comfort (including energy), construction and water. Thermal comfort risk was initially assessed based on three overheating benchmark (CIBSE Guide A, Building Bulletin 101 (BB101) and BS EN 15251 Standard). CIBSE Guide A benchmark was then selected to evaluate the performance of adaptation measures using dynamic building simulation tool. The energy implication of adaptation measures were also simulated and the energy saving/penalty were fed into cost benefit analysis, which also included adaptation strategies for construction stability and water management.

What is the adaptation strategy for your building/s over their lifetime to improve resistance and resilience to climate change and thus extend the commercial viability?

The adaptation measure for the Dragon School assessed on following five criteria:

- Measures already included in the design (1);
- Measures that should be considered for inclusion in the design (2);
- Measures that could be retrofitted in the future but implication worth considering for present design to avoid compromising this possibility (3);
- Measures that could be retrofitted in the future but need no action at present (4);
- Measures not suitable for inclusion (5);

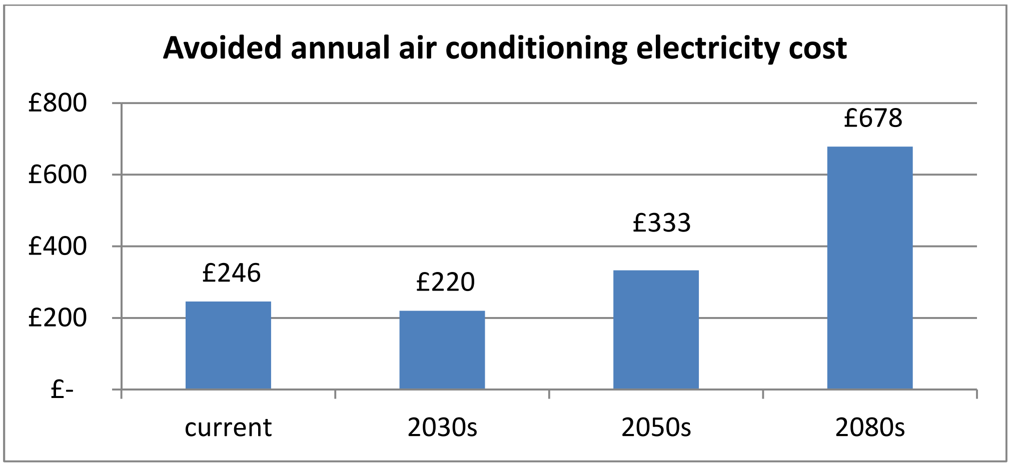
Based on the cost benefit analysis of all these measures, clients are in favour of following measures as they could potentially have significant amount of savings over building life time.

- Secure and bug free night ventilation
- External Shading
- Low water use fittings
- Rain water collection
- Robust construction

Most of above measures do not have potential saving in money or defined payback periods as the adaptation measures provide a reduction in overheating alone rather than reducing defined energy consumption. However low water use fittings and rainwater collection can reduce significant amount of water usage.

Avoided air conditioning operating cost

If there is no adaptation measures applied to the school in future, air conditioning will be needed for avoiding overheating in 12 classrooms in future. The predicted annual electricity costs for air conditioning units are £333 in 2050s and £678 in 2080s respectively. This is based on the assumption of 3.2 COP and 16.3p per kWh electricity price (average price of electricity for the Big 6).



What is the best way to conduct adaptation work?

To develop adaptation measures the following methodology was developed:

1. Understanding the changing climate;
2. Climate change risks identified for Dragon School;
3. Desktop research and simulation of adaptation measures (from projects and D4fC programme):
   Dynamic thermal simulation showed the overheating implications of each adaptation measure using future weather years, and helped to inform our thinking as to which adaptation measure minimised the overheating risk now, and in the future;
4. Options appraisal and selection of suitable adaptation measures:
   a. Project team workshop was held for grading adaptation measures, drawing on results from modelling, collective wisdom and practical implementation.
   b. Workshop helped to develop a list of selected adaptation measures that have been included in the baseline model already, measures that could be implemented now, or measures that could be implemented in the future (and measures that could not be implemented or are irrelevant);
5. Energy savings of selected adaptation measures;
6. Detailed design of selected adaptation measures and cost benefits of selected adaptation measures;
7. Uptake of adaptation measures by the client: Project team workshop was held with the client to discuss which measures can be implemented now, or in the future, using findings from:
   - Simulation
   - Estimate of energy savings
   - Cost benefit analyses
8. Implementation of adaptation.

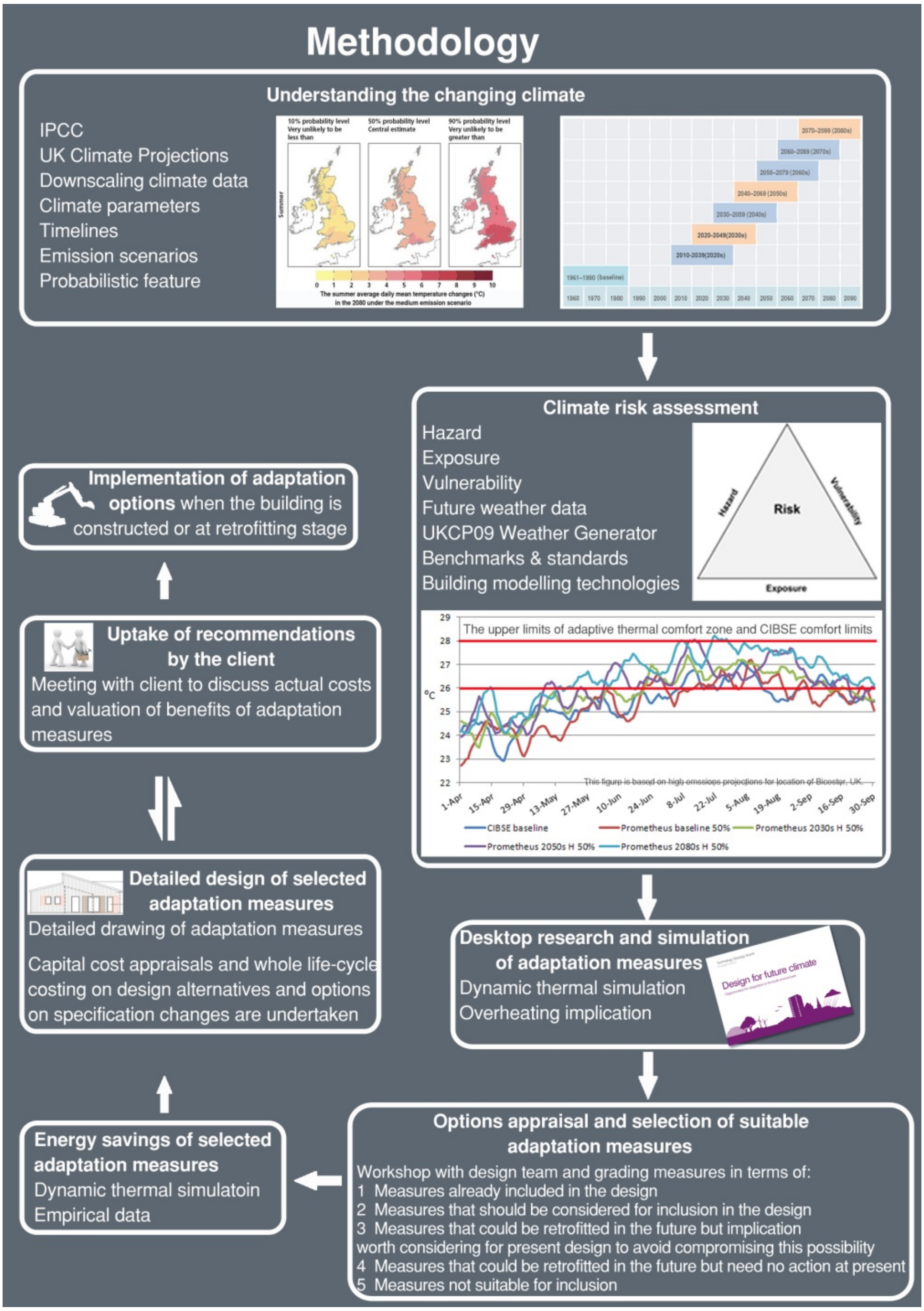


Figure 1 Methodology

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

The methodology for climate change risk assessment based on the UKCP09 projections is developed. Such methodological approaches could be applied to other buildings and building projects. For large multi-building development projects, selection of case studies may be required to reduce the amount of building energy and overheating simulation work. The selected case studies may be the worst performing or most vulnerable case buildings or/and typical building archetypes. The selection of overheating benchmark may differ depending on the building usage. A cost benefit checklist of adaptation measures (section 3.4) is developed and it could help designers and clients quickly identify the most cost effective adaptation measures. As most of measures are for improving indoor comfort environment, there is not direct payback in term of money. The adaptation measures can avoid the energy bills for air-conditioning if the building equipment air-conditioning in future.

Summary of potential savings, measures considered, recommended and implemented

- Measures already included in the design (1);
- Measures that should be considered for inclusion in the design (2);
- Measures that could be retrofitted in the future but implication worth considering for present design to avoid compromising this possibility (3);
- Measures that could be retrofitted in the future but need no action at present (4);
- Measures not suitable for inclusion (5);
- Measures that be implemented in the design stage through this study (6);

Table 1 Grading of adaptation measures

	No.	Adaptation measures	Grading
Designing for comfort		Keeping cool - internal	
	1	Shading - manufactured	2 and 6
	2	Shading -building form	1
	3	Glass technologies	1
	4	Film technologies	2
	5	Green roofs/ transpiration cooling	1
	6	Shading - planting	2
	7	Reflective materials	2 and 6
	8	Conflict between maximising daylight and overheating (mitigation vs adaptation)	2 and 6
	9	Secure and bug free night ventilation	2 and 6
	10	Interrelationship with noise & air pollution	1
	11	Interrelationship with ceiling height	1
	12	Role of thermal mass in significantly warmer climate	1
	13	Enhancing thermal mass in lightweight construction	1
	14	Energy efficient/ renewable powered cooling systems	1/3
	15	Groundwater cooling	2
	16	Enhanced control systems - peak lopping	
	17	Maximum temperature legislation	1
		Keeping cool - spaces around	
	18	Built form - building to building shading	1
	19	Access to external space -overheating relief	1
	20	Shade from planting	1
	21	Manufactured shading	2
	22	Interrelationship with renewables	1
	23	Shading parking/ transport infrastructure	1
	24	Role of water - landscape/ swimming pools	5
		Keeping warm at less cost	
	25	Building fabric insulation standards	1
	26	Relevance of heat reclaim systems	1
	27	Heating appliance design for minimal heating - hot water load as design driver	1
g for		Structural stability -below ground	

	28	Foundation design - subsidence/ heave/ soils/ regions	1
	29	Underpinning	1
	30	Retaining wall and slope stability	1
		Structural stability -above ground	
	31	Lateral stability -wind loading standards	1
	32	Loading from ponding	1
		Fixings and weatherproofing	
	33	Fixing standards - walls, roofs	2
	34	Detail design for extremes - wind - 3 step approach	2
	35	Lightning strikes (storm intensity)	2
	36	Tanking/ underground tanks in relation to water table contamination, buoyancy, pressure	2
	37	Detail design for extremes - rain -thresholds/ joints	2
	38	Materials behaviour in high temperatures	2
		Construction - materials behaviour	
	39	Effect of extended wetting -permeability, rotting, weight	2
	40	Effect of extended heat/ UV -drying out, shrinkage, expansion, de-lamination, softening, reflection, admittance, colour fastness	2
	41	Performance in extremes - wind - air tightness, strength, suction/ pressure	2
	42	Performance in extremes - rain 2	2
		Construction - work on site	
	43	Temperature limitations for building processes	5
	44	Stability during construction	2
	45	Inclement winter weather -rain (reduced freezing?)	2
	46	Working conditions -Site accommodation	2
	47	Working conditions - internal conditions in incomplete/unserviced buildings (overlap with robustness in use)	2
Designing to manage water		Water supply/ conservation	
	48	Low water use fittings	2 and 6
	49	Grey water storage	2
	50	Rain water storage	1
	51	Alternatives to water based drainage	2
	52	Pools as irrigation water storage	5
	53	Limits to development	1
	54	Water intensive construction processes	2
		Drainage - external	
	55	Drain design	2
	56	Soakaway design	2
	57	SUDS design	2
		Drainage - building related	
	58	Gutter/ roof/ upstand design	2
		Flood - Avoidance	
	59	Environment Agency guidance -location, infrastructure	1
	60	Combination effects -wind + rain + sea level rise	2
		Flood - Resistance/ resilience	
	61	Flood defence – permanent	5
	62	Flood defence - temporary -products etc	5
	63	Evacuation/self sufficiency	5

	64	Flood tolerant construction	5
	65	Flood tolerant products and materials	5
	66	Post-flood recovery measures	5
Designing for landscape		Landscape	
	67	Plant selection - drought resistance vs cooling effect of transpiration	2
	68	Changes to ecology	2
	69	Irrigation techniques	2
	70	Limitations on use of water features - mosquitoes etc	5
	71	Role of planting and paving in modifying micro climate & heat island effect	2
	72	Failsafe design for extremes - water	2
	73	Firebreaks	5

1 Building Profile Dragon Junior School

1.1 The project

The Dragon was founded in 1877; it is one of the most successful junior schools in the country. The founders were visionary educationalists and were pioneering in their approach and this ethos is still at the heart of all that the Dragon does. The School is at the forefront in terms of curriculum development, pastoral care and social responsibility.

It is an Ofsted "Outstanding" school and caters for children between the ages of 4 to 13. The need for a new "Junior School" is to provide new premises for years three and four i.e. 7 to 9 year olds who are currently housed on separate sites. The Governors appointed Ridge and Partners after a competitive interview on the basis of the proposals for a School for the Future. This concept which is based upon adaptability and flexibility encompasses all aspects of the project including curriculum development, carbon management and building fabric design. The client is fully committed to the building concept as it accords with the guiding principles of the School 2009 -2020. As described in the letter of intent, the client is fully committed to participating in this project, viewing it as an excellent opportunity to develop an exemplar scheme future-proofed for a changing climate, and capable of delivering long-term benefits and adding value to the building.

Figure 2 Location of Dragon School

The new Dragon Junior School will make use of the existing playground (Figure 2), located on the south end of the school. The site is bounded to the west by residential buildings, to the east by playground and beyond that, the River Cherwell, to the south and north by existing buildings in the school. The main route used by students and staffs to the site is from Bardwell Road. There is also a secondary access off Norham Road. Bus stops are available within 0.3 miles distance on A4165.

1.2 The building

The building project is for a new Junior School (Figure) to house 180 children between the ages of 7 to 9 (years three and four). It is designed as a stand-alone school with classrooms, informal learning spaces, library, IT facilities, a school hall and dining area, changing rooms, play and garden spaces. The building will be located on the site of the existing school on an existing astro turf site. The self-contained school will provide an important "stepping stone" for this age group before moving to the upper school which accommodates in excess of 500 children.

The gross internal area of the new Dragon School is 2060 square metres and is arranged over two floors. It is compact in form with flexible informal learning spaces and the hall forming an L shape which is the main circulation area and source of light and ventilation to the internal spaces. The library and ICT spaces are at the centre of the building and designed to be flexible and inviting. The central staircase is placed within a large light well which allows daylight into the heart of the school; it is also a route for natural ventilation. The shared spaces such as the Art room, music rooms and upper roof garden will encourage movement between floors in a controlled way. We have imagined the common area as a dynamic, shared space that is stimulating in form and a pleasure to move through. Roof garden, canopy and shading create protection from the sun, shelter from wind and rain and enclosure for outdoor learning and play areas. Play structures and equipment extend into the playground.

Figure 3 Dragon Junior School, Oxford (Ridge and Partners LLP 2013)

The concept that the Dragon School are pursuing is that of a School for the Future; this is intended to be a school which is designed to be flexible and adaptable over its lifetime and needs to be designed with change in mind. The aspiration is for a building which is fit for purpose for many years. The school is taking a long term view of the building and overall site and is aware of the likelihood of change in the short, medium and long terms. Such changes which are under consideration which are informing the design are; changes in educational curriculum, class sizes, personalised learning approaches, development of IT functionality, environmental change, energy costs, water conservation, indeed all aspects of the building project are under consideration to develop a robust future proof building.

We envisage a framed structure to the classroom and hall component with floors offering good sound separation and thermal mass for stable temperatures. We see the freeform component made from timber exposing this to celebrate the structure and material. The main freeform facade will be in glass with shading devices and a combination of timber and steel structural details. This will express the qualities of materials and lend the building both a serious and friendly character which will age well. We see the formal wings which relate more to the north Oxford context and the existing school to be in brickwork and finished with high quality modern detailing around windows and junctions to continue the local vernacular in a contemporary way. Our design approach is based upon passive principles and a long term view. The building will be fully designed and procured under a traditional form of contract.

The extensive use of glazing promotes the distribution of natural daylight. Whilst reducing operating hours (and therefore energy consumption) of electrical lighting, natural daylight has a proven beneficial effect on occupant wellbeing and productivity. To counteract the negative impact of glazing through solar heat gain, shading devices have been simulated to reduce overheating by up to 50%. However this needs to be tested for a changing climate. The opportunity for natural ventilation through sufficient openings and efficient room design significantly reduces the energy consumption of the building, and negates the requirement for an extensive air conditioning or cooling system. Openings of 30% throughout all glazing including the rooflight have been proven through simulation to enable the teaching spaces to pass the requirements of Building Bulletin 101 for internal environmental temperature conditions. Utilising efficient heat pumps connected to an underfloor heating system, the building has the opportunity to improve upon 2006 Building Regulations' target CO_2 emission rate by up to 40%.

1.3 Context

A Planning Application for the New Music School and Junior School at the Dragon School, Oxford is about to be submitted for consideration for approval by the Local Authority. In the first part of this report we will outline the design principles and concepts for the project including; how much development is proposed; the layout, scale, landscaping and appearance of the development.

We will attempt to explain and expand upon the design thinking behind the planning application, including showing how we have carefully thought about how people use the new buildings and site.

We will also demonstrate how the local context has influenced the design, how materials and landscapes in the area have informed our ideas and how the proposal fits in with the character and urban fabric of the area.

This is accompanied by a background analysis of the site and the surrounding area as well as a summary of the main issues and opportunities that have been analysed through assessment processes including; Natural Resource Impact Analysis (NRIA), BREEAM Pre-assessment and strategies for Lower and Zero Carbon Systems (LZC).

The document sets out the design principles of the building scheme, as well as the landscape scheme principles and opportunities. Also how the design has been informed by studies undertaken to date, including, Ecology, Arboriculture, Geology, Hydrology and Acoustic analysis.

1.4 Proposed Summary

The proposed design forms a new external quadrangle on the main campus of the school. To the north side a new music school building is located adjoining the existing main school hall.

On the south side a new Junior School building brings the Year 3 and Year 4 pupils onto the main campus in an integrated but secure environment.

An enhanced landscape setting will deliver new learning and play environments in the external spaces formed by the project, including the quadrangle, the space adjoining Dragon Lane, part of the existing astro-turf pitch and the roof of the Junior School building.

The Junior School incorporates:

- A school hall for assembly, lunch, teaching and performance
- Year 3 classrooms
- Year 4 classrooms
- Open plan learning areas
- An art room
- Changing rooms for games

Figure 4 Aerial view of the Dragon School looking from the east

1.5 Site Location

The Dragon School main campus and the proposed site are located in the North Oxford Conservation Area, on the west side of the River Cherwell, between Bardwell Road and Benson Place. To the northern boundary of the school is the Cherwell Boathouse with Wolfson College beyond, to the southern boundary Norham Flats and Lady Margaret Hall. To the west are; Dragon Lane and the rear gardens of Park Town Crescent, while to the east the school playing fields and the flood plain of the River Cherwell.

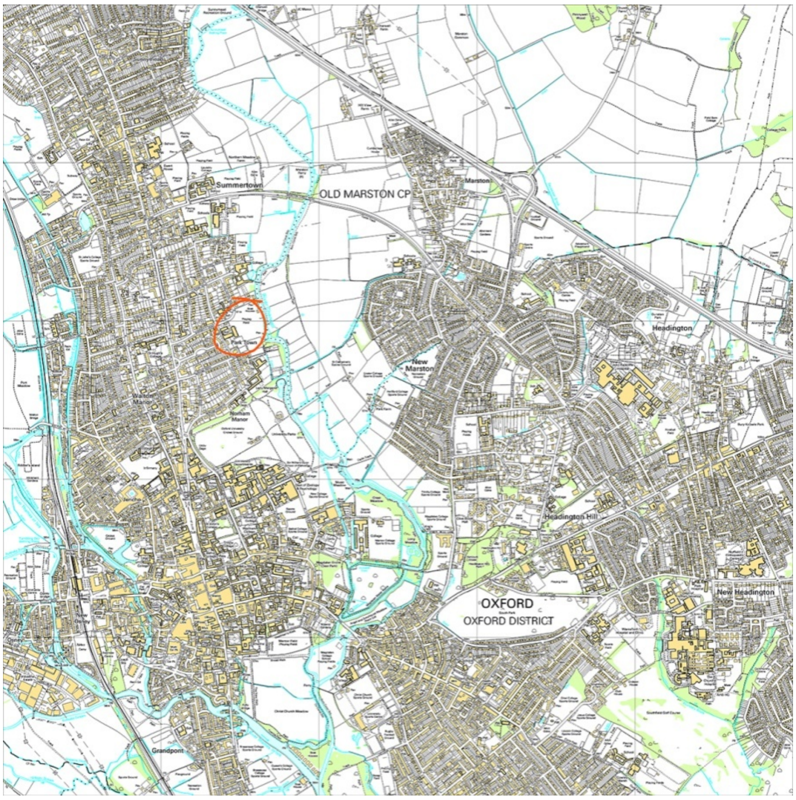


Figure 5 Location Plan

1.6 Social and Economic Context

The Dragon School is a Preparatory School for 4 to 13 year olds. It is currently split across two sites with ages 4 to 7 (Years 1 to 3) located at Lynams Junior School away from the main campus.

This proposal aims to bring the Junior School onto the main campus by moving Year 3 from Lynams School and Year 4 from across Bardwell Road. The Music School, adjoining the Junior School on the proposed scheme, is also relocated from the periphery into the heart of the main campus.

The Dragon School's roots lie in progressive educational theory of the late nineteenth century. Founded as the Oxford Preparatory School in 1877 the school was started by a group of Oxford University dons for their own children. Run for many years by the Lynam family, the Dragon reflected their unconventional approach to education which was based on the belief that children should enjoy school and understand the world around them.

The School today reflects its radical roots and has an ethos that hinges on a dynamic balance of relaxed unpretentiousness and academic discipline which has been described as 'robust informality and relaxed rigour'. Children's needs are at the heart of the Dragon and pastoral care is paramount; discipline relies on common sense, kindness and individual responsibility. The joy of learning and the fun of childhood exploration are shared throughout a warm school community where every child is encouraged to try everything and do his or her best.

School life centres on a broad curriculum designed and delivered by a large, very well qualified teaching staff. A huge range of after school activities and clubs extend timetabled subjects and games with every kind of interest and activity. The extensive Dragon music programme has orchestras, choirs, bands and performances of every kind. Bringing the Junior School and the Music School into the centre of the school, will partly integrate and manage the transition of younger pupils into the main body of the school and re-enforce the importance of the performing arts within the Dragon.

For the past fifty years the Dragon has been a charitable trust dedicated to providing all that is best in education for boarding and day children up to the age of 13. The school is administered by a governing body.

1.7 Surrounding Land Uses and Development

A: North - School campus to the north of Bardwell Road with residential areas beyond.

B: East - School playing fields, the river, pasture and recreation grounds

C: South - Norham Flats, Lady Margaret Hall and University Parks

D: West - Dragon Lane, Park Town and Banbury Road

Figure 6 Land Use and Access

1.8 Landscape Context

The proposed new buildings are located on the boundary between the city and the ‘countryside’ where the suburb of North Oxford meets the flood plain of the Cherwell. It is along this east west boundary formed by The Cherwell River that many of Oxford’s colleges and recreation grounds are located; from St Catherine’s and Linacre College in the south, via University Parks to Lady Margaret Hall, Wolfson College and The Cherwell School in the north.

The North Oxford Conservation Area is a leafy suburb with broad streets, large period homes and mature trees. The flood plain and riverside is characterised by open meadows, hedges and trees. Dragon Lane at the boundary between these areas is a cut through between Bardwell Road and Benson Place. Here the back gardens of Park Town Crescent end and the school buildings and playing fields begin. At the Bardwell Road end the school buildings are constructed right up to the edge of the lane; at the Benson place end the lane becomes a pedestrian route with hedges and trees with set back buildings. The character of Dragon Lane is that of a cut through, a ‘back’ area with a semi-rural, informal feeling.

The landscape proposal for the setting of the new building will retain this character routing pupils and parents through the main entrance of the school on Bardwell Road and introducing additional appropriate planting. The timber from trees lost to the new buildings will be re-used in the new external spaces created by the project. The landscape strategy for the project extends to the wider school area with proposals to introduce new areas of tree planting to enhance the wider views and spaces of the school whilst mitigating against the loss of a few mature specimens**.**

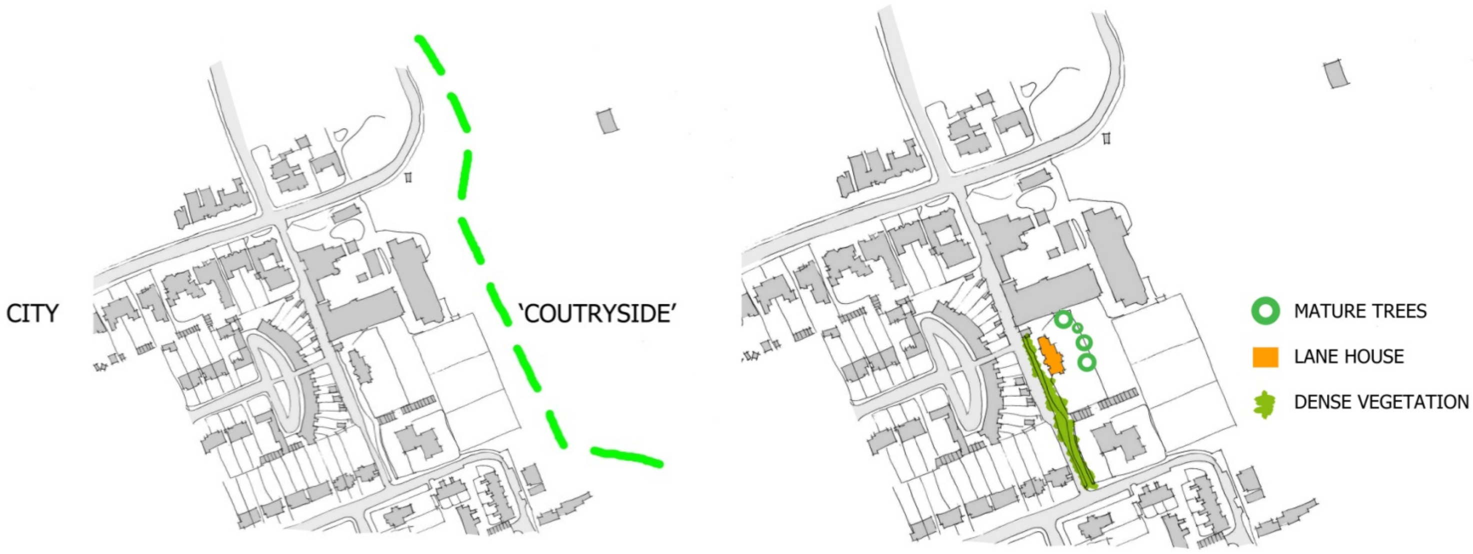


Figure 7 Site Context

1.9 Site Description

The existing site comprises of an asphalt area of playground, the northern third of the astro-turf pitch, Lane House which is two storey residential accommodations for staff and associated gardens with some mature trees and plants, 2 storage garages and an area of parking.

Lane House is considered to be an unremarkable early 20th century house, probably built between 1900 and 1914 and subsequently added to over time. There were originally two of these houses; the other was demolished to make way for Norham Flats around 1980.

Lane House occupies a large space at the centre of the school and in an area where it is possible to build new school buildings. By freeing up this space it will be possible to bring both the Music School and the Junior School right into the heart of the main campus.

The key site features include the mature trees to be removed, the relationship to Dragon Lane on the west side and the playing fields on the east.

From above the strong geometry of Park Town and the proximity of the river meadows and the open space dominate.

At ground level the site is hidden from the public realm in part due to the vegetation along Dragon Lane and the proximity of school buildings, but also due to fact that the site slopes away towards river to the east.

Figure 8 View looking west towards the rear of Land House

Figure 9 View looking west towards the proposed site from the Dragon School playing fields

1.10 Site Constraints

Figure 10 Constraints Plan

A. School boundary

B. Notional project boundary

C. Lane House and garages to be demolished

D. Area where trees are to be removed

E. Line of underground storm water drain

F. Mature hedge and trees along Dragon Lane

G. 1/3 of the existing astro-turf pitch to be re-landscaped as a Junior School Play area

H. Park Town Terrace rear gardens, garages & back gates.

I. Dragon Lane public pedestrian access and vehicle access to the rear of Park Town Terrace properties

J. Approximate maximum extent of extreme flood from the River Cherwell (Environment Agency Flood Map)

K. Main school entrance

L. Norham Flats garages

M. North Oxford Conservation area

N. Existing vehicular access route for school drop-off and collect along Bardwell Road

O. Drop-off area

1.11 Design Vision

The design vision for the Junior School is to bring the Year 3 and Year 4 pupils onto the main campus; to create an inspiring, flexible and secure learning environment that will also help manage the transition though to the upper school. The proposed spaces will be carefully considered to allow a transformative pedagogy where the learning experience and the learner is placed at the centre of everything, allowing the Dragon to continue its heritage of offering a progressive educational approach. The entire school site is to be a learning environment with ‘play’ also forming a key part of the learning experience. The design of the internal and external environments together with the physical transitions between designed to inform the appropriate use of the spaces – informal/formal for example.

The project has a strong sustainability agenda with the approach focusing on all areas impacted by such a project, not just energy and carbon. Design targets have been set from the outset to achieve a BREEAM ‘Excellent’ rating. The aspiration where possible to seek to incorporate passive design strategy using sensible design, specification and detailing to minimise energy consumption, where required active solutions will be investigated to supplement these to further reduce the buildings environmental impact.

1.12 Design Concept

The urban design concept for the new Junior School, in combination with the proposed Music School is to create a new ‘quad’ within the school site to the south of the main quad. The purpose of this is to provide a new outside ‘forum’ (the existing internal ‘forum’ is an open plan, multi-use circulation hub at the centre of the school that is regularly used for performance/display etc.) that can be used daily by the Junior School but offer a whole school area when required for outdoor plays/concerts etc.

The building sits within a carefully considered landscape that also acts as a learning environment. The external spaces are designed to offer a range of experiences, from contemplative play through to high energy sports activities to extend learning from within the school building to all areas of the site. A roof garden is also proposed across the entire building. This will further expand the external teaching environments offered at the school and will be designed such that a range of types of planting can be incorporated to further enhance learning, particularly about the environment.

The spaces are organised to provide a clear transition from the informal external areas, through semi-formal open plan internal teaching spaces to the formal classbases. Internally the design has been considered to allow for a transition to the transformative agenda where self learning is promoted, as is employed by the Dragon, rather than teacher led learning. There is a clear difference in the spaces provided for year 3 and year 4 to allow the transition to be gently introduced to the pupils across the 2 years the pupils will be taught in the Junior School.

The ‘Lighthouse’ structure is proposed to sit at the heart of the school and as well as providing the main vertical circulation with an ‘Alice-in-wonderland’ scale stair, which has been expanded to provide spaces for cloaks, books and quiet tutorial spaces.

The buildings form has been considered to provide an appropriate scale and massing when compared with it surrounding buildings (Norham Flats to the South and Park Town Crescent to the East). The appearance of the building is broken down using a grid with the elevational approach responding directly to the function of the space internally.

The material palette has been carefully considered to provide a contemporary aesthetic that has a quality/crafted feel that sits well within in its historic context as well as working with the more modern buildings found at the school.

Figure 11 - South West view along facade

Figure 12 - North-East view into courtyard

Junior School Areas

Room Name	Room No.	Floor	Area (m²)
Ground Floor			
Circulation	GJ01	Ground Floor	285.19
Cloaks	GJ02	Ground Floor	27.26
Female Changing	GJ03	Ground Floor	34.46
Female WC	GJ04	Ground Floor	14.57
Male WC	GJ05	Ground Floor	14.57
Male Changing	GJ06	Ground Floor	43.85
Female Shower	GJ07	Ground Floor	6.37
Male Shower	GJ08	Ground Floor	6.37
Lobby	GJ09	Ground Floor	2.79
Lobby	GJ10	Ground Floor	2.32
Dis WC	GJ11	Ground Floor	3.30
Cleaners Store	GJ12	Ground Floor	2.20
Classbase 1	GJ13	Ground Floor	44.89
Classbase 2	GJ14	Ground Floor	44.89
Classbase 3	GJ15	Ground Floor	44.89
Classbase 4	GJ16	Ground Floor	44.89
Classbase 5	GJ17	Ground Floor	44.89
Hall	GJ18	Ground Floor	155.27
Store	GJ19	Ground Floor	3.34
Store	GJ20	Ground Floor	6.10
Store	GJ21	Ground Floor	2.44
Store	GJ22	Ground Floor	5.51
Lobby	GJ23	Ground Floor	5.51
Servery	GJ24	Ground Floor	11.38
Store	GJ25	Ground Floor	11.56
Head of Year 3	GJ26	Ground Floor	14.20
Head of School	GJ27	Ground Floor	14.20
Admin/First Aid	GJ28	Ground Floor	14.36
Interveiw Room	GJ29	Ground Floor	10.00
Ground Floor - Total Net Area			921.57

Table 2 Ground Floor Schedule of Accommodation

Room Name	Room No.	Floor	Area (m²)
First Floor			
Art Room	FJ01	First Floor	70.44
Classbase 6	FJ02	First Floor	45.34
Cloaks	FJ03	First Floor	26.91
Classbase 7	FJ04	First Floor	44.88
Classbase 8	FJ05	First Floor	44.88
Classbase 9	FJ06	First Floor	44.88
Classbase 10	FJ07	First Floor	44.88
Classbase 11	FJ08	First Floor	44.88
Breakout Space	FJ09	First Floor	40.40
Stairwell	FJ10	First Floor	8.38
Flexible learning	FJ11	First Floor	34.75
Work/Play Area	FJ12	First Floor	24.67
ICT Area	FJ13	First Floor	64.05
Meeting Room 10 People	FJ14	First Floor	22.57
Meeting Room 4 People	FJ15	First Floor	5.51
Meeting Room 4 People	FJ16	First Floor	5.51
Meeting Room 8 People	FJ17	First Floor	11.70
Meeting Room 6 People	FJ18	First Floor	8.27
Learning Resource Lobby	FJ19	First Floor	14.42
Cleaners Store	FJ20	First Floor	3.56
Dis. WC	FJ21	First Floor	3.56
Female WC	FJ22	First Floor	17.33
Male WC	FJ23	First Floor	17.33
Staff Lockers	FJ24	First Floor	14.53
Staff WC	FJ25	First Floor	4.53
Staff WC	FJ26	First Floor	4.53
Staff Room	FJ27	First Floor	24.60
Staff Resource	FJ28	First Floor	30.00
Head of Year 4	FJ29	First Floor	11.84
Circulation	FJ30	First Floor	13.54
Circulation	FJ31	First Floor	238.87
First Floor - Total Net Area			991.54
Second Floor			
Work/Play Area	SJ01	Second Floor	24.71
Second Floor - Total Net Area			24.71
Total Net Area			**1937.82**

Table 3 First Floor Schedule of Accommodation

1.13 Outline Specification

This specification defined the ‘base building’ design that the potential 73 adaptation measures were assessed against. Many of the 73 potential adaptation measures were found to already in these scheme and graded 1 highlighted in Table 1.

Structure:

Frame General – In-situ cast reinforced concrete frame – High quality finish to atrium and heart space where exposed.

Slab – In-situ cast 300mm deep multi-directional slab at each floor and to roof. – High quality finish to atrium and heart space incorporating stencilling into exposed soffit.

Roofs (All to achieve U-Value of 0.1 W/m^{2}K):

Pitched Roof Areas

Zinc – VM zinc standing seam roof (pre-finished), on Breathable Membrane, on 200mm PUR insulation board, on vapour control layer, on metal deck.

Flat Roof Areas

Green Roof – Bauder Total Green Roof system (incorporating Bauder intensive substrate incl. approx 300mm growing medium filter fleece, reservoir board, protection matt, PE foil, capping sheet, vapour barrier, 200mm PUR insulation board, vapour control layer), on tapered screed, on structural slab. Some of this will be seeded and other areas will be hard landscaped.

External Walls (All to achieve U-Value of 0.15 W/m^{2}K):

Basement – Cast concrete retaining structure with RIW external tanking linked to below slab tanking, include for backfilling with permeable material and drainage sheet. Form isolated wall construction – gypliner or similar with 90mm insulated plasterboard on ply pattress.

Brick Finish – Block work inner leaf, 175mm cavity partially filled with 125mm rigid insulation (Kingspan KA or similar, Brick outer leaf.

Timber Cladding Finish – Block work inner leaf, 175mm cavity partially filled with 125mm rigid insulation (Kingspan KA or similar Block outer leaf, vertical battens, horizontal counter battens, vertical open boarded chestnut cladding.

Green Wall Finish - Block work inner leaf, 175mm cavity partially filled with 125mm rigid insulation (Kingspan KA or similar, block outer leaf, irrigated vertical living wall system.

Internal Partitions:

General Partitions – 2 layers 12.5mm soundbloc plasterboard to both sides of 70mm c studs with 50mm acoustic insulation batting between studs.

55-60 dB Partitions – 2 x 15mm thick plasterboard each side of two independent rows of 70mm metal studs (total width 260mm) including 60mm acoustic batting in cavity

60-65 dB Partitions – 3 x 15mm thick plasterboard each side of two independent rows of 70mm metal studs (total width 290mm) including 60mm acoustic batting in cavity

65-70 dB Partitions – 3 x 15mm thick plasterboard each side of two independent rows of 70mm metal studs (total width 340mm) including 110mm acoustic batting in cavity

Ground Floor (All to achieve U-Value of 0.15 W/m^{2}K):

General – 75mm sand/cement screed (incorporating U/F heating where specified), on 500 gauge isolation layer, on 100mm PUR insulation (Kingspan TF70 or similar), on 150mm reinforced ground bearing concrete slab, on 1200 gauge DPM, on sand/cement blinding, on 150mm hardcore.

Basement – Power Floated Concrete slab, on 500 gauge isolation membrane, on 100mm PUR insulation (Kingspan TF70 or similar), on RIW tanking membrane (lapped to wall tanking), on 75mm concrete blinding/slip plane, on 150mm hardcore.

Upper Floors:

General Floor – 75mm sand/cement screed (incorporating U/F heating on 25mm insulation board to Junior School), Iso-rubber resilient layer, on concrete floor slab (exposed soffits in Junior School, absorbent plasterboard.

Stairs & Balustrades:

Feature steel staircase to wrap around central feature element with glass and stainless steel balustrade.

Rear Stairs – Concrete stairs with brushed stainless steel handrails and balustrades

Windows & Doors (U-value 1.6 W/m^{2}K, g-value 0.65, T-value 0.7):

Curtain Walling – Pilikington Planar with glass structural fins.

Windows & Doors – High performance double glazed units with warm edge spaces in composite Timber and PPC Aluminium – Velfac or similar

Roof Lights – Bespoke High performance double glazed units with warm edge spaces in PPC Aluminium

Internal Glazing:

General Partitions – Single glazed toughened safety glass (fire rated where required) in timber frames

Acoustic Partitions – Double Glazed units - 16.8mm laminate, 16mm airspace, 10mm float glass in timber frames

Internal Doors:

General – Timber veneer finish door sets.

Acoustic – Specialist acoustic timber veneer finish door sets, glazed where required to receive double glazed unit comprised of 16.8mm laminate, 16mm airspace, 10mm float glass

Ironmongery:

Brushed stainless steel ironmongery throughout – Allgood PLC – Modric Range or similar**.**

Sanitary Ware:

Armitage Venesta Equinox HPL cubicle system with Ideal Spec WC's & Basins

Hans Grohe Brassware – taps, showers etc**.**

Kitchen Fittings:

Tea Points – Howdens Joinery fittings including; base units, work tops, wall cupboards, stainless steel sinks and taps, hydroboil & fridge.

Junior School Servery – Commercial stainless steel fittings for serving only (no cooking – food to be delivered hot from main kitchen), inclusion for storage and washing**.**

Floor Finishes:

Corridors/Circulation – Good Quality Carpet

WC's and Changing – Rubber Flooring – Forbo Nairn (or similar)

Classrooms, Offices, Rehearsal spaces and Recital hall – Engineered Timber Flooring

Hall – Specialist timber flooring

Specialist Finishes:

Acoustic Absorbers – Ecophon (or similar) suspended and wall mounted absorbers. Classrooms to incorporate central raft to provide route and location for services. Acoustic absorbers included to 2no walls of all music pods**.**

Solar Shades:

PPC aluminium support structures with timber fins – Refer to elevations for locations

External Louvres:

PPC aluminium weatherproof and acoustic louvres – Refer to elevations for locations

External Quad Balcony Structure

Painted galvanised steel primary structure with timber decking, glass balustrade with stainless steel handrails

Figure 13 South West view from the river

1.14 Civil & Structural Proposals

The structure of the new building to accommodate Junior school will generally be a reinforced concrete frame with flat slab floor plates. The frame will be cast insitu using traditional construction techniques. This form of construction has the advantages of:

- Maximum flexibility for floor plate shapes and column positions.
- Flat soffit with minimum downstand beams reduces depth of structural zone allowing higher ceilings or a lower overall building with the associated reduction in cladding costs etc.
- The flat soffit allows freedom of services distribution which has cost savings for design and construction.
- A Reinforced concrete frame does not require separate fire protection when compared to a steel frame
- The soffit of flat slabs can be left exposed without appearing unsightly which allows the thermal mass of the concrete to be used for heating and cooling which is useful for a more sustainable solution.
- Reinforced concrete frames are becoming cheaper than steel alternatives due to increased cost per tonne of steel.
- Some elements of the structure including the roof, recital and assembly halls will be constructed from steel members. This is to allow the form of the roof to meet the Architectural requirements.
- There follows a description of the building structure on a level by level basis

First Floor

The first floor structure will be a reinforced concrete flat slab which is supported by reinforced concrete columns. Where possible the columns will be positioned in wall lines to maximise the useable floor space. Allowance has been made for the weight of the screed and underfloor heating in the Junior School. Partition walls in the Junior School will be lightweight stud partitions.

Ground Floor

The ground floor will be designed as a suspended floor slab spanning between pile caps which will be integral with the slab. Allowance has been made for the weight of a screed to cover insulation on top of the slab. The need for a suspended slab will be confirmed following the completion of the geotechnical site investigation, if the ground conditions permit it may be possible to switch to a ground bearing slab which is more economical as is continually supported rather than spanning between columns.

Roof

Areas of typical pitched roof structure will be constructed from timber or steel rafters spanning between main beams on the column lines.

Areas of green roof will be supported by a reinforced concrete flat slab. The depth of soil material has been estimated at 300mm this will need to be confirmed as the design develops as any increase in soil depth will lead to an increase in load which will mean the slab depth will increase**.**

Basement

A section of the building has a basement area below ground floor level. The basement retaining walls and slab will be of reinforced concrete construction. The basement is to be used as plant areas and storage will be designed to meet a Grade 4 "Special" environment as per BS8102-Part 1 basement design guide. This will be achieved by using either integral waterproofing additives to the concrete mix and/or by traditional external tanking techniques with a drained cavity. Hydrophilic strips will be installed at all concrete construction joints.

Foundations

Based on the published geological information available we anticipate that the site is underlain by made ground over river terrace gravel over clay. The design of the foundations will depend upon the thickness of the river terrace gravel. If the gravel is of sufficient thickness it will be possible to use pad foundations cast on top of the gravel. If the gravel is of insufficient thickness piled foundations will be required which will be CFA bored into the underlying clay.

Stability

The lateral stability of the building will be provided by a system of shear walls located around the lift shafts and stair cores. These will act as vertical cantilevers to resist the imposed wind loads and notional horizontal forces. The floor slabs will act as diaphragms to connect the shear walls and distribute the horizontal loads around the building.

1.15 Mechanical and Electrical

Heating and Ventilation

Heat Source

It is proposed that the main heat source for the buildings is an electrically driven heat pump.

Ground source heat pumps are the preferred option as it provides the best efficiency and has no unsightly external condenser units. It does however require either a large area of excavation for trench type ground loops or numerous boreholes. Further design stages will determine the exact number required based on ground conductivity tests and trial boreholes to determine how deep they can be.

An air source heat pump installation would also be suitable but would have lower efficiency than a ground source system and requires external condensers. On the plus side, there is no requirement for costly ground trenches or boreholes.

Junior School

The Junior School will mainly be heated by underfloor heating, fed from the main Low Temperature Hot Water (LTHW) system.

The Junior School will be naturally ventilated. This will be designed to comply with the Building Regulations and Building Bulletin 101 – Ventilation and indoor air quality in Schools.

The means of ventilation will be through opening windows and appropriately located ventilation stacks (or "chimneys") rising from the ground floor classrooms up to the roof.

Other areas such as the changing rooms and servery will be provided with local extract ventilation systems.

The hall shall mainly rely on natural ventilation, again using ventilation stacks to increase air flow, but it will work on a mixed mode philosophy with fans provided within the stack for a boost mode when required, such as at times of high occupancy

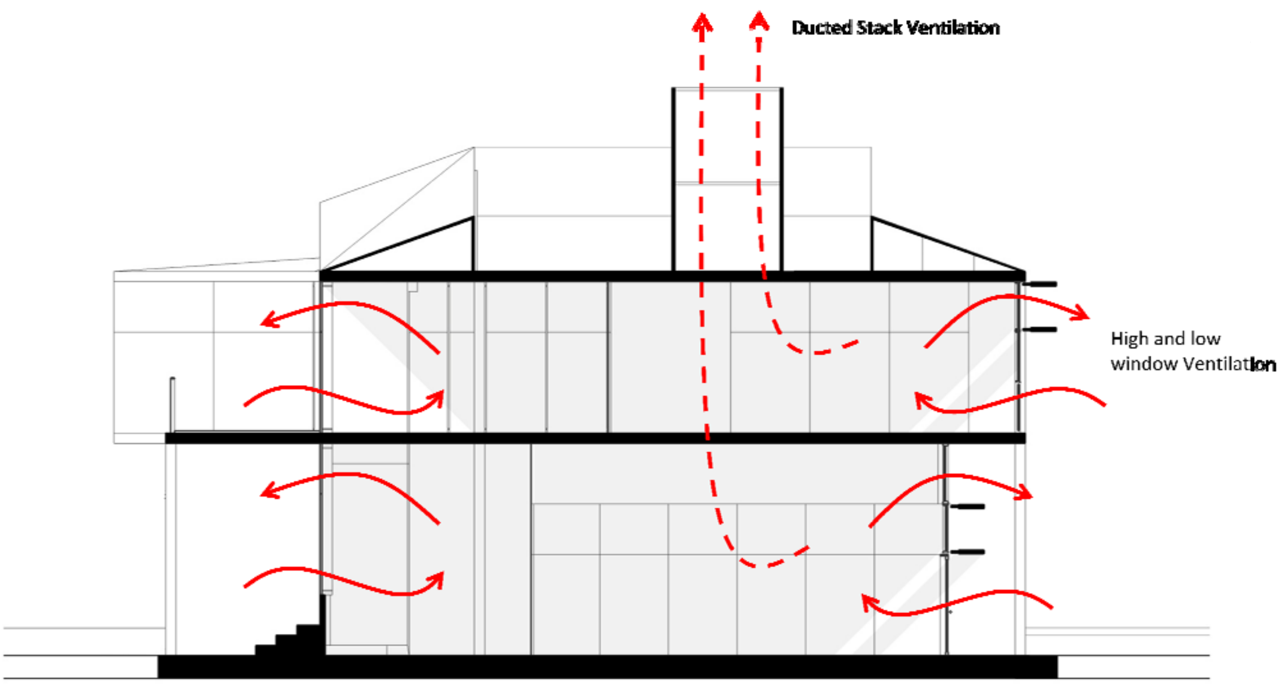


Figure 14 Building Section highlighting natural ventilation strategy

Domestic Water Services

Since the building is relatively low-rise, it is proposed that the cold water will be direct mains fed, with the hot water also working on an unvented basis to ensure reasonable water pressures. The domestic hot water will also be produced from the heat pump system, therefore the heat pump system will be designed such that the high temperatures required to heat water to a safe storage temperature can be achieved.

Above Ground Drainage

The above ground drainage system will be standard, single stack, primary ventilated system connecting into the below ground system and venting at high level.

Controls

Control of heating and mechanical ventilation systems will be by a central BMS linked to the existing school system, with no local user controls. Where natural ventilation is proposed, simple user controls will be provided together with CO2 indicators so that the teachers can control the ventilation locally.

Energy Saving Measures

The Mechanical and Electrical design team will work closely with the architects from the outset to ensure that the passive design of the building is optimised (i.e. building fabric, orientation, fenestration and air tightness). This will be achieved through the detailed use of thermal modelling software that allows the operation of the building to be simulated for a wide variety of weather and occupancy variables, typically using data for normal and worst case annual conditions.

All mechanical and electrical equipment will be selected so that it uses as little energy as possible. High efficiency fans and pumps with EC motors will be selected, heat recovery systems will be incorporated in all ventilation systems, pipe and duct systems will be sized to minimise the pump and fan power required and all central plant will be selected to be as energy efficient in use as possible. Lighting shall use high efficiency T5 fluorescent and LED lamps, together with appropriate controls.

The design uses daylight within each space to create a bright and stimulating environment for the pupils and teachers. Lighting will be provided by high efficiency fluorescent, LED and discharge lamp sources.

1.16 Massing and Building Heights

- Roofscape broken down into individual components to reflect function and to be in keeping with the neighbouring buildings

- Solar chimneys size and rhythm echo the scale of the Park Town Crescent roof scape

- Proposed building heights fit in with the neighbouring buildings of Norham Flats, the Park Town Crescent and the existing Dragon School buildings

Figure 15 - Concept view showing how the proposed new buildings fit with the scale and heights of surrounding buildings

Figure 16 - Norham Flats, Park Town Terrace and Dragon Lane looking south showing restricted vehicular access

1.17 Landscape Strategy

Approach

Children need the freedom to appreciate the infinite resources of their hands, their eyes and their ears, the resources of forms, materials, sounds and colours.

They need the freedom to realise how reason, thought and imagination can create continuous inter-weaving of things, and can move and shake the world'.

L. Malaguzzi (1998) The Hundred Languages of Children

The Dragon School is committed to creating a rich and welcoming environment where children can rest, socialise, explore their bodies, learn with nature and play with freedom. In the spirit of ecological design, three principles guide the development of the outline plan:

Figure 17 - Proposed Site Plan

Zones

A – Dragon Courtyard

B – Cloister Courtyard

C - Birch Field

D – Dragon Garden

E – Arrival

F – Roofscape

New Tree Species

1 - Crataegus Laevigata

2 – Ilex Aquifolium

3 – Crataegus Monogyna

4 – Prunus Avium

5 – Tilia Europaea

6 – Carpinus Betulus

7 – Salix Alba Caerulea

8 – Quercus Robur

9 – Betula Pendula

10 – Populus Nigra Betulifolia

11 – Betula Pubescens

12 – Salix Babylonica

(i) Work with what is here

To enhance existing habitats and where possible use recycled and sustainably sourced materials;

(ii) Enrich the diversity of each child's experience

Allow children to learn through the body and their senses and to support imaginative games and diverse social spaces;

(iii) Strengthen feelings of connection and responsibility for each other and nature

Make visible living cycles and invite children to take responsibility together for decisions about use resources including water, food waste, energy and recyclable materials**.**

1.18 Landscape Character Zones

The Outline Plan describes six main areas to be developed in more detail**:**

Area A

The *Dragon Courtyard* area runs alongside Dragon Lane. Its main use is as a supervised outdoor learning environment and rear access point to the Junior School. The boundary treatment retains the rural character of the Lane, with a mixed yew and holly hedge over planted with specimen, native hawthorns and a holly tree. Within the space, the children can encounter rainwater storage barrels, recycling storage bins, raised beds for herbs, and a small covered workshop and display area for hand-made projects. The ground surface is hard and includes recycle brick from Lane House. There is generous flexible seating made from recycled timber**.**

Figure 18 External features

Area B

The *Cloister Courtyard* is the main circulation and performance space of the Junior School. The space remains relatively clear of fixed furniture, with path textures indicating main routes between entrance-ways. There is scope for the courtyard to have vertical planting from generous planters positioned at the base of the main pillars.

Area C

Birch Field is the main soft play area for the Junior School. It is bounded from the main school buildings by generous, mixed hedge and shrub planting, over-spilling a simple.

This area is complemented by access to the astro-turf for higher-energy running games and ball games.

Figure 19 External features

Area D

The *Dragon Garden* is a space shared between the Upper and Junior Schools. It is planted with specimen Wild Cherries to provide a link with the Birch Field play area, and offer a flourish of spring blossom. Small, unusual fruit trees – a medlar, a quince and a mulberry – are planted alongside the main path in amongst order beds of drought tolerant herbs, including salvias, rosemary, lavender varieties, box and thymes. A green hedge provides a screen for the staff garden, which is repaved and planted with small beds of scented herbs. There are seats within the *Dragon Garden* set against a backdrop of evergreen shrubs, including viburnums and daphnes.

Figure 20 External features

Area E

The *Entrance way* to the Junior School is a shared space between the Music School, Upper School and Junior School. The entrance itself is a [thatched shelter] with internal seats.

Figure 21 External features

Area F

The *Roof Garden* is a magic place where children can see plants thriving on basic substrates of recycled building materials, local river sand and even recycled clothing. This is an experimental garden, combining ground level growing of sedums and wildflowers in amongst raised beds and generous seating. The garden will demonstrate how some plants grow in challenging places, as well as offer richer growing beds for herbs and flowers that the children can pick, taste, study and decorate their classrooms with.

Figure 22 External features

Wider School Strategy

The new Junior School landscape and planting works will take place alongside a wider strategy to strengthen the biodiversity of the main school grounds. The first stage of tree planting begins with: planting a specimen *Tree of Life* native oak near to the main school building; creating a woodland walk of native trees leading down towards the river; adding to the river-edge planting with weeping willows, birches, cricket bat willows and a black poplar.

1.19 Environmental - Part L Compliance

Approved Document L2A (2010) of the Building Regulations requires that a carbon emissions calculation is undertaken using approved calculation software to prove compliance. The user inputs the building geometry, fabric details and mechanical and electrical services details and assigns room types from a standard list. From this information, the calculation works out the building carbon emission rate (BER), expressed in $kgCO_2/m^2$/annum for the building. The calculation tool then compares the BER to a target carbon emission rate (TER) for the building, that it also calculates based on the user inputs. The BER must be less than the TER to show compliance.

To demonstrate compliance with this requirement, initial calculations have been carried out based on the following:

- Highly insulated building fabric;
- Windows with excellent insulating properties;
- Excellent building envelope air tightness;
- Low energy lighting throughout, with efficient controls;
- Heat pumps providing heat for space heating and hot water;
- Underfloor heating and natural ventilation to the Junior School.

In addition to the carbon emissions criteria, L2A also requires that the potential for the building overheating in summer is controlled. For schools, the designers are referred to Building Bulletin 101, which lays down the overheating criteria that much be achieved. It must be shown that the temperature in each room deemed a teaching space much not exceed 28°C for more than 120 of the occupied hours and that the temperature also does not exceed 32°C.

Dynamic simulations of the building in operation have been carried out using Integrated Environmental Solutions' "Virtual Environment" software (known as IES). The simulations have shown that by using high performance glazing that limits solar gains and a heavyweight building structure, together with the natural ventilation and mechanical ventilation systems proposed for the building, the building meets the above criteria for limiting overheating under current climatic conditions.

This IES thermal model created the 'base model' for the 'base building' design that the potential 73 adaptation measures, highlighted in Table 1, were assessed against. Many of the 73 potential adaptation measures were found to already in these scheme.

1.20 Natural Resource Impact Analysis (NRIA)

The Oxford City Council lays down four additional sustainability criteria on energy efficiency, renewable energy, materials and water resources. The NRIA works on a scoring system, whereby a score of 6/11 must be achieved, along with meeting the minimum standard for each section, for a new building development to be approved.

The scoring system is summarised in the table below.

			Minimum standard		Preferred standard		Target standard		Score achieved
Energy efficiency	C1	**Residential uses:** What is the SAP rating? (See table 1)	SAP "good" (GS1)	1 pt	SAP "best" (BS1)	2 pts	SAP "advanced" (AS1)	3 pts	
		Non-residential uses: Under criterion 1 of SBEM: what is the relationship of the Building Emissions Rating (BER) to the Target Emissions Rating (TER)?	BER = TER	1 pt	BER is 2% better than TER	2 pts	BER is 5% better than TER	3 pts	
Renewable energy	C2	What percentage of energy requirements will be produced by on-site renewables?	20%	1 pt	30%	2 pts	40%	3 pts	
Materials	C3	What score is achieved in table 2?	4	1 pt	5-7	2 pts	8-11	3 pts	
Water resources	C4	What score is achieved in table 3?	1	1 pt	2	2 pts			
							Total checklist score:		**/11**

Table 4 NRIA Assessment Extract

The minimum standard for Energy Efficiency (C1) is met by meeting the minimum requirements of Part L of the Building Regulations, as discussed in section 5.1 above.

In order to meet the minimum requirement of 20% of the building's energy requirements being met by on-site renewable energy sources (C2), the use of heat pumps to provide for both space heating and 'Domestic Hot Water' to meet the Part L carbon criterion mean the 20% requirement is exceeded.

A more in-depth analysis of the building energy use and renewables contribution is provided in the Energy Strategy Report provided in the Appendices.

Materials section (C3) requires careful consideration of material specification, sourcing and waste generation. The requirement is met with the specification of recycled aggregates, FSC registered timbers, zero o-zone depleting insulations and where possible these will be locally sourced. Materials arising from the demolition of the existing structures where possible will be retained on site. Where this is not possible they will be dealt with in line with a 'Best Practice' Site Waste Management Plan.

The targets set out in the C4 Water Resources section are met with the use of 'low water use' fittings installed throughout. Proposals also include for the use of water butt rain water collection to collect water for irrigation purposes.

1.21 Low and Zero Carbon (LZC) Technologies

Heat pumps are proposed as the main heat source, which as well as reducing energy use, avoid the requirement for a large gas supply to the new buildings. Modern ground source heat pumps have a seasonal efficiency of up to 6.0, meaning that for every 1kW of electrical power required to run them, the produce 6kW of heat. They operate less efficiency when producing the high temperatures required for water heating but the latest systems now have an efficiency in excess of 2.5, which is roughly the point at which they show an improvement in carbon savings and running costs compared to a conventional gas boiler and hence make them worthwhile.

In addition to the heat pump systems, other LZC technologies will be investigated for feasibility, with the systems most likely to be technically, practically and economically feasible for the proposed building being photovoltaic (PV) solar electrical generation systems and appropriate roof space has been identified that could accommodate the panels. Designing such systems in from the early stages also allows for such systems be integrated into the building fabric design. It has already been determined that approximately 200m² of PV will be required to meet the carbon emissions criterion of Part L2A of the Building Regulations when assessing both the Music School and Dragon School together.

1.22 BREEAM Pre-Assessment

The school project is aspiring to achieve a BREEAM Excellent Rating to demonstrate Dragon Schools' commitment to the issues of sustainable design and the environment. An initial BREEAM pre-assessment workshop was carried out for the Dragon School on 09 April 2013 using the BREEAM New Construction 2011 Design and Procurement methodology and based upon the BREEAM 2011 pre-assessment estimator tool V2.6. The aim of this workshop was to provide an early indication of how the proposed building will score under the BREEAM 2011 New Construction V3.2 scheme.

A summary of the Pre Assessment is shown below (Table 5).

The results of this shows that the project is currently expected to score 70.62%, which equates to a BREEAM rating of "Excellent". This allows a very small margin above the 70% rating required for BREEAM Excellent (experience suggests that this small margin should be increased as a result it's recommended to review this pre-assessment and target more credits). The score is currently an accurate estimate; the final score may change if the design or processes are amended by others in a way that prevents the award of the currently identified credits.

BREEAM Section	Credits Available	Credits predicted at pre-assessment stage	% of Credits Achieved	Section Weighting	Section Score
Management	22	15	68.18%	0.12	8.18%
Health and Wellbeing	15	10	66.67%	0.15	10.00%
Energy	27	16	59.26%	0.19	11.26%
Transport	7	6	85.71%	0.08	6.86%
Water	9	7	77.78%	0.06	4.67%
Materials	13	12	92.31%	0.125	11.54%
Waste	6	6	100.00%	0.075	7.50%
Land Use & Ecology	10	5	50.00%	0.1	5.00%
Pollution	13	6	46.15%	0.1	4.62%
Innovation	10	1	10.00%	0.1	1.00%
BREEAM Pre-Assessment total Score		**70.62%**			

Table 5 BREEAM Pre Assessment

1.23 Adaptation Measures

The NRIA and BREEAM assessments show a base building the has been designed to exceed current minimum construction standards, creating an enhanced design that meets the Dragon School aspirations. The ‘base model’ created in the IES programme for the ‘base building’ design was used as our reference in reviewing the 73 potential adaptation measures, highlighted in Table 1. Many of the 73 potential adaptation measures were found to already in these scheme. However appropriate adaption measures for; comfort, construction, water, green landscape and infrastructure have been considered and outlined in Appendix 1.

The primary element of the study focuses on maintaining internal comfort levels by reducing summer overheating. This was modelled using the highest predicted 2030s, 2050s and 2080s weather data for building performance simulation.

Selected individual measures to reduce overheating of the Dragon Junior School were categorised in 5 groups: high albedo surface, window type, ventilation, shading and insulation. The performance of these individual measures was tested based on the modelling results of 12 classrooms in the Dragon Junior school project.

Three adaptation packages were developed based on the effectiveness of individual adaptation measures outlined in Appendix 1.

Package 1 includes the two most effective adaptation measures; night time ventilation and external louvres.

Package 2 combines night time ventilation, external louvres and white paints surfaces.

Package 3 combines night time ventilation, external louvres and white paints surfaces and triple glazing.

The other adaption measures for construction, water, green landscape and infrastructure were elements that could not be modelled in performance based software. These measures were interrogated and assessed in plan, section or elevation; taking into account the professional judgment of the project Design Team, the Client’s project aspirations and priorities and the context of the site.

Please refer to Section 3.2 and Appendix 1 for more details.

2 Climate change risks for Dragon School

The information of our methodology for climate change risk assessment based on the UKCP09 Weather Generator is described in section 4.1 and more detailed information can be found in Appendix 2.

2.1 Assessment of the risk exposure of the building

2.1.1 Climate change in the UK

The impacts of climate change are currently observable in many places around the world and further change is deemed unavoidable. According to the scenario of greenhouse gas (GHG) emissions developed by the Intergovernmental Panel on Climate Change (IPCC), it would take a convergent world 40 years to turn around emissions and to begin a downward trajectory resulting in a best estimate of 1.8°C global average surface warming by the end of the century (IPCC 2007).

The UKCP09 provides publicly accessible climate change data free of charge to raise awareness and improve communication about climate change and to assist in UK adaptation. UKCP09 is the fifth generation of information based on methodology from the Met Office and reflects the most recent, best insight into how the climate system works and how it might change in the future with built-in logical uncertainties. UKCP09 presents data as a result of three different possible future climate change scenario levels: low, medium and high greenhouse gas emissions up to 2099. Based on evidence, the UKCP09 provides a range of possible outcomes defined regionally across the UK with varying probabilities linked to each outcome (UKCP09, 2010a; Jenkins *et al.*, 2009).

The key findings of the UKCP09 are represented as an aggregated collection of 25km x 25km squares covering 16 administrative regions of the UK (Figure 2a). Individually defined probabilistic climate projections are available for each 25km x 25km square in the grid (Figure 2b). Using the background data of the UKCP09 projections, the Weather Generator (WG) is used to spatially downscale the 25km data to 5km and to temporally downscale the monthly data to daily or hourly data. Additionally, river basins and marine regions have been aggregated but will not be directly relevant to this study (Jenkins *et al.*, 2009).

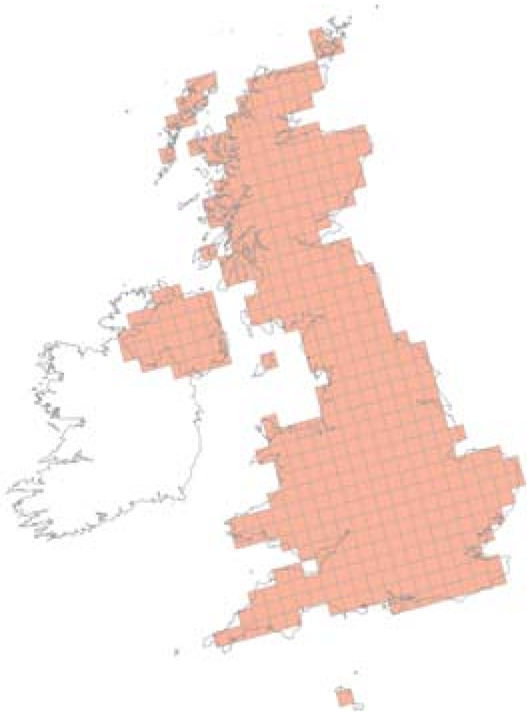


Figure 23 (a) Map of UK administrative regions (b) 25km^2 grid covering the UK *(Jenkins et al., 2009)*

Climate parameters are the physical measurements of weather variables which define a climate. The following weather variables have impacts on building performance:

- Temperature change
- Precipitation change
- Solar radiation
- Could cover
- Humidity
- Wind speed

2.1.2 Changes of climatic variable for Dragon School site

The carbon emissions have the greatest impact on temperature and precipitation. Other climate parameters, cloud cover and relative humidity for example, tend to be less impacted by the variation in emissions scenarios. The preliminary analysis results of future climate condition at Dragon School site indicate that:

- Overall summer mean temperature increases are projected to be higher than winter mean temperature increases.
- Throughout the century for the central estimate, annual mean precipitation shows **little change**, meaning the offset between summer mean precipitation decrease and winter mean precipitation increase is almost equivalent. In the long-term the difference between the summer increase and winter decrease is negligible.
- Decrease in annual cloud cover and RH with **little change** in winter cloud cover and RH, meaning greater decreases in summer cloud cover and RH.

- Increase in annual solar radiation with little change in winter solar radiation, meaning greater increases in summer solar radiation. Summer solar radiation changes by an approximate **3-4 W/m²** increase with every selected time slice progression.

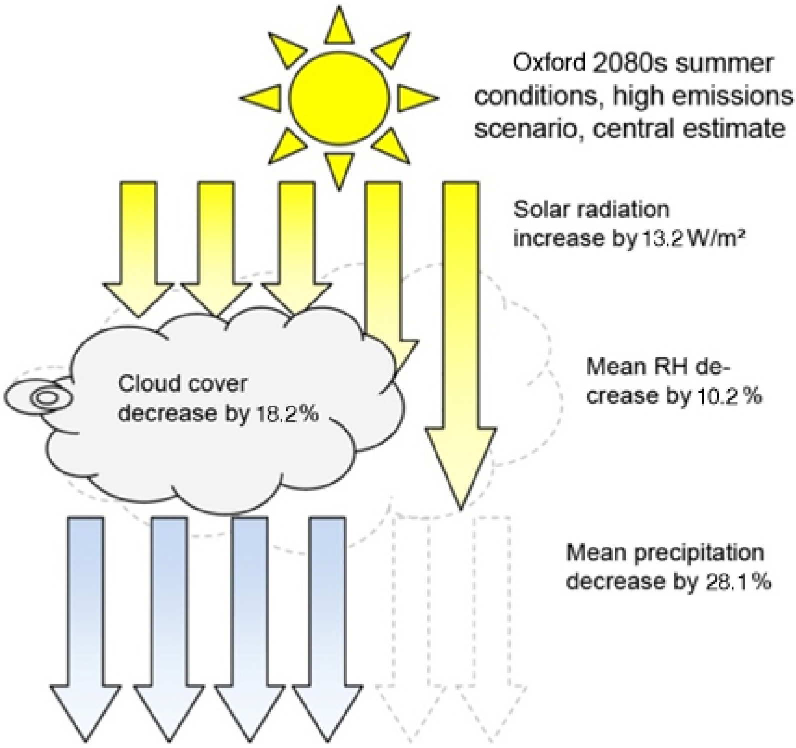


Figure 24 Dragon Junior School summer conditions for the 2080s

The synergistic relationship between all weather variables can be seen, for example, in Figure 24 for summer changes. Table gives more information on changes of climatic variables for Dragon School site.

Table 6 Changes of climatic variable for Dragon School site

Climatic variable	Description of central estimate trend
Temperature	Increase in summer maximum temperatures of approximately 2.6°C by 2030s rising to approximately 4.0°C by the 2050s and 6.3°C by the 2080s. Summer mean temperature increase 2.0°C by 2030s rising to 3.1°C by the 2050s and approximately 4.9°C by the 2080s.
Precipitation	Increase in mean winter precipitation of approximately 9.0% by 2030s, rising to 16.8% by the 2050s and 26.8% by the 2080s. Decrease in mean summer precipitation of approximately 10.4% by 2030s, 18.7% by the 2050s and 28.1% by the 2080s.
Solar radiation	Minimal to no change in winter net surface shortwave flux. Increase in summer net surface shortwave flux of 4 W/m^2 by 2030s, rising to 6 W/m^2 by the 2050s and 8 W/m^2 by the 2080s.
Cloud cover	Minimal to no change in winter mean cloud cover. Decrease in mean summer cloud cover of 6.5% by 2030s, 10.6% by the 2050s and 18.2% by the 2080s.
Humidity	Negligible change in winter mean RH. Decrease in mean summer RH of 4.3% by 2030s, 6.8% by the 2050s and 10.2% by the 2080s.

2.1.3 Local environmental features

The Local Climate Impacts Profile (LCLIP) uses current weather phenomenon, hazards and impacts as an introduction to projected future weather impacts. An LCLIP is to be used to learn about some of the consequences of weather that could be expected for a locality in the future. The LCLIP identifies the significant weather issues for a locality and is used to raise awareness about weather, impacts, consequences and adaptation options in response to weather events. The intention of the LCLIP is that it should focus on the impact rather than weather events themselves and the final objective is to be a gateway for action (UKCIP, 2009).

A LCLIP report was completed for Oxfordshire County Council in October 2006 reviewing records in past 10 years about extreme weather events and their implications for the county. The report identified 32 different types of impact, 36 major weather events, 263 total recorded incidents, total incidents cost of £16,413,000 and 19,870 man hour costs of incidents. Oxfordshire County Council was the first council to embark on a Local Climate Impacts Profile.

The quantitative results finding, such as number of events, incidents and costs, are presented in the table and charts below (Source: OCC and UKCIP, 2006).

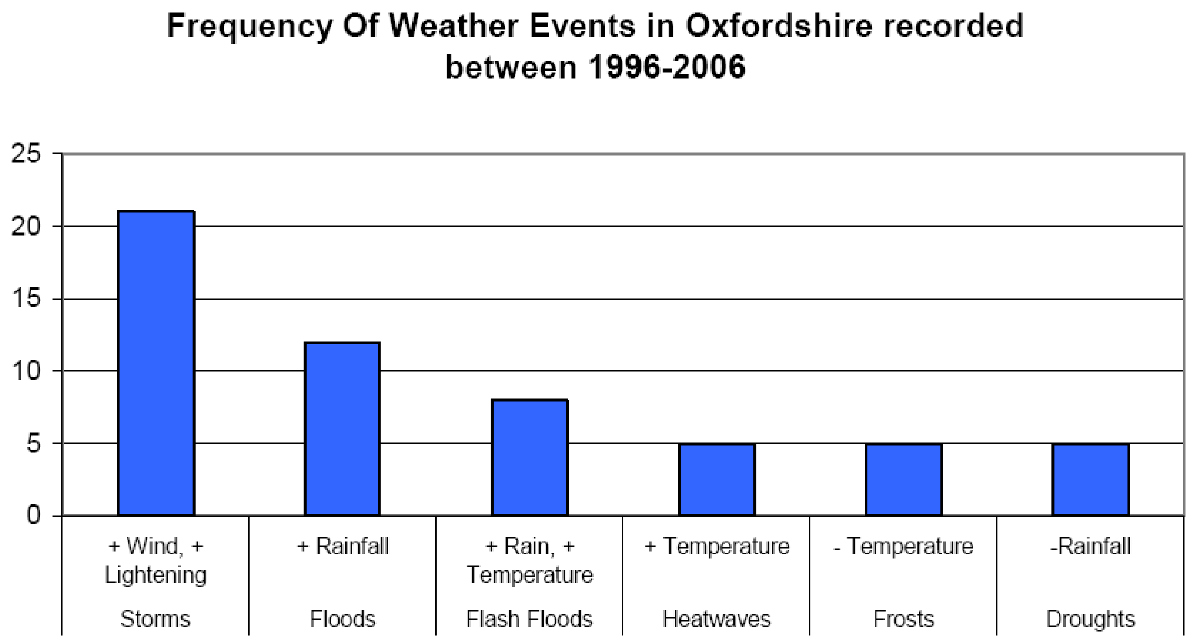


Figure 25 Frequency of Weather Events in Oxfordshire (OCC and UKCIP, 2006)

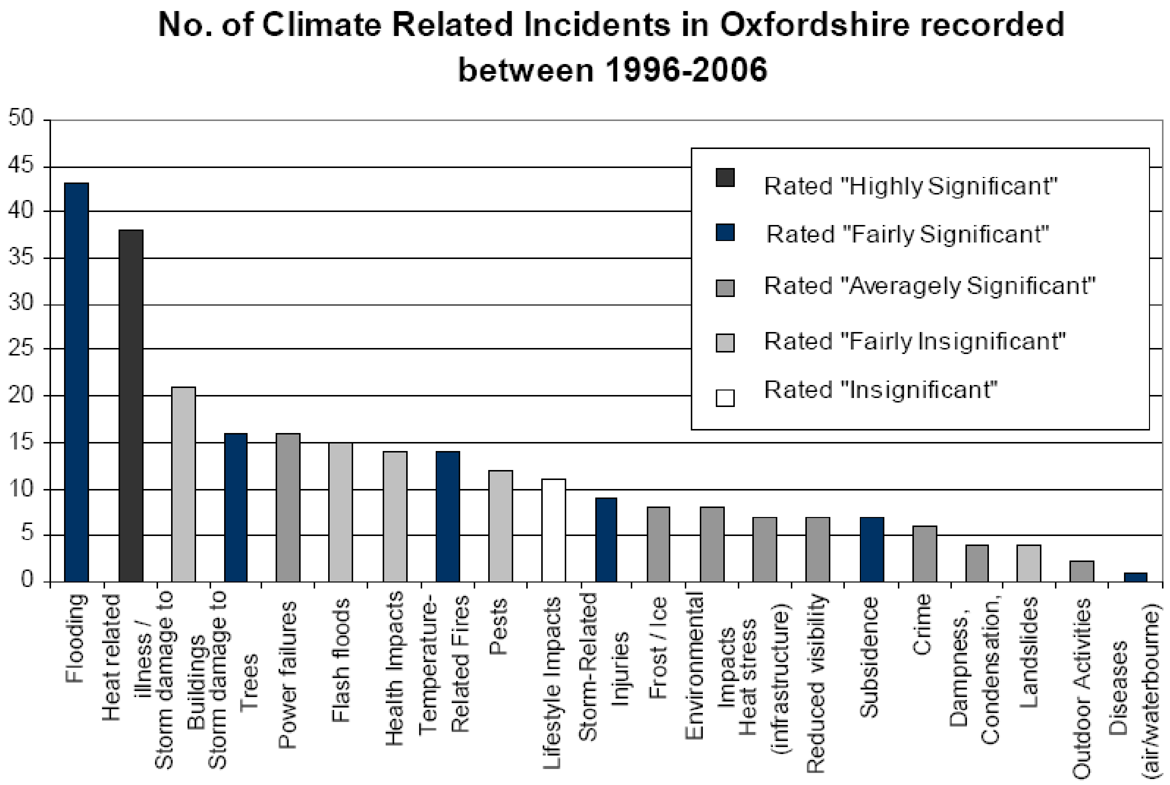


Figure 26 Climate related incidents in Oxfordshire (OCC and UKCIP, 2006)

Flooding: More than 40 incidents have been reported in Oxfordshire due to flooding over the past 15 years, from 14 heavy flood periods, summer and winter. There have been more than 12 incidents of summer flash flooding over the last six years (1999-2006).

Heat-waves: The heat-waves of August 2003 and July 2006 had a range of impacts and consequences across the county – illustrated by varied media accounts.

Drought – subsidence: A long dry spell over the UK with two noticeable dry spells, February to April and August to October 2003 gave rise to episodes of subsidence in areas of clay soils in Oxfordshire.

Increasing the spatial resolution allows researchers to apply the UKCP09 data to more detailed regional or local environmental information. Local features that can either ameliorate or exacerbate the impact of climate change on a locality include proximity to the coast, elevation and surrounding topography, urban density, tree and green space coverage, etc. A site's exposure to floods, for example, is dependent on these local conditions and is projected to only be exacerbated by climate change. Table 2 categorises the characteristics of LEFs of the site that could positively or negatively affect or be affected by the impacts of climate change hazards.

Building characteristics can also exacerbate and ameliorate the impacts of climate change (varying exposure). These characteristics can include: surrounding building types and density, building heights, street width and surface material, and building orientation.

Table 7 Local environmental features for Dragon Junior School

LEFs	Dragon Junior School	Hazard relevance
Latitude	51.77° N	Temperature change and solar intensity change
Proximity to coast	70 miles to coast	Temperature increase and precipitation increase

Urban cover[1]	Surrounded by school playground in east direction, school building and three-story residential buildings in north and west direction. Relatively good urban cover with green. (Figure 2)	Temperature increase, solar intensity increase and precipitation increase
Elevation (Google earth, 2012)	63m above sea level	Temperature change and precipitation increase
Fluvial flood risk (EA, 2012)	Outside Flood Zone 2 (Figure 28)	Precipitation increase
Water stress (EA, 2012)	Serious	Precipitation decrease and temperature increase
Wind driven rain potential (Graves and Phillipson, 2000)	Moderate: 33 to less than 56.5 litres/m^2/spell	Precipitation increase/wind speed change

[1]Urban cover refers to built-up areas, e.g. asphalt, concrete and buildings and has many implications for proximity to green space and urban heat island potential.

The local environmental features and climate related incidents in Oxfordshire show that importance of conducting this study. The adaptations measures for future proofing extreme weather events (heavy wind, floor and heatwave) were developed based on above information.

Figure 27 Surroundings of Dragon Junior School site

OX2 6SS at scale 1:10,000

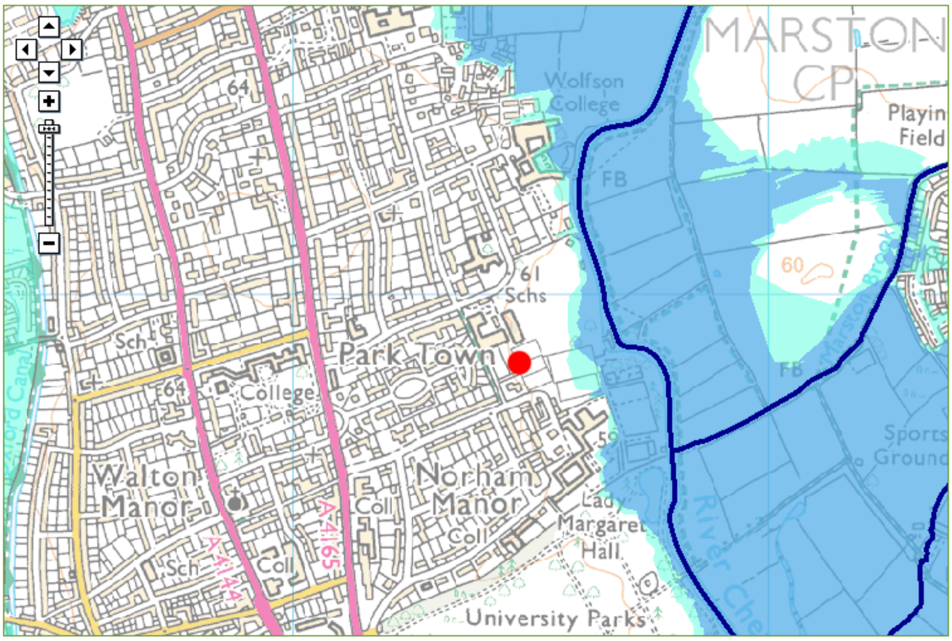


Figure 28 Dragon Junior School site flood risk zones (Environmental Agency, 2012) and the proposed site that is away from the risk zones

The dark blue area could be affected by flooding (1% chance of happening each year); light blue area shows the additional extent of an extreme flood from the river. This outlying area is likely to be affected by a major flood (1 in 1000 chance). The no blue shading area (where the building located) shows the area where flooding from rivers and the sea is very unlikely (less than 1 in 1000 chance of flooding occurring each year).

The local environmental features show that importance of conducting this study. The adaptation measures for future proofing against extreme weather events (heavy wind, floor and heatwave) were developed based on this information.

2.2 Identification of the climate scenarios and climate data

2.2.1 Downscale climate information

In order to provide more detailed impact, assessment, the research must undertake spatial and temporal downscaling of the UKCP09 data. Downscaling through UKCP09 is done via the Weather Generator. Downscaling spatially means to increase the spatial resolution of climate change projections. Increasing the spatial resolution allows researchers to apply micro-climatic and more detailed regional or local geographical/environmental information to the UKCP09 data for more meaningful analysis.

Four assumptions were made to choose suitable weather data for building simulation. They are **location, time periods, carbon emission scenarios** and **risk percentiles**.

Location: The latitude and longitude of Dragon school project are 51.77N, 1.25 W. The UKCP09 5km by 5km grid (4550210) covers the development area (Figure 29).

London Heathrow (51.48N, 0.45W) is the nearest location which has CIBSE historical weather data available. The both CIBSE Test Reference Year and Design Summer Year for London are selected from 1983 to 2004. The year with the third warmest April-August period during 1983 and 2004 is 1989 which is the Design Summer Year. The calendar months in Test Reference Year are selected from following years:

Table 8 Selected calendar months in London Test Reference Year

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1988	2004	2004	1992	2000	2001	1991	1996	1987	1988	1992	2003

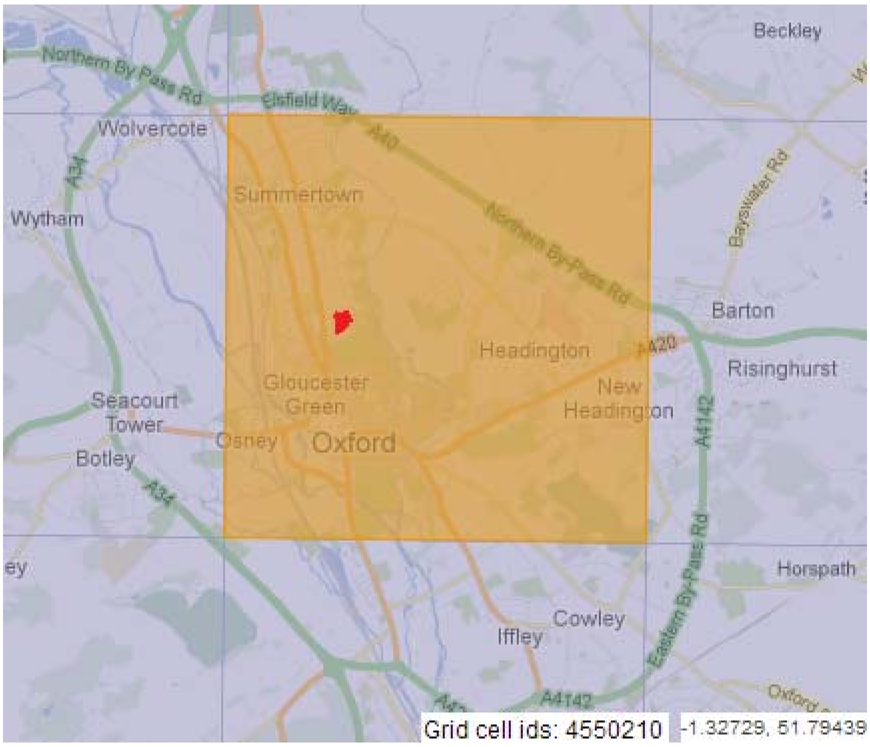


Figure 29 UKCP09 5km grid for Dragon school project

Time periods: UKCP09 provide projections for seven time periods. For each time period, 30 years weather data are made available. The authors select three time periods (Figure) to present short, medium and long term climate condition. They represent a sample of future time slices looking sufficiently far towards a time horizon likely to be of interest for the life span of buildings currently under development and construction. The new buildings constructed today will have replacement of building services assets typically every 15-20 years (short term). The buildings themselves would have minor refurbishment at every 35-45 years (medium term), and normally major refurbishments would occur in 60-100 years (long term).

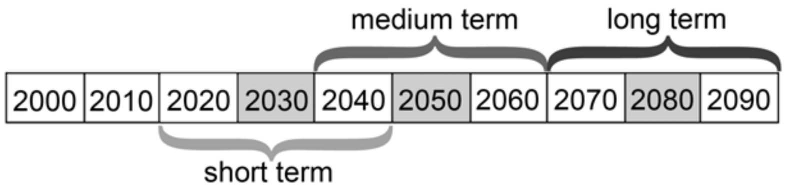


Figure 30 Climate time scale diagram (climate periods cover 30 years of climate data)

Carbon emission scenarios: UKCP09 offers climate projections based on three carbon emission scenarios (low, medium and high). The authors decided to test building overheating risks based on the high carbon emission scenario; because the observed emissions during 2000 to 2010 from both the International Energy Agency (2012) and the Carbon Dioxide Information and Analysis Centre (CDIAC) are very close to the IPCC's high emission scenarios (A1F1) assumed in 2000 (Figure).

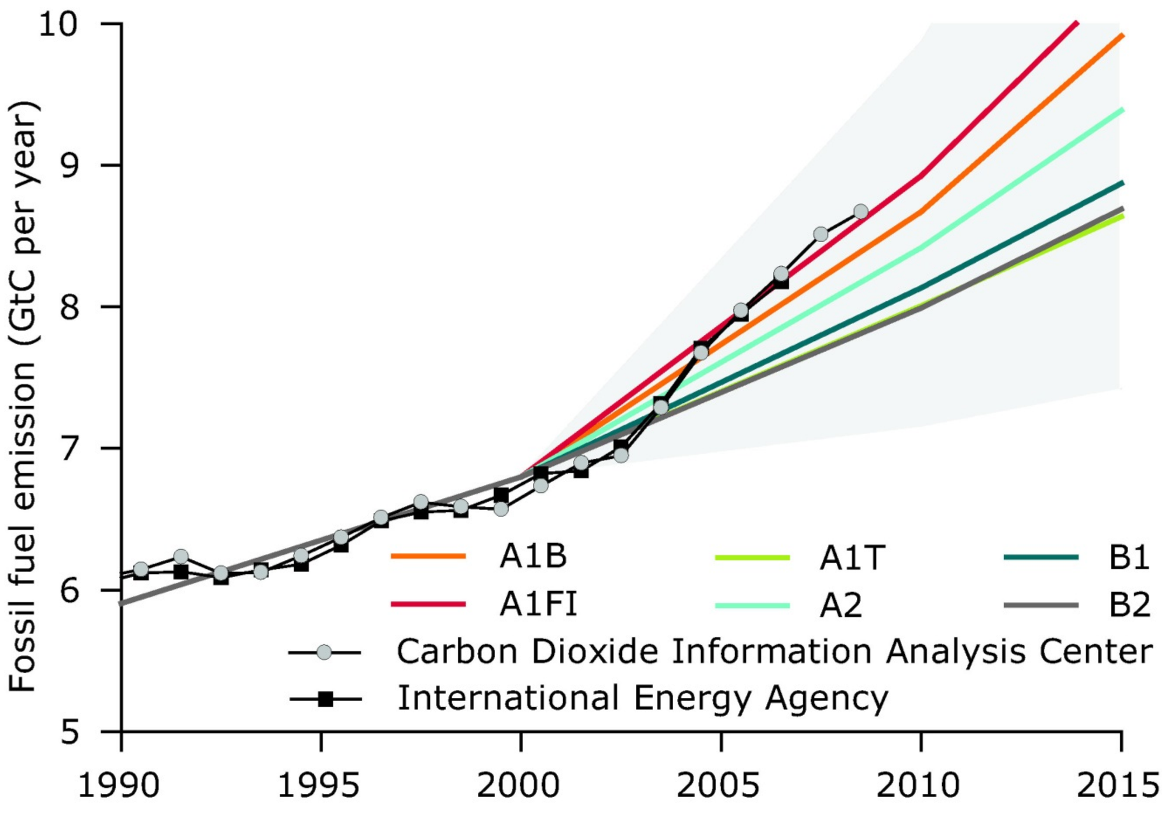


Figure 31 Observed global fossil fuel CO2 emissions (black lines) compared with IPCC scenarios (European Environment Agency 2013)

Risk percentiles: By examining all available method (PROMETHEUS (Coley et al. 2011), COPSE-Manchester (Watkins et al. 2013), COPSE-Northumbria (Du et al. 2012a), ARUP (ARUP 2011)) of deriving future weather data from the UKCP09, the authors have decided to use the COPSE-Northumbria weather data (Du et al. 2012b, Du et al. 2012a). Note that COPSE-Northumbria 85 percentile is equivalent to PROMETHEUS 50 percentile data.

2.2.2 Weather data for building simulation

The method of generating weather data from the UKCP09 is the research outcome of EPSRC funded COPSE (Coincident Probabilistic climate change weather data for a Sustainable built Environment) project (Levermore et al. 2012) conducted at Northumbria University during 2008-2011. The weather data generated by COPSE-Northumbria team contains a single Test Reference Year (TRY) file and two Design Reference Year files (DRY85 and DRY99) for each location, timeline and carbon emission scenario. The weather data employed in this project is based on the site at Oxford (UKCP09 5km by 5km grid, 4550210).

The Test Reference Year consists of hourly data for 12 ‘typical’ calendar months, selected from 3000 example years produced by UKCP09 Weather Generator. E.g. the most typical January from 3000 Januaries is jointed with the most typical February, March and so on. It represents the most ‘typical’ weather condition within the given 3000 examples.

The Design Reference Year (DRY) consists five hotter months (May to September) and five colder months (November to March) and two mild months (April and October). It represents near-extreme hot summer and cold winter which can be used for overheating/under heating analysis and cooling/heating design load calculation. The mild months (April and October) are the most typical months selected from 3000 example calendar months, which are same as Test Reference Year.

The hotter and colder calendar months were selected by two-step process (Figure). For example, for May, firstly, 3000 Mays were ranked by their monthly mean temperatures in descending order and a 30-month band at a particular risk level (85^{th} percentile or 99^{th} percentile) was selected. Secondly, the most typical May was selected from the 30-month band using Finkelstein-Schafer statistic method (Finkelstein and Schafer 1971). This process was repeated for generating June, July, August and September. For cold months (November to March individually), the 30-month band is located at (15^{th} percentile or 1^{st} percentile).

The five hot months at 85^{th} percentile, five cold months at 15^{th} percentile and two mild months then are jointed as Design Reference Year 85 (DRY85). The five hot months at 99^{th} percentile, five cold months at 1^{st} percentile and two mild months then are jointed as Design Reference Year 99 (DRY99).

Figure 33 demonstrates the monthly mean temperature of COPSE-Northumbria TRY, DRY85 and DRY99 weather data for Oxford’s baseline period (1970s).

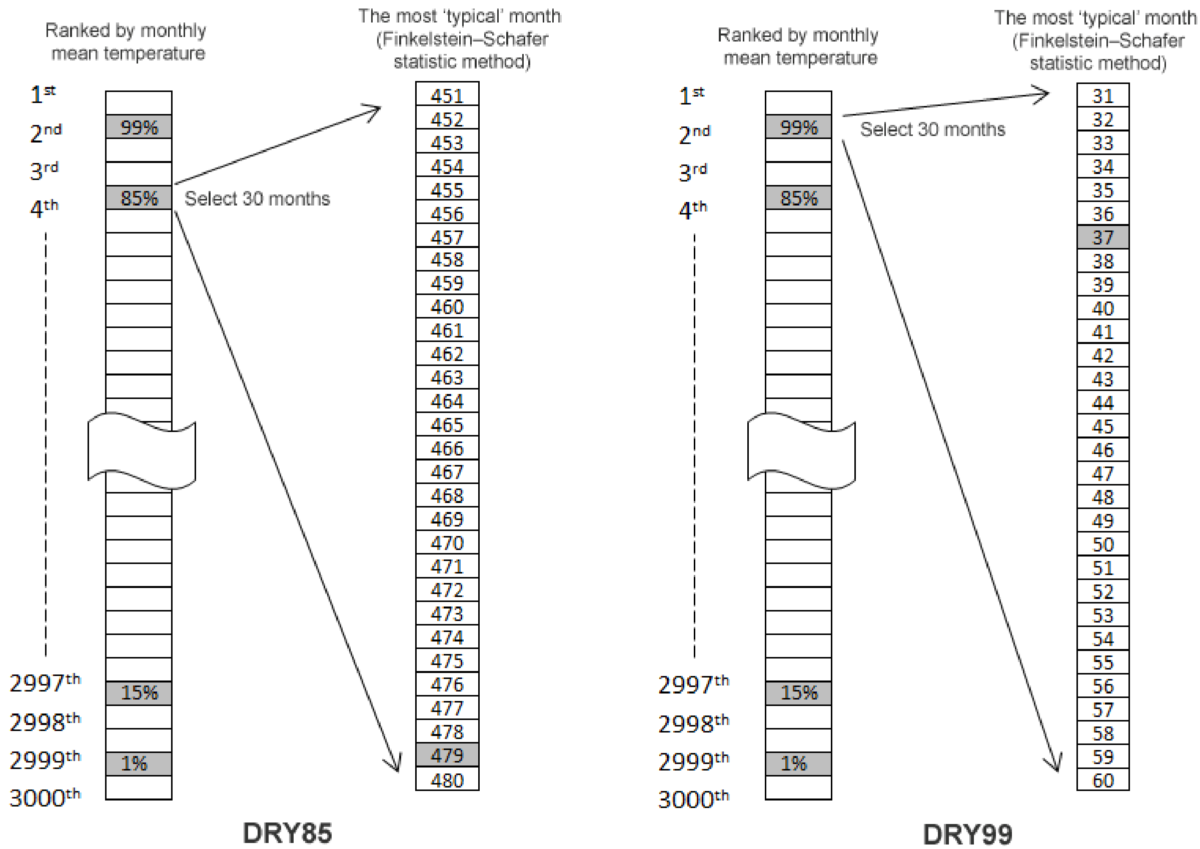


Figure 32 COPSE-Northumbria 2-step process of generating DRY data

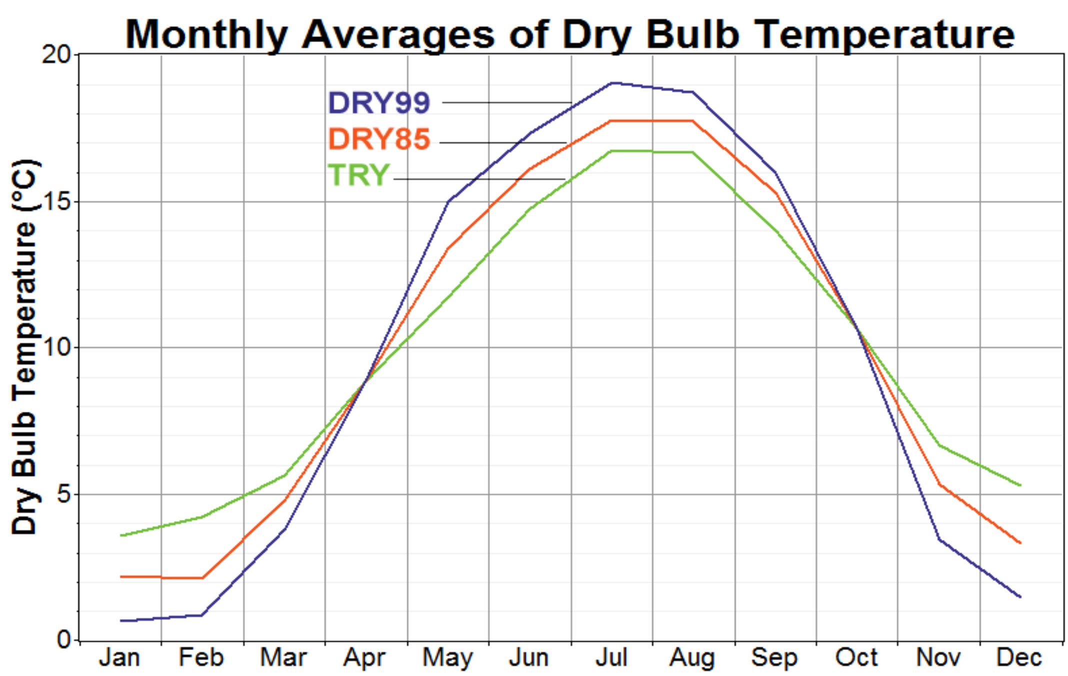


Figure 33 Monthly average temperatures of TRY and DRYs for Oxford in 1970s

The 85th percentile was used because the CIBSE Design Summer Year (DSY) have previously been extracted by choosing the third warmest summer from about 20 years data (1-3/20=85%) giving near-extreme conditions. For comparison, for a much higher design risk of overheating, the 99th percentile was also used because it forms the medium-risk value of the three percentiles (98%, 99% and 99.6%) recommended for use in current practices for calculating UK cooling design loads (CIBSE 2006b).

Note that the definition of percentile here is different with the one used in PROMETHEUS project (Coley et al. 2011).

Above process was coded in numerical computing program Matlab. As the outputs of Matlab program, weather data files in Table were used for energy consumption modelling, and the weather data files in Table were used for overheating analysis in this report. Note that two sets of baseline files were used for testing, CIBSE historical TRY/DSY and COPSE-Northumbria TRY/DRY at the control period (1970s). The CIBSE weather data is for location of London Heathrow airport and the COPSE-Northumbria weather data is for location of Dragon school, Oxford.

Table 9 Weather data for building energy simulation

Source	Location	Type	Timeline	Emission	Percentile	Name of weather files
CIBSE	Heathrow	TRY	1983-2004	/	/	LondonTRY05.fwt
COPSE Northu-mbria	Oxford	TRY	1970s (1961-1990)	/	/	Oxford1970CTRY.epw
			2030s (2020-2049)	H	/	Oxford2030HTRY.epw
			2050s (2040-2069)	H	/	Oxford2050HTRY.epw
			2080s (2070-2099)	H	/	Oxford2050HTRY.epw

Table 10 Weather data for overheating analysis

Source	Location	Type	Timeline	Emission	Percentile	Name of weather files
CIBSE	Heathrow	DSY	1989 (1983-2004)	/	85%	LondonDSY05.fwt
COPSE-Northumbria	Oxford	DRY85	1970s (1961-1990)	/	85%	Oxford1970CDRY85.epw
			2030s (2020-2049)	H	85%	Oxford2030HDRY85.epw
			2050s (2040-2069)	H	85%	Oxford2050HDRY85.epw
			2080s (2070-2099)	H	85%	Oxford2080HDRY85.epw
		DRY99	1970s (1961-1990)	/	99%	Oxford1970CDRY99.epw
			2030s (2020-2049)	H	99%	Oxford2030HDRY99.epw
			2050s (2040-2069)	H	99%	Oxford2050HDRY99.epw
			2080s (2070-2099)	H	99%	Oxford2080HDRY99.epw

A brief comparison of all weather data above was made to show the increase of average temperature during May-September period from baseline to 2080s. As shown in Figure , the average temperature of May-September increases 5.4 ºC from COPSE baseline TRY (1970s) to 2080s' TRY. The May to September period was selected because Building Bulletin 101(Department for Education 2006) requires this period for overheating analysis.

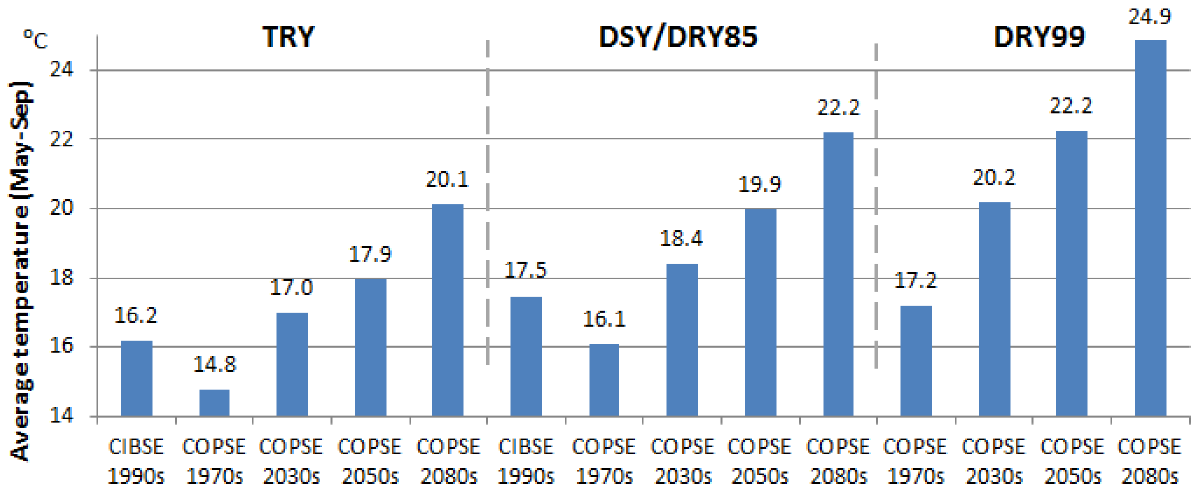


Figure 34 May-September average temperatures (°C)

For comparison, the average temperatures of five cold months (November to March) were illustrated in Figure . The figure shows that average temperature of five cold months also increases due to climate change. However, due to the method of generating DRY and the risk level embedded, the average temperatures of five cold months from COPSE DRY85/99 are significantly lower than CIBSE TRY/DSY data.

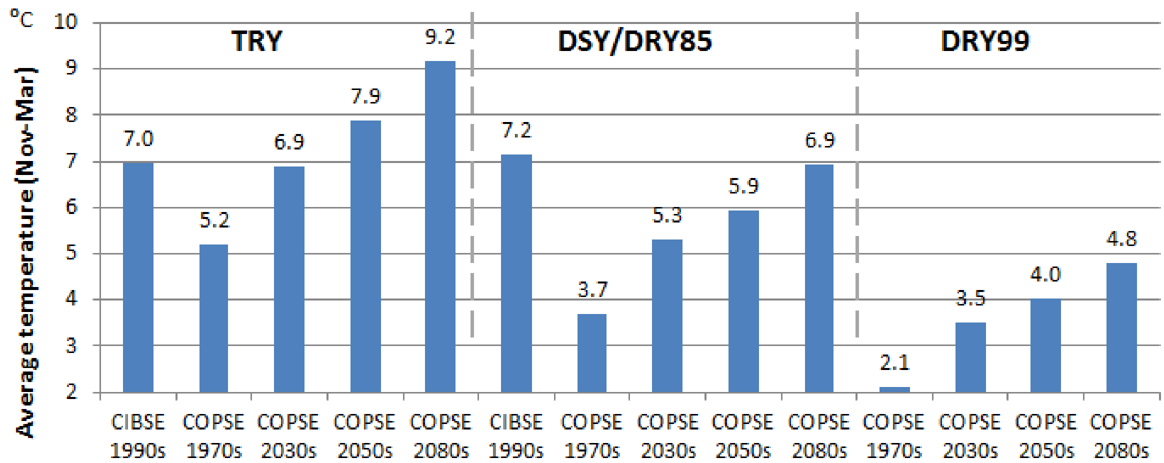


Figure 35 November-March average temperatures (°C)

The numbers of hours of external temperature over 25, 26, 27 and 28 °C during May-September period are illustrated in Figure . Both Figure and Figure indicate that a warming climate will occur in the latter part of this century. Note that the numbers of hours experiencing high temperature (>25 °C) at COPSE 2030s DRY85 is higher than the numbers in CIBSE baselines, and the average temperature of May-Sept at COPSE 2030s DRY85 is less than CIBSE baselines' average temperatures.

The temperatures of COPSE baseline (1970s) are significantly lower than CIBSE baseline (1990s). This is due to the difference of timelines and locations.

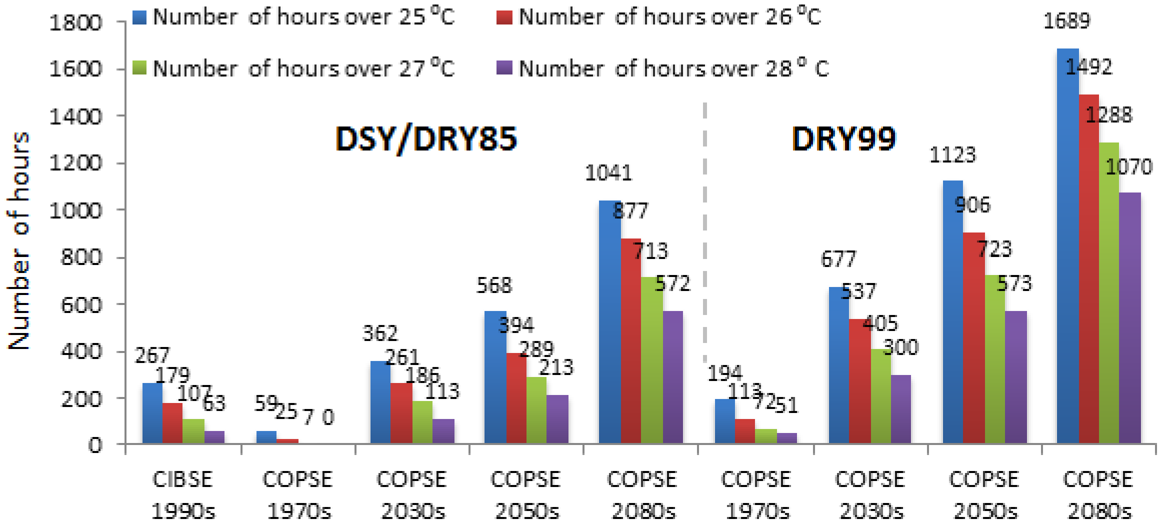


Figure 36 Number of hours over 25-28 ^{o}C during May to September in CIBSE DSY, COPSE DRY85 and COPSE DRY99

2.3 Other features significant to the adaptation strategy developed

2.3.1 Vulnerability

Many indicators of vulnerability to climate change cannot be quantified at this moment. Overheating risk on building occupants is one of few which can be calculated.

Specifically the site will accommodate 200 children aged 7-9 and adult teaching and support staffs for which age can vary widely. Most literature on age related vulnerability places the greatest risk age groups outside of the 5-64 age range, however many people within this age group can have varying mental and health circumstances which can increase the vulnerability to risk. There are certain factors that predispose people with health problems to heightened vulnerability during a heat wave as following (DH, 2010):

- Certain medications: People with severe illness are more vulnerable to the effects of heat because of medications that potentially affect renal function, the body's ability to sweat, thermoregulation or electrolyte balance.
- Inability to adapt behaviour to keep cool: Having a disability or being bed bound make this group less able to adapt to warmer environment.

Vulnerability is usually determined by the socio-economic status, health conditions and demography of the occupants. In this case the occupants are pupils (7-9 years olds) who may not understand the health risks associated with overheating, whereas the risks with flooding or water stress are more visible and obvious. Also overheating risk is one of few risks which can be calculated. Therefore this report is focused on the overheating modelling.

2.3.2 Other features

Shift work is one of recommendations from other research projects, however due to the school usage limitation; the adaptation measure of shift work is not explored in this study.

Above information is a summary of the work conducted by Oxford Brookes University and Ridge and Partners. More detailed reports can be found in appendix 2 - Climate changes hazards and impacts report for dragon junior school.

3 Adaptation strategy

3.1 Review and identify suitable adaptation measures

This section reviewed relevant adaptation measures from recent research projects as well as TSB: Design for future climate projects.

3.1.1 Recent research outcomes

TARBASE project

The Engineering and Physical Sciences Research Council (EPSRC) funded TARBASE (Technology Assessment for Radically Improving the Built Asset baSE) project during 2004-2009. Researchers at Heriot-Watt University (Jenkins et al. 2009) investigated the overheating problem of future low-carbon schools in the UK. The study highlights the effect that future small power and lighting energy use could have on reducing the overheating of school teaching areas. However the risk that the school building cannot cope with the overheating problem might still remain, although introducing external shading and increasing ventilation in classrooms can reduce overheating significantly.

DeDeRHECC project

From 2009, the Engineering and Physical Sciences Research Council (EPSRC) funded 18 different research consortia, which are brought together within the Adaptation and Resilience to a Changing Climate (ARCC) Coordination Network. Among the 18 research consortia, DeDeRHECC (Design & Delivery of Robust Hospital Environments in a Changing Climate) project investigated the adaptation for hospitals. The project is collaborated between Cambridge University (lead), Loughborough University, Leeds University and the Open University. Lomas *et al.* (2012) at Loughborough and Cambridge University are responsible for the building design, refurbishment strategies, environmental monitoring and modelling. They predicted the future thermal comfort of a ward in Bradford Royal Infirmary under three refurbishment options using simulation software IES.

Table 11 The characteristics of existing and proposed refurbishment options for a ward (Lomas et al. 2012)

Description	Wall 'U' value (W/m^{2}K)	Roof 'U' value (W/m^{2}K)	Volume (m^3)	Window opening and shading	Upper level trickle vent	Space conditioning strategy	Set point temperature (°C)
Existing	1.0	0.3	958	Middle pane opened but no shading	NA	Perimeter heating only	Winter: 23 Summer: 22
Opt-1	0.2	0.1	958	All three window panes are opened and shading above the two pane	NA	Perimeter heating only	Winter: 23 Summer: 22
Opt-2	0.2	0.1	958	All three window panes are opened and shading above the two pane	NA	Perimeter heating and ceiling fan	Winter: 23 Summer: 22
Opt-3	0.2	0.1	868	All windows are fixed and shading above the two pane	25 no. 100 mm diameter louvre units	Heating and cooling through radiant ceiling	Heating Winter: 26 Summer: 21; Cooling Summer: 16

The three refurbishment options comprise insulation, shading and improved natural ventilation. Detailed information is given in **Table 11**. The adaptive comfort standard BS EN 15251 was used as a basis for evaluation. Their refurbishment option 1 could ensure that in extreme temperature years the wards remain comfortable right through to the 2080s and option 2 could reduce the overheated hours further. The option 3 (introducing of radiant cooling) ensures that overheating is eliminated entirely, but will have first cost, maintenance and energy demand implications which the passive options do not have. In contrast, there are a greater number of hours outside comfort zone by the 2050s for the ward without refurbishment.

SNACC project

The Suburban Neighbourhood Adaptation for a Changing Climate (SNACC) project is another project funded by EPSRC within ARCC Coordination Network. The SNACC project involves a multi-disciplinary team of academic partners from University of the West of England, Oxford Brookes University, and Heriot-Watt University, as well as stakeholder partners (Bristol City, Oxford City and Stockport Councils, and White Design) and expert consultant, Arup. The SNACC team (Gupta and Gregg 2012) at Oxford Brookes University reviewed range of passive adaptation measures which can be used to negative impacts of climate change on existing English homes. They are:

- Internal insulation
- Cavity wall insulation
- External insulation
- High albedo exterior
- Exposed thermal mass
- Louvered shading on glazing

They found that though some adaptation measures were effective in reducing overheating hours and even more so when combined into packages, no measures were able to entirely eliminate the risk of overheating in existing English homes, especially in the 2080s.

Priority School Building programme

The Education Funding Agency (EFA) launched their baseline designs for schools to show examples achieving Priority School Building Programme (PSBP) Output Specification.

After supporting the development of Priority School Building, Breathing Buildings (2013) has created a guidance paper to help contractors and engineers comply with the new ventilation requirements. The measures suggested by Breathing Buildings are:

- Cross ventilation (enhanced airflow in all parts of a room leads to improved thermal comfort especially in warmer weather);
- Low energy hybrid (some fan use within an otherwise natural ventilation scheme provides a much more robust way of minimising energy use whilst at the same time preventing cold draughts in winter and managing the risks of overheating in summer);
- Not using windows in winter as these invariably cause cold draughts;
- Using thermal mass to manage risks of summertime overheating.

The proposed adaptive comfort criteria and CIBSE DSY weather data were used for the demonstration project conducted by Breathing Buildings.

3.1.2 TSB: Design for future climate: Adapting building projects

The Technology Strategy Board Design for Future Climate: Adapting Buildings program has funded 50 projects in 2 phases in 2010 and 2011. Among the 50 projects, there are 10 projects in type of school. They are:

- **Wyre Forest Primary school;**
- **Harris Academy;**
- **Ebbw Vale School;**
- **St faith's School Master plan;**
- **Hinguar Primary School;**
- Welland Primary School;

- The Royal Academy for Deaf Education;
- Ellingham Primary School;
- Westbrook Primary School;
- Dragon Junior School (this project).

Five out of ten projects (bold above) have published their report on Connect platform (Technology Strategy Board 2013). All measures which have been implemented in these projects are summarized in following tables. The additional measures which have been considered could be found in their final reports.

Note that shading and ventilation are the most common measures implemented in all projects to tackling overheating issue under changing climate.

Table 12 Adaptation measures implemented Project 1

Adaptation category	Project 1
Comfort	• Additional thermal mass • Evaporative cooling • Shading • Ventilation • Vegetation • Green and brown roofs
Landscape	• Vegetation • Sustainable urban drainage systems(SUDS) • Swales
Management	• Change the start time of the school day

Table 13 Adaptation measures implemented in Project 2

Adaptation category	Project 2
Comfort	• Natural ventilation • Increasing the free area (increases the potential for external air to replace internal air at times when the external dry-bulb temperature is lower than the internal air temperature) • Thermal mass • Shading – manufactured • Glass technologies/film • Secure, bug free and maximum ventilation • Ceiling height
Water	• Run-off water management • Water use management
Construction	• External cladding systems
Management	• Building Services Information • Emergency Information • Energy & Environmental Strategy • Water Use • Transport Facilities • Materials & Waste Policy • Re-fit/Re-arrangement Considerations

	• Reporting Provision • Training • Links & References • Building Log Book

Table 14 Adaptation measures implemented in Project 3

Adaptation category	Project 3
Comfort	• Green roof • Ventilation (Naco Storm Louvre) • Solar control glazing • Brise soleil
Water	• Below ground drainage (sizing of pipes)

Table 15 Adaptation measures implemented in Project 4

Adaptation category	Project 4
Comfort	• Night ventilation • Green roof • External shading • Ground cooling (earth tubes) • Film and glass technologies • Stack effect • Internal roof insulation • Internal wall insulation • Phase changes materials
Management	• Review Handover, early occupation and educational policies in relation to the Soft Landings process and future legacy. • Review IT requirements and management systems in design and in use. • Ensure log book is in place, monitoring equipment commissioned and used. • Engage with users through design and curriculum activities such as Eco-schools.

Table 16 Adaptation measures implemented in Project 5

Adaptation category	Project 5
Comfort	• External shading to south-facing • Alteration to external shading to library • Additional planting (deciduous trees) to provide shading • Brise soleil • Electrical fans • GSHP or ASHP for reverse cooling using UFH system • Review of school timetable to avoid peak temperatures in summer • Flexible layout in future school design • Installation of CoolPhase system to teaching spaces
Water	• Touch-free sensors to all wash basins • Installation of localised rainwater butts to serve vegetable planting area

	• Installation of below ground drainage tank for rainwater harvesting • Future review of SUDS strategy recommended if more detailed rainfall data available in the future • Artificial sports pitch to be installed in lieu of current grass pitch • Dry-proofing of sensitive rooms at ground floor

3.2 Adaptation strategy

3.2.1 Methodology

Following the guidance provided by the Design for Future Climate report (Gething 2012), this report investigated the climate change impacts for the built environment on three categories:

- Comfort and energy;
- Construction;
- Water;
- Landscaping / Infrastructure.

The previous section identified future climate changes for the site of Dragon School project, e.g. increase in maximum temperatures of 2.6°C by 2030s rising to 4.0 °C by the 2050s and 6.3°C by the 2080s; increase in summer mean and minimum temperature of 1.8°C by 2030s rising to approximately 2.7°C by the 2050s and approximately 3.9°C by the 2080s. To develop adaptation measures, following methodology (

Figure 37) is developed:

1. Understanding the changing climate;
2. Climate change risks identified for Dragon School;
3. Desktop research and simulation of adaptation measures (from projects and D4fC programme): Dynamic thermal simulation showed the overheating implications of each adaptation measure using future weather years, and helped to inform our thinking as to which adaptation measure minimised the overheating risk now, and in the future;
   - Adaption measures that could not be modelled in performance based software were interrogated and assessed in plan, section or elevation; taking into account the professional judgment of the project Design Team, the Client's project aspirations and priorities and the context of the site.
4. Options appraisal and selection of suitable adaptation measures:
   a. Project team workshop was held for grading adaptation measures, drawing on results from modelling, collective wisdom and practical implementation.
   b. Workshop helped to develop a list of selected adaptation measures that have been included in the baseline model already, measures that could be implemented now, or measures that could be implemented in the future (and measures that could not be implemented or are irrelevant);
5. Energy savings of selected adaptation measures;
6. Detailed design of selected adaptation measures and cost benefits of selected adaptation measures;
7. Uptake of adaptation measures by the client: Project team workshop was held with the client to discuss which measures can be implemented now, or in the future, using findings from:
   a. Simulation
   b. Estimate of energy savings/penalty
   c. Cost benefit analyses
8. Implementation of adaptation.

This section is focused on adaptation measures for comfort, energy, construction and water. The adaptation measures for water and construction are given based on empirical experience. The adaptation measures for comfort were tested by numerical modelling of the school. The modelling and simulation of 8 individual adaptation measures for comfort were conducted in Model IT and ApacheSim using Integrated Environmental Solution's Virtual Environment (IES).

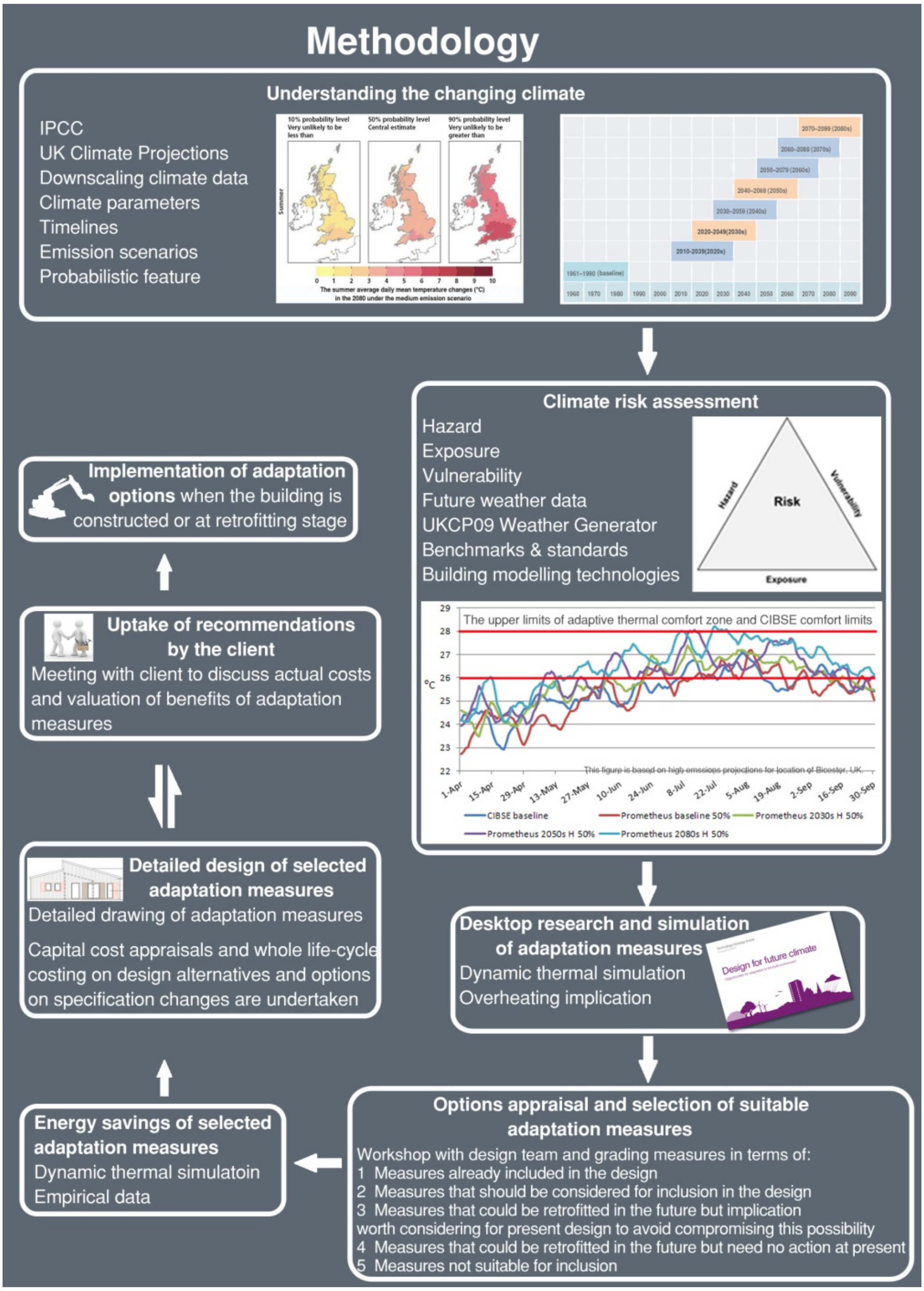


Figure 37 Methodology

To assist in designing buildings for a future climate without overheating issues, the following steps were conducted to develop adaptation measures for Dragon School project.

1. The performance of the base model was tested using three overheating metrics.
2. Adaptation measures for comfort mentioned in Design for Future Climate report (Gething 2010) were considered.
3. The adaptation measures which are applicable for Dragon School project were selected (highlighted 17).
4. To test the performance of these adaptation measures, detailed building level overheating models were modelled in the building thermal simulation package IES.
5. The performance of individual measures was tested on the building model. CIBSE overheating guidance was selected, because it is efficient, transparent, and widely used by practitioners. The CIBSE guidance of overheating is 1% annual occupied hours over operative temperature of 28ºC (CIBSE 2006a).
6. The most effective adaptation measures were proposed for Dragon School project.

Table 17 Adaptation measures for comfort

No.	Adaptation measures		Grading	Adapted element	Overheating modelling in IES
1	Shading - manufactured	Internal shading	2	Shading	IES model case 1
		External fixed shades		Shading	IES model case 2
		External adjustable shading		Shading	IES model case 3
2	Shading -building form		1		already included in the design
3	Glass technologies	Double glazing	2	Windows	already included in the design
		Triple glazing		Windows	IES model case 4
4	Film technologies		2	Windows	Not applicable due to requirements of daylight
5	Green roofs/ transpiration cooling		1		already included in the design
6	Shading - planting	Plant tree	2	Surroundings	IES model case 3 is more effective
7	Reflective materials	White paint	2	Façade	IES model case 5
		Cream paint		Façade	IES model case 6
8	Conflict between maximising daylight and overheating		2	Windows	has been considered
9	Secure and bug free night ventilation		1	Ventilation	IES model case 7
10	Interrelationship with noise & air pollution		1		already included in the design
11	Interrelationship with ceiling height		1		already included in the design
12	Role of thermal mass in significantly warmer climate		1		already included in the design
13	Enhancing thermal mass in lightweight construction		1		already included in the design
14	Energy efficient/ renewable powered cooling systems		1		already included in the design
15	Groundwater cooling		2	Space nearby	Not applicable for overheating modelling
16	Enhanced control systems		2	HVAC system	Not applicable for overheating modelling
17	Maximum temperature legislation		1		Included in all models this study
18	Insulation			Wall and roof	IES model case 8

3.2.2 Overheating metrics

For this project, three overheating metrics are used to evaluate overheating risks of the base model and they are summarized in following table.

Table 18 Assessment metrics

Source	Assessment metric	Applicability
Adjusted BB101	Number of hours over dry bulb temperature of 28 ºC; The internal to external temperature difference should not exceed 5°C; The internal air temperature when the space is occupied should not exceed 32°C.	Naturally ventilated teaching area DSY data
CIBSE Guide A (CIBSE 2006a)	Percentage of hours over operative temperature of 28 ºC is no more than 1% of occupied hours	School DSY data
CIBSE TM 52 (Proposed adaptive thermal comfort standard) (see section 1.3.5)	The difference between indoor operative temperature and **adaptive thermal comfort limit** shall not exceed 4 degree; **Hours of exceedance** is no more than 3% of occupied hours; The **weighted exceedance** shall be less than or equal to 6 in any one day.	Naturally ventilated spaces with operable windows DSY data

CIBSE overheating task force (Spires 2011) proposed a new approach to diagnose overheating in buildings. For free-running buildings, the approach follows the methodology and recommendations of European Standard BS EN 15251 and revised criteria were defined. Similar to BB101, CIBSE overheating task force defined three criteria, and in order to show that the proposed free-running building will not suffer overheating, two of these three criteria must be met. The three criterions are:

A. **Upper limit temperature**: the difference between indoor operative temperature and adaptive thermal comfort limit shall not exceed 4 degrees.

B. **Hours of exceedance**: the number of hours that indoor operative temperature equal or over adaptive thermal comfort plus 1 degree during the period of May to September inclusive shall not be more than 3% of occupied hours.

C. **Daily weighted exceedance**: the weighted exceedance shall be less than or equal to 6 in any one day.

In mathematic expression, above three criteria could be described as:

A. Upper limit temperature:

$$t_{max,i} = 0.33t_{rm} + 18.8 + (2\sim4) \qquad \text{Equation 1}$$

$$\Delta t_i = t_{operative,i} - t_{max,i} \qquad \text{Equation 2}$$

$$For\ \Delta t_i\ at\ any\ time, if\ \Delta t_i > 4, \qquad criterion\ A\ is\ ture \qquad \text{Equation 3}$$

B. Hours of exceedance H_e:

$$H_e = \text{countif}\,(t_{operative,i} \geq (t_{max,i} + 1)) \qquad \text{Equation 4}$$

$$If\ (H_e > 3\% \times total\ occupied\ hours), \qquad criterion\ B\ is\ ture \qquad \text{Equation 5}$$

C. Daily weighted exceedance W_e:

$$\Delta t_i = t_{operative,i} - t_{max,i} \qquad \text{Equation 6}$$

$$W_e = sumif_{i=1}^{24}[\Delta t_i, (\Delta t_i > 0)] \qquad \text{Equation 7}$$

$$For\ W_e\ in\ any\ day, if\ W_e > 6, \qquad criterion\ C\ is\ ture \qquad \text{Equation 8}$$

Where

$$t_{rm} = daily\ running\ mean\ outdoor\ temperature, calcuate\ by\ Equatin\ 3$$

$$t_{max,i} = upper\ limit\ of\ adaptive\ thermal\ comfort\ at\ time\ i$$

$$t_{operative,i} = indoor\ operative\ temperature\ at\ time\ i$$

$$\Delta t_i = difference\ between\ indoor\ operative\ temperature\ and\ adaptive\ thermal\ comfort\ upper\ limit$$

$$H_e = number\ of\ hours\ of\ exceedance\ during\ the\ period\ of\ May\ to\ September$$

$$W_e = daily\ weighted\ exceedance$$

$$countif(), \qquad counts\ the\ number\ of\ t_{operative,i}\ that\ meet\ the\ given\ criteria$$

$$sumif(variable, criteria), \qquad adds\ all\ variables\ that\ meet\ the\ given\ criteria$$

Note that the equation 7 used for calculating daily weighted exceedance is still under discussion at the time of preparing this report. Different reports used different expression, for example:

In Cundall's document (Fogarty 2013),

$$W_e = \sum[H_e(1,2,3) \times (\Delta t)2(1,2,3)]$$

In Arup's document (ARUP 2012),

$$W_e = H_{e1} \times (\Delta t_1)^2 + H_{e2} \times (\Delta t_2)^2 + H_{e3} \times (\Delta t_3)^2$$

In CIBSE's document (Spires 2011),

$$W_e = \sum[H_{e(1,2,3)} \times (\Delta t)^2_{(1,2,3)}]$$

By reviewing all methods above and BS EN 15251 Standard, author thought that equation 7 is the best expression for examining hourly simulation data.

Also note that the order of three criteria in this document is different from previous literature. In this report, they are arranged in a logic order which is suitable for computer programming.

According to the BS EN ISO 15251 (British Standards Institution 2007) standard, the level of thermal expectation for new buildings with normal level of thermal expectation (category II) should be calculated by equation 1, and the constant should be 3. Therefore the upper limit of the adaptive thermal comfort can be calculated by equation 9.

$$t_{max,i} = 0.33t_{rm} + 18.8 + 3 \qquad \text{Equation 9}$$

Figure 38 illustrates the upper limits of adaptive thermal comfort zone for part of weather data mentioned in Table 10. Note that the upper limits for CIBSE DSY (green line) are always lower than the 28^{o}C (CIBSE threshold, yellow line). The upper limits for COPSE DRY85 at 2080s (grey line) could reach 29^{o}C in July and August. In the extreme situation (COPSE 2080 DRY99, red line), the limit could reach about 31^{o}C in July.

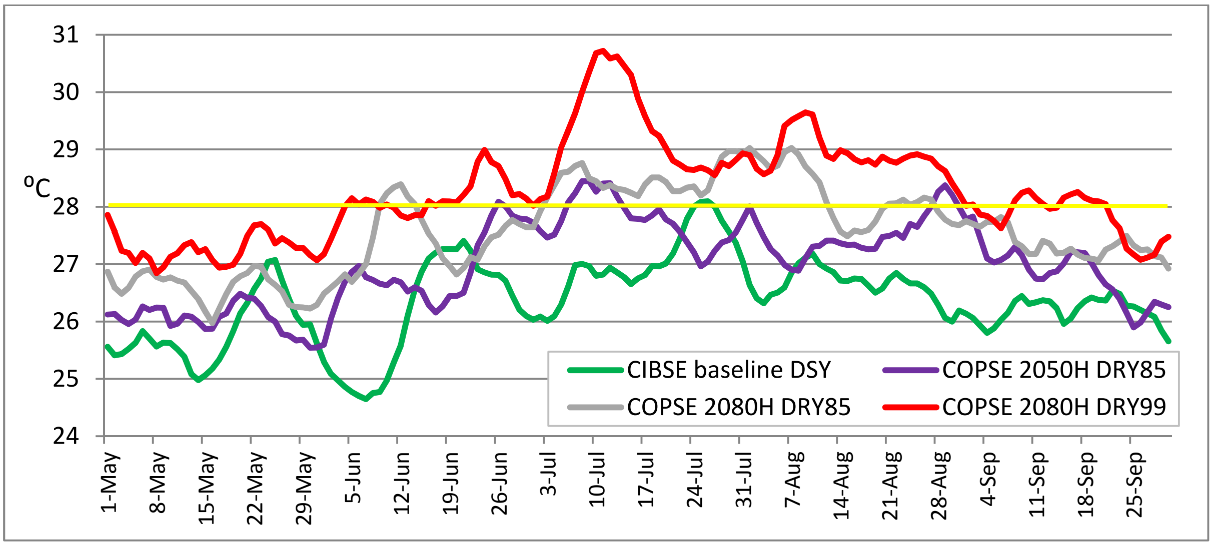


Figure 38 The upper limit of adaptive comfort zone at CIBSE DSY baseline and COPSE DRY 2050s and 2080s

3.2.3 Design for comfort

The IES model of the Dragon School for overheating analysis was created by Ridge and Partners (Castro 2013). The model supplied has already included certain sustainable features, such as double glazing, heavy weight constructions. The detailed information of construction layers in the base model is attached in Climate Change Adaptation Report. The brief information of the base model is summarized in the **Table 9** and **Table 20**.

Table 19 Opaque building material

Construction elements	EN ISO U-value (W/m^2K)	SBEM thermal capacity ($kJ/(m^2K)$)	Admittance (W/m^2K)
External wall	0.1437	132.78	3.7639
Ground floor	0.1412	76.80	3.3973
Roof	0.1062	176.78	4.1294

Internal partition	1.2097	47.08	3.4243
Internal ceiling/floors	1.2097	97.02	5.6068

Table 20 Glazed building material

Construction elements	U-value (including frame) (W/m^2K)	G-value (BS EN 410)	Visible light normal transmittance
Double glazing	1.1512	0.399	0.71

The building model has 70 zones in total which include 12 classrooms, 10 offices, 2 staff room, 3 wet rooms, 1 main hall, 1 light house, 1 server room, 1 LRC, 9 toilets, 23 stores and 7 circulation areas. Detailed information of zone thermal templates and size are given in Climate Change Adaptation Report. This section focuses on overheating analysis of the 12 classrooms which don't have a cooling system.

All building spaces have been modelled with an infiltration rate of 0.25 air change per hour.

Internal conditions (such as minimum fresh air ventilation rates, occupants, and lighting and equipment gains) in the model were set according to NCM database. As defined in the NCM standard, the school is not occupied during 30th May-6th Jun and 25th July- 5th September (**Figure**).

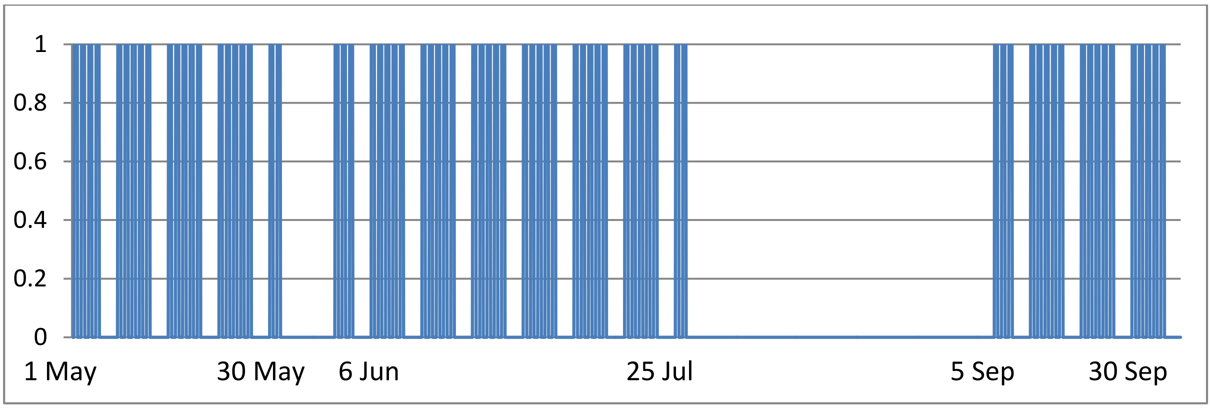


Figure 39 Occupied period of the school

The internal heat gain and ventilation rate of classrooms are given to highlight in Climate Change Adaptation Report. The heating set point of the consulting area is 20 ^{0}C (19 ^{0}C for stores) and cooling set point is 23 ^{0}C. Note that the cooling is provided by natural ventilation. The IES model was run with all the assumptions made above and the simulation results were tested against three overheating metrics mentioned in section 3.2.2 (Table 18). Twelve classrooms (red in Table 21) are key space for overheating analysis.

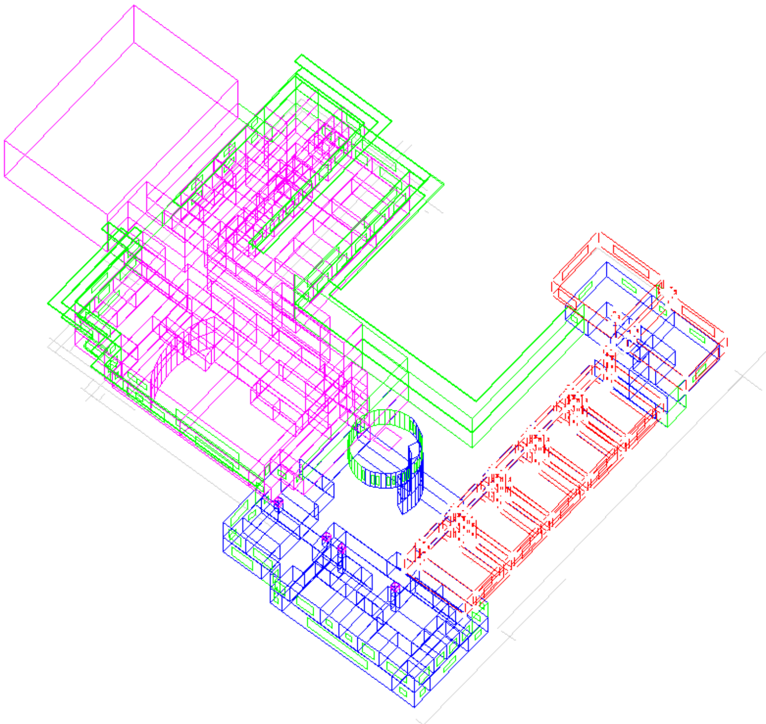


Figure 40 Classrooms in the IES model (highlighted in red)

The results (**Table 21 - Table 4**) indicate that proposed CIBSE TM52 and CIBSE Guide A benchmark are stricter than the adjusted BB101 benchmark for the given school building model and location. Note that as the method of generating TRY data is not suitable for overheating analysis, the adjusted BB101 use DSY data rather than the required TRY weather data. Even at current climate condition, the building model fails to meet CIBSE Guide A and TM52 benchmark. Author noticed four reasons causing the significant difference among these benchmarks:

Firstly, BB101 defined its occupied period as 09:00 to 15:30, Monday to Friday, from 1st May to 30th September; while CIBSE Guide A and proposed TM52 benchmarks doesn't specify the time period. For this building model, the occupied period defined in BB101 benchmark is 518 hours; the 'real' occupied period from NCM standard is 814 hours during May to September and 2123 hours per year. Some hotter afternoons (15:30-17:30) have be treated as occupied period in CIBSE Guide A and proposed TM52 benchmarks;

Secondly, the second criterion of BB101 benchmark compares **average** internal/external temperature difference; while first criterion of proposed TM52 compares internal with adaptive comfort limit at each time instant. The latter is very easy to be exceeded.

Thirdly, the limit of daily weighted exceedance in proposed TM52 benchmark is very strict. None of classrooms met this criterion.

Fourthly, the hours of exceedance thresholds in three benchmarks are different. The exceedance of BB101 benchmark is 120 hours which is 5.65% (=120/2123); the exceedance of CIBSE Guide A is 1%; and 3% for proposed CIBSE TM52 benchmark.

The use of dry bulb temperature in BB101 and operative temperature in others benchmarks also cause the difference in results.

The result indicates that the number of hours over operative temperature of 28^{o}C and maximum operative temperature increase significantly by 2080s. There is a general trend that overheating tends to occur more widely in future.

CIBSE overheating benchmark (1% annual occupied hours over operative temperature of 28^{o}C) is used as an indicator to rank the performance of adaptation measures, because it is efficient, transparent, and widely used by practitioners. Then three overheating metrics are used to evaluate the performances of climate change adaptation packages at 2080s.

The proposed comfort adaptation measures were reviewed in a design workshop on Friday 28 March 2013. We reviewed the overheating metrics and the base building IES model as well as the Climate change adaptation strategy with the building Design Team.

The potential adaption measure highlighted in Table 1 were reviewed along with the average overheating percentages of the selected adaptation measures highlighted in Table13. It was agreed we should review both Design Summer Years (DSY) as well as (TRY) Test Reference Years to give a true reflection of the building overheating potential.

Table 21 Overheating analysis of base model at current climate conditions

Room	BB101 - DSY - Air temperature				CIBSE Guide A - DSY - Operative temperature		CIBSE TM52 - DSY - Operative temperature			
	Number of hours over dry bulb temperature of 28 oC (threshold 120 hrs)	Internal/external average Temperature difference (threshold 5 oC)	Max air temperature (threshold 32 oC)	BB101 Compliant	Percentage of hours over operative temperature of 28 oC (threshold 1%)	CIBSE Guide A Compliant	Difference between indoor operative temperature and adaptive thermal comfort upper limit (threshold 4 oC)	Hours of exceedance (threshold 3% of occupied hours)	Daily weighted exceedance (threshold 6)	CIBSE TM52 Compliant
JS GF Y3 CLASSROOM 5	39	3.87	31.9	□	2.83%	□	4.05	3.30%	28.4	□
JS GF Y3 CLASSROOM 4	39	3.80	31.8	□	2.83%	□	4.00	3.16%	27.4	□
JS GF Y3 CLASSROOM 3	40	3.95	32.0	□	2.83%	□	4.11	3.34%	29.0	□
JS GF Y3 CLASSROOM 2	40	3.95	32.0	□	2.83%	□	4.12	3.34%	29.2	□
JS GF Y3 CLASSROOM 1	40	3.94	32.0	□	2.83%	□	4.15	3.30%	29.6	□
JS FF Y4 CLASSROOM 2	47	4.15	32.4	□	3.30%	□	4.39	4.19%	32.5	□
JS FF Y4 CLASSROOM 3	48	4.25	32.4	□	3.34%	□	4.37	4.10%	32.6	□
JS FF Y4 CLASSROOM 4	48	4.25	32.4	□	3.34%	□	4.37	4.10%	32.6	□
JS FF Y4 CLASSROOM 5	49	4.35	32.4	□	3.34%	□	4.38	4.24%	33.1	□
JS FF Y4 CLASSROOM 1	30	3.14	31.9	□	3.01%	□	4.64	3.53%	28.1	□
JS FF SPARE IT	41	3.87	32.2	□	3.11%	□	4.25	3.67%	30.7	□
JS FF ART CLASSROOM	28	3.16	31.5	□	2.54%	□	4.57	3.06%	22.0	□

Table 22 Overheating analysis of base model at 2030s climate conditions

Room	BB101 - DRY85 - Air temperature				CIBSE Guide A - DRY85 - Operative temperature		CIBSE TM52 - DRY85 - Operative temperature			
	Number of hours over dry bulb temperature of 28 oC (threshold 120 hrs)	Internal/external average Temperature difference (threshold 5 oC)	Max air temperature (threshold 32 oC)	BB101 Compliant	Percentage of hours over operative temperature of 28 oC (threshold 1%)	CIBSE Guide A Compliant	Difference between indoor operative temperature and adaptive thermal comfort upper limit (threshold 4 oC)	Hours of exceedance (threshold 3% of occupied hours)	Daily weighted exceedance (threshold 6)	CIBSE TM52 Compliant
JS GF Y3 CLASSROOM 5	44	4.61	33.9	□	3.82%	□	5.47	2.21%	34.7	□
JS GF Y3 CLASSROOM 4	45	4.59	33.9	□	3.67%	□	5.51	2.17%	34.4	□
JS GF Y3 CLASSROOM 3	45	4.70	33.9	□	3.96%	□	5.48	2.45%	35.1	□
JS GF Y3 CLASSROOM 2	45	4.71	33.9	□	3.96%	□	5.48	2.45%	35.2	□
JS GF Y3 CLASSROOM 1	46	4.69	33.9	□	3.96%	□	5.50	2.50%	35.5	□
JS FF Y4 CLASSROOM 2	54	5.05	34.2	□	4.24%	□	5.76	3.77%	37.0	□
JS FF Y4 CLASSROOM 3	55	5.10	34.2	□	4.29%	□	5.74	3.77%	36.9	□
JS FF Y4 CLASSROOM 4	55	5.11	34.2	□	4.29%	□	5.74	3.77%	36.9	□
JS FF Y4 CLASSROOM 5	55	5.15	34.2	□	4.29%	□	5.74	3.72%	37.1	□
JS FF Y4 CLASSROOM 1	41	4.73	34.3	□	3.67%	□	6.11	3.49%	36.2	□
JS FF SPARE IT	51	4.84	34.1	□	4.15%	□	5.71	2.97%	36.1	□
JS FF ART CLASSROOM	40	4.48	34.2	□	3.44%	□	6.13	2.97%	34.5	□

Table 23 Overheating analysis of base model at 2050s climate conditions

Room	BB101 - DRY85 - Air temperature				CIBSE Guide A - DRY85 - Operative temperature		CIBSE TM52 - DRY85 - Operative temperature			
	Number of hours over dry bulb temperature of 28 oC (threshold 120 hrs)	Internal/external average Temperature difference (threshold 5 oC)	Max air temperature (threshold 32 oC)	BB101 Compliant	Percentage of hours over operative temperature of 28 oC (threshold 1%)	CIBSE Guide A Compliant	Difference between indoor operative temperature and adaptive thermal comfort upper limit (threshold 4 oC)	Hours of exceedance (threshold 3% of occupied hours)	Daily weighted exceedance (threshold 6)	CIBSE TM52 Compliant
JS GF Y3 CLASSROOM 5	95	4.36	33.8	□	8.67%	□	5.42	6.83%	37.2	□
JS GF Y3 CLASSROOM 4	94	4.34	33.7	□	8.67%	□	5.32	6.74%	36.3	□
JS GF Y3 CLASSROOM 3	100	4.48	33.8	□	8.81%	□	5.40	7.07%	37.5	□
JS GF Y3 CLASSROOM 2	100	4.48	33.8	□	8.81%	□	5.41	7.07%	37.6	□
JS GF Y3 CLASSROOM 1	99	4.46	33.9	□	8.81%	□	5.48	7.07%	38.1	□
JS FF Y4 CLASSROOM 2	110	4.84	34.4	□	9.89%	□	6.09	8.43%	44.4	□
JS FF Y4 CLASSROOM 3	115	4.92	34.4	□	10.46%	□	6.05	8.71%	44.0	□
JS FF Y4 CLASSROOM 4	115	4.92	34.4	□	10.46%	□	6.05	8.76%	43.9	□
JS FF Y4 CLASSROOM 5	118	4.97	34.4	□	10.50%	□	6.06	8.86%	44.2	□
JS FF Y4 CLASSROOM 1	87	4.22	34.0	□	8.20%	□	5.99	7.30%	44.8	□
JS FF SPARE IT	102	4.60	34.3	□	9.19%	□	5.92	7.68%	42.3	□
JS FF ART CLASSROOM	80	3.89	33.5	□	7.63%	□	6.35	6.92%	38.6	□

Table 24 Overheating analysis of base model at 2080s climate conditions

Room	BB101 - DRY85 - Air temperature				CIBSE Guide A - DRY85 - Operative temperature		CIBSE TM52 - DRY85 - Operative temperature			
	Numberof of hours over dry bulb temperature of 28 oC (threshold 120 hrs)	Internal/external average Temperature difference (threshold 5 oC)	Max air temperature (threshold 32 oC)	BB101 Compliant	Percentage of hours over operative temperature of 28 oC (threshold 1%)	CIBSE Guide A Compliant	Difference between indoor operative temperature and adaptive thermal comfort upper limit (threshold 4 oC)	Hours of exceedance (threshold 3% of occupied hours)	Daily weighted exceedance (threshold 6)	CIBSE TM52 Compliant
JS GF Y3 CLASSROOM 5	157	3.92	35.7	□	13.09%	□	6.63	11.54%	49.6	□
JS GF Y3 CLASSROOM 4	156	3.90	35.5	□	12.95%	□	6.57	11.49%	49.2	□
JS GF Y3 CLASSROOM 3	161	4.03	35.7	□	13.24%	□	6.63	11.68%	51.2	□
JS GF Y3 CLASSROOM 2	161	4.03	35.7	□	13.24%	□	6.64	11.68%	51.2	□
JS GF Y3 CLASSROOM 1	162	4.01	35.7	□	13.28%	□	6.68	11.73%	50.7	□
JS FF Y4 CLASSROOM 2	188	4.44	36.3	□	14.98%	□	7.24	13.52%	56.5	□
JS FF Y4 CLASSROOM 3	190	4.52	36.3	□	14.93%	□	7.22	13.52%	58.3	□
JS FF Y4 CLASSROOM 4	190	4.52	36.3	□	14.93%	□	7.22	13.52%	58.3	□
JS FF Y4 CLASSROOM 5	191	4.56	36.4	□	14.93%	□	7.25	13.61%	59.5	□
JS FF Y4 CLASSROOM 1	165	3.81	35.5	□	14.13%	□	7.31	13.09%	64.7	□
JS FF SPARE IT	178	4.20	36.1	□	14.08%	□	7.05	12.67%	53.6	□
JS FF ART CLASSROOM	146	3.40	35.1	□	12.76%	□	7.49	11.40%	59.4	□

Extract Table 1 Grading of adaptation measures

	No.	Comfort Adaptation measures	Grading
Designing for comfort		**Keeping cool - internal**	
	2	Shading -building form	1
	3	Glass technologies	1
	5	Green roofs/ transpiration cooling	1
	10	Interrelationship with noise & air pollution	1
	11	Interrelationship with ceiling height	1
	12	Role of thermal mass in significantly warmer climate	1
	13	Enhancing thermal mass in lightweight construction	1
	14	Energy efficient/ renewable powered cooling systems	1/3
	16	Enhanced control systems - peak lopping	/
	17	Maximum temperature legislation	1
		Keeping cool - spaces around	
	18	Built form - building to building shading	1
	19	Access to external space -overheating relief	1
	20	Shade from planting	1
	22	Interrelationship with renewables	1
	23	Shading parking/ transport infrastructure	1
	24	Role of water - landscape/ swimming pools	5
		Keeping warm at less cost	
	25	Building fabric insulation standards	1
	26	Relevance of heat reclaim systems	1
	27	Heating appliance design for minimal heating - hot water load as design driver	1

- Measures already included in the design (1);
- Measures that should be considered for inclusion in the design (2);
- Measures that could be retrofitted in the future but implication worth considering for present design to avoid compromising this possibility (3);
- Measures that could be retrofitted in the future but need no action at present (4);
- Measures not suitable for inclusion (5).

The extract from Table 1 above shows the number of potential adaption measure already provided in the base building design and therefore allowed for within the IES base model.

The extract from Table 1 below shows the remaining 8nr adaptation measures considered appropriate for review. These measures were modelled in IES by Oxford Brookes for effectiveness to reduce overheating potential.

Extract from Table 1 Grading of adaptation measures

No.	Comfort Adaptation measures	Grading
1	Shading – manufactured – Internal environment	2
4	Film technologies	2
6	Shading - planting	2
7	Reflective materials	2
8	Conflict between maximising daylight and overheating (mitigation vs adaptation)	2
9	Secure and bug free night ventilation	2
15	Groundwater cooling	2
21	Manufactured shading – External environment	2

The description and modelling specification (Table 25 - Table 26) of the adaptation measures in IES are shown below. Based on these assumptions, the overheating modelling results of adaptation measures are summarized in Table 25. It indicates that **external shutters, window film, white painted surfaces and triple glazing** have significant impact on reducing overheating percentage. Note that window film should have limited effect due to installation of shading devices; therefore dark film is not suggested if shading devices are installed.

Three adaptation packages were developed based on the effectiveness of individual adaptation measures.

- **The package 1** (P1) includes the two most effective adaptation measures (night time ventilation and external louvres).
- **The package 2** (P2) combines night time ventilation, external louvres and white paints surfaces.
- **The package 3** (P3) combines night time ventilation, external louvres and white paints surfaces and triple glazing.

Table 25 Average overheating percentages of adaptation measures

Adaptation measures		Current	2050s	2080s	P1	P2	P3
Base model		3.0%	9.2%	13.9%			
High albedo surface	Cream paint	3.0%	9.1%	13.8%			
	White Paint	2.9%	8.9%	13.6%		√	√
Glazing	Triple glazing	3.0%	9.1%	13.7%			√
Ventilation	Night time ventilation	0.6%	1.3%	7.3%	√	√	√
Shading	External shutter with control at 300 W/m^2	2.3%	7.6%	11.7%	√	√	√
	Internal curtain with control at 300W/m^2	2.5%	7.9%	12.0%			
	Fixed shading	2.3%	7.9%	12.0%			
Insulation	Better insulated wall and roof	3.1%	9.3%	14.0%			

The performances of 3 packages were tested under current, 2030s, 2050s and 2080s climate condition. The averages of overheating percentages of 12 classrooms are listed in Table 6. The results show that the adaptation packages can significantly reduce the overheating percentages and all classroom could avoid overheating in 2050s based on CIBSE Guide A's benchmark.

The detailed overheating analysis of package 1-3 based on alternative benchmarks such as the adjusted BB101 and CIBSE TM52 is shown in Table - Table . The results indicate that all 3 packages could help to the school avoid overheating issue at 2080s' climate condition based on the BB101 and CIBSE TM52 benchmarks. However these packages could not help the building pass CIBSE Guide A benchmark. One solution of this is to install reversible heat pump to provide cool in summer.

Table 26 Overheating percentages of adaptation packages

Average percentage of occupied hours over 28 ^{o}C	CIBSE DSY baseline	2030s DRY85	2050s DRY85	2080s DRY85
Base model	3.01%	3.98%	9.17%	13.88%
Package 1	0.36%	0.26%	0.89%	4.49%
Package 2	0.35%	0.22%	0.85%	4.09%
Package 3	0.31%	0.20%	0.82%	3.74%

Description of measures

- **Base model**: No shading devices. This ventilation strategy in the base model assumes that windows open when indoor temperature is higher than 22 ^{o}C or RH is higher than 70% during 8:30-17:00. The simulation of this ventilation strategy was conducted in IES MacroFlo using network ventilation calculation method.
- **White paint**: paint outside surface of roof and external wall in white colour.
- **Cream paint**: paint outside surface of roof and external wall in cream colour.
- **Triple glazing**: Triple glazing windows with specifications in Table .
- **Night time ventilation**: Similar to above method, the ventilation is on at any time during working days including night time, when indoor air temperature is greater than 20 and also greater than outdoor air temperature.
- **External louvres with control at 300 W/m^2**: This shading strategy assumes that external louvres could block all direct incident radiation. Designer could decide the form of external shading device. However vertical louvres are suggested for southwest facing windows and horizontal louvres for southeast facing windows. Examples of horizontal and vertical louvres are illustrated in Figure .
- **Internal curtain with control at 300 W/m^2**: This shading strategy assumes that building occupants draw curtains closed when incident radiation is higher than 300 W/m^2.
- **Fixed shading panels**: Fixed one meter overhang projection shading for all were assumed in this model. The dimension of the shading device is listed in Table . Again it is designers' option to choose suitable shading panels and their forms.
- **Better insulated wall and roof**: external wall with 300mm polyurethane board insulation and roof with 350mm polyurethane board insulation were modelled as an adaptation measure. The original model used 160mm polyurethane board for external wall and 225mm polyurethane board for roof. Detailed descriptions of based model and better insulated model are listed in Table and Table .

Modelling specifications of adaptation measure in IES:

Table 27 Modelling specifications of high albedo surface in IES

Settings	Base model	White paint	Cream paint
Outside surface emissivity	0.9	0.9	0.87
Outside surface solar absorptance	0.7 for external wall 0.5 for roof	0.2	0.4

Table 28 Modelling specification of windows in IES

Settings	Base model	Triple glazing
Glazing type	Double	Triple
G-value (BS EN 410)	0.3989	0.3504
Inside surface emissivity	0.837	0.837
Visible light normal transmittance	0.71	0.71
Transmittance of internal layer	0.783	0.783
Inside/outside reflectance	0.072	0.072
U-value (W/m^{2}K, including frame)	1.4848	1.0205
Frame	8% metal frame	

Table 29 modelling specifications of shading strategies in IES

Shading strategies	Modelling specifications in IES
Base model	No shading device
External louvre with control at 300 W/m^2	Set louvre as external shading devices Incident radiation to lower device: 300 W/m^2 Incident radiation to raise device: 300 W/m^2
Internal curtain with control at 300W/m^2	Set curtains as internal shading devices Incident radiation to lower device: 300 W/m^2 Incident radiation to raise device: 300 W/m^2
Fixed shading panels	Set local shade as external shading devices Device: projections Overhang projection 1m, window height 1.6m, window width 1m

Figure 41 Examples of horizontal and vertical louvres

Table 30 Descriptions of external wall and roof in base model

Construction elements	EN ISO U-value (W/m^{2}K)	SBEM thermal capacity (kJ/(m^{2}K)	Admittance (W/m^{2}K)
External wall (160mm polyurethane board)	0.1437	132.78	3.7639
Roof (225mm polyurethane board)	0.1062	176.78	4.1294

Table 31 Descriptions of better insulated model

Construction elements	EN ISO U-value (W/m^{2}K)	SBEM thermal capacity (kJ/(m^{2}K)	Admittance (W/m^{2}K)
External wall (300mm polyurethane board)	0.0796	132.78	3.7639
Roof (350mm polyurethane board)	0.0693	164.81	4.1293

Table 32 Overheating analysis of package 1 at 2080s climate conditions

Room	BB101 - DRY85 - Air temperature				CIBSE Guide A - DRY85 - Operative temperature		CIBSE TM52 - DRY85 - Operative temperature			
	Numberof of hours over dry bulb temperature of 28 °C (threshold 120 hrs)	Internal/external average Temperature difference (threshold 5 °C)	Max air temperature (threshold 32 °C)	BB101 Compliant	Percentage of hours over operative temperature of 28 °C (threshold 1%)	CIBSE Guide A Compliant	Difference between indoor operative temperature and adaptive thermal comfort upper limit (threshold 4 °C)	Hours of exceedance (threshold 3% of occupied hours)	Daily weighted exceedance (threshold 6)	CIBSE TM52 Compliant
JS GF Y3 CLASSROOM 5	68	1.42	31.4	□	4.00%	□	2.43	1.37%	10.8	□
JS GF Y3 CLASSROOM 4	69	1.40	31.4	□	4.24%	□	2.41	1.37%	10.6	□
JS GF Y3 CLASSROOM 3	71	1.47	31.4	□	4.47%	□	2.38	1.37%	10.4	□
JS GF Y3 CLASSROOM 2	70	1.47	31.4	□	4.43%	□	2.39	1.37%	10.5	□
JS GF Y3 CLASSROOM 1	68	1.45	31.4	□	4.05%	□	2.38	1.37%	10.5	□
JS FF Y4 CLASSROOM 2	69	1.63	32.2	□	4.29%	□	2.86	2.17%	11.8	□
JS FF Y4 CLASSROOM 3	75	1.68	32.3	□	4.71%	□	2.93	2.12%	12.3	□
JS FF Y4 CLASSROOM 4	75	1.68	32.3	□	4.71%	□	2.94	2.12%	12.4	□
JS FF Y4 CLASSROOM 5	74	1.70	32.3	□	4.66%	□	2.93	2.12%	12.3	□
JS FF Y4 CLASSROOM 1	72	1.36	32.0	□	4.85%	□	2.87	2.21%	13.7	□
JS FF SPARE IT	67	1.53	32.0	□	4.19%	□	2.75	2.03%	10.7	□
JS FF ART CLASSROOM	80	1.35	31.6	□	5.28%	□	2.56	2.21%	12.6	□

Table 33 Overheating analysis of package 2 at 2080s climate conditions

Room	BB101 - DRY85 - Air temperature				CIBSE Guide A - DRY85 - Operative temperature		CIBSE TM52 - DRY85 - Operative temperature			
	Number of hours over dry bulb temperature of 28 °C (threshold 120 hrs)	Internal/external average Temperature difference (threshold 5 °C)	Max air temperature (threshold 32 °C)	BB101 Compliant	Percentage of hours over operative temperature of 28 °C (threshold 1%)	CIBSE Guide A Compliant	Difference between indoor operative temperature and adaptive thermal comfort upper limit (threshold 4 °C)	Hours of exceedance (threshold 3% of occupied hours)	Daily weighted exceedance (threshold 6)	CIBSE TM52 Compliant
JS GF Y3 CLASSROOM 5	64	1.39	31.3	□	3.82%	□	2.35	1.27%	10.1	□
JS GF Y3 CLASSROOM 4	66	1.37	31.3	□	4.05%	□	2.33	1.27%	9.9	□
JS GF Y3 CLASSROOM 3	67	1.44	31.4	□	4.15%	□	2.30	1.37%	9.8	□
JS GF Y3 CLASSROOM 2	67	1.44	31.4	□	4.10%	□	2.31	1.37%	9.8	□
JS GF Y3 CLASSROOM 1	65	1.41	31.3	□	3.82%	□	2.30	1.27%	9.9	□
JS FF Y4 CLASSROOM 2	61	1.57	32.0	□	3.77%	□	2.79	2.03%	11.2	□
JS FF Y4 CLASSROOM 3	67	1.62	32.1	□	4.10%	□	2.86	2.07%	11.8	□
JS FF Y4 CLASSROOM 4	68	1.62	32.1	□	4.15%	□	2.87	2.07%	11.8	□
JS FF Y4 CLASSROOM 5	69	1.63	32.1	□	4.10%	□	2.86	2.07%	11.7	□
JS FF Y4 CLASSROOM 1	67	1.30	31.8	□	4.47%	□	2.80	2.12%	12.4	□
JS FF SPARE IT	60	1.47	31.9	□	3.72%	□	2.68	1.84%	10.2	□
JS FF ART CLASSROOM	74	1.29	31.5	□	4.80%	□	2.46	2.03%	11.2	□

Table 34 Overheating analysis of package 3 at 2080s climate conditions

Room	BB101 - DRY85 - Air temperature				CIBSE Guide A - DRY85 - Operative temperature		CIBSE TM52 - DRY85 - Operative temperature			
	Number of hours over dry bulb temperature of 28 °C (threshold 120 hrs)	Internal/external average Temperature difference (threshold 5 °C)	Max air temperature (threshold 32 °C)	BB101 Compliant	Percentage of hours over operative temperature of 28 °C (threshold 1%)	CIBSE Guide A Compliant	Difference between indoor operative temperature and adaptive thermal comfort upper limit (threshold 4 °C)	Hours of exceedance (threshold 3% of occupied hours)	Daily weighted exceedance (threshold 6)	CIBSE TM52 Compliant
JS GF Y3 CLASSROOM 5	59	1.35	31.2	□	3.44%	□	2.10	1.18%	8.2	□
JS GF Y3 CLASSROOM 4	62	1.33	31.2	□	3.67%	□	2.14	1.08%	8.1	□
JS GF Y3 CLASSROOM 3	63	1.40	31.2	□	3.77%	□	2.19	1.22%	8.4	□
JS GF Y3 CLASSROOM 2	63	1.40	31.2	□	3.77%	□	2.19	1.22%	8.4	□
JS GF Y3 CLASSROOM 1	61	1.37	31.2	□	3.53%	□	2.10	1.13%	7.9	□
JS FF Y4 CLASSROOM 2	60	1.53	31.9	□	3.63%	□	2.71	1.93%	10.6	□
JS FF Y4 CLASSROOM 3	64	1.58	32.0	□	3.82%	□	2.79	2.03%	11.3	□
JS FF Y4 CLASSROOM 4	65	1.59	32.0	□	3.82%	□	2.80	2.03%	11.4	□
JS FF Y4 CLASSROOM 5	66	1.60	32.0	□	3.82%	□	2.79	2.07%	11.3	□
JS FF Y4 CLASSROOM 1	61	1.24	31.6	□	3.82%	□	2.63	1.74%	10.0	□
JS FF SPARE IT	58	1.43	31.7	□	3.49%	□	2.59	1.79%	9.8	□
JS FF ART CLASSROOM	67	1.21	31.2	□	4.29%	□	2.25	1.60%	9.3	□

No.	Comfort Adaptation measures Reviewed	Comments
1	Shading – manufactured – Internal environment	Effective Solar Control should be developed in detailed design.
4	Film technologies	Not appropriate in school environments as would need to be too dark or too reflective to be effective. Views through the glazing are important in the school to obscure the glass and good quality solar control glazing is already specified.
6	Shading - planting	Not desired due to maintenance required. Fixed shading is preferred.
7	Reflective materials	Not appropriate due to conservation area context
8	Conflict between maximising daylight and overheating (mitigation vs adaptation)	As noted item 4
9	Secure and bug free night ventilation	Effective over night temperature control to reduce surface temperatures of thermal mass. Should be developed in detailed design
15	Groundwater cooling	Ground sourced heat pumps in reverse to be provided cool water supply to reduce surface temperatures may be considered if night time temperatures no longer fall sufficiently to allow night time cool to be effective. But not considered at present.
21	Manufactured shading– External environment	Considered to bike shelters – ref infrastructure section in Appendix A.

Comfort adaption measures carried forward to detail design

- Night time cooling
- External louvres
- Triple glazing
- External Shading.

Please refer to Appendix A for further details

3.2.4 Energy consumption

The IES energy model of Dragon school is almost the same as the model for overheating analysis. The only difference is that the energy model uses whole year data of the Test Reference Year file as it needs annual energy consumption. The weather data files used for simulation are listed in Table .

Detailed energy consumption breakdown for the base model is illustrated in

Figure . Note that the heating for the junior school is provided by a heat pump with CoP of 4.6964. The cooling is provided by natural ventilation. 200 m^2 Monocrystalline silicon PV array is applied in the model to provide electricity for the building and exporting back to gird. The PV electrical conversion efficiency is 0.85.

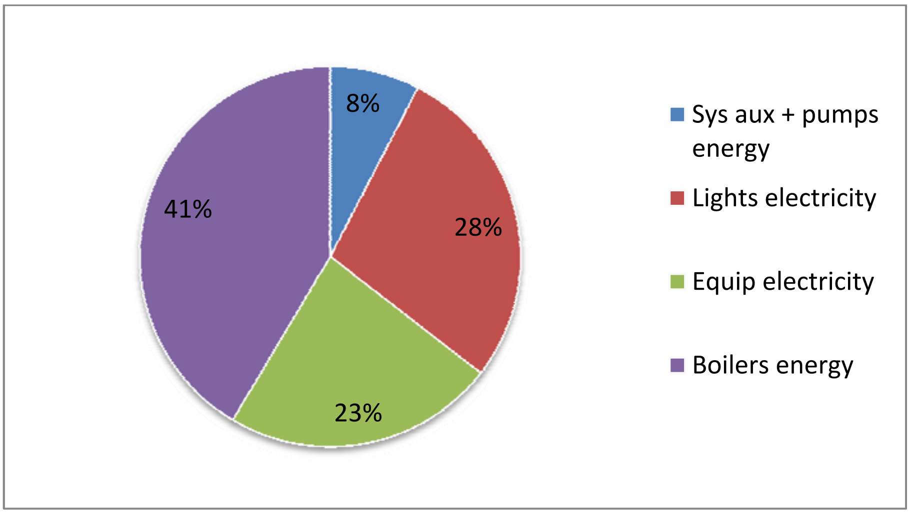


Figure 42 Annual energy consumption at current climate (91.1 MWh consumption plus 20.7 MWh PV generation)

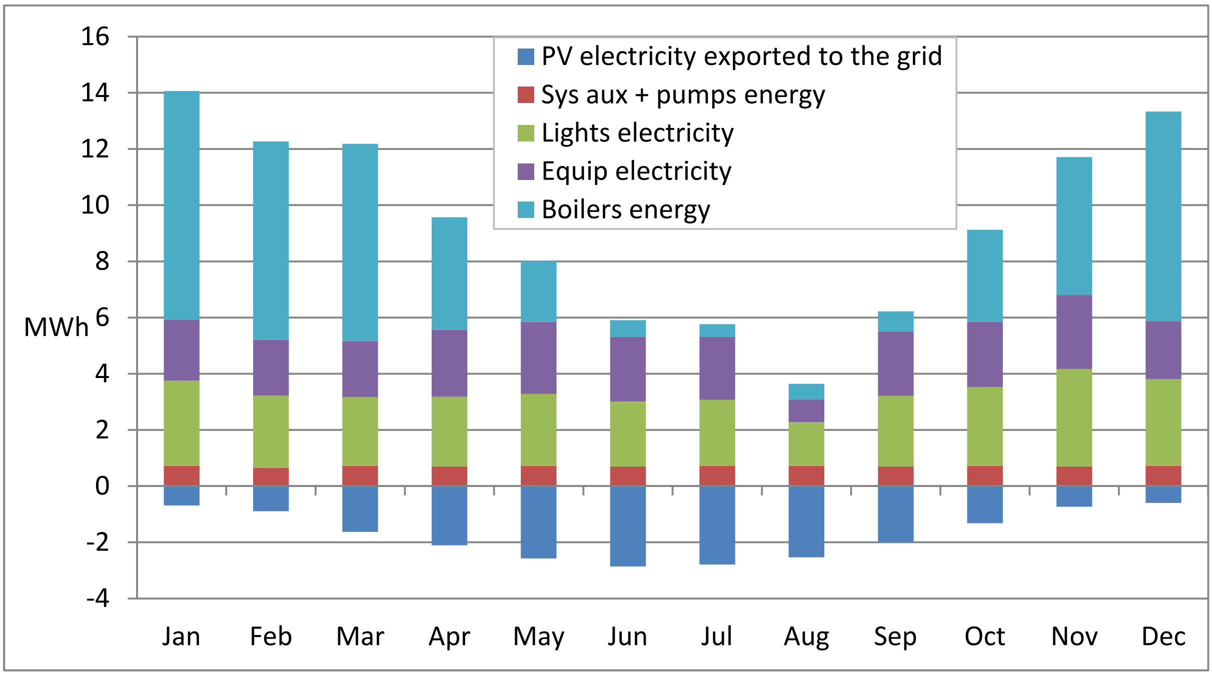


Figure 43 Monthly energy consumption at current climate

The monthly distribution of energy usage is illustrated in the above bar chart. Note that the system electricity consumption remains constant during the whole year. Lighting and equipment consumptions remain relatively constant during school terms. Boiler energy (for heating) consumption and PV exporting vary in different seasons.

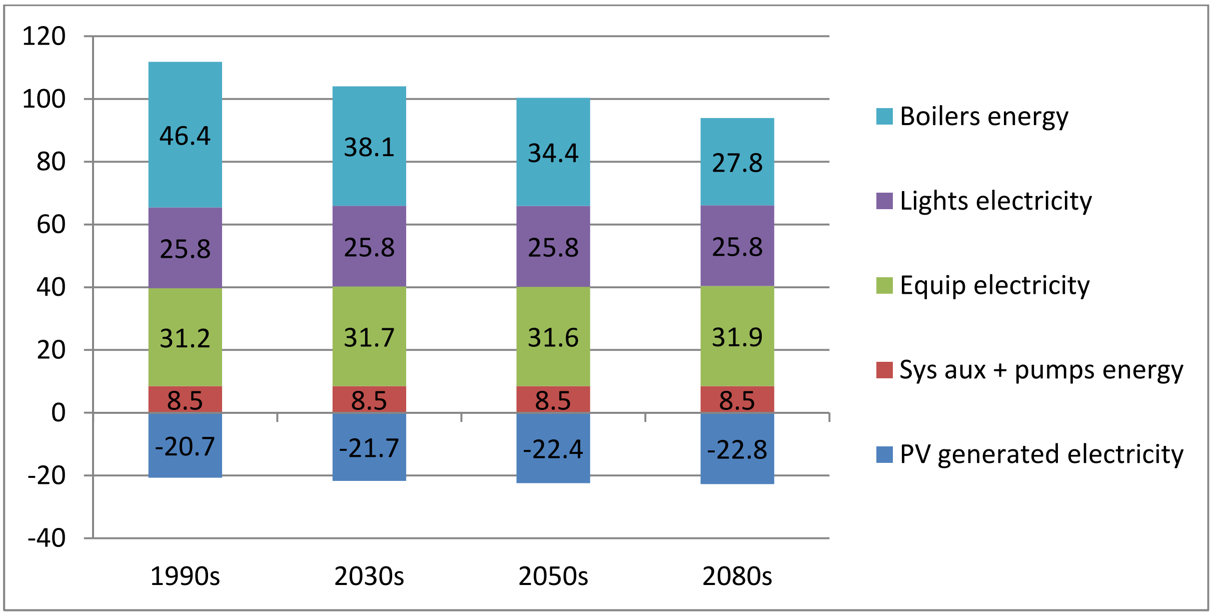
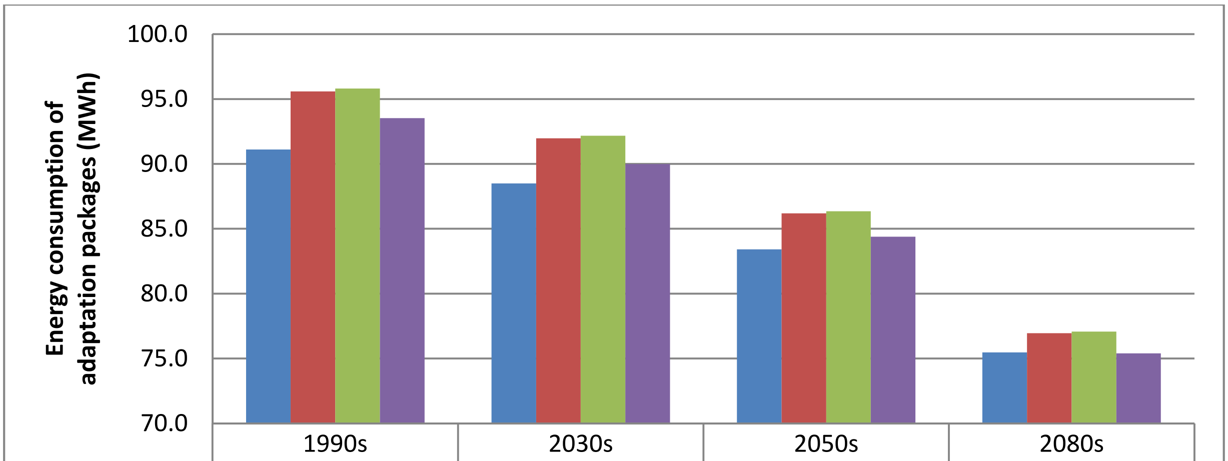


Figure 44 Energy consumption / PV generation at current, 2030s, 2050s and 2080s climate (MWh)

As the benefits of climate change, warming climate will reduce the heating energy consumption by 40% (12.5 MWh) by 2080s. The increasing solar radiation will make 16.4% (2.0 MWh) more PV generations by 2080s comparing with 1990s' baseline (20.7MWh as illustrated in Figure).

The energy consumptions of adaptation packages suggested in section 3.2.3 are listed in following figure. It shows that there is an energy penalty of using adaptation measures, because adaptation measures are general summer solutions which reduce the heat gain of the building. In the heating dominated climate, these solutions can increase the heating energy consumption in winter. As a benefit of a warming climate, the total energy consumption will decrease due to the reduction of heating demand.



	1990s	2030s	2050s	2080s
Base model	91.1	88.5	83.4	75.5
P1	95.6	92.0	86.2	76.9
P2	95.8	92.2	86.4	77.1
P3	93.5	90.0	84.4	75.4

Figure 45 Energy consumption of adaptation packages (MWh)

3.2.5 Construction

Wind load: Due to a high degree of variation of wind speed and a lack of systematic change, wind speed projections were not included in the UKCP09 probabilistic output (Murphy et al. 2009). But it is possible to access wind speed in the regional climate model output on which UKCP09 was partly based. The regional climate model provided 11 perturbed physic projections which has approximately 25km resolution. The upper limits of these projections could be used to calculate wind load.

Another approach to calculate wind speed which was used by COPSE and PROMETHEUS projects is to obtain it by the Penman-Monteith equation (Allen et al. 1998). Watkins et al. (2011) evaluated the reliability of this equation by non-UKCP09 data.

The well-established wind load calculation tool was developed by BRE. It is dependent on location (height above sea level, distance from sea, surrounds) and the shaping (height and form) of the building itself. E.g. the historical wind speed is illustrated in Figure .

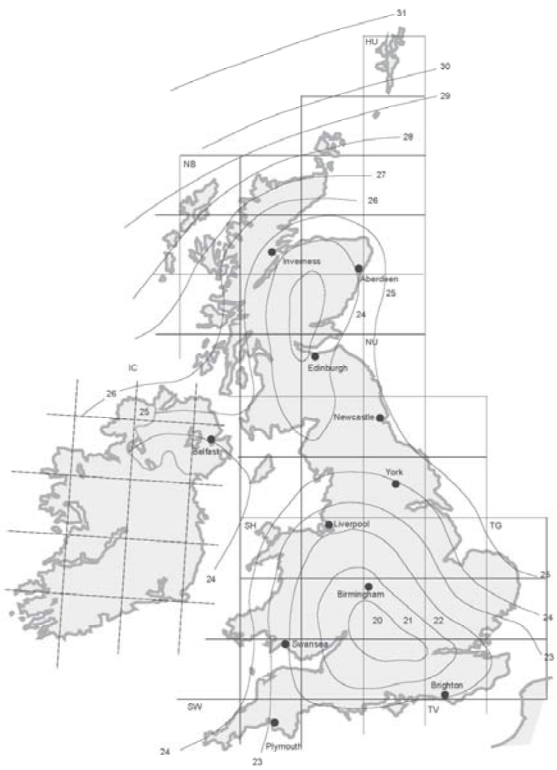


Figure 67 Basic wind speed map 1997 (Gething 2010)

An online wind load calculator (Roofconsult 2012) is also available to carry out calculation based on the method in British Standard (BS 6399-2:1997).

Wind driven rain

In the long-term (2080s), mean winter precipitation is very likely to increase 26.8%, and summer precipitation is very likely to decrease 28.1%. Both are based on 50% percentile risk level of high emissions scenario.

The current approximate wind driven rain for the project site is moderate (33-56.5 Litres/m^2 per spell) based on the map illustrated in Design for future climate report (Gething 2010).

To prevent the increase of winter wind driven rain, following protections would be introduced at a relatively small cost.

Extract from Table 1 Grading of construction measures

Structural stability -below ground		
28	Foundation design - subsidence/ heave/ soils/ regions	1
29	Underpinning	1
30	Retaining wall and slope stability	1
Structural stability -above ground		
31	Lateral stability -wind loading standards	1
32	Loading from ponding	1
	Construction - work on site	
43	Temperature limitations for building processes	5

- Measures already included in the design (1);
- Measures that should be considered for inclusion in the design (2);
- Measures that could be retrofitted in the future but implication worth considering for present design to avoid compromising this possibility (3);
- Measures that could be retrofitted in the future but need no action at present (4);
- Measures not suitable for inclusion (5);

The extract from Table 1 above shows the number of potential adaption measure to improve construction robustness already provided in the base building design and therefore allowed for within the IES base model.

The extract from Table 1 below shows the remaining 14nr adaptation measures considered appropriate for review. These measures were modelled in IES by Oxford Brookes for effectiveness to reduce overheating potential.

Extract from Table 1 Grading of construction measures

Fixings and weatherproofing		
33	Fixing standards - walls, roofs	2
34	Detail design for extremes - wind - 3 step approach	2
35	Lightning strikes (storm intensity)	2
36	Tanking/ underground tanks in relation to water table contamination, buoyancy, pressure	2
37	Detail design for extremes - rain -thresholds/ joints	2
38	Materials behaviour in high temperatures	2
Construction - materials behaviour		
39	Effect of extended wetting -permeability, rotting, weight	2
40	Effect of extended heat/ UV -drying out, shrinkage, expansion, de-lamination, softening, reflection, admittance, colour fastness	2
41	Performance in extremes - wind - air tightness, strength, suction/ pressure	2
42	Performance in extremes - rain 2	2
Construction - work on site		
44	Stability during construction	2
45	Inclement winter weather -rain (reduced freezing?)	2
46	Working conditions -Site accommodation	2
47	Working conditions - internal conditions in incomplete/ unserviced buildings (overlap with robustness in use)	2

These measures were reconsidered with the adaptation measures recommended within Oxford Brookes assessment Climate Change Hazards and Impacts – refer to Appendix 2 for more details.

Table 31 below highlight the specific adaptation measures consider for issues of wind driven rain.

Table 35 Adaptation measures for wind driven rain

Adaptation Element	Measures for Adapting to impacts from	Climatic change that the adaptation is responding to	Climate change hazard	Climatic change impact
Construction element	Recessed window and door reveals	Structural stability	Winter precipitation increase and wind change	Fabric damage
	Render finishes	Structural stability	Winter precipitation increase and wind change	Fabric damage
	Projecting sills with drips	Structural stability	Winter precipitation increase and wind change	Fabric damage
	Extended eaves	Structural stability	Winter precipitation increase and wind change	Fabric damage
	Greater laps and fixings to roof and cladding fixings	Structural stability	Winter precipitation increase and wind change	Fabric damage
	Avoidance of fully filled cavities	Structural stability	Winter precipitation increase and wind change	Fabric damage

This was an important factor regarding the predicted increase in storm force rain fall. We considered existing Building Regulation reveal and opening details for more exposed areas of the UK in Scotland or Cornwall and their suitability for the Dragon School, as well as how a standard cavity wall detail could be improved to reduce heat loss through cold bridging while reducing the risk of driving rain from breaching the cavity separating the internal and external leaves of the wall construction.

Robust details were developed as shown in Appendix 1 assuming that the relatively sheltered Oxford site was now an extreme exposed condition. We took reference from standard construction details in current exposed conditions around the UK. These references allowed a review of materials and construction details to enhance the robustness of the construction details.

Measures for Adapting Construction	Comments
Recessed window and door reveals	Effective robust cavity wall details developed should be developed further in detailed design.
Render finishes	No rendered areas in current proposals due to conservation area restrictions.
Projecting sills with drips	Increased storm weather protection should be developed further in detailed design.
Extended eaves	The current design does not allow an extension of the existing eaves.

Greater laps and fixings to roof and cladding fixings	Increased storm weather protection should be developed further in detailed design.
Avoidance of fully filled cavities	Increased storm weather protection should be developed further in detailed design.

3.2.6 Water

The water conservation elements of the scheme are an optional extra adaptation that may be considered, however they would be nice to have rather than essential elements of the scheme design. The management and maintenance of any water storage systems are not to be underestimated and specialist advise will need to be sort to avoid water contamination issues.

Low water use fittings

Low water use fittings (e.g. dual flush toilet, automatics taps) are currently specified in the base building because they are effective ways of reducing the water usage.

Rainwater catchment system

The rainwater could be used in flush toilets in the Dragon School project. Rainwater Catchment System is defined as a system that utilizes the principal of collecting and using precipitation from a rooftop or other manmade, above ground collection surface. The rainwater reaching a roof in a year can be estimated as the annual rainfall times the roof's plan area. The collection of run-off water from roof is typically 85% of rainwater reaching a roof due to evaporation and splashing.

Extract from Table 1 Grading of water measures

Water supply/ conservation		
53	Limits to development	1
52	Pools as irrigation water storage	5
Flood - Avoidance		
59	Environment Agency guidance -location, infrastructure	1
Flood - Resistance/ resilience		
61	Flood defence – permanent	5
62	Flood defence - temporary -products etc	5

- Measures already included in the design (1);
- Measures that should be considered for inclusion in the design (2);
- Measures that could be retrofitted in the future but implication worth considering for present design to avoid compromising this possibility (3);
- Measures that could be retrofitted in the future but need no action at present (4);
- Measures not suitable for inclusion (5);

The extract from Table 1 above shows the number of potential adaption measure already provided in the base building design and therefore allowed for within the IES base model.

The extract from Table 1 below shows the remaining 10nr adaptation measures considered appropriate for review. These measures were modelled in IES by Oxford Brookes for effectiveness to reduce overheating potential.

Extract from Table 1 Grading of water measures

Water supply/ conservation		
48	Low water use fittings	2
49	Grey water storage	2
50	Rain water storage	1/2

51	Alternatives to water based drainage	2
54	Water intensive construction processes	2
Drainage - external		
55	Drain design	2
56	Soakaway design	2
57	SUDS design	2
Drainage - building related		
58	Gutter/ roof/ upstand design	2
Flood - Avoidance		
60	Combination effects -wind + rain + sea level rise	2

A fluvial flood risk assessment has been carried out to determine that the building is not in the current flood plain, however a detailed Flood Risk Assessment (FRA) analysis of the drainage flow rates from the site due to the propose building work has not yet been carried out. This will be required as part of the detail design phase due to commence following the Planning process.

This FRA will determine the level of SUDS required, accommodating below ground attenuation works to provide resilience to the 100 year flash flood. This normally would have a 10% increase applied for future climate change, however flowing this study the prediction is closer to 30% increase in winter precipitation.

Water adaption measures carried forward to detail design.

- Rainwater catchment system for water use inside the building
- SUDS
- Increase rainwater good sizing

Refer to Appendix 1 for more details.

3.2.7 Landscaping and Infrastructure

Extract from Table 1 Grading of lanmdscape measures

Landscape		
67	Plant selection - drought resistance vs cooling effect of transpiration	2
68	Changes to ecology	2
69	Irrigation techniques	2
70	Limitations on use of water features -mosquitoes etc	5
71	Role of planting and paving in modifying micro climate & heat island effect	2
72	Failsafe design for extremes -water	2
73	Firebreaks	5

- Measures already included in the design (1);
- Measures that should be considered for inclusion in the design (2);
- Measures that could be retrofitted in the future but implication worth considering for present design to avoid compromising this possibility (3);
- Measures that could be retrofitted in the future but need no action at present (4);
- Measures not suitable for inclusion (5).

These measures were reconsidered with the adaptation measures recommended within Oxford Brookes assessment Climate Change Hazards and Impacts – refer to Appendix 2 for more details.

	Green Landscaping	Comments
1	Plant more street trees	There are already a number of trees in the current landscaping plan. No further action is proposed at this time.
2	Convert selected streets into greenways	This was reviewed in detail with the Design Team, however the initial capital cost and maintenance burden prohibit further uptake of this adaptation measure. No further action is considered appropriate at this time
3	Enhance vegetation if the soil has good infiltration qualities	No further action is considered appropriate at this time
4	Plant trees with large canopies - using caution not to compromise building stability	This is to be reviewed with the Arborculturalist and the estates bursar at a more appropriate time.
5	Plant heat, drought and pollution tolerant plants	This is to be reviewed with the Arborculturalist and the estates bursar. However this will be quite a drawn out discussion not appropriate at this time.
6	Remove/ reduce non-porous garden surfaces	There are already areas non-porous areas replaced with alternative porous materials as part of the current landscaping plan. The school has large areas of allotments as wells gardens and adjacent flood plain. No further action is proposed at this time.
	Infrastructure	
1	Add shading to transport infrastructure, such as bus stops and cycle racks	This has been consider in Appendix 1
2	Add seating in shaded areas, on streets	There are currently a number of outdoor seating areas planned in shaded areas around the landscaped areas of the site. This is something that the school can add to over time if required
3	Identify and allocate appropriate buildings as ‘community cool rooms’	This has been consider in Appendix 1
4	Ensure pedestrian and cycle routes are sheltered from high winds/storms, e.g. by soft landscaping	This has been consider in Appendix 1
5	Replace pavements and roads with porous, ‘cool’ materials	This has been consider in Appendix 1
6	Use energy efficient street lighting and/ or switch street lights off for periods of the night	This has been consider in Appendix 1
7	Remodel streets to encourage walking, cycling and public transport, e.g. reduce parking spaces, develop ‘home zones’	This is not appropriate considering the location in North Oxford
8	Install blue infrastructure: lakes, ponds, and other water landscape features	This has been consider in Appendix 1

3.3 Timescales for recommendations

The time line for implementation is being controlled by the Planning Submission required for the development and a fund raising programme prior to construction. The design of the new primary school has been linked to the design of adjoining Music School, which may be constructed before the Primary School itself.

The approved adaptation measures that influence the external appearance of the new Primary School will be incorporated into the Planning submission.

All approved adaptation measures will be included in the detail design development to be priced in the project cost plan and then tender documentation if funding allows.

If a Planning application is submitted in spring 2014, construction may start in 2015.

3.3.1 Timescales for Implementation of Adaption Measures

Comfort Adaptation	**2015**	**2030**	**2050**	**2080**
Night time ventilation				
External louvres / Shading				
Triple glazing				
Construction Adaptation				
Recessed Window and Door Reveals				
Projecting Cills and drips				
Greater laps and fixings				
Avoidance of fully filled cavities				
Water Adaptation				
Sustainable drainage systems				
Increase gutter, downpipe and drainage sizing				
Rainwater catchment system				
Landscaping and Infrastructure Adaption				
Add shading to transport infrastructure, such as bus stops and cycle racks				
Replace pavements and roads with porous ‘cool’ materials.				
Use energy efficient street lighting and/ or switch street lights				
Install blue infrastructure: lakes, ponds, and other water landscape features				

3.3.2 Triggers for adaptation measures for Comfort

Heat is a slightly subjective element, as you can't see it, people don't notice it creeping up on them as easily as flood water levels. This often leads to action to mitigate flooding sooner than comfort levels.

The school questioned whether 32'C as an upper internal temperature limit still provided a comfortable internal environment for a classroom. The comfort experience by an individual or group of building users may vary drastically with a number of variable influences such as; external temperature compared to internal, air movement, style of clothing and materials worn as well as surface temperatures and humidity. Encouraging temperature monitoring is a good way to track and record actual internal temperatures as a trigger for the adaptation measures to improve comfort levels.

- Night time cooling is an extension of the existing natural ventilation strategy designed to lower surface temperatures over night. Ideally this is installed at initial construction but could be retrofitted at a later date when conditions require it.
- The external louvres to shade the building could be fitted on initial construction or could be fitted at a later date when the summer sun intensifies. We do require a certain amount of louvres to provide shading to prevent current summer overheating. So the adapted shading could replace an existing louvre arrangement if staged funding required. However the larger louvres will be part of the planning application and there is a desire to fit and forget the passive elements of the scheme.
- Triple glazing is likely not to be fitted on initial construction and maybe considered when windows require replacement.

3.3.3 Triggers for adaptation measures for the construction

Adaption measures for construction should be carried out on initial build phase to avoid excess additional expense at a later date.

3.3.4 Triggers for adaptation measures for Water Conservation

Adaptation measures for Water Conservation and Building/Site Drainage may be split into two areas.

- Below ground storage systems should be implemented on initial construction, however this is seen as a nice to have not effecting comfort levels, so will be considered if they can be accommodated within the construction cost plan. The triggers for this maybe when the cost of water rises significantly to be seen as an expensive utility. A modest tank could be considered now, if positioned away from the building, this could be increase in size at a later date.
- Increased rain water goods may be implemented when the original installation show signs of reach full capacity.

3.3.5 Triggers for adaptation of Building/Site Drainage

Drainage adaption measures need to be carried out on initial build phase to avoid excess additional expense at a later date.

3.3.6 Triggers for adaptation of Landscaping and Infrastructure

It is unlikely that these adaption measures are on the same time line as the initial building construction. Landscaping often follows building construction; however the current landscaping proposals are sufficiently extensive for these to take a number of years to complete before any adoptions will be considered.

The existing scheme has extensive landscaping proposals many of which are independent to the actual building design and may be carried out sometime after the Primary School construction works.

Adapting existing pavement and roadways and other site wide infrastructure issues are really separate projects to the primary school construction so there implementation time scales are unknown but certainly not on the same time line as the primary school development.

3.4 Cost benefit analysis

Adaption Number	Adaption Measure	New element or Variation of current element or already Existing in scheme	Capital Cost	Lifespan (yrs)	Operational Cost	Maintenance Cost	Payback period
1.0 Comfort							
1.1	Night time ventilation	New	£56,000	25	£25.50	£37,500	n/a
1.2	External louvres	Variation	£71,000	60	n/a	n/a	n/a
1.3	Triple glazing	Variation	£30,000	25	n/a	n/a	n/a
2.0 Construction							
2.1	Recessed Window and Door Reveals	Variation	£8000	60	n/a	n/a	n/a
2.3	Projecting Cills and drips	Variation	£1000	60	n/a	n/a	n/a
2.5	Greater laps and fixings	Variation	£9000	60	n/a	n/a	n/a
2.6	Avoidance of fully filled cavities	Variation	£25,000	60	n/a	n/a	n/a
3.0 Flood							
3.1	Sustainable drainage systems	Variation	£16,000	60	n/a	n/a	n/a
3.5	Increase gutter, downpipe and drainage sizing	New	£10,000	60	n/a	n/a	n/a
4.0 Water Conservation							
4.2	Rainwater catchment system	Variation	£26,000	60	n/a	£30,000	n/a

5.0 Landscaping and Infrastructure							
5.1	Add shading to transport infrastructure, such as bus stops and cycle racks	New	£1,500 per cycle stand	60	n/a	n/a	n/a
5.5	Replace pavements and roads with porous 'cool' materials.	New	£97,000	60	n/a	n/a	n/a
5.6	Use energy efficient street lighting and/ or switch street lights	New	£10,000	25	n/a	n/a	n/a
5.9	Install blue infrastructure: lakes, ponds, and other water landscape features	New	£30,000	60	n/a	n/a	n/a

- All costs are an indication of an extra over cost of each adaption measure to the base building cost.
  The base building was the current building design, before any adaption measures were considered. The current building cost plan highlights construction cost of approx £4M with total estimated outturn cost including VAT at £8M.
- Proposed adaptation cost excluding landscaping and infrastructure = £252,000 which equate to a 6.3% increase in base build construction costs.
- Please refer to Appendix 3 for a cost summary of the Climate Change Adaptation study.
- The 'base building'; complied with Part L and current building regulation in 2013, complied Building Bulletin 101 (BB101): Ventilation of school buildings through dynamic simulation modelling in IES shown in the 'base model'.
  The base building achieves a BREEAM Pre Assessment Excellent rating and complied with the Natural Resource Impact Analysis.
  So the base building was a highly efficient sustainable design that went beyond the minimum design standards to provide excellent quality of indoor and outdoor environments.
- If the adaptation measure was noted as **New** – had not been allowed for in the base building design.
- If the adaptation measure was noted as **Variation** – was an adaptation of an existing element allowed for in the base building design
- The life span of the elements has been assessed with a traditional view of 60 years for building elements and 25 year for services.
- The operation cost has been defined as the cost of any KWhs per year of the element lifespan.
  Most of the adaptations would have no operation energy without moving parts or fans.
  The night time ventilation and rainwater catchment are the only adaptation that may have an operation load.
- Rainwater catchment would require pumps to supply water from the below ground tank into the building. These pumps would be supplied by small stand alone solar cells that would supply all of the operation energy. Therefore these operational costs have been shown zero.

- Night time ventilation would require a power supply to internal thermostats linked to actuators to open the louvres over night time. However it only takes a few seconds to open and close the louvres. This would only be required in the summer months which we have defined as 90 days.
- System = 200Watts per opening bay
  3 bays per room
  20 rooms require openings
  <u>200Watts x 3 bays x 20 rooms = 12kW</u>

  Operating time = 5 seconds to open or close = 10 seconds total per day
  10 seconds of operation x 90 days = 0.25hours a year

  12kW x 0.25hrs = 3kW/h

  <u>At 17 pence per kW/h = 3kW/h x £ 0.17 = £0.51 a year.</u>

  To allow for increase cost of electricity over the 25 year life of night time ventilation system we have assume electricity prices at:

£0.17 kW/h for 10 years	=	3kW/h x £ 0.17 = £0.51/year x 10 years = £ 5.10
£0.34 kW/h from 10 – 20 years	=	3kW/h x £ 0.34 = £1.02/year x 10 years = £10.20
£0.68 kW/h from 20 – 25 years	=	3kW/h x £ 0.68 = £2.04/year x 10 years = £10.20

  <u>Total Operation Energy Cost over 25 years = £25.50</u>

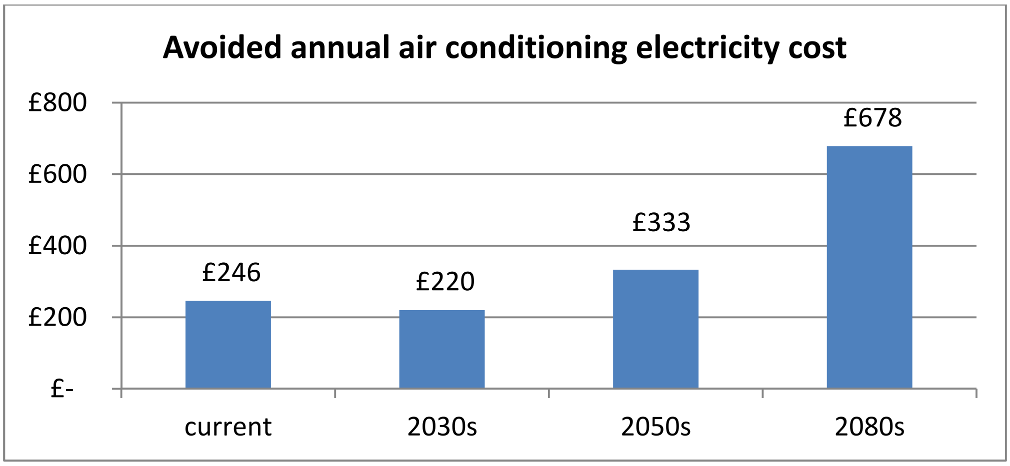
- Maintenance costs were defined as annual service cost if servicing would be required form outside contracts rather than within the existing school resources. A standard cost of £1500 per year was applied to night time ventilation and rainwater catchment to allow annual maintenance by a specialist contractor.
- There are no defined payback periods highlighted as the adaptation measures provide a reduction in overheating or flooding potential alone rather than reducing defined energy consumption. This could be re-assessed as a saving on air conditioning costs averted / being not required due to the night time ventilation allowing lower surface temperatures or reduced water bills from Thames Water.
- The cost benefit analysis has been carried out by the Adrian Kite - D4FC Study Ridge Architect, Richard Pouter - Ridge QS with input from the project Design Team.

This assessment underlines the fact that most of the adaption measures proposed are 'fit and forget' measures that do not carry excessive operational or maintenance costs. The two measures with a significant life time maintenance cost are not considered as excessive within the context of the school campus.

However this assessment also shows there is a high capital cost required to achieve comfort levels in 2080. Deciding when to expend this capital cost and the drivers / triggers is something that has been debated with the school at length.

Avoided air conditioning operating cost

If there is no adaptation measures applied to the school in future, air conditioning will be needed for avoiding overheating in 12 classrooms in future. The predicted annual electricity costs for air conditioning units are £333 in 2050s and £678 in 2080s respectively. This is based on the assumption of 3.2 COP and 16.3p per kWh electricity price (average price of electricity for the Big 6) based on the cooling load required during the occupied hours in term time only to maintain temperature below 32'C calculated with the IES model for energy use. This would obviously increase with extensions to the working day or the school being occupied over the summer break.



This shows an energy saving around £26,000 between 2015 and 2080 from avoiding air conditioning in the classrooms. This shows a 20% saving of the initial capital cost of the louvres and the night time cooling of £127,000. While this percentage may increase slightly if energy prices increase as suggested by the Night time cooling assessment above, this would not lead to a realistic payback period for the adaptation measures alone.

However when we include a maintenance cost of £195,000 based on potential annual maintenance, that may be a £3000 a year x 65 years and initial capital / replacement costs of the fan coil units every 20 years at approx £4500 each x 12 classrooms= £162,000, the payback period of avoiding air conditioning begins to make sense.

When we combine all of these saving from avoiding air conditioning:

- Operational energy saving £26,000
- Maintenance saving £195,000
- Initial capital and replacement cost = £162,000
- Total saving for avoiding air condition between 2015 and 2080 is around £383,000.

If we also extrapolate the night time cooling costs from 2015 – 2080 with the system, replaced 3 times at a cost of £56,000, a maintenance cost of £1500 a year and an operational cost of £25.50 every 25 years

- Operation energy used = £76.50
- Maintenance costs = £97,500
- Initial capital and replacement cost = £168,000
- Total cost of Night time cooling is around £266,000

When we include the initial capital cost of external louvres that may last until 2080 the total cost is still only approx. £337,000, which is almost £50,000 less that installing and running air condition in the school until 2080.

There has to be a desire to have a naturally ventilated building in the first place to accept a higher initial capital cost. However the very broad brush, longer term cost analysis above supports the economic benefit of a natural ventilation strategy, if it can be made to work in warmer summer months, rather than relying on air conditioning to control internal comfort.

3.5 Barriers to implementation

The Dragon School received the adaption measures in a positive manner understanding them to be extensions to the existing strategy of the building design. All of the 10 building adaption measures in the 4 building categories noted in Section 3.4 will be taken up in detailed design to be reviewed in the pre-tender estimate cost plan.

The landscaping measures may be considered at a later date and are not going to be included in the current scheme design.

Many of the potential adaptation measures were already included within base building design and graded (1) in Table 1. The measures that should be considered for inclusion in the design were graded (2) in Table 1. These measures have been were had been reviewed in detail with the project Design Team and are highlighted below.

Extract from Table 1 Proposed adaption measures

1	Shading – manufactured – Internal environment	2
4	Film technologies	2
6	Shading - planting	2
7	Reflective materials	2
8	Conflict between maximising daylight and overheating (mitigation vs adaptation)	2
15	Groundwater cooling	2
21	Manufactured shading– External environment	2

3.5.1 Measure 1 – Manufactured Shading

This was an early focus to control internal solar gain evoking a detailed sun path study by the Design Team – detailed in Appendix 1. This study lead to the adoption of an increase in external solar shading to limit direct solar gain. The sun path study highlighted in Appendix 1, lead to an increase in solar shading being proposed, which would be useful now as well as in 2080.

3.5.2 Measure 4 – Film technologies

Applied films were investigated, however they are more typically used as a retrofitted application as similar, more durable finishes are available in standard glass technologies. This led to a review of Measure 8 Conflict between maximising daylight and overheating (mitigation vs adaptation) see the measure 8.

3.5.3 Measure 6 – Shading planting

There is currently a green roof proposed on top of the primary school, however the eaves design doses not allow for this to be expanded to provide additional shading. There is currently a section of Green Wall proposed on the flood plain aspect of the school; however the Design Team did not wish to expand this to other elevations. The Design Team preferred Measure 1 to provide external shading, so this measure was abandoned.

3.5.4 Measure 7 – Reflective materials

This measure was reviewed at length with the Design Team however due to the context in North Oxford and the existing school site it was not considered appropriate to allow white or cream external materials for the new building. The Planning considerations of the new building and the design guide of the new building suggests it should appear comfortable and in harmony with in existing site and adjacent streetscape. Therefore this adaption measure was abandoned.

3.5.5 Measure 8 – Conflict between maximising daylight and overheating (mitigation vs adaptation)

This measure was reviewed at length with the Design Team and related specifically to the glass specification being developed. The Design Team needed to maintain views out of the classrooms, so a darker tint or reduced light transmission glass was not acceptable. Very dark glass with a low light transmission would mean internal lights would be on longer, increase in energy load of the building. The Design Team also did not want to allow very reflective glass, as they wished to allow views into the classrooms from outside to allow teacher to keep slight of children. However we wanted to manage and reduce direct solar gain getting through the external shading. We agreed that the high performance double glazed units in the current building specification would have solar control glass allowing 70% light transmission and 30% solar gain. This 70/30 glass would be a standard solar control window element on South East, South and South West elevations. This is a standard glass specification we included in the detail design and therefore not a specific climate change adaptation measure. The adaptation measure became the option to include triple glazing rather than double. This would provide an improved thermal break of benefit in both winter and summer while maintaining a high level of light transmission.

3.5.6 Measure 15 – Groundwater cooling

This measure was reviewed with the Design Team and would involve using the Ground Source Heat Pumps (GSHP's) in reverse to pump cold water into the floor slab to cool the surface temperatures. Instead of using hot water for underfloor heating it uses cold water for underfloor cooling. The down side of this is that the pump load would increase the building energy demand. It was agreed that the internal surface temperatures could be lowered by utilising a night time cooling strategy as an extension of the existing natural ventilation strategy. This would allow a passive method of lowering the surface temperature without using the pumps. This night time cooling strategy was assessed in the IES model to confirm its suitability. The GSHP's would be amended in the future if an increased cooling load was required.

3.5.7 Measure 21 – Manufactured shading– External environment

This measure was reviewed with the Design Team and become shading to transport infrastructure, such as bus stops and cycle racks. In reality the Dragon School are not in any rush to carry out this adaptation. The shading would be to cycle racks that currently have clear Perspex covers. The option to retrofit these cycle stands may be superseded with new cycle racks at the end of their life as the external summer environment warms.

The implemented adaptation measures for Dragon School project are summarised in Table .

Table 36 Adaptation measures implemented in Dragon School project

Adaptation category	Project name: Dragon School Project
Comfort	• Secure and bug free night ventilation • External Shading • Balance between maximising daylight and overheating
Construction	• Generally to provide a robust construction which may include: • Recessed Window and Door Reveals • Projecting Cills and drips • Greater laps and fixings • Greater laps and fixings
Water	• Low water use fittings • Ground storage systems • Rainwater catchment system • Sustainable drainage system which may include: • Increase rainwater goods sizing

The comfort information above is a summary of the work conducted by Oxford Brookes University and Ridge and Partners. More detailed reports can be found in appendix 3 - Overheating modelling and climate change adaptation report.

4 Learning from work on this contract

4.1 Summary of your approach to the adaptation design work

We have developed a methodology for climate change risk analysis based on UKCP09 Weather Generator, described in more detail in Climate Change Hazards and Impacts Report. Our overall framework for developing an adaptation strategy for the buildings is as follows:

A. CLIMATE RISK ASSESSMENT FOR THE BUILDING, CONSIDERING FUTURE USERS: We identify the risks and exposure of the building to the projected future climate by modelling the impact of climate change scenarios (medium and high emissions; 2030s, 2050s and 2080s; probability levels of 50%) and data from UKCP09 and informed by CIBSE, BB101 and ISO methods. This is combined with vulnerability assessment of the future users. Suitable criteria will be developed for winter and summer external conditions, internal comfort conditions, rainfall intensity and wind loading using statistical techniques and in conjunction with the design team and client.

B. OPTIONS APPRAISAL OF SUITABLE ADAPTATION MEASURES: To improve the resistance and resilience to climate change now and in the future, the adaptation strategy incorporates the following:

- Impact on comfort levels: This will address: orientation + shading + facade design; cooling load – options; ventilation strategies to be tested; natural + passive stack concept against low voltage mechanical; optimisation of ceiling heights; heat recovery in winter; passive solar in winter - impact on fuel saving
- Building Structure: This will include exposed internal thermal mass - optimum areas required; use of reflective materials; design for storm water; oversized rainwater goods; attenuation vs. collection; green roof vs. quick run-off and collection; frame design and durability; foundation design and soil conditions; as well as performance in extremes - wind, rain, heat waves - air tightness, strength, suction/ pressure
- Open space design will include role of: landscaping - planting and paving strategy in modifying micro-climate and heat-island-effect; seasonal robustness of hard paved areas - flood/ heat/ ice; outdoor comfort
- Water management strategies to include: flood resilience and resistance measures; roof design and rainwater collection; irrigation and recycling; sustainable urban drainage systems and soakway design; grey water recycling and grey water heat recovery.

Most of the above is analysed through scenario testing of variables (overheating and energy) within a dynamic thermal modelling programme (such as IES) and empirical evidence to develop a holistic adaptation strategy. A stakeholder review workshop is undertaken prior to incorporating adaptation measures into the design.

C. DETAILED DESIGN OF SELECTED ADAPTATION MEASURES:

- Using the feedback from previous stages, design options and construction detailing are drawn up at 1:50 (1:20) scale, where required larger details (1:5) are drawn.
- Capital cost appraisals and whole life-cycle costing on design alternatives and options on specification changes are undertaken.

D. UPTAKE OF RECOMMENDATIONS BY THE CLIENT: Meetings are held with the client to discuss actual costs and valuation of benefits of adaptation measures so as to explore take-up of recommendations.

E. REPORTING AND DISSEMINATION: The project is completed with the production of a costed strategic adaptations report for the client. Key conferences and events are identified for dissemination of good practice on climate change adaptation.

With this framework, we have also developed an approach for designing for comfort for single-building projects, given the risks posed by overheating in buildings:

- Review suitable adaptation measures for the project drawing from current literature such as those mentioned in Design for Future Climate report (Gething 2010);
- Build detailed room level energy model (s) in a dynamic building thermal simulation package (for hourly simulation);
- Select appropriate overheating metric;
- Test the performance of individual adaptation measures on reducing the overheating risk in the energy models under current, 2030s, 2050s and 2080s' climate;
- Discuss the overheating results with building design team and grade each measure against the following criteria:
    - Measures already included in the design (1);
    - Measures that should be considered for inclusion in the design (2);
    - Measures that could be retrofitted in the future but implication worth considering for present design to avoid compromising this possibility (3);
    - Measures that could be retrofitted in the future but need no action at present (4);
    - Measures not suitable for inclusion (5);
- Develop adaptation measures which do not have energy implication (e.g. measures for natural ventilated spaces);
- Investigate the energy implication of measures proposed (categories 1-4) for building spaces which need active cooling;
- Conduct cost benefit analysis for measures proposed;
- Discuss with the cost benefit analysis results with clients and making decision on uptakes.

Such methodological approaches will have a widespread application.

4.2 Who was involved in the work

The Project team comprises Ridge and partners who are the architects and lead designers for the new Dragon School Building; Oxford Institute for Sustainable Development (OISD) at Oxford Brookes University who are experts in climate change impact modelling, risk assessment and adaptation.

RIDGE AND PARTNERS is a multidisciplinary consultancy with over 250 staff including Architects, M&E engineers, Structural engineers, Quantity surveyors and Project Managers. Ridge and Partners was appointed as Architect and lead consultant for the project following a competitive interview process in which we provided multidisciplinary design from our in house resources. Our thorough understanding of the evolving design and site conditions will enable them to identify opportunities to innovate and adapt, and to guide the design process in parallel with the adaption project. In partnership with Oxford Brookes University we have undertaken the lead role, design and project management of a TSB Retrofit for the Future project which is currently in its monitoring phase.

Those involved in the CCA study from Ridge include:

- **Graham Blackburn - Dragon School Project Lead - Partner**
  Graham is the partner in charge of architecture at Ridge and leads the Dragon Design Team as well as managing the moderating the CCA study.
- **Matthew Richards - Dragon School Design Team - Project Architect**
  Matthew is the project architect for the Dragon School and along with Graham and Phil has managed the Design Team meetings and carried out design workshops with the client.

These workshop have allowed the base building design to develop with the proposed adaptation measures.

- **Phil Graham - Dragon School Design Team - Design Co-ordinator**
  Phil has carried out the design assessments for the primary school, including the sun path study to review the external louvres and the sketch up model building design seem in Appendix 1.
- **Felipe Castro - Dragon School Design Team - Part L and IES Environmental assessment**
  Felipe developed the base building IES model to show Part L compliance but also so review the internal environment and current overheating potential. This IES base model was then used a the basis for Oxford Brookes to review implication of the future climate data on the primary school building.
- **Phil Baker** - **Dragon School Design Team – Mechanical Design**
  Phil is the project Mechanical Engineer. He advised on the mechanical issues for the school with particular focus on the natural ventilation strategy for the building and Part L compliance. Phil was involved in the review of the 73 potential adaption measures, assisting in understand which elements were already part of the base design scheme.
- **Mike Sudlow** - **Dragon School Design Team –Electrical Engineer**
  Mike is the project Electrical Engineer. He advised on the electrical issues for the school with particular focus on the low energy fittings and lighting design. Mike assisted in the life cycle cost assessment for the cost benefit analysis.
- **Matthew Calvert - Dragon School Design Team - Structural Engineer**
  Matthew is the project structural and civil engineer. He has advised on the concrete frame of the proposed school as well as the drainage and flood risk assessment. His input has lead directly to discussions on SUDS and rainwater collection.
- **Adrian Kite - D4FC Study Architect**
  Adrian is a project architect at Ridge and the CCA study manager. Adrian co-ordinate the review workshop processes with Oxford Brookes and the Dragon School Design Team.
- **Richard Pouter - QS**
  Richard is the CCA Quantity Surveyor. He has provided cost advice for the adaptation measures summarised in Appendix 3 and the cost benefit analysis above.

LOW CARBON BUILDING GROUP, OXFORD INSTITUTE FOR SUSTAINABLE DEVELOPMENT: The Oxford Institute for Sustainable Development (OISD) at Oxford Brookes University is the largest academic research institute in the UK dedicated to research on sustainable development in the built environment. The Low Carbon Building (LCB) group at OISD holds world-leading expertise in carbon counting and climate change adaptation of buildings and cities. Professor Rajat Gupta, Director of LCB group is the Principal Investigator from OISD for this project.

Oxford Brookes University

- **Professor Rajat Gupta Director of OISD**
  Rajat Gupta is the Principal Investigator from OISD for this project. He leads the climate change risk assessment, appraisal of adaptation strategies and supports the detailed design and uptake of recommendations.
- **Dr Hu Du - Lecturer in Architecture and energy simulation**
  Hu conducted climate change risk assessment and IES modelling of adaptation measures for Dragon School project. He also produced the UKCP09 future weather data for Dragon School project.

THE DRAGON SCHOOL is a Preparatory School (for 8-13 year olds), together with the Dragon Pre-Preparatory School, Lynams (for 4-7 year olds), is one of the best known schools in the country and numbers amongst its former pupils a very wide range of successful men and women. Currently situated on two sites in leafy North Oxford, its roots lie in progressive educational theory of the late nineteenth century. Founded as the Oxford Preparatory School in 1877 the school was started by a group of Oxford University dons for their own children. Run for many years by the Lynam family, the Dragon reflected their unconventional approach to education which was based on the belief that children should enjoy school and understand the world around them.

The School today reflects its radical roots and has an ethos that hinges on a dynamic balance of relaxed unpretentiousness and academic discipline which has been described as ‘robust informality and relaxed rigour’. Children’s needs are at the heart of the Dragon and pastoral care is paramount; discipline relies on common sense, kindness and individual responsibility. The joy of learning and the fun of childhood exploration are shared throughout a warm school community where every child is encouraged to try everything and do his or her best.

The Dragon School has a clear aspiration for a green agenda. The school wishes to use renewable technologies where possible and maintain low levels of operational energy, while provide high levels of internal comfort appropriate for the teaching environments they maintain.

- John Baugh – Headmaster

  John Baugh has been Headmaster of the Dragon since 2002. Offered the post after five happy years as Head of Edge Grove in Hertfordshire and, prior to that, eleven equally happy years as Head of Solefield School, Sevenoaks, he was delighted to be offered his ‘dream’ post in preparatory education. Together with his wife Wendy, who works full time at the Dragon, and his two graduate daughters he has made his home in Oxford at the heart of this unique school.

- Ian Caws – Bursar

  The Dragon is a charitable trust and company limited by guarantee with an annual turnover of £14M, 300 staff and 850 pupils. As Bursar (akin to Operations and Finance Director), Ian is responsible for all support functions across the School including: strategic planning (with the Headmaster); financial planning and management; facilities management including capital works, estates, grounds and catering; HR; administrative management.

- Steve Poyntz - Estates Bursar

  Estates Bursar at Dragon School
  Former Administrative Officer at Royal Air Force.

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

Our initial project plan was for the new Junior Dragon School building is be low energy and future-proofed, which would set a new standard for flexible, pupil-centred teaching and learning. The project was ideally suited to the Design for Future Climate programme as it covers planned low impact new school building that is now at the design stage, which provides substantial opportunity to improve its resistance and resilience to climate change.. The project will utilised a range of professional skills from both academic and industry backgrounds. The combination of these backgrounds working together will ensure that the best research, design and analysis skills will be used to deliver the project.

The methodological approach is based on the risk triangle developed to understand the implications of climate change for the insurance industry. With this approach, hazards and impacts of climate change are assessed along with exposure of the site, and vulnerability of the potential occupants.
To demonstrate this approach: first the hazards for the site were quantified at an appropriate scale, this entailed analysis of probabilistic climate change projections developed by the UKCP09. Second, climate change impacts were defined and thirdly the local environmental features (LEFs), which can exacerbate or ameliorate the impacts, were defined for their potential influence and finally the general adaptation strategies were detailed. Mitigation strategies that share synergistic relationships with specific adaptation strategies were also identified.

The initial plan was to finish the CCA project in March 2012 with the Design Team submitting a Planning application scheduled for September 2011 and detail design due to commence January 2012. However due to the primary school design being linked to an adjoining Music school design, which has slowed progress of the overall scheme design, the CCA study was not completed until November 2013 prior to the Stage C design being completed.

The building has been designed with low energy features to mitigate the effects of climate change. To quantify the benefits of these features is not to define the energy saved by these measures over the life of the building. But more over the modelling allowed the comfort adaptation assessments to be carried out using the IES model developed to shown Part L compliance and the management of internal environment in today's climate.

The assessment of the other adaptation measures were hindered by the project time line being delayed as this meant that the Design Team did not progress from the outline design stages into detail design in 2012 as our original plan. This formed a natural barrier to not only developing the school design but assessing the construction, water and landscaping adaption measures in more detail, as consideration of these aspects of the project had not been further developed by the project design team.

The programme delay also impacted on the development of the project cost. As this has not been finalised, the building budget has not been interrogated in detail to allow the school to confirm the cost of the proposed adaptation measures can be accommodated within their budget.

The school are in the process of a fund raising programme for the Music School which may be progress before the Primary School building, so the actual budget available is really yet to be defined.

The framework and the methodology of our project plan was followed as originally defined:

- KICK-OFF: A workshop with all stakeholders was held on Friday 4 May 2012 to familiarise team with the process and scope.

- CLIMATE RISK ASSESSMENT FOR THE BUILDING, CONSIDERING FUTURE USERS: This phase identifed the risks and exposure of the building to the projected future climate by modelling the impact of climate change scenarios (medium and high emissions; 2030s, 2050s and 2080s; probability levels of 10%, 50% and 90%) and data from UKCP09 and informed by CIBSE and ISO methods. This combined with vulnerability assessment of the future users. In a workshop for all stakeholders on Friday 5 Oct 2012, Oxford Brookes University explained climate change prediction results and the context of future scenarios. Criteria will be developed for winter and summer external conditions, internal comfort conditions, rainfall intensity and wind loading using statistical techniques and in conjunction with the design team and client.

OPTIONS APPRAISAL OF SUITABLE ADAPTATION MEASURES: In a workshop for all stakeholders on Friday 28 March 2013 we reviewed options to improve the resistance and resilience to climate change now and in the future, we anticipate that our adaptation strategy incorporated the following:

1. Impact on comfort levels: This addressed: orientation + shading + facade design; cooling load – options; ventilation strategies to be tested; natural + passive stack concept against low voltage mechanical; optimisation of ceiling heights; heat recovery in winter; passive solar in winter - impact on fuel saving;

2. Building Structure: This included exposed internal thermal mass - optimum areas required; use of reflective materials; design for storm water; oversized rainwater goods; attenuation vs. collection; green roof vs. quick run-off and collection; frame design and durability; foundation design and soil conditions; as well as performance in extremes - wind, rain, heat waves - air tightness, strength, suction/ pressure;

3. Open space design included role of: landscaping - planting and paving strategy in modifying micro-climate and heat-island-effect; seasonal robustness of hard paved areas - flood/ heat/ ice; outdoor comfort;

4. Water management strategies included: flood resilience and resistance measures; roof design and rainwater collection; irrigation and recycling; sustainable urban drainage systems and soakway design ; grey water recycling and grey water heat recovery.

The impact on the comfort levels was mainly analysed through scenario testing of variables within a dynamic thermal modelling programme (IES) where as the other categories were analysed through empirical evidence to develop a holistic adaptation strategy.

A stakeholder review workshop was undertaken on Tuesday 03 September 2013 prior to incorporating adaptation measures into the design.

DETAILED DESIGN OF SELECTED ADAPTATION MEASURES: Using the feedback from previous stages, design options and construction detailing were drawn. This is outlined in Appendix 1.

Capital cost appraisals and whole life-cycle costing on design alternatives and options on specification changes were be undertaken. This is outlined in Appendix 3. However a number of high level assumption had to be made as the detail design for the building or the drainage had not yet been carried out to allow a true add and omit exercise from the cost plan.

UPTAKE OF RECOMMENDATIONS BY THE CLIENT: A further workshop meeting with the Dragon School was undertaken on Friday 8 November 2013 to review the projected climate risks, the proposed adaptation measures, the projected costs and re-evaluation of benefits of adaptation measures so as to ensure recommendations align with the Client's strategic estates plan.

REPORTING: The project has been completed with the production of a costed strategic adaptations report for TSB. In addition, a guidance document on best practice will be developed by Oxford Brookes and Ridge to impact on future of construction projects.

DISSEMINATION: (Yet to be completed): A final project workshop meeting was undertaken on Thursday 12 December 2013 to review the dissemination plan. The project team is committed to the dissemination of good practice on climate change adaptation through industry conferences (Ecobuild, RIBA, Constructing Excellence) and other TSB events. A project press release will be agreed with the School and an expanded building case sttudy will be distributed sumarisng the project findings.

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

This project used the following resources/tools and their strengths are listed below. The limitations are summarized at the end of this section.

4.4.1 Overheating Guidance

CIBSE Guide A Overheating Guidance

The CIBSE benchmark of overheating for school is 1% annual occupied hours over operative temperature of 28°C (CIBSE 2006). It is a simple definition of overheating and widely used by practitioners.

Building Bulletin 101

BB101 is suggested by Department for Education for all schools. It has three criteria:

- There should be no more than 120 hours when the air temperature in the classroom rises above 28°C
- The average internal to external temperature difference should not exceed 5°C (i.e. the internal air temperature should be no more than 5°C above the external air temperature on average)
- The internal air temperature when the space is occupied should not exceed 32°C.

BS EN 15251 Overheating Guidance

The adaptive comfort limits mentioned in BS EN 15251 standard are based on a daily running mean outdoor temperature. It could allow part of building spaces to stay within comfort range to some extent.

CIBSE TM 52

CIBSE overheating task force defined three criteria, and in order to show that the proposed free-running building will not suffer overheating, two of these three criteria must be met. The three criterions are:

- Upper limit temperature: The difference between indoor operative temperature and adaptive thermal comfort limit shall not exceed 4 degree.
- Hours of exceedance: the number of hours that indoor operative temperature equal or over adaptive thermal comfort plus 1 degree during the period of May to September inclusive shall not be more than 3% of occupied hours.
- Daily weighted exceedance: the weighted exceedance shall be less than or equal to 6 in any one day.

4.4.2 Climate and weather data

UKCP09

The UK Climate Projections (UKCP09) gives climate information for the UK up to the end of this century. Projections of future changes to our climate are provided, based on simulations from climate models. The purpose of providing information on the possible future climate is to help those needing to plan how they will adapt to help society and the natural environment to cope with a changing climate.

UKCP09 Weather Generator (http://ukclimateprojections-ui.metoffice.gov.uk/ui/admin/login.php)

UKCP09 Weather Generator is a downscaling tool that can be used to generate statistically plausible daily and hourly time series. These time series comprise a set of climate variables at a 5 km^2 resolution that are consistent with the underlying 25 km^2 resolution climate projections.

UKCP09 Threshold Detector

The UKCP09 Threshold Detector is a post-processing tool that can be applied to the output from the Weather Generator. It allows users to define their own basic weather events made up of simple conditions such as temperatures or daily rainfall totals greater/lower than a certain threshold. The Threshold Detector could count the number of occurrences of the prescribed event. It also produces a set of summary statistics across all the runs.

COPSE weather data (http://www.arcc-network.org.uk/project-summaries/copse/)

COPSE weather data is created at Prof Chris Underwood at University of Northumbria and Dr Hu Du at Oxford Brookes University under EPSRC funding. The weather data is in EPW format which is already for use for most of building simulation tools.

DView (http://beopt.nrel.gov/downloadDView)

DView is free software developed by US National Renewable Energy Laboratory. The epw weather files could simply be loaded for visualizing hourly, monthly values and cumulative distribution of hourly values. Graphic comparisons of different weather data are also can be made in this tool.

MATLAB (http://www.mathworks.co.uk/products/matlab/)

MATLAB is a powerful numerical computing programming language developed by MathWorks. A function was created by the author to quickly calculate adaptive thermal comfort limits based on external weather data. MATLAB also generated COPSE weather data and helps post-processing numerical outputs from thermal modelling software.

4.4.3 Thermal modelling tool

IES ApacheSim

IES is market leading environmental building modelling software. Detailed building level climate change impact analysis is being undertaken through building thermal simulation modelling in IES ApacheSim. IES ApacheSim was selected partly due to the wide international usage by both research and practice communities, and partly due to the extensive historical testing and verification (Gough and Rees 2004).

4.4.4 Limitations of resources and tools

All resources and tools used in this project are carefully selected based on our knowledge; therefore they are recommended for other projects. The limitations of these resources and tools are listed in following table.

Resources and tool	Limitations
UKCP09 Weather Generator	Time consuming when generating hourly and daily data; Do not support batch processing.
MATLAB	Programing experience is needed.

IES VE	Does not support batch post-processing of simulation results.

4.4.5 Other resources, tools and materials we developed

A function was developed in Matlab to calculate adaptive thermal comfort limits based on external weather data.

Following reports were produced as part of the project:

Gupta, R. & Du, H. (2013) Overheating modelling and climate change adaptation report – Dragon Junior School for the Future. Submitted to Ridge and Partners LLP, Oxford in May 2013. (Appendix 2)

Gupta, R., Du, H. & Gregg, M. (2012) Climate changes hazards and impacts report – Dragon Junior School for the Future. Submitted to Ridge and Partners LLP, Oxford in September 2012. (Appendix 3)

Gupta, R., Du, H. & Gregg, M. (2014) Design for future climate - adaptation strategies for homes, schools and hospitals, Oxford: Oxford Brookes University, ISBN: 978-1-873640-82/1 (to be published)

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

The challenges of assessing the Comfort adaptation measures were ameliorated by the detail assessment necessary to comply with current Part L and current overheating analysis required such as Building Bulletin 101. So adapting to future climate conditions was simply an extension of the current strategy with a different set of base criteria. This provided an integrated approach for our client, viewing the adaptation measures as useful design development rather than imposed criteria.

Through this work, it has been realised that to have confidence in overheating risk assessment for future climate, there is a need to have consistent metrics for all projects. This includes agreeing on an appropriate overheating risk criterion, a standardized calculation method for assessing risk and future climate data (for different locations in the UK).

The metrics may differ for building typologies and occupant categories but would still have a common approach. A consistent approach to overheating analysis is required if the central/local Government and professional bodies would like to incorporate a requirement for designers and developers to undertake overheating risk analysis for new buildings against future climate, as part of future building regulations or planning requirements.

The Climate Risk Assessment for the building was very thorough and lead to measures to combat overheating issues. This lead to detailed studies of the building external features influencing the internal and external environments.

It also has been realised that cost benefit analysis (CBA) isn't the only way to determine the uptake of adaptation measures. CBA tends to work for those measures which have energy implication. For the measures which don't have energy saving but improve thermal comfort, thermal comfort and its health benefit should also be considered. There is a need to develop a methodology to quantify the health benefits of adaptation measures beyond purely comfort levels related into temperature. The issues of air quality influencing comfort could be studied further when considering the ability of naturally ventilated buildings to maintain lower internal temperatures compared to allowing air condition. However these principles are defined from the outset of concept design, in decisions of the kind of building we want and the quality of internal environment we are creating.

But heat is a very subjective thing. The school questioned whether 32'C as an upper limit was still providing a comfortable internal environment for a classroom. The comfort experience by an individual or group of building users may vary drastically with a number of variable influence such as; external temperature compared to internal, air movement, style of clothing and materials worn as well as surface temperatures and humidity. Having fresh rather than conditioned air may have more long term effects on users related to germ transfer in communal areas, but that is beyond the scope of this study.

We have developed a robust and replicable methodology for climate change risk analysis based on UKCP09 Weather Generator, described in more detail in Climate Change Hazards and Impacts Report. Such methodological approaches could be applied to other building projects.

What did not work so well were the empirical assessment of construction, water and landscaping which were hindered by the project time line being adjusted, reducing the level of detail that was developed by the design team.

The construction assessment was based on the outline specification rather than proposed detailed construction drawing from the design team.

Detailed design elements such as the below ground drainage design and a Flood Risk Assessment (FRA) were not carried out by the engineers as we are still in Stage C of the design process. These activities are normally carried out in Stage E during the Detail Design phase. A FRA assesses the risks of site flooding from below ground drainage, which influences the drainage design by providing the projected out flow of below ground drainage from the site, defining pipe sizes, SUDS design with attenuation requirements.

So we did not have robust data set predictions for storms and flooding conditions to allow simulated analysis such as carried out with the comfort levels. However as noted above heat is a subjective element, as you can see it, people don't notice it creeping up as easily as flooding water levels. This often leads to action to mitigate flooding sooner than comfort levels.

Without this detailed information a number of assumptions were made to allow a cost review regarding then provision allowed for in the base design to of certain adaptation measures.

4.6 Decision making processes by the client

For this project we developed a two stage review process to assess the principle of each adaptation measure in order to then focus on a detailed review of a smaller number of measures.

The first stage review was carried out by the project Design Team on behalf of the school to allow continuity and regular contact with the CCA team. The second phase review of the detailed measures was then presented to the School once reviewed by the Design Team. In this way the school were presented with a summary of our findings. As the school are not construction experts they are relying on the advice of the design team throughout the design process. In this way the assessment of the adaptation measure became an integral part of the building design development.

The client was involved in a workshop in which the climate risks, proposed adaptations and their benefits were presented. The Design Team had made a number of decisions on behalf of the Dragon School in design development, however these were presented and assumptions explained.

The whole team both Ridge and Oxford Brookes presented the climate change study and findings to the Dragon School. This raised a number of questions with school on confirm levels and climatic conditions for children in their school. We presented the adaptations as extension of design they knew and had signed off, so they were comfortable with the concepts and origins.

However the programme delay also impacted on the development of the overall project cost plan. As this has not been finalised the building budget has not been interrogated in detail to allow the school to confirm the cost of the proposed adaptation measures can be accommodated within their budget.

The school are in the process of a fund raising programme for the Music School which may be progress before the Primary School building, so the actual budget available is really yet to be defined.

This has clouded the detail of the decision making process, creating a natural barrier to concrete acceptance of any kind of detail proposals until the project cost plan is finalised and aligned with the schools budget restrictions.

5 Extending adaption to other buildings

5.1 An assessment of how this strategy, recommendations and analyses might be applied to other buildings and building projects

Our methodology for climate change risk assessment based on the UKCP09 Weather Generator is described in Section 4.1 and Appendix 2. Such methodological approaches could be applied to other buildings and building projects. For the large multi-building development projects, selection of case studies may be required to simplify the process.

The selection of overheating benchmark may differ depending on the type of building usage.

This study reinforced that we are designing good quality buildings suitable for the current climate we have and next few decades. It highlighted that the building performance modelling tools we are using with IES thermal modelling and 3D sun path review to assess our current designs performance are working well and can easily provide advice on future climate conditions and required energy performance.

The combination of designer and academics works well, because it increases the whole project team better understanding of climate change information, building physics and the latest building standard/code.

5.2 A description of the limitations of applying this strategy to other buildings

A cross comparison of all adaptation measures is conducted in following table. It shows that shading and ventilation are the measures which have been used cross all projects. Due to the specific requirement in each building, various ventilation strategies including night time ventilation, earth tube, and mechanical ventilation were applied. Other adaptation measures, such as green roof, thermal mass, glass/film technologies should be considered case by case.

Table 37 Cross-comparison of measures in school-related projects

	Adaptation measures for comfort
Case 1	• Additional thermal mass • Evaporative cooling • Shading • Ventilation • Vegetation • Green and brown roofs
Case 2	• Natural ventilation • Increasing the free area (increases the potential for external air to replace internal air at times when the external dry-bulb temperature is lower than the internal air temperature) • Thermal mass • Shading – manufactured • Glass technologies/film • Secure, bug free and maximum ventilation • Ceiling height
Case 3	• Green roof • Ventilation (Naco Storm Louvre)

	• Solar control glazing • Brise soleil
Case 4	• External shading to south-facing • Alteration to external shading to library • Additional planting (deciduous trees) to provide shading • Brise soleil • Electrical fans • GSHP or ASHP for reverse cooling using UFH system • Review of school timetable to avoid peak temperatures in summer • Flexible layout in future school design • Installation of Cool Phase system to teaching spaces
Case 5	• Night ventilation • Green roof • External shading • Ground cooling (earth tubes) • Film and glass technologies • Stack effect • Internal roof insulation • Internal wall insulation • Phase changes materials
Case 6	• Secure and bug free night ventilation • Shading • White paint surface • Balance between maximising daylight and overheating

We also noticed following limitations of applying these strategies to other buildings:

- Building performance modelling tools have limited function on testing some of adaptation measures, such as on testing green roof, planting on façade and water use in the landscape. To quantify the benefit of these measures, the developments of experiential data or robust modelling methods are required.
- Some of these measures may be better assessed under a building user survey rather than theoretical modelling software.
- The sizing of rainwater tank in rainwater harvesting system is normally based on current climate change information. This could be adapted to future climate. The maintenance of harvesting system requires the internal filter to be washed about once a quarter.
- Future projections of flood maps could be developed based on the UKCP09 projection.
- A number of future weather datasets are available at this moment. It is recommended that future research should consider harmonisation of the various downscaling approaches so as to either ensure that methodologies create future weather data in an acceptable range of variation or generate a unified dataset of future weather data for a given location and climate change projection.

5.3 An analysis of which buildings across the UK might be suitable for similar recommendations

Following measures have significant influence on cost benefit and they are suggested for other educational buildings:

- Secure and bug free night ventilation
- Considered solar shading

- Low water use fittings
- Rainwater storage
- Energy efficient lights.

Low water use fittings in general could be applied to any building which has water usage; however it is subject to the condition of building or space purpose.

Control of lights and energy efficient lights are suitable for office buildings. Understanding the use pattern is essential to the design of lighting system.

Rainwater harvesting system is useful for the building with large roof area.

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

A cost benefit checklist of adaptation measures (section 3.4) is developed by Ridge. It could help designers and clients quickly understand the benefit of these measures.

A Design for Future Climate workshop is planned to present the learning outcomes of the D4fC projects conducted by Oxford Brookes University. For this particular project, following documents and papers were produced:

Gupta, R. & Du, H. (2013) Overheating modelling and climate change adaptation report – Dragon Junior School for the Future. Submitted to Ridge and Partners LLP, Oxford in May 2013. (appendix 2)

Gupta, R., Du, H. & Gregg, M. (2012) Climate changes hazards and impacts report – Dragon Junior School for the Future. Submitted to Ridge and Partners LLP, Oxford in September 2012. (appendix 3)

Gupta, R., Du, H. & Gregg, M. (2014) Design for future climate - adaptation strategies for homes, schools and hospitals, Oxford: Oxford Brookes University, ISBN: 978-1-873640-82/1 (to be published)

5.5 Further needs you have in order to provide adaptation services

Funders are needed in order to provide further adaptation services.

Trainings for designers about climate change and adaptation strategies are needed through CPD sessions.

References

Allen, R. G., *et al.*, 1998. *Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56.* Food and Agricultural Organization of the United Nations.

ARUP, 2011. *SNACC Internal Report: Generation of DSY and TRY weather years for the case study locations using the UKCP09 climate change projections.* Ove Arup & Partners Ltd Job number 212178.

ARUP, 2012. *UoS Grad School TSB adaptation study Appendix 3.1 - Calculation procedures for overheating metrics* [online]. Available from: https://connect.innovateuk.org/c/document_library/get_file?folderId=6662732&name=DLFE-67902.pdf [Accessed 14 March 2013].

Breathing Buildings, 2013. *Priority School Building Programme* [online]. Available from: http://www.breathingbuildings.com/media/183957/priority_schools_guidance_lores.pdf [Accessed 18 March 2013].

British Standards Institution, 2007. BS EN 15251:2007 Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics. London: British Standards Institute.

Castro, F., 2013. Email communication with Felipe Castro, Ridge and Partners LLP on 8 Mar. FW: You have successfully sent: Junior School IES.zip.

CIBSE, 2006a. *CIBSE Guide A: Environmental Design.* London: Chartered Institution of Building Services Engineers.

CIBSE, 2006b. *CIBSE Guide A: Environmental Design - Chapter 2 external design data.* London: Chartered Institution of Building Services Engineers.

Coley, D., Kershaw, T. and Eames, M., 2011. *PROMETHEUS The Use of Probabilistic Climate Change Data to Future-proof Design Decisions in the Building Sector* [online]. Available from: http://centres.exeter.ac.uk/cee/prometheus/downloads.html [Accessed 2011 3 Oct].

Department for Education, 2006. *Ventilation and indoor air quality in schools - Building Bulletin 101.*

Du, H., Underwood, C. P. and Edge, J. S. 2012a. Generating design reference years from the UKCP09 projections and their application to future air-conditioning loads. *Building Services Engineering Research and Technology,* 33(1), 63-79.

Du, H., Underwood, C. P. and Edge, J. S. 2012b. Generating test reference years from the UKCP09 projections and their application in building energy simulations. *Building Services Engineering Research and Technology,* 33(4), 387-406.

European Environment Agency, 2013. *Observed global fossil fuel CO2 emissions compared with six scenarios from the IPCC* [online]. Available from: http://www.eea.europa.eu/data-and-maps/figures/observed-global-fossil-fuel-co2 [Accessed 8 March 2013].

Finkelstein, J. M. and Schafer, R. E. 1971. Improved Goodness-Of-Fit Tests. *Biometrika,* 58(3), 641-645.

Fogarty, A., 2013. *Cundall EFA baseline designs - Natural ventilation strategy* [online]. Available from: http://www.cundall.com/Cundall/fckeditor/editor/images/UserFilesUpload/file/EFA%20-%20Ventilation%20and%20Thermal%20Comfort.pdf [Accessed 14 March 2013].

Gething, B., 2010. *Design for future climate - Opportunities for adaptation in the built environment [online]* [online]. Available from: http://www.innovateuk.org/ourstrategy/innovationplatforms/lowimpactbuilding/design-for-future-climate-report-.ashx [Accessed 2012 4 May].

Gething, B., 2012. *Design for Future Climate Report:Opportunities for adaptation in the built environment.* London: Technology Strategy Board.

Gough, M. and Rees, C., 2004. *Tests performed on ApacheSim in accordance with ANSI/ASHRAE Standard 140-2001.* Glasgow: IES Ltd.

Gupta, R. and Gregg, M. 2012. Using UK climate change projections to adapt existing English homes for a warming climate. *Building and Environment DOI: 10.1016/j.buildenv.2012.01.014*.

Gupta, R., Gregg, M., and Du, Hu. (2013) Evaluative application of UKCP09-based downscaled future weather years to simulate overheating risk in typical English homes, *Structural Survey Journal,* 31:4, 231-252 DOI: http://dx.doi.org/10.1108/SS-01-2013-0005

International Energy Agency, 2012. *CO2 EMISSIONS FROM FUEL COMBUSTION Highlights (2012 Edition).* France: International Energy Agency

IPCC, 2007. Climate Change 2007: Synthesis Report - An Assessment of the Intergovernmental Panel on Climate Change. Geneva.

Jenkins, D. P., Peacock, A. D. and Banfill, P. F. G. 2009. Will future low-carbon schools in the UK have an overheating problem? *Building and Environment,* 44(3), 490-501.

Levermore, G*., et al.*, 2012. *Deriving and using future weather data for building design from UK climate change projections – an overview of the COPSE Project.* Manchester University, UK.

Lomas, K. J*., et al.* 2012. Resilience of 'Nightingale' hospital wards in a changing climate. *Building Services Engineering Research and Technology,* 33(1), 81-103.

Murphy, J*., et al.* 2009. UK Climate Projections science report: Climate change projections.

Ridge and Partners LLP, 2013. *Detailed design of selected adaptation measures: climate change adaptation report dragon junior school for the future*

Roofconsult, 2012. *Wind load Calculations to BS 6399:Part 2:1997* [online]. Available from: http://www.roofconsult.co.uk/calculations/wind/main.asp [Accessed 21 June 2012].

Spires, B., 2011. *How to assess overheating: key design issues* [online]. Available from: http://www.cibse.org/content/Summer_time_overheating_2011/Brian%20Spires.pdf [Accessed 13 March 2013].

Technology Strategy Board, 2013. *Connect platform* [online]. Available from: https://connect.innovateuk.org [Accessed 18 March 2013].

Watkins, R., Levermore, G. and Parkinson, J. 2011. Constructing a future weather file for use in building simulation using UKCP09 projections. *Building Services Engineering Research and Technology,* 32(3), 293-299.

Watkins, R., Levermore, G. J. and Parkinson, J. B. 2013. The design reference year – a new approach to testing a building in more extreme weather using UKCP09 projections. *Building Services Engineering Research and Technology,* 34(2), 165-176.

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