ADAPTING THE DESIGN OF A NEW SUSTAINABLE HOSPITAL BUILDING AGAINST A WARMING CLIMATE

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ABSTRACT

A set of future weather data derived from UK Climate Projections 2009 is used to assess the risk of overheating in the design of a sustainable hospital in the UK under, current, and future climate. Modelling results of indoor operative/air temperature are compared with three distinct overheating metrics including the Department of Health's Technical Memorandum 03-01, CIBSE Guide A and BS EN 15251 Adaptive Thermal Comfort Standard. To tackle future overheating of the building spaces, eighteen individual passive design measures (covering low-energy ventilation, shading and cooling) are tested in IES ApacheSim and the most effective measures are combined as adaptation packages for further testing. This work has developed a replicable methodological approach for adapting new buildings against a future warming climate.

INTRODUCTION

Importance and urgency

The UK Office for National Statistics (Johnson et al. 2005) have reported that 2,091 excess deaths are attributed to the 2003 heatwave in England and Wales (Stedman 2004). Other European countries also suffered considerably, such as 15,000 heat-related deaths in France (Valleron and Boumendil 2004), 3,100 in Italy (Bisanti et al. 2004), and 2,399 in Portugal (Trigo et al. 2009). Such heatwaves are expected to be more frequent and widespread in England's future (Oven et al. 2012).

To mitigate climate change, the UK Government has introduced the Climate Change Act (Great Britain 2008) to reduce greenhouse gas emissions at least 80% by 2050s based on 1990's baseline. The National Health Service (NHS) is the largest employer in Europe with 1.3 million employees. The NHS in England contributes around 25% of public sector carbon emissions (LCB Healthcare 2011), which is equivalent to about 5% of the country's total carbon emissions. This includes emissions from healthcare buildings, movement of people (e.g. patients, staff and visitors) and embedded carbon from healthcare goods and services. Based on the NHS England carbon footprint report 2004 (NHS Sustainable Development Unit 2009), healthcare buildings contribute 22% of the healthcare sector's total carbon emissions. Therefore, it is vital to explore the building performance of hospitals under future climate and develop adaptation measures for 'future climate proofed' hospitals.

Feasibility

The UK Climate Projections 2009 (UKCP09) (Jenkins et al. 2010) forms the most comprehensive set of climate change predictions for the UK to date. As one of the main products of UKCP09, the Weather Generator generates daily and hourly future weather variables for 2020s to 2080s based on carbon emission scenarios (low, medium and high) at 5km^2 grid resolution. Using the weather generator, Eames et al. (2011) have created future weather files ready for use in dynamic building simulation, which provides an opportunity to design 'climate-proofed' hospitals tested using dynamic building simulation.

RESEARCH METHODOLOGY

This paper uses a dynamic simulation based approach to systematically test and evaluate the potential for incorporating adaptation strategies into the design of hospital buildings in the UK, so as to future-proof them against climate change driven overheating, without increasing CO_2 emissions.

The approach adopted in the research is based on risk analysis, which involves assessing impacts of climate change to arrive at robustly tested (by modelling), technically feasible and practical adaptable measures appropriate for the case study hospital building located in the UK.

It is a replicable methodological approach for adapting new buildings against future climate change. The method adopted in the research is:

1. Conduct climate risk assessment for the building site using UKCP09 Weather Generator Threshold Detector and understand changes of the key design parameters under future climate;
2. Review relevant performance metrics and select appropriate metric for the case study building (e.g. overheating metric for this research);
3. Review suitable adaptation measures for the project;
4. Build detailed room level energy models in a dynamic simulation software such as IES VE for hourly simulation and evaluate the building performance against the performance metric selected (e.g. establish the overheating risk for

the main occupied spaces under current, 2030s, 2050s and 2080s' climate);

5. Develop adaptation packages which combine the most effective individual adaptation measures and test them again in building model under current and future climate;
6. Implement the most effective adaptation measures in detailed building design in collaboration with the design team and deploy adaptation measures in the project;
7. Monitor and evaluate the impact of the adaptation measures in practice for continuous feedback and improvement.

Note that the results of step 6 and 7 will be published in due course, as this is an on-going project.

CLIMATE CHANGE MODELLING

Climate and weather data information for the case study

UKCP09 provides publicly accessible climate change data free of charge. It 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 (Jenkins et al. 2010). To investigate the impacts of climate change on buildings, four assumptions are made to choose suitable weather data. These include: appropriate time slices, emission scenario, probability percentiles and location.

UKCP09 provide projections for 7 time slices. For each time slice, 30 years weather data are made available. For the scope of this research, the authors are interested in the short, medium and long-term building performance as they represent a sample of future time slices looking sufficiently far towards a time horizon likely to be of interest for the lifespan of buildings currently under development. The three time slices used for this study are 2030s, 2050s and 2080s (figure 1).

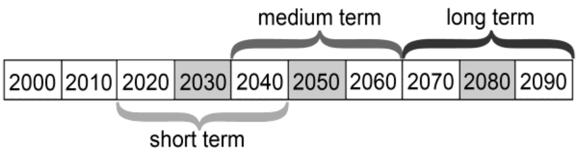

Figure 1 Time slices

The UKCP09 provides projections based on three different possible future climate change scenarios: low, medium and high greenhouse gas emissions. The observed emissions during 2000 to 2010 are very close to the high emission scenarios assumed in 2000 (International Energy Agency 2012) which is why, high emission scenario is selected for this study.

By examining the process (Eames et al. 2011) of generating future weather data, the authors selected the 50 percentile weather data to conduct simulation, because it has the highest probability to happen.

The case study building is located in Welwyn Garden city. The latitude and longitude of the site are 51.78N, 0.19W. The UKCP09 5km by 5km grid (ID: 5300215) covers the development area. London Heathrow (51.48N, 0.45W) is the nearest location which has CIBSE historical weather data available. The Design Summer Year for London is 1989, which has the third warmest April-August period during 1983 and 2004. Note that Design Summer Years (DSY) are used for overheating analysis and Test Reference Years (TRY) are used for energy analysis in this study. Based on all assumptions made above, the weather data used for building simulation are listed.

Table 1 Weather data for simulation

Time slices	Description of weather data
Baseline	Heathrow CIBSE DSY/TRY(1983-2004)
2030s	Short term high emission 50% DSY/TRY (2020-2049)
2050s	Medium term high emission 50% DSY/TRY (2040-2069)
2080s	Long term high emission 50% DSY/TRY (2070-2099)

A brief comparison of all DSY weather data above was made to show the increase of average temperature during April-September period from baseline to 2080s. As shown in Figure 2, the April-September average temperature increases 2.69 ^{0}C from CIBSE baseline to 2080s.

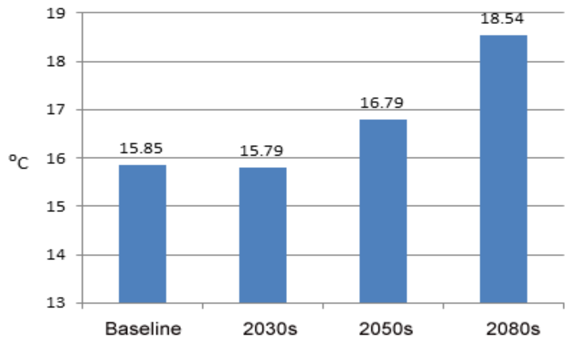

Figure 2 Average temperature (Apr-Sep)

The numbers of hours of external temperature over 25, 26, 27 and 28 ^{0}C during April-September period are illustrated in figure 3. Both figure 2 and 3 indicate that a warming climate will occur in the latter part of this century.

Overheating metrics for hospital buildings

Overheating in this paper is defined as an environmental condition that exceeds the upper limit of thermal comfort standard. Carlucci and Pagliano (2012) summarized 71 comfort related indices and systematically reviewed 15 long-term thermal comfort indices. For hospital environment, Predicted Mean Vote (PMV)/ Predicted Percentage Dissatisfied (PPD) indices were used in recent studies (De Giuli et al. 2013, Pourshaghaghy and Omidvari 2012, Adamu et al. 2012) to exam comfort conditions.

Khodakarami and Nasrollahi (2012) reviewed three environmental conditions for surgery rooms defined by ASHRAE, AIA and US department of Veterans Affairs. Lomas and Giridharan (2012) compared CIBSE, BSEN and ASHRAE adaptive thermal comfort standards for free-running hospital wards. Most of comfort standard treat occupants as identical, however evidence (Skoog et al. 2005) shows that patients accept higher degree of thermal comfort than hospital staff, because they will leave the hospital in foreseeable time.

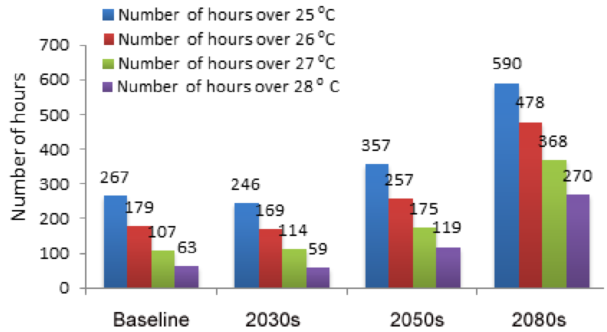

Figure 3 Number of hours over 25, 26, 27 and 28 ℃

On reviewing the overheating metrics commonly used in the UK, it is realised that *overheating hours* and *overheating percentage* are the most transparent and efficient way to evaluate overheating. The PPD-PMV Index is well accepted by industry and academia, however the usage of PPD-PMV need other factors, such as clothes and metabolic rate. Adaptive comfort is an approach to develop sustainable thermal comfort standards, potentially widening a currently accepted thermal comfort range. For this research, the authors are interested in the overheating situation of 89 consulting rooms that do not have a cooling system. Therefore, three distinct metrics are selected to evaluate overheating risks of this hospital building model and they are:

- Departments of Health's Technical Memorandum 03-01 (Department of Health 2007)
- CIBSE Guide A (CIBSE 2006)
- BS EN 15251 Adaptive Thermal Comfort Standard (British Standards Institution 2007)

Note that the assessment metric, criterion and applicability are listed in table 3. For BS EN 15251 standard, category I (very sensitive and fragile occupants with special requirements like handicapped, sick, very young children and elderly persons) is used for the hospital environment. The equations of calculating upper limit of the adaptive thermal comfort are given below:

$$t = 0.33t_{rm} + 18.8 + 2$$

$$t_{rm(d)} = (1 - 0.8)(t_{e(d-1)} + 0.8t_{e(d-2)} + 0.8^2 t_{e(d-3)} + 0.8^3 t_{e(d-4)} + 0.8^4 t_{e(d-5)} + 0.8^5 t_{e(d-6)} + 0.8^6 t_{e(d-7)})$$

t_{rm} is the daily running mean of outdoor temperature, and it is calculated based on the previous 7 days outdoor temperature t_e.

Figure 4 illustrates the upper limits of adaptive thermal comfort zone at baseline and 2080s. Note that the 2080s' limit (red) is generally higher than current baseline value (blue) due to future warmer climate. However, both of them are lower than the CIBSE 28 ^{0}C threshold (green line).

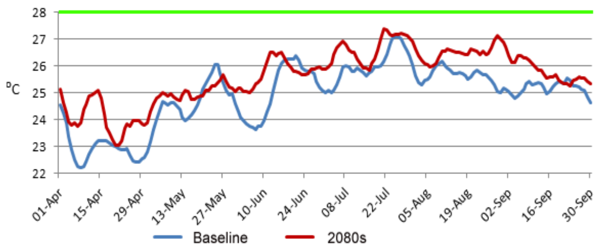

Figure 4 The upper limit of adaptive comfort zone

MODELLING ASSUMPTIONS: ASSESSING OVERHEATING RISK

Simulation tool

IES ApacheSim is selected as a modelling tool due to its wide application in the industry, it is tested according to ANSI/ASHRAE Standard 140-2007(IES 2011a, IES 2011b).

Building profile

The case study is a new 8,000m^2 purpose built healthcare facility which is made up of three 'L' shaped clinical wings (figure 5) arranged around a central soft-landscaped courtyard to maximise day lighting, natural ventilation and access to green external spaces. The new facility will accommodate a new local accident & emergency department, a large diagnostic imaging department. It will also include outpatients department, children's services, therapies, the breast clinic and a day treatment suite.

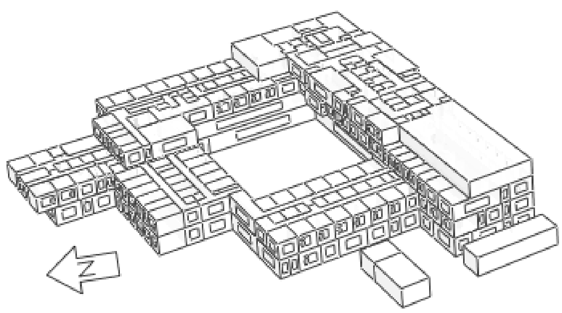

Figure 5 Thumbnail of the hospital IES model

The building model has 461 zones in total, which include 89 consulting rooms, 135 circulation areas, 125 auxiliary ventilation areas, 39 specialist areas with medical machines and 73 areas for WC/dirty utilities. All building spaces have been configured with an infiltration rate of 0.15 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 (DCLG 2010). The thermal properties of the hospital's construction elements are listed in following table. The heating set point of the consulting area is 21°C with setback at 12°C at night time. Heating is provided by a heat pump with a designed Coefficient of Performance (CoP) of 3.8. No active cooling is provided for consulting rooms.

Table 2 U-value of construction elements

Construction elements	EN ISO U-value (W/m^2K)
External wall	0.2000
Ground floor	0.2074
Roof	0.1502
250mm ceiling	1.8341
100mm ceiling	2.2826
Door	2.1944
Internal partition	1.6896
Double glazing	1.5006

PERFORMANCE OF BASE MODEL

To investigate the climate change impact on the hospital, two sets of simulations of the base model were conducted: energy simulation using baseline and future TRY data; free-running temperature simulation using baseline and future DSY data.

Baseline energy consumption of the hospital

The IES model was run with all the assumptions made above. The makeup of baseline model energy usage is illustrated in following pie chart. Note that gas is only used for providing domestic hot water in the hospital. In order to investigate the climate change impact only, it is assumed that the usage of hot water, equipment and lights will not change in the future. Therefore, gas consumption and electricity consumption for equipment and lighting stay the same in the future. The only changing factor due to climate is electricity consumption for building services system.

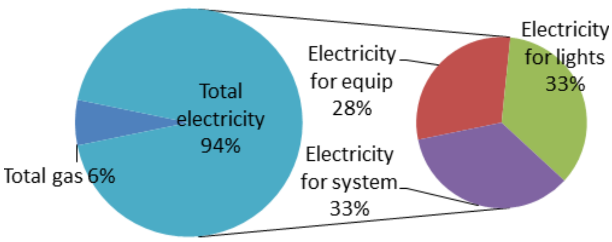

Figure 6 Energy consumption (total 471.7MWh)

A detailed breakdown of services system electricity consumption is illustrated in figure 8. Note that the electricity consumption for domestic hot water pumps would not change due to climate and adaptation measures. The changing factors due to climate change are PV electricity generation, heating, cooling and system fans/pumps. Figure 7 illustrates the increase in electricity generation in 2050s and 2080s.

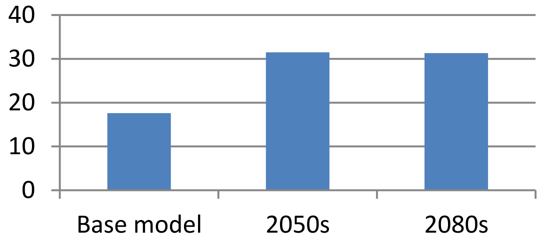

Figure 7 PV generated electricity (MWh)

Overheating risk in the future

Free-float air/operative temperatures of 89 consulting rooms are compared with three distinct overheating metrics listed in table 3. Due to the paper limit, some results are shown in table 4. Overheated zones are highlighted in red. The table indicates that BS EN 15251 adaptive thermal comfort limit is the strictest metric for the future climate of the case study building. Therefore, it is not always true that adaptive comfort limit could potentially widen a currently accepted thermal comfort range, especially for sensitive occupants.

As CIBSE overheating metric (1% occupied hours over operative temperature of 28 °C) is currently widely used in building services industry in the UK, it is used in following studies to test performance of adaptation measures.

TACKLING THE OVERHEATING RISK

Modelling of adaptation measures

To tackle the overheating issues in the building spaces, 18 passive design measures (covering low-energy ventilation, shading, glazing, high albedo surface and orientation) are tested individually against future weather data and the most effective measures are combined as adaptation packages to conduct further testing.

The percentages of annual occupied hours over operative temperature 28 °C of 89 consulting rooms in the hospital were calculated in building thermal simulation software. The average value of overheating percentages of 89 consulting at current, 2050s and 2080s are listed in table 5. The results shows that the white paint, dark film and triple glazing can help reduce overheating percentages at current climate and in the future. The results also show that external shading devices have better performance than internal shading devices. The external shutter can significantly reduce overheating percentages and performs best among all other options. Other orientations are investigated in this study, but due to site limitations and current design phase of the building, the current orientation cannot be changed.

Performance of adaptation packages

Two adaptation packages were developed based on the effectiveness of individual adaptation measures. They are highlighted in the last 2 columns of table 5. Detailed designs of selected adaptation packages are discussed with the project team, and incorporated into the design. They are:

- Package 1 (P1) includes the most effective adaptation measure (external louvres) only.
- Package 2 (P2) combines white paints surfaces, triple glazing and external shutters. Note that window film should have limited effect due to installation of shading devices; therefore dark film is not included in this package.

The performances of the two adaptation packages were tested under current, 2030s, 2050s and 2080s climate condition. Averages of overheating percentages of 89 consulting rooms are shown in table 6, while the total electricity consumption of the whole building is listed in table 7. The results show that the adaptation packages can significantly reduce the overheating percentages from 4.0% to 0.5% in 2080s for the hospitals and do not have significant impact on energy usage. Detailed analysis shows that heating energy consumption decreases in the future while cooling (for other spaces, not consulting rooms) energy consumption would increase.

DISCUSSION

In reflecting on the work undertaken, it is useful to address the following three issues experienced. Firstly, this work selected high carbon emission scenario and 50 percentile risk level. It could be good to have consistent design target recommended by governments or professional bodies. Secondly, three overheating metrics were compared in this study. The selection of metric may result in different adaptation measures. Again, consistent metric should be applied to the design of same type of buildings. Thirdly, the assumptions were made in this study that all occupants and internal heat gain stay the same in the future. This may not be true due to technologies developing.

CONCLUSION

This work creates a replicable methodological approach for adapting new buildings against future climate change. It is used a dynamic simulation based approach to systematically test and evaluate the potential for incorporating adaptation strategies into the design of a hospital buildings in the UK, so as to future-proof them against climate change driven overheating, without increasing CO_2 emissions. Eighteen adaptation measures were modelled using dynamic building simulation software IES ApacheSim. The most effective individual measures were combined as two adaptation packages. Both packages allow all consulting rooms to stay within comfort range in 2050s. They also allow most of consulting rooms to stay within comfort range during the 2080s.

The simulation results were compared against three overheating evaluation metrics: HTM03-01, CIBSE Guide A and BS EN 15251. BS EN 15251 is the strictest metric for this particular building because category I limit (for very sensitive and fragile occupant) was used.

This work also helps policy makers and designers understand the impact of climate change and the effectiveness of adaptation measures in avoiding overheating now and in the future.

ACKNOWLEDGEMENT

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Table 3 Overheating assessment metrics

Source	Assessment metric	Criterion	Applicability
HTM03-01 (Department of Health 2007)	Number of hours over dry bulb temperature of 28 °C	No more than 50 occupied hours	All spaces
CIBSE Guide A (CIBSE 2006)	Percentage of hours over dry operative temperature of 28 °C	No more than 1% of occupied hours	Offices (Consulting rooms)
BS EN 15251 (British Standards Institution 2007)	Number of hours over category I adaptive comfort upper limit	No more than 5% (or 3%) of occupied hours during a year	Naturally ventilated spaces with operable windows

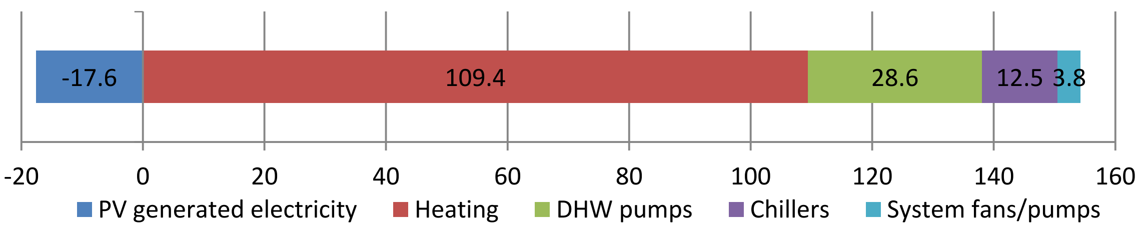

Figure 8 Breakdown of electricity usage for services system (MWh)

Table 4 Overheating results using different metrics

	HTM03-01				CIBSE				BS EN 15251			
Zone name	Percentage of occupied hours over dry bulb temperature of 28 °C Threshold of 2.13% (50 of 2349 occupied hours)				Percentage of occupied hours over operative temperature of 28 °C Threshold of 1%				Percentage of occupied hours over adaptive comfort limits Threshold of 5%			
	Baseline	2030s	2050s	2080s	Baseline	2030s	2050s	2080s	Baseline	2030s	2050s	2080s
1-C EXAM 5	0.6%	0.3%	1.5%	4.3%	0.5%	0.1%	1.0%	3.2%	2.4%	5.7%	5.9%	10.0%
1-C EXAM 6	1.4%	1.0%	2.9%	7.0%	1.3%	0.3%	2.3%	6.5%	4.6%	7.7%	8.5%	14.0%
1-C EXAM 7	1.1%	0.4%	2.3%	6.0%	0.8%	0.2%	1.9%	5.6%	3.5%	7.2%	7.7%	13.1%
1-C EXAM 9	1.0%	0.3%	2.2%	6.1%	0.7%	0.2%	1.9%	5.5%	3.2%	7.1%	7.6%	13.0%
1-ECHO	0.7%	0.0%	1.1%	3.9%	0.6%	0.0%	0.6%	2.9%	1.7%	3.2%	3.9%	8.4%
1-HOLTER	0.7%	0.0%	0.9%	3.3%	0.5%	0.0%	0.4%	2.2%	1.6%	4.4%	4.3%	8.8%
1-HOTDESK 1	0.9%	0.3%	1.7%	4.9%	0.6%	0.1%	0.9%	3.2%	3.0%	5.1%	6.5%	10.2%
1-HOTDESK 2	0.7%	0.1%	1.1%	4.2%	0.5%	0.0%	0.6%	2.9%	1.7%	4.2%	4.9%	9.0%
1-INTERV 1	1.1%	0.3%	1.9%	4.9%	0.9%	0.1%	1.2%	3.9%	3.3%	7.9%	7.7%	11.5%
1-PRE ASS 1	0.5%	0.0%	0.6%	2.8%	0.3%	0.0%	0.3%	1.8%	2.0%	5.1%	5.2%	8.5%
1-PRE ASS 2	0.6%	0.1%	0.8%	3.2%	0.4%	0.0%	0.3%	2.1%	2.1%	5.2%	5.2%	8.7%
1-PRE ASS 3	0.8%	0.1%	1.6%	4.6%	0.5%	0.0%	0.9%	3.6%	2.5%	5.8%	6.3%	10.2%
1-RECEPTN	0.8%	0.2%	1.5%	4.4%	0.6%	0.1%	0.8%	3.3%	2.9%	8.5%	8.0%	11.5%
2-ADMIN 1	1.4%	0.8%	2.4%	5.8%	1.0%	0.3%	1.9%	4.7%	4.3%	8.3%	8.6%	12.6%
2-ADMIN 2	1.3%	0.9%	2.6%	6.0%	0.9%	0.2%	1.9%	5.0%	4.8%	11.6%	9.5%	14.6%
2-ADMIN 3	1.5%	1.7%	3.1%	6.9%	1.3%	1.2%	2.6%	6.7%	4.8%	9.8%	9.6%	14.7%
2-C EXAM 01	1.5%	1.4%	3.2%	7.7%	1.3%	0.8%	2.9%	7.7%	6.5%	11.4%	10.7%	17.2%
2-C EXAM 02	1.3%	1.2%	2.9%	7.1%	1.0%	0.3%	2.4%	6.4%	5.6%	9.7%	9.4%	15.4%
2-C EXAM 03	1.4%	1.2%	3.0%	7.2%	1.2%	0.4%	2.5%	6.8%	5.9%	9.8%	9.6%	15.9%
2-C EXAM 05	1.8%	1.6%	3.4%	8.4%	1.7%	1.2%	3.4%	8.5%	7.2%	11.5%	11.2%	18.1%
2-C EXAM 06	2.0%	1.8%	3.9%	9.1%	1.7%	1.4%	3.7%	9.6%	8.0%	12.7%	12.7%	19.5%
2-C EXAM 07	1.1%	0.3%	2.1%	5.8%	0.9%	0.2%	1.4%	4.8%	3.1%	5.4%	6.6%	11.1%
2-C EXAM 08	1.1%	0.3%	2.0%	5.7%	1.0%	0.1%	1.3%	4.7%	2.9%	5.2%	6.4%	11.0%
2-C EXAM 09	1.7%	1.1%	2.9%	7.2%	1.5%	0.7%	2.6%	7.2%	4.9%	6.6%	8.6%	13.7%
2-C EXAM 10	1.4%	0.9%	2.5%	6.6%	1.3%	0.3%	2.0%	6.2%	4.0%	5.9%	7.4%	12.4%
2-C EXAM 11	1.1%	0.4%	2.2%	6.3%	1.0%	0.2%	1.4%	5.1%	3.1%	5.6%	6.8%	11.7%
2-C EXAM 12	1.1%	0.2%	1.8%	5.4%	0.9%	0.1%	1.1%	4.4%	2.6%	5.2%	6.3%	10.7%
2-COUNSEL 1	0.6%	0.0%	0.8%	3.2%	0.4%	0.0%	0.3%	2.0%	2.3%	5.3%	5.4%	9.0%
2-COUNSEL 2	0.6%	0.0%	0.7%	3.1%	0.4%	0.0%	0.3%	1.8%	2.4%	5.3%	5.4%	9.1%
2-COUNSEL 3	0.7%	0.1%	1.1%	4.0%	0.5%	0.0%	0.6%	2.8%	2.6%	5.9%	6.0%	10.1%
2-COUNSEL 4	0.8%	0.1%	1.4%	4.3%	0.6%	0.0%	0.7%	3.2%	2.6%	5.9%	6.2%	10.3%
2-CUB 1	1.0%	0.4%	2.4%	5.9%	0.8%	0.1%	1.8%	5.1%	4.0%	9.7%	8.8%	14.2%
2-CUB 2	0.9%	0.2%	2.0%	5.2%	0.6%	0.1%	1.5%	4.3%	3.6%	8.6%	8.1%	12.9%
2-CUB 3	0.5%	0.0%	0.9%	3.4%	0.3%	0.0%	0.4%	1.9%	2.7%	6.5%	5.9%	10.3%
2-CUB 4	0.4%	0.0%	0.6%	2.6%	0.3%	0.0%	0.3%	1.4%	2.5%	5.8%	5.4%	9.6%
2-CUB 5	0.4%	0.0%	0.6%	2.6%	0.3%	0.0%	0.3%	1.4%	2.5%	5.8%	5.4%	9.5%
2-CUB 6	0.5%	0.0%	0.8%	2.9%	0.3%	0.0%	0.3%	1.6%	2.6%	6.2%	5.7%	10.1%
2-INFO	1.4%	1.6%	3.2%	7.3%	1.1%	1.2%	2.8%	7.2%	4.6%	9.0%	9.0%	14.9%
2-INTERVW 1	0.9%	0.2%	1.5%	4.4%	0.6%	0.1%	0.9%	3.2%	3.0%	7.4%	7.2%	11.0%
2-INTERVW 2	0.8%	0.1%	1.1%	4.0%	0.5%	0.0%	0.5%	2.8%	2.7%	5.9%	6.3%	9.7%
2-INTERVW 3	1.1%	0.3%	1.9%	4.9%	0.8%	0.1%	1.2%	4.0%	3.0%	6.3%	6.8%	11.0%
3-ADMIN	0.8%	0.2%	1.4%	4.3%	0.6%	0.0%	0.7%	3.1%	2.6%	6.5%	6.4%	10.4%
3-HOTDESK 1	1.9%	1.6%	3.5%	8.3%	1.6%	1.3%	3.2%	8.6%	7.2%	14.2%	13.0%	19.1%
3-STAFF	1.4%	1.1%	2.7%	6.6%	1.0%	0.3%	1.9%	6.0%	4.2%	7.0%	8.3%	13.3%

Table 5 Overheating results of difference adaptation measures

Adaptation measures		Current	2050s	2080s	P1	P2
Base model, double glazing, user controlled ventilation, no shading, IES site rotation angle 330^0		0.7%	1.2%	4.0%		
High albedo surface	Cream paint	0.7%	1.2%	3.8%		
	White Paint	0.6%	1.1%	3.6%		√
Windows and film tech-nologies	Triple glazing	0.6%	1.0%	3.6%		√
	Light film	0.7%	1.1%	3.8%		
	Dark film	0.6%	1.0%	3.5%		
Ventilation	Two air change rate	8.2%	16.4%	24.5%		
	3.5 air change rate	4.1%	9.4%	16.9%		
	Five air change rate	2.7%	5.9%	12.6%		
Shading	External shutter with control at 300 W/m^2	0.3%	0.1%	0.8%	√	√
	Fixed shading	0.3%	0.8%	1.7%		
	Internal curtain with control at 300W/m^2	0.4%	0.2%	1.5%		
Orientation	15^0	0.6%	1.0%	3.4%		
	60^0	0.4%	0.5%	2.1%		
	105^0	0.3%	0.1%	1.1%		
	150^0	0.3%	0.1%	0.9%		
	195^0	0.3%	0.1%	1.2%		
	240^0	0.5%	0.7%	2.5%		
	285^0	0.7%	1.2%	3.8%		

Table 6 Overheating percentages of adaptation packages

Average percentage of occupied hours over 28 ^{0}C	CIBSE DSY baseline	2030s H 50% DSY	2050s H 50% DSY	2080s H 50% DSY
Base model	0.7%	0.2%	1.2%	4.0%
Package 1	0.1%	0.0%	0.1%	0.8%
Package 2	0.2%	0.0%	0.0%	0.5%

Table 7 Overheating percentages of adaptation packages

Total electricity consumptions (MWh)	CIBSE TRY baseline	2030s H 50% TRY	2050s H 50% TRY	2080s H 50% TRY
Base model	441	448	438	431
Package 1	444	458	447	437
Package 2	442	457	445	435