FUTURE CLIMATE EFFECT ON BUILDING REFURBISHMENT USING VENTILATION FOR COOLING: A CASE STUDY

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ABSTRACT

This paper presents the effect of specific future climate changes scenarios on the resilience of the refurbishment of a 1960s office building in suburban London. A model of the building was created and simulated using IESVE to predict current energy consumption calibrated with operational energy data. Energy efficient improvements were incorporated which mainly consist of improving the insulation and air-tightness of external envelope, reducing solar and internal gain and utilising natural ventilation during the day and night for improving thermal comfort in the summer. Climate change scenarios were investigated by using future climates weather files available for the UK. It was found that thermal comfort in the summer can be significantly improve and provide acceptable condition in most areas of the building at present and in the future. Energy consumption can be improved by 80% of present consumption. This can be compared with projections that office CO_2 emissions from office building will increase two to three-fold in the future due to increased cooling requirements.

KEYWORDS

Future climate, building simulation, refurbishment, passive design.

INTRODUCTION

In recent years, global temperature has increased significantly [1] and it is probable that the average annual temperature will increase by several degrees during this century. In the UK, work on climate change projections are carried out under the umbrella of UKCIP (UK Climate Impact Programme) [2].

Literature review has revealed that there exist significant recent work on the effect on climate change on energy consumption by building; for example [3-5] which examine the impact of temperature changes on the building energy consumption for heating and cooling in the US, [6] which examines the case in the UK, [7] for Hong Kong, [8] in Australia and in the UK for office buildings [9,10]. In addition, work is under progress in many countries to construct weather files suitable for building energy consumption simulation taking into consideration future climate change scenarios. In the UK, the creation of future climate weather files for building simulation (termed 'morphing') is currently based on the methodology developed by [11] and implemented by [12] based on UKCIP02 scenarios. Recently more detailed and probabilistic-based UKCIP09 climate projections are made available [2], and researchers have constructed weather files based on these projections [13].

Recent work by the authors using UKCIP02 weather files to examine energy consumptions and CO_2 emissions by typical office buildings has revealed that with no passive design intervention, overheating hours will increase in the future and therefore active cooling is likely to be added to existing buildings. A comparison on the environmental impact (CO_2 emissions) was carried out between non-cooled office of today (2000) versus comfort cooled offices of the future (2050) [14] indicating that CO_2 emissions can increase between 230% to 340% in existing offices in suburban London. Another study [15] has revealed that in non-cooled offices night ventilation coupled with thermal mass is very effective in reducing internal temperatures. The cooling potential of night cooling is expected to be even greater in the future due to the greater diurnal temperature range.

This paper presents a study of passive design refurbishment of an existing building and how present refurbishment proposals will perform in the future. The study used the commercial software ISEVE for the simulations and UKCIP09 future weather files.

BUILDING DESCRIPTION

The case-study presented in this paper of the Howell Building on Brunel University Campus which was constructed in the 1968. The building has a square planform with a large central well. As originally conceived, there were three floors with the lowest supported on ‘stilts’ allowing full access to an open central court. In the 1990s, the central court was replaced by a large lecture theatre and additional teaching rooms were inserted under the original lowest floor, providing a full four storey building. The ground floor consists of the lecture theatre and a number of teaching and meeting rooms, together with a plant room. Floor 1 and 2 principally contain individual cellular offices linked by a central corridor. Floor 3 contains teaching rooms, two large open-plan postgraduate offices and a number of individual offices. The floor area of the building is 4650 m^2 and it consists of 35% of offices, 18% of teaching rooms, 31% of circulation areas and the rest of computer/meeting rooms and plant rooms.

Figure 1 shows external views of the North and South facades of the building and Figure 2 is a view of the model of the building developed for analysis and shows the general layout, including the inner well and, within the well, the roof of the lecture theatre situated at Ground Floor level. A geometrical and thermal model of the building was created within the simulation model IESVE which is used by many researchers and building services consultants for building design. It should be noted that IESVE is listed as one of the approved tools for compliance with the current Building Regulations in the UK and therefore comply with the national implementation of EPBD.

A survey was carried out to determine construction details as close to the existing building as possible and also internal heat gains based on observed use of the building due to occupancy levels, equipment and lighting. These were inputed in the model for each room and use and a simulation for energy cosumption was carried out using weather files as will be described in the next section.

Gas and electricity actual consumption of the actual building were available as used for DEC (Display Energy Certificate) and the simulated results for the building as is currently were compared with the actual consumption favourably. The current energy consumption on DEC is 426 $kWh/m^2/year$ and the emissions 640 tonnes CO_2 (137 $kgCO_2/m^2/year$).

Figure 1: Howell Building, North and South Facades

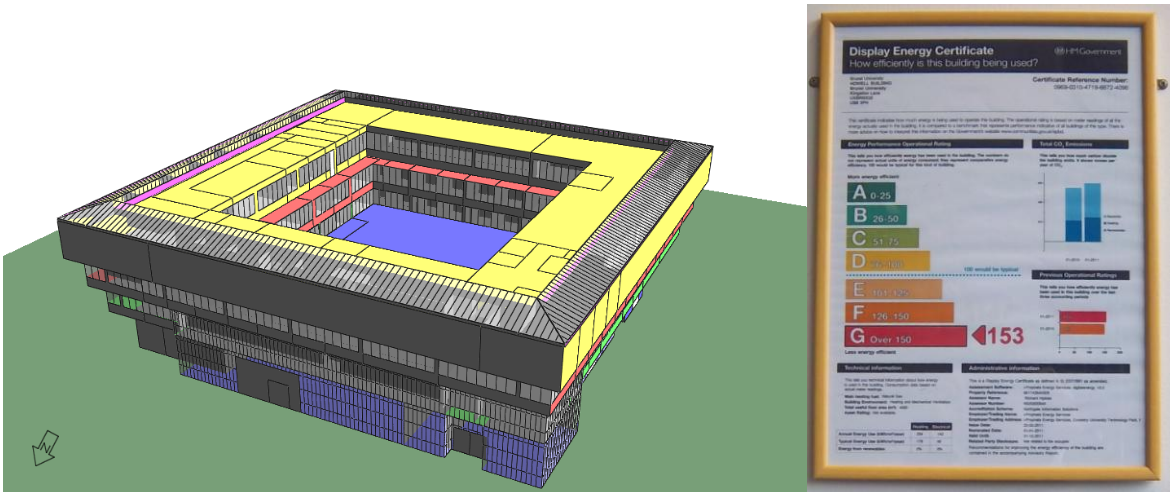


Figure 2: Computer model of the Howell Building and the current DEC.

CLIMATE CHANGE SCENARIOS AND WEATHER FILES FOR BUILDINGS

The weather files used for simulation are derived from the ‘Emissions Scenarios’ used in the UKCP09 from the IPCC SRES (2000) [16] report; are A1FI (High), A1B (Medium) and B1 (Low), each projects a global mean temperature range.

What does this mean in terms of external weather parameters? As an example the following projections of weather variables are based on the 2050 (Medium Emissions), 50% Probability (Central Estimate), this corresponds to the Howell building being renovated now to handle climate change during its 40-50 year (typical) life and renovated again in the 2060s. This provides a qualitative insight of what weather variables to expect in the London region for the 2050s under the medium-emissions-scenario, 50% probability, relative-to the 1961–1990 (Baseline).

Key findings for London, 2050s (medium emissions scenario), central estimate;

- Increase in winter mean temperature is 2.2ºC; it is very unlikely to be less than 1.2ºC or more than 3.5ºC. A wider range of uncertainty is from 0.9ºC to 3.8ºC.

- Increase in summer mean temperature is 2.7ºC; it is very unlikely to be less than 1.3ºC or more than 4.6ºC. A wider range of uncertainty is from 1.1ºC to 5.2ºC.
- Increase in summer mean daily maximum temperature is 3.7ºC; it is very unlikely to be less than 1.4ºC and more than 6.6ºC. A wider range of uncertainty is from 1.2ºC to 7.4ºC.
- Increase in summer mean daily minimum temperature is 2.9ºC; it is very unlikely to be less than 1.3ºC and more than 5ºC. A wider range of uncertainty is from 1.2ºC to 5.7ºC.
- Change in annual mean precipitation is 0%; it is very unlikely to be less than –5% and more than 5%. A wider range of uncertainty is from –5% to 5%.
- Change in winter mean precipitation is 14%; it is very unlikely to be less than 2% and more than 32%. A wider range of uncertainty is from 0% to 35%.
- Change in summer mean precipitation is –19%; it is very unlikely to be less than –41% and more than 7%. A wider range of uncertainty is from –43% to 16%. [17].

From these scenarios a weather generator was constructed which can provide seven weather variables at an hourly signal for; precipitation, temperature, vapour pressure, relative humidity, sunshine fraction and direct & diffuse radiation for a given location, time and future emissions scenario. However, in order to facilitate dynamic building thermal modelling, weather variables for; wind speed, wind direction, air pressure and cloud cover also need to be generated in a consistent manner with the rest of the (UKCP09 WG) weather signal and needs to be in the same file format as the reference years used currently by building simulation programs [18]. This study used these weather files to simulate projected energy consumption of the studied building as shown in Table 1[available from 19]:

Weather File Name	Location	IPCC SRES	CDF%	Date Range
WG_COMBINED_cntr_5100180_DSY.epw (Baseline)	London/Heathrow	N/A	N/A	1961-1990
LondonDSY05.fwt (Current)	London/Heathrow	N/A	N/A	1983-2004 Current CIBSE
WG_2050_5100180_a1b_50_percentile_DSY.epw	London/Heathrow	Medium (A1B)	50% Central Est.	(2050s) 2040-2069
WG_2050_5100180_a1fi_50_percentile_DSY.epw	London/Heathrow	High (A1FI)	50% Central Est.	(2050s) 2040-2069
WG_2080_5100180_a1b_50_percentile_DSY.epw	London/Heathrow	Medium (A1B)	50% Central Est.	(2080s) 2070-2099
WG_2080_5100180_a1fi_50_percentile_DSY.epw	London/Heathrow	High (A1FI)	50% Central Est.	(2080s) 2070-2099

Table 1. Simulation weather file names, location, cumulative distribution percentage and date range.

ADAPTED BUILDING

Guidelines have been published on how to adapt buildings in the UK for future climate change [20, 21]. The investigation comprised 11 examples of various building types (dwellings, offices and schools) and a single climate scenario (UKCP02 Medium-High) for his analysis, the purpose was to show how buildings with particular features respond to climate change and what can be done to obtain a more acceptable performance in the future. The results showed that buildings with a high thermal mass combined with an intelligent ventilation strategy performed best, new modern buildings performed better than older buildings, due to greater insulation and air-tightness from build quality. It was also evident that, with the exception of air-conditioned buildings, all unadapted buildings showed instances of overheating (1% occupied hours > 28ºC) after the 2020s. From the results [21] a simple design philosophy termed 'adaptation strategy' was proposed that can reduce the effects of the risk of thermal discomfort (overheating) and simultaneously reduce energy consumption, these principles are as follows;

i. Switch off - Reduce unnecessary internal heat gains, and use solar shading,
ii. Absorb - increase thermal mass (new builds only), or effectively use thermal mass,
iii. Blow away - introduce an intelligent ventilation strategy i.e. night cooling then mixed-mode if required,
iv. Cool - introduce active cooling only when all passive options have been assessed, minimise active cooling use to times when thermal discomfort are probable, this is termed 'peak lopping', [21].

Changes to the building were made inline with the overall adaptation strategy as follows:

- Office equipment load has been reduced by 30% over the base case building to reduce internal gains,
- Lighting has been reduced to 9 W/m2 for all offices to reduce internal gains,
- Shading has been added on the east, west & south facade to minimise solar gain/cooling load, the atrium roof also offers shading to the central well and offices,
- Glazing has been changed to reduce direct & diffuse solar radiation, by using tinted glass and/or reflective films & using triple glazing (xenon gas) with a thermal break in the frame,
- Cool Roof (reflective paint coating) has been used to reduce heat gain to the top floor offices and thermal storage to the roof slab to improve thermal comfort,
- Improvements to the building fabric were aimed at reducing the wall elements thermal transmittance (U-value) to reduce heat flow, which was achieved by using vacuum insulation panels,
- Building air tightness & infiltration has been improved and a value of 0.25 ACH has been used to simulate a well sealed envelope.
- Natural ventilation with night cooling has been used to pre-cool the structure during the summer months, designed to allow air to cross flow across the floor slab and exhaust out through the atria,
- Mixed mode ventilation system employed to minimise energy use and only switch on the A/C system (generic convective) when thermal comfort thresholds are breached 25°C,
- Heating system (generic system) has been replaced with efficiencies representing those of a modern condensing boiler and new pipe distribution.

Ventilation Strategy: The current Howell geometry lends itself well to applying cross flow ventilation with a passive stack, with relatively minor alterations to the building i.e. no structural changes. It is well known that cross flow ventilation relies on establishing an unimpeded air flow path between the inflow and outflow air streams, which should pass through the zone of occupancy; calculations shown in Figure 3. There is a practical limit for cross ventilated air penetrating the building, i.e. cross flow maximum depth 5*height = (5*2.56m = 12.8m), the Howell building is within limits as the cross section for the 1st, 2nd & 3rd floor are 9m, 10m & 11m respectively.

The operation of the external window openings in the offices are separated for summer and winter conditions as follows:
<u>Summer</u>: Apr to Sept (The controller is ON, IF)

- During Night; 23:00 - 07:00, (Inside DB Air Temperature > Outside DB Air Temperature AND Inside DB Air Temperature > 20°C)

- During Day; 07:01 - 22:59, (Inside DB Air Temperature > Outside DB Air Temperature AND (Inside Air Temperature > 23°C, Step function 3°C) OR CO2 > 1200ppm)

<u>Winter</u>: Oct to Mar (The controller is ON, IF)

- All Day; 00:00 - 23:59, (Outside DB Air Temperature > 12°C AND Inside DB Air Temperature > Outside DB Air Temperature AND (Inside DB Air Temperature > 25°C, Step function 2°C) OR CO2 > 1200ppm)

Due to these modification the floor area of the building is increased to 5275 m^2 because of the addition of the atrium.

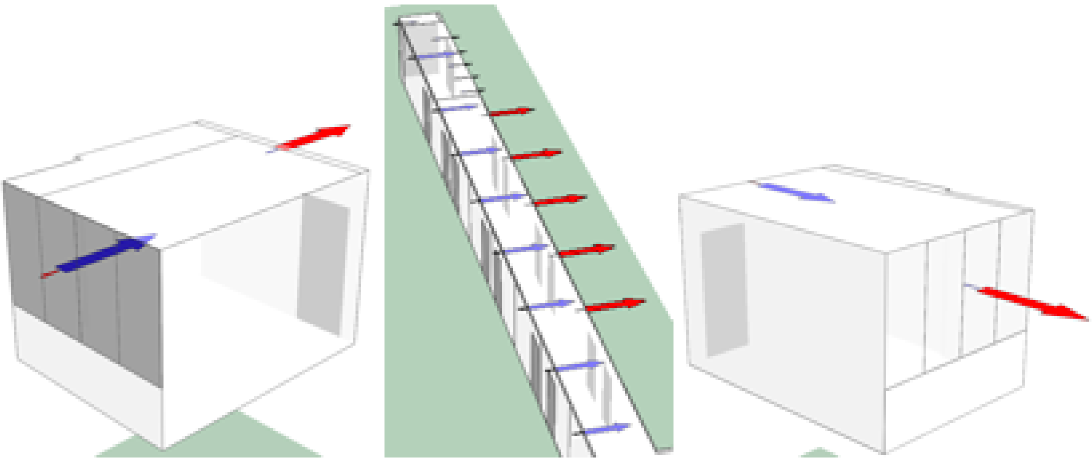


Figure 3: IES Cross flow ventilation through Office 119, Corridor 102a, Office 116 (July CIBSE 05 DSY). Inflow (Blue), Outflow (Red).

An atrium (glass covered internal void for the Howell building) has been added to allow air flow to vent up and out through the atrium openings (see Figure 4). Natural ventilation can be applied by just using the atrium itself as a passive stack, where the atrium is extended above the 3rd Floor Roof.

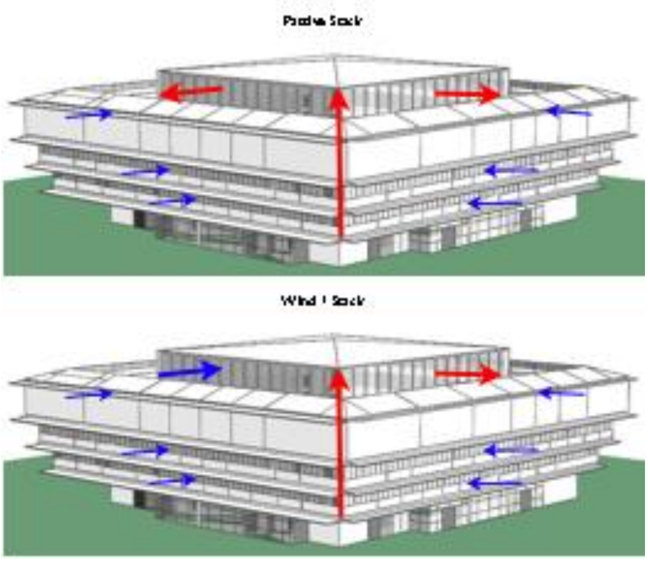


Figure 4: (a) Howell building atrium (passive stack) and (b) wind & stack. Inflow (Blue), Outflow (Red).

RESULTS: EXISTING BUILDING

Simulations were carried out with the building as is and summarised results are presented in Figures 5-7. Figure 5 shows the overheating hours on the top floor of the building (which suffered worse overheating than the other floors. There are some overheating problems presently and as expected these will be increased in the future. Figure 6 shows the specific energy consumption which is mainly due to heating requirements - these will reduce in the future so the building will perform better in terms of energy consunption and CO_2 emissions (Figure 7).

Simulations were carried out with the adapted building and summarised results are presented in Figures 8-10. Figure 8 shows the overheating hours on the top floor of the building; it can be seen that temperatures above 28 ^{o}C have been eliminated at present although there might be some overheating problems in the future that might require some cooling - however this is very small proportion of the total required energy as shown in Figure 9. This is because of the refurbishment according to energy efficient design principles and the use of ventilation for cooling during the day and utilising night time ventilation.

DISCUSSION

The passive adaptation strategy (no active cooling) demonstrated that there were reductions in the yearly overheating hours in both the >25°C & >28°C thresholds for the mid-floor offices and for all scenarios the >28°C threshold was reduced by 100%. This showed that for the future climate scenarios, the mid-floor adapted case is resilient to the climate change, and a required change, would be to extend the current night cooling strategy into October for the future climate.

However, the adapted case top-floor only showed reductions in overheating hours in the baseline and current (CIBSE DSY '05) weather scenarios for the dry-resultant temperature >25°C for 5% of occupied hours. In all the future scenarios the >25°C is above 5% of the occupied hours, and the solution to extend the Night Cooling strategy into October (and even November for the top-floor) was seen to reduce overheating hours, but was insufficient to lower them below the 5% of occupied hours threshold. The improvement in the overheating risk by extending night cooling to October and November is shown in Figure 11.

The Cool-Roof was successful in reducing the dry-resultant temp. >28°C for 1% of occupied hours. This was achieved in all weather scenarios for the top-floor except for the 2080(High), which is marginally above the limit at 1.17%. This showed that part of adaptation strategy had been successful at lowering the internal dry-resultant temperature below the upper range of thermal comfort levels and the internal dry-resultant temperature is maintained within the 25-28°C temperature range.

The cooling loads in the adapted case were determined to be an increase over the base case as there is no current cooling system in the base case, but its operation was designed to be less energy intensive than a conventional fully air-conditioned office by employing a mixed-mode system. Therefore, the cooling load progressively increases through each scenario relative-to the baseline period. This indicates that, there will be an increase in cooling demand to maintain the offices at the lower comfort threshold >25°C (5% of occupied hours) in the future weather scenarios.

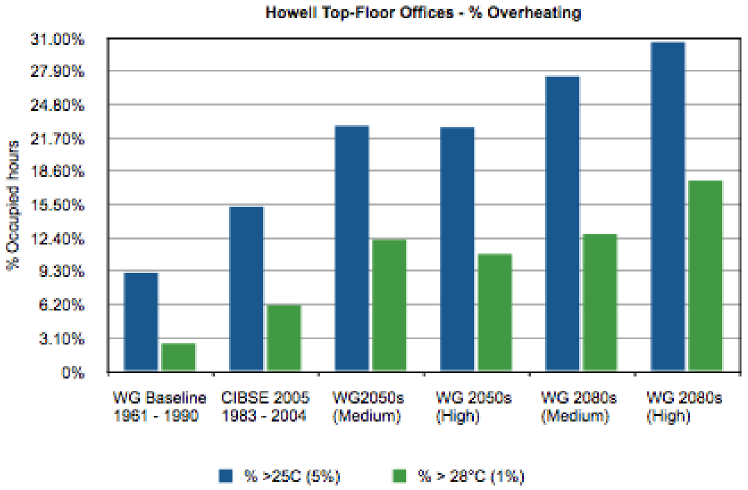
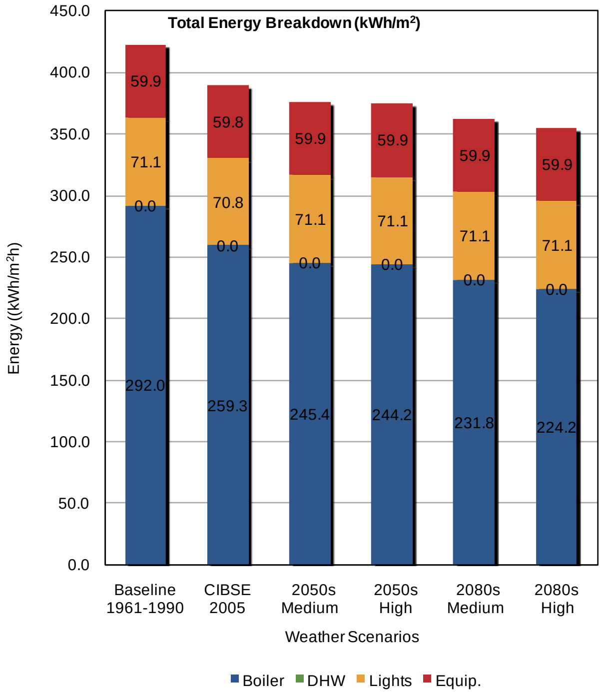


Figure 5: Base Case, Top-Floor Offices overheating hours for defined comfort thresholds.



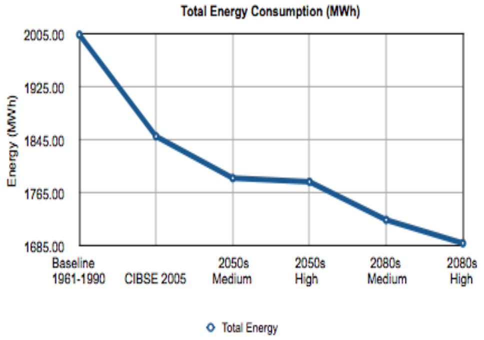
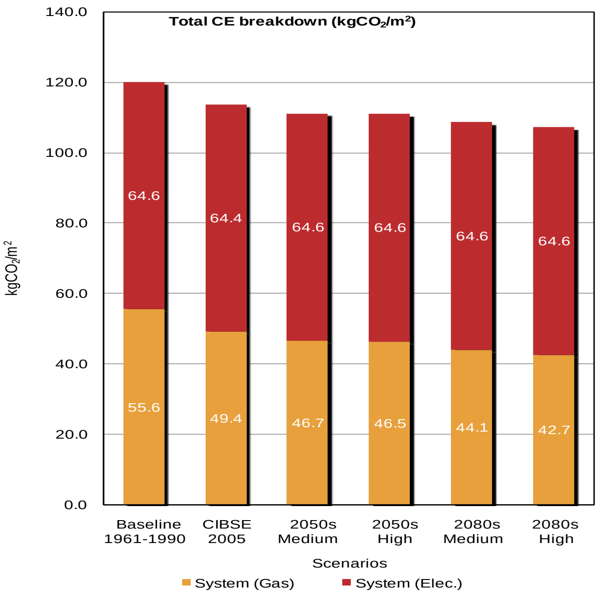


Figure 6: Base case, normalised energy breakdown and total energy per scenario



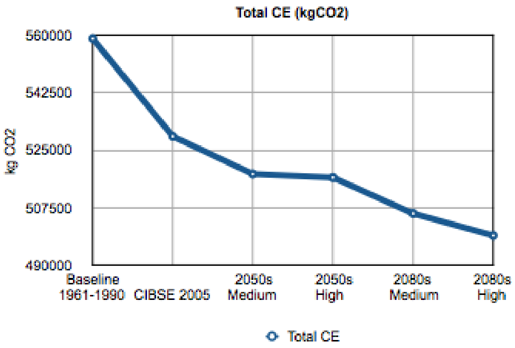


Figure 7: Base case, normalised carbon emissions breakdown and total carbon emissions per scenario

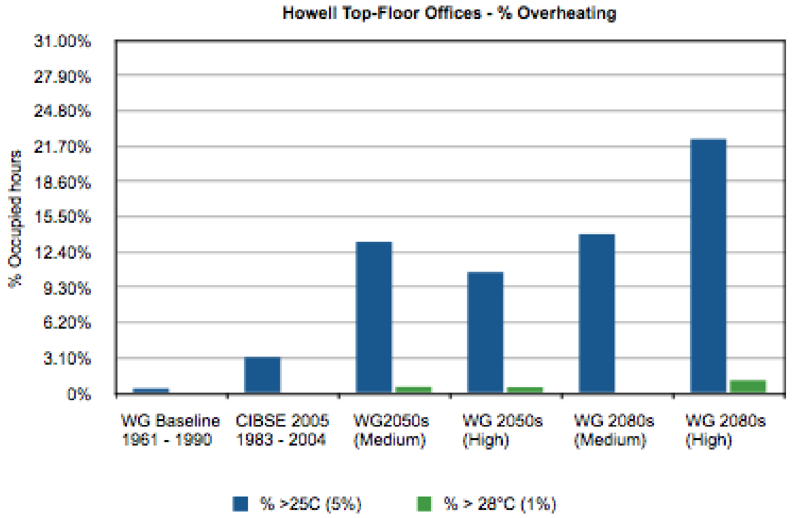
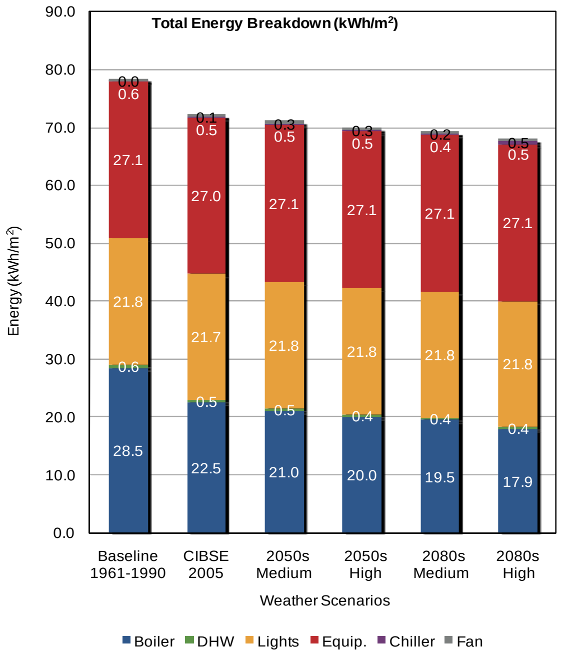


Figure 8: Adapted Case, Top-Floor Offices overheating hours for defined comfort thresholds.



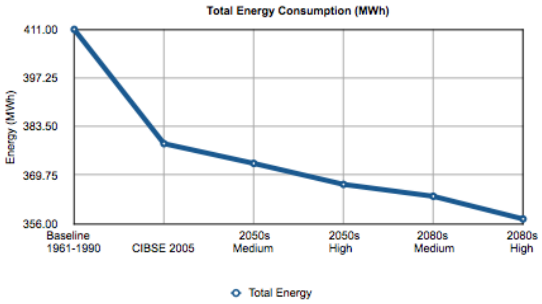
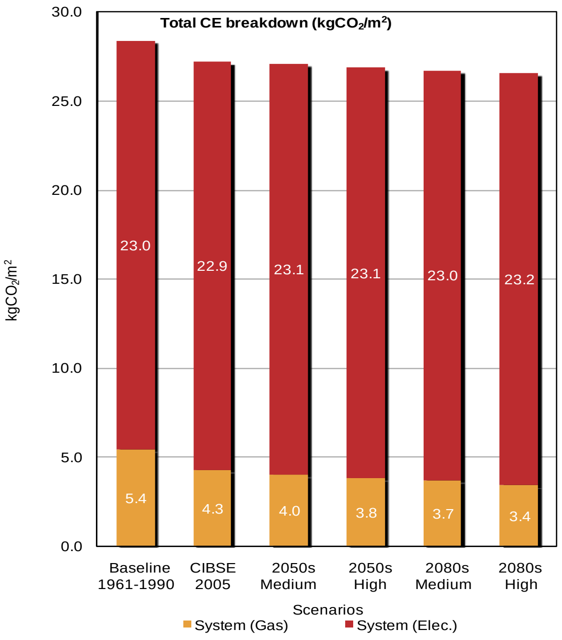


Figure 9: Adapted case, normalised energy breakdown and total energy per scenario



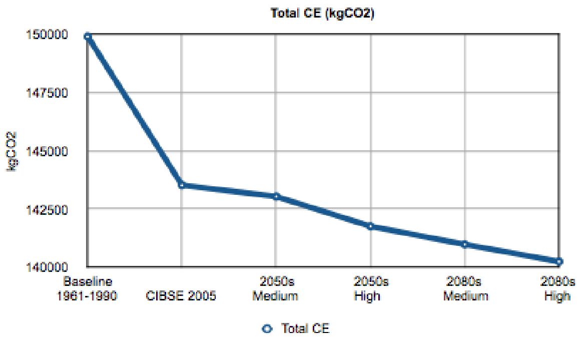


Figure 10: Adapted case, normalised carbon emissions breakdown and total carbon emissions per scenario

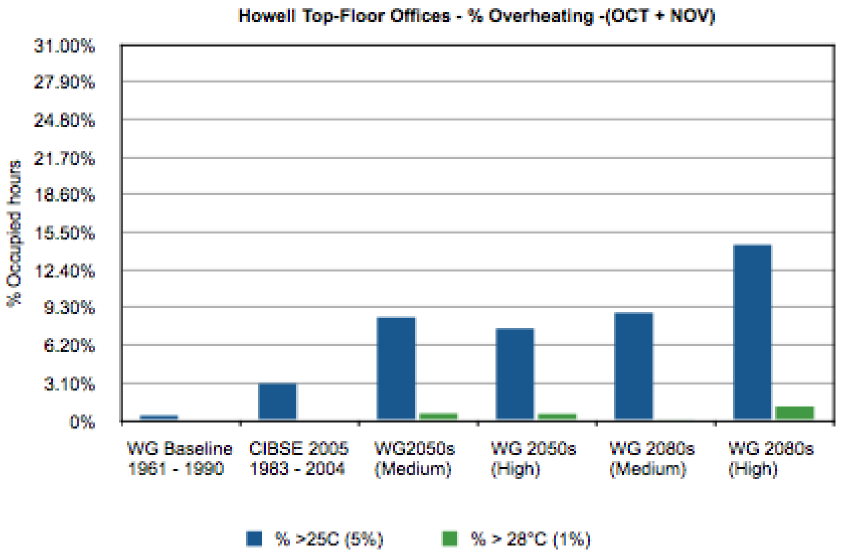


Figure 11: Adapted Case, Top-Floor Offices overheating hours minus the Oct & Nov hours.

In terms of energy consumption, improvements were seen in the winter months, and the analysis of the boiler plant consumption showed that there were reductions for the adapted case, similarly, the peak heating plant load was reduced in each weather scenario.

The adapted case (relative to the base case) was shown to reduce the specific energy consumption and carbon emissions by the quantities shown in Tables 2 and 3.

ΔkWh/m^2	Total Gas	Total Elec.	Total kWh/m^2	%
Baseline, 1961-1990	-263.5	-89	-353.0	82
CIBSE 2005	-236.8	-89	-326.1	82
2050s, Medium	-224.3	-89	-313.6	82
2050s, High	-224.1	-89	-313.5	82
2080s, Medium	-212.3	-89	-301.7	81
2080s, High	-206.2	-89	-295.4	81

Table 2. Difference between Adapted & Base cases ΔkWh/m^2 and % reduction.

$\Delta kgCO_2/m^2$	Total Gas	Total Elec.	Total kWh/m^2	%
Baseline, 1961-1990	-50.1	-41.6	-91.7	76
CIBSE 2005	-45.0	-41.5	-86.5	76
2050s, Medium	-42.6	-41.5	-84.2	76
2050s, High	-42.6	-41.5	-84.2	76
2080s, Medium	-40.4	-41.6	-82.0	75
2080s, High	-39.2	-41.4	-80.7	75

Table 3. Difference between Adapted & Base cases ΔkgCO$_2$/m^2 and % reduction

CONCLUSION

The adapted case reductions have shown that the adaptation strategy has provided the required level of thermal comfort, (in accordance with the defined thermal comfort criteria), while, simultaneously reducing energy consumption and carbon emissions. For this particular case study, there is good evidence that, with the right approach, engineers are able to mitigate the effects of climate change with passive design measures which consists of improved insulation and air-tighness, solar and internal heat gain reduction and utilising day and night natural ventilation for cooling during the summer months., However, there is need to be mindful of the fact that the weather data are probabilistic in nature and the degree of adaptation required for a actual refurbishment project may preclude certain changes due to cost factors.

It appears, that, there are greater reductions to be achieved now, than to wait until the future and there were greater reductions that could have been achieved in the past baseline period. This point of view is one of an economic (return of investment) view, where government incentives based on carbon reductions would provide a greater return of investment, if one took advantage of such a scheme to reduce their operational emissions now, rather than later. This is because a passive refurbishment will alleviate the need to active cooling and climate change predicts higher external temperatures thus reducing the need for heating.

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