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Adaptation to the Future Climate: A Low Carbon Building Design Challenge

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Abstract

In this paper an attempt has been made to assess the performance of an office building located in London (one of the case study buildings in CIBSE TM36: 2005) in relation to energy consumption, carbon emissions and potential for adaptability to the 2050s climate. Overheating is a particular issue in office buildings due to internal heat gains from computers and other electrical equipment. In addition, buildings in London are affected by the urban heat island, which is likely to intensify with warmer summer temperatures, reducing the capacity for night-time cooling of buildings. This paper proposes various passive design strategies which aim to address both mitigation (by reducing carbon emissions) and adaptation (by improving human comfort and reducing energy consumption).

Keywords: Adaptation; climate change; carbom emissions; enrgy consumtion; mitigation.

1. Introduction

The climate is changing, and this has an impact on the robustness of buildings to provide habitable indoor environments. Irrespective of the causes of climate change, there is a need to adapt our buildings so that they can cope with higher temperatures, more extreme weather and changes in rainfall. Due to the inertia in the climate system, even if global emissions are capped immediately the effect of past emissions would continue to be felt for decades. The construction industry is already working to make buildings more energy efficient, reducing green-house gas emissions to limit their effect on the future climate (known as mitigation) [1-3]. However, the industry has been slower to recognise that some changes to our climate cannot be avoided. These changes will have a significant impact on how our buildings will perform. Moreover, depending on the success of our global mitigation strategies, much more significant changes are likely in the second half of the century which will have a correspondingly greater effect. Clearly, there is a need to change the way buildings are designed, constructed, upgraded and occupied to accommodate the expected changes and this is the challenge of adaptation. This represents a fundamental change in the way we think about design. The design approaches should no longer be based on past experience; rather these should be based on the calculated projections of future climate.

Adaptation and mitigation measures can be complementary. However, there can be direct conflicts. For instance, a drive to reduce the use of artificial lighting energy by incorporating large areas of glazing to make better use of daylight can cause summer overheating unless glazing is very comprehensively shaded. On the other hand, even if new low carbon sources of

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energy become the norm, energy is likely to be more expensive, and probably scarcer, in future. Adaptation strategies which rely on high levels of energy use should be avoided, both to avoid increasing emissions from fossil-based energy and to husband precious low carbon energy resources. Designers should use intelligent design based on a clear understanding of the projected changes to design out problems rather than, for example, relying on energy-intensive high-emission cooling technologies to condition poorly designed buildings. The existing stock is a real challenge, much of which performs poorly even in today's climate. We need to develop strategies not only for retrofitting adaptation measures, but also to recognise critical thresholds where the practicalities and costs of adaptation mean that replacing a building becomes the only viable option. Climate change projections [4] suggest a robust pattern of warming of daytime and night-time temperatures annually and across all seasons, which will act to enhance the urban heat island effect. The projected hotter, drier summers pose a particular problem for managing buildings and ensuring occupant thermal comfort. Increasing summer night-time temperature will also limit the possibility for night-time cooling of buildings via natural ventilation.

2. Performance criteria

The performance criteria for the open plan space and core space as per CIBSE Guide [5] are presented in Table 1.

Table 1. Performance criteria

Thermal comfort	Winter temp (^oC)	Open plan	21-23
		Core	19-21
	Summer temp(^oC)	Open plan	22-24
		Core	21-23
	Overheating	Max 5% occupied hours above 28^oC	
	Fresh air supply rate (l/s/p)	8	
Energy consumption	Fabric U-value (W/m^2K)	0.15	
	Window U-value (W/m^2K)	1.8	

3. Building materials and occupancy pattern

The baseline building is a modern medium-sized 3 storied office building located in Suburban London having floor to ceiling height of 3m and floor to floor height of 3.5m. The long facades of the building face north and south as shown in Fig. 1. The building is constructed using block (inner leaf), insulated cavity, brick (outer leaf) and internal block walls. The ceiling is made of thermally massive exposed cast concrete and the floors are suspended. The fenestration and shading comprise of double glazing (U value = 1.5 W/m^2K; SC = 0.66; typical glazed area = 29%. The windows are recessed by 300 mm and have an overhanging shade of depth 1 m, 200 mm above. The external walls have the U values of 0.2 W/m^2K.

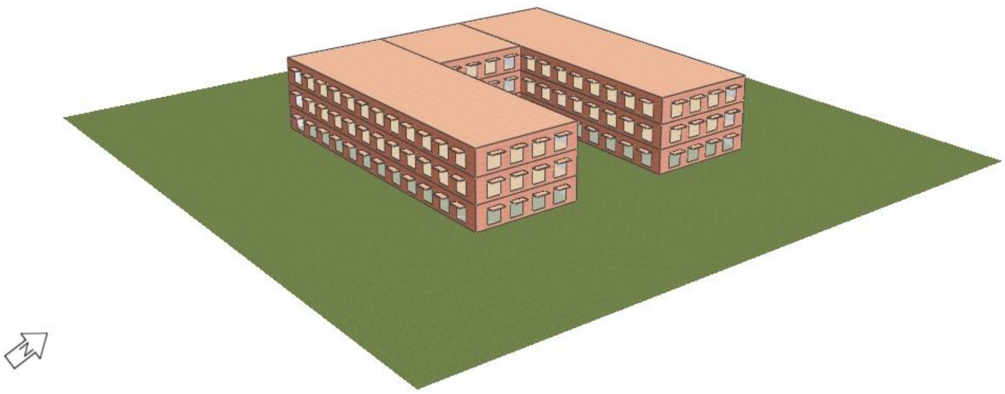

Fig.1: Model schematic of baseline building

4. Assessment method and strategy

In this study dynamic building simulation is used. In office buildings internal gains are often a significant component of space heat gains. Internal heat gains are an important contributor to over- heating in buildings. Therefore, an obvious precaution is to limit these gains wherever possible, e.g. by switching off lights and appliances at night or using low energy devices. With the higher external air temperatures expected under climate change, these precautions alone cannot solve the overheating problem but they can improve the effectiveness of other measures. Solar gain control using either high-performance windows with low shading coefficient (tinted or reflective) or clear high-performance windows with a low-e coating in combination with operable external shading to block solar gains during summer and shoulder seasons and admit solar gains during winter. Good insulation values reduce heating energy consumption. Building orientation determines the amount of solar radiation it receives. It is one of the key elements of passive design strategies. Façade orientation affects the energy and comfort implications of solar shading, window to wall area ratio, window position and performance and choice of exterior colour.

5. Multicriteria performance assessment of baseline and proposed building

5.1. Baseline building

It can be seen from Fig. 2 that for both present day and 2050, ground floor north facing office meets the overheating criteria of not exceeding the internal temperature of 28°C for more than 5% of occupied hours. The south facing top floor office under both present day and 2050 climate fails to meet the overheating criteria. This is due to high solar gains through windows in summer. Table 2 shows that the baseline building performs very well in terms of energy consumption and CO_2 emissions and is within the limit of UK energy consumption benchmark as per TM46 [6]. However, present DSY simulation exceeded energy benchmark by 1%. It can also be noted from Table 2 that there is a reduction in CO_2 by 2.8% and in energy consumption by 6.2% by the year 2050. The building uses less energy than present TRY weather due to the fact in 2050 the climate will be warmer and less heating will be required.

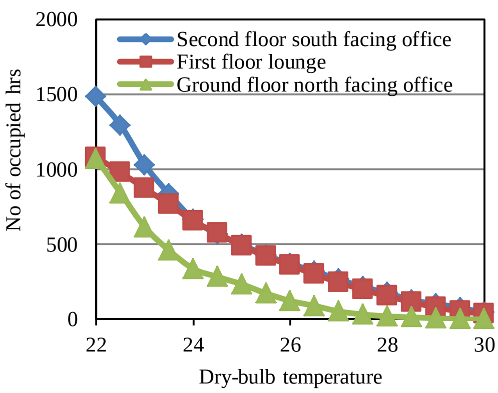

Fig. 2a: No of occupied hrs over each temperature DSY Today

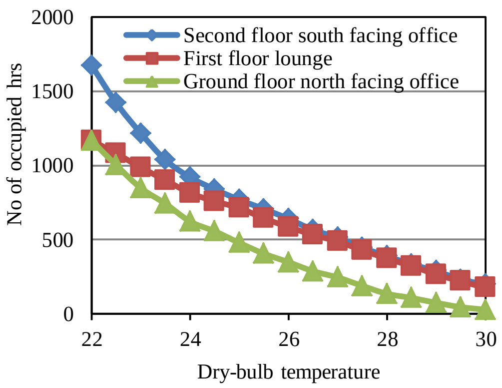

Fig. 2b: No of occupied hrs over each temperature 2050 DSY

Table 2. CO_2 emissions and Energy consumption in baseline building

TRY	Source	CO_2 emissions benchmark (kgCO_2/m^2)	Annual CO_2 emissions (kgCO_2/m^2)	Energy consumption benchmark (kWh/m^2)	Annual energy consumption (kWh/m^2)
Today	Gas boiler	22.8	4.3	120	21.6
	Electricity	52.3	36.7	95	70.94
	Total	75.1	41.0	215	92.54
2050s	Gas boiler	22.8	3.2	120	15.9
	Electricity	52.3	36.7	95	70.94
	Total	75.1	39.9	215	86.84

5.2. Modified case Strategy 1

The advancement in the use of LED lights would help to reduce the internal heat gains substantially. So, the heat gain from lighting is considered to be 4 Watts/m^2. The heat gain from computers in the open plan office is also limited to 10 Watts/m^2. It can be seen from Fig. 3 that for all the spaces although thermal comfort is reached for present day DSY, it has not been able to combat the overheating problem under the 2050 DSY weather. The implementation of strategy 1 enables in achieving thermal comfort for all the three spaces for the present day climate with none of the spaces exceeding 5% of the occupied hours above 28^{o}C. However, the strategy fails to achieve thermal comfort under the 2050 climate. This shows that due to the future becoming warmer in summers it will be difficult to maintain a comfortable office environment just by limiting the internal gains in the offices. Table 3 also shows that limiting the internal gains has led to a reduction in electricity consumption under both present day and future climate. Thus, the total annual energy consumption has been further reduced as compared to the baseline building which in turn leads to a reduction in CO_2 emissions.

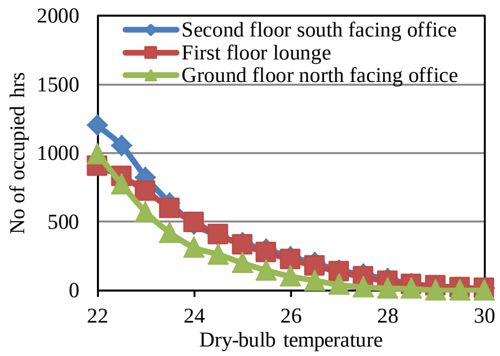

Fig. 3a: No of occupied hrs over each temperature DSY Today

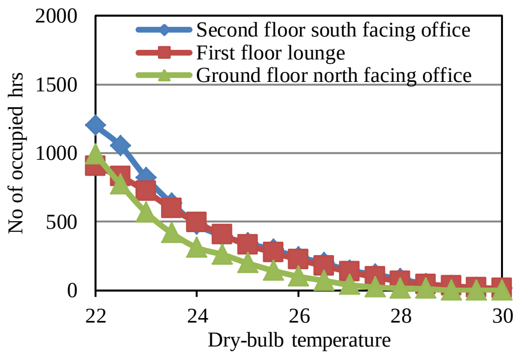

Fig. 3b: No of occupied hrs over each temperature 2050 DSY

Table 3: CO_2 emissions and Energy consumption in modified building (Strategy 1)

TRY	Source	CO_2 emissions benchmark	Annual CO_2 emissions	Energy consumption benchmark	Annual energy consumption
		(kgCO_2/m^2)		(kWh/m^2)	
Today	Gas boiler	22.8	7.1	120	35.7
	Electricity	52.3	23.2	95	44.8
	Total	75.1	30.3	215	80.5
2050s	Gas boiler	22.8	5.6	120	28.2
	Electricity	52.3	23.2	95	44.8
	Total	75.1	28.8	215	73.0

5.3. Modified case Strategy 2

Keeping the internal gains as is in strategy 1, the model is upgraded with triple glazed windows with low emissivity and improved U-value of 1.18 W/m^2K. The floor, wall and roof construction have been revised with increased insulation with U-values of 0.1109 W/m^2K, 0.1010 W/m^2K and 0.1021 W/m^2K respectively. It can be seen from Fig. 4 that the thermal comfort criteria are achieved for both the present day and future climate for all the three spaces. This is due to increased fabric insulation and cutting down of solar gains by using triple glazed windows. The effect of limiting the solar gains has also contributed to the overall effectiveness of implementing this strategy. Due to high insulation value, the heating energy intensity is low and the effect of window performance is significant because of the extent of windows on the building. The effective of external shading was also increased in controlling unwanted solar gains especially on the south facing façade. From Table 4 it can be seen that the elements assigned in this strategy results in significant annual energy savings. The greatest contribution seem to come from triple glazed windows. However, the final result is a function of all the elements interacting. This results in a significant decrease in the CO_2 emissions as well.

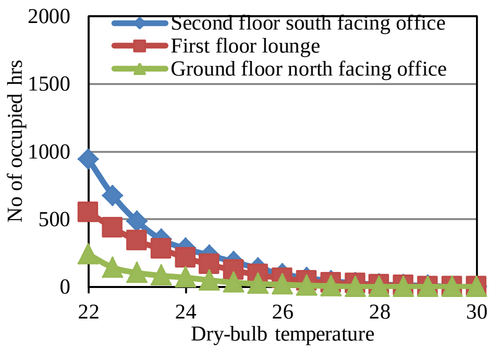

Fig. 4a: No of occupied hrs over each temperature DSY Today

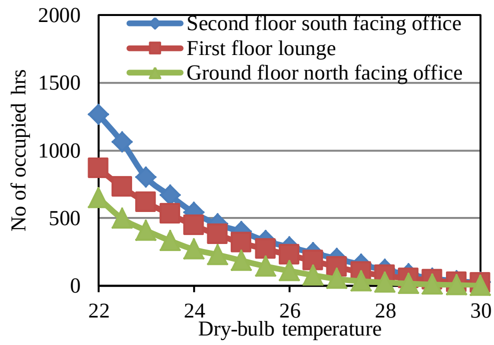

Fig. 4b: No of occupied hrs over each temperature 2050 DSY

Table 4: CO_2 emissions and Energy consumption in modified building (Strategy 2)

TRY	Source	CO_2 emissions benchmark	Annual CO_2 emissions	Energy consumption benchmark	Annual energy consumption
		($kgCO_2/m^2$)		(kWh/m^2)	
Today	Gas boiler	22.8	4.6	120	23.4
	Electricity	52.3	23.2	95	44.8
	Total	75.1	27.8	215	68.2
2050s	Gas boiler	22.8	3.4	120	17.3
	Electricity	52.3	23.2	95	44.8
	Total	75.1	26.6	215	62.1

5.4. Modified case Strategy 3

The changes implemented in strategy 2 were simulated in 3 different orientations with the core façade facing towards the north, east and south. All facades were simulated with the same window to wall ratio. The energy consumption could be more evenly distributed in the building if different window to wall ratios were applied to different exposures. It can be observed from Fig. 5 orientating the core towards the south leads to more overheating problem under present climatic conditions which is expected. Orientating the core space towards east seems to be a better option for the present day climate for the building. The scenario seems to be completely different for the 2050 climate as can be seen in Fig. 6. The orientation of the building has little or no impact on the second floor office. This could be due to the angle of the sun and hence the solar gains.

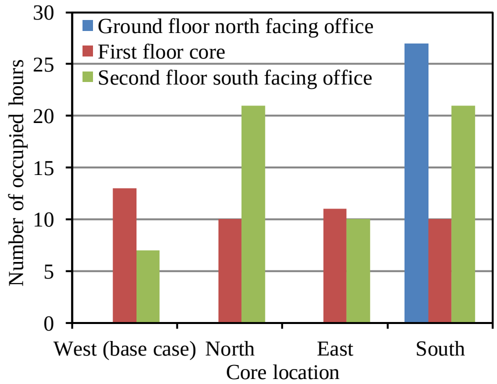

Fig. 5: No of occupied hrs above 28°C today

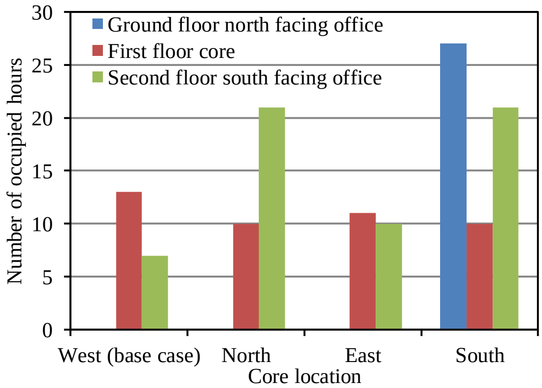

Fig. 6: No of occupied hrs above 28°Cin 2050s

6. Design solution

The elements assigned in Stategy1 produced heating energy savings as well, however fewer changes were implemented and the overall savings are not as impressive as in Strategy 2. High envelope insulation had minimal effect on the heating energy because heat gained was offset by the resulting in the reduction in solar heat gain. The design finally selected for the building which can adapt to the 2050s climate is Strategy 2 with the core space facing towards the south. This means that the long facades of the building will face east and west as indicated in Fig. 7. This means that the open plan offices will not be exposed to the south façade which will prevent overheating in summer and also lead to reduced energy consumption. The building is already very airtight. Hence, preventing the office spaces from exposure to the south façade, using high performance triple glazed windows, limiting the internal gains and extreme levels of fabric insulation to the standards of Passivhaus can help in the adaptation of the building to future climate in terms of achieving thermal comfort, reducing energy consumption and CO_2 emissions significantly.

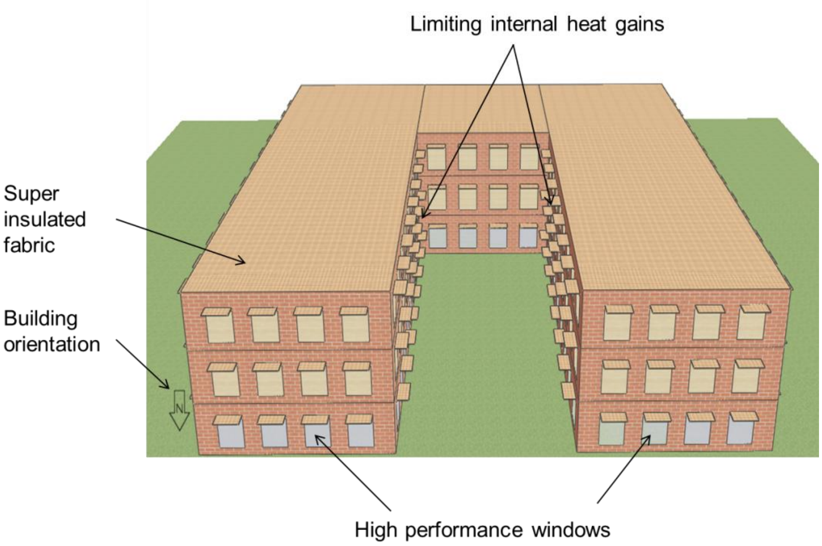

Fig. 7: Schematic diagram showing the passive design elements selected for the building

7. Concluding remarks

The performance of an office building located in London (one of the case study buildings in CIBSE TM36: 2005) is assessed in relation to energy consumption, carbon emissions and potential for adaptability to the 2050s climate. Various passive design strategies addressing both mitigation and adaptation have been proposed. It was observed that by interlinking the passive design elements with each other potentially greater improvements in comfort and building energy performance can be achieved. Therefore, the final design solution is an implementation of building orientation, window performance, super insulation of fabric and limiting internal gains as passive design elements.

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