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Thermal Mass Performance in Commercial Office Buildings

Steel Construction Institute
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Thermal Mass Performance in Commercial Office Buildings

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1	Simulation with *SlimDek* floor included in report; minor corrections	26/07/2007
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Introduction

1 Introduction

1.1 Overview

This study has been commissioned by the Steel Construction Institute to investigate the effects of building thermal mass on thermal comfort and heating energy for naturally ventilated office building. This is particularly crucial in the light of potential climate change where more severe climate might be expected.

Building fabric energy storage (FES) systems make use of thermal mass from building fabric components such as exposed concrete floors/ceilings and walls to store thermal energy for both space heating and cooling purposes. During the cooling period, the FES system stores heat during the day-time and gradually releases it back into the occupied space in the night-time, minimising heating demand. On the other hand, in summer months, building FES system absorbs excessive heat of the day to prevent overheating as well as delaying peak temperature to later hours in the day when outside temperature has dropped allowing more effective natural ventilation. The use of night-cooling ventilation makes the FES system more effective.

This study focuses on the fabric elements (floor construction, external walls, and glazing) as well as climate, with the output in terms of comparisons of annual frequencies of over heating during occupied periods (i.e. 08:00 to 18:00 weekdays) and annual heating demand.

1.2 Objectives

The research objectives outlined in this study, as specified by the client, are to carry out a parametric analysis involving a range of parameters which can be summarised as follows:

- Five different floor constructions all of which have exposed thermal mass (i.e. no suspended ceilings but with raised floor)
- Two types of facade construction (heavy and light weight walls)
- Two types of glazing in terms of solar heat gain performance (i.e. g-value)
- Two weather locations (London and Manchester) for current and projected 2050

In addition to these parameters, there was also a requirement to demonstrate that the test building analysed was capable of meeting the Building Regulations ADL2A CO_2 emissions targets.

1.3 Acknowledgement

A key part of this work involved creating projected weather data for the year 2050 for both London and Manchester, and the authors of this report would like to extend their gratitude to Oxford-Brooke's University for their help in generating the weather tapes used in this work.

Building model

2 Building model

2.1 Building type and geometry

Figure 1 illustrates the building model as constructed in the IES <VE> package

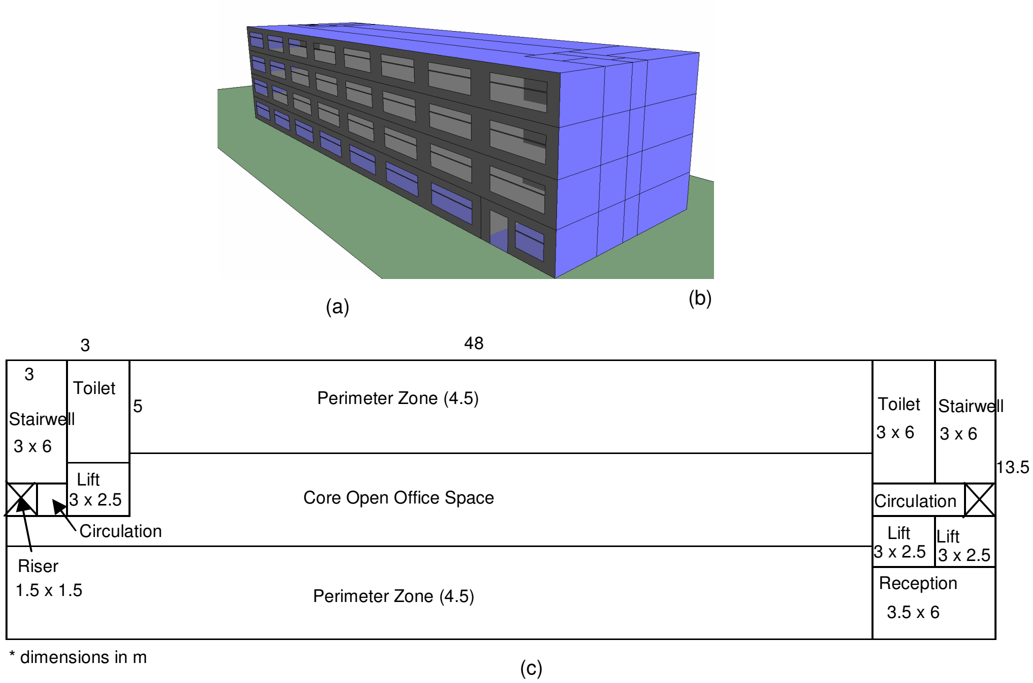

Figure 1 Simple visualisation of the test building and typical plan layout.

The focus of this study is to determine how thermal mass affects overheating and heating demand in a typical commercial office building. With this in mind, a typical/standard medium sized office building has been formulated. It is a four-storey (2.7m floor to ceiling height) 48 x 13.5m^2 narrow aspect ratio building with open plan office. The stairwells and lift shafts are located at the extreme ends of the building. The office building is orientated with its long axis aligned with the east-west bearing and is 40% glazed along the south and north facades.

2.2 IES <VE> software (version 5.6.1)

Faber Maunsell uses the industry standard IES <Virtual Environment> software suite for thermal modelling calculations. The IES <VE> is an integrated suite of applications based around one 3D geometrical model. The modules used for this project include “Apache-Sim” for dynamic thermal simulation and “MacroFlo” for bulk air flow modelling.

Apache-Sim is a dynamic thermal simulation program based on first-principles mathematical modelling of the heat transfer processes, and qualifies as a Dynamic Model in the CIBSE system of model classification, and exceeds the requirements of such a model in many areas.

MacroFlo uses standard wind pressure coefficients with wind data from the weather tapes to predict bulk air flow in and out of openings. In addition to this, it also models single sided ventilation due to wind turbulence, as well as, stack driven ventilation.

2.3 Glazing

Two types of glazing were used in the model throughout the analysis; a typical clear double glazed low-e glazing system and a high performance neutral solar control double glazed system. Table 1 summarises the properties of the two glazing options:

Glazing type	U-value [W/m^{2}K]		g-value
	Centre of pane	Overall	
[1] Clear low-e double glazing	1.5	2.00	0.65
[2] High performance neutral solar control double glazing	1.5	2.00	0.40

Table 1 Glazing properties used in the analysis.

The test building has two types of windows: main windows (1m high) with openable free area equivalent to 20% of the projected area and top-lights (0.5m high) with free openable area equivalent to 10% of the projected area. For the solar gain and daylight calculations, the windows are assumed to have frame factor[1] of 10%.

2.4 Floor construction

5 floor constructions were investigated for their role as the building fabric energy storage (FES) system. These comprise of a concrete slab with raised floor providing a 150mm cavity space. There is no suspended ceiling so as to expose underside of the floor slab. The key variations in ceiling constructions with respect to the thermal mass properties are highlighted in Table 2:

Floor construction	Construction	Thermal mass	
	Modelled concrete thickness [mm]	Admittance[2] [W/m^{2}K]	Decrement factor[3]
[1] SlimDek	137	6.93	0.454
[2] Composite flat slab – ComFlor70	104	6.35	0.547
[3] Pre-cast concrete	200	5.87	0.268
[4] Reinforced concrete	300	5.64	0.146
[5] Hollow core pre-cast	200 (with circular cavities; 145mm diameter at 189mm pitch)	5.15	0.398

Table 2 Floor constructions and thermal characteristics used in the analysis.

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[1] Please refer to Appendix 1 for explanation of Frame factor

[2] Please refer to Appendix 1 for definition of the Admittance value

[3] Please refer to Appendix 1 for definition of Decrement factor

2.5 Façade/wall constructions

Two different types of façades were considered in this study derived on the basis of thermal mass factor: a light-weight and a heavy-weight façade construction. Table 3 lists the thermal properties of these two types of façade construction:

Façade type	U-value [W/m^{2}K]	Admittance [W/m^{2}K]	Decrement factor
[1] Light weight façade [aluminium sheet | insulation | aluminium sheet]	0.3	0.54	0.993
[2] Heavy weight façade [brickwork | insulation | concrete block | plaster]	0.3	3.29	0.143

Table 3 Thermal characteristics for external walls used in the analysis.

2.6 HVAC and ventilation strategy

The office building is naturally ventilated with LTHW radiator heating situated on stairwells and the office perimeter zones. The office perimeter zones are heated to 20ºC during occupied periods with 2 hour pre-heat and night set-back of 12ºC. The inner office areas do not have heating, while the toilets and stairs are assumed to be heated to 18ºC.

Ventilation is from wind and stack driven ventilation achieved using openable windows. There is night time cooling during warmer periods when the cooler night time air is used to cool the office spaces, which pre-cools the exposed thermal mass so as to offset heat gains the following day. The opening strategy is summarised in Table 4.

Operating periods	Main windows	Top-lights
Non-occupied	Closed	Modulate from minimum to maximum based on internal air temperature between 20ºC and 24ºC, only if free cooling is available and external air temperature is greater than 15ºC.
Occupied	Open to maximum when internal air temperature exceeds 24ºC	Modulate from minimum to maximum opening based on the greater of either: [internal air temperature between 20ºC and 24ºC] **OR** [CO_2 concentration between 600ppm and 1000ppm].

Table 4 Window operation strategy for natural ventilation.

2.7 Control of lighting

Electric lighting is based on high efficiency T5 fluorescents, which are assumed to have the appropriate sensors and controls to allow automatic dimming in the office perimeter zones (i.e. 4.5m deep) to take account of daylight availability.

The average daylight factor[4] in the perimeter zone was calculated using DIALux (v4.3) based on a typical perimeter bay (6m wide, 4.5m deep, 2.7m high) with 40% glazing (windows are 4.32m wide, main window is 1.0m high, top-light 0.5m high).

The analysis indicated an average day-light factor of around 3.6% on the working plane. This was taken into account in the thermal model based on a more conservative average daylight factor of 3% to allow for furniture within the office perimeter zones. For more information on how the daylight factors were calculated, please refer to Appendix 2.

The lighting level in the office areas is based on 500 lux on the working plane. With an average daylight factor of 3% in the perimeter zones and appropriate controls the office perimeter lighting would be completely off when external illuminance exceeded around 15,000 lux. Statistical data from CIBSE Guide A[5] show that in the UK, a global horizontal illuminance of 15,000 lux is exceeded for around 60% of the working year. This effectively means that the office perimeter lighting would be off for around 60% of the working year.

2.8 Furniture mass factor

Furniture mass factor is a method of taking account of the thermal mass of furniture and equipment within a building, and is set relative to the thermal mass of the air within the space. The default value in IES is 1, which assumes no furniture. For this study a furniture mass factor of 10 is used, which is based on typical furniture layout for an open plan office. The justification for using a furniture mass factor of 10 is provided in Appendix 3.

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[4] Please refer to Appendix 1 for an explanation of daylight factor

[5] CIBSE Guide A – Environmental Design, Table 2.37 (2006).

2.9 Seasonal mixed-mode strategy

Naturally ventilated buildings will generally consume much less energy than air-conditioned buildings, but changes in climate conditions are beginning to result in certain parts of the UK becoming impractical for offices to be naturally ventilated while maintaining acceptable comfort conditions. The compromise is to use seasonal mixed-mode, which in this analysis is described as a building which operates as a naturally ventilated building for the majority of the year, but during warmer periods has mechanical cooling to limit peak temperatures.

The system modelled is based on DX cooling of the office areas when internal air temperatures exceed 25ºC. The DX units only re-circulate cooled air so the ventilation of the building is still based on naturally ventilation via openable windows (i.e. the top-lights). The ventilation strategy is similar to the base case, except the main windows are assumed to also modulate but shut when internal air temperatures exceed 25ºC. The top-lights will also shut when internal air temperatures exceed 25ºC unless over-ridden by CO_2 concentration to maintain air quality. The modified ventilation strategy is summarised in Table 5.

Operating periods	Main windows	Top-lights
Non-occupied	Closed	Modulate from minimum to maximum based on internal air temperature between 20ºC and 24ºC, only if free cooling is available and external air temperature is greater than 15ºC.
Occupied	Modulate from minimum to maximum opening based internal air temperature between 22ºC and 24ºC but shut when 25ºC is reached.	Modulate from minimum to maximum opening based on the greater of either: [internal air temperature between 20 ºC and 24ºC but shut when 25ºC is reached] **OR** [CO_2 concentration between 600ppm and 1000ppm].

Table 5 Window operation strategy for seasonal mix-mode.

2.10 Internal gains

The internal gains are based on typical office loads and are summarised in Table 6.

	Occupancy			Equipment		Lighting	
	Load [per person]	Density m²/person	Profile [time]	Load [W/m²]	Profile [time]	Load [W/m²]	Profile [time]
Open office space	75W sensible; 55W latent	7.5	0800 to 1800	15	0800 to 1800	12.5	0800 to 1800
Circulation space (corridor and stairwell)	-	-	-	-	-	5.2	0800 to 1800
Reception	-	-	-	-	-	5.2	0800 to 1800
Toilet	-	-	-	-	-	5.2	0800 to 1800

Table 6 Internal gains associated with the respective areas in the test building

2.11 Weather tapes

The second major component in this study was to investigate the effect of climate by running the tests with the CIBSE Test Reference Year weather data for London and Manchester. Test Reference Year weather is meant to represent mean weather conditions over a period of typically 20 years.

The effect of the climate change was also considered, which required the generation of projected weather data based on the current CIBSE Test Reference Year data but adjusted to 2050. These weather tapes were created based on CIBSE TM36[6] and using climate trend morphing techniques developed by Belcher *et al*. (2005)[7] based on the UKCIP02 climate change scenarios. UKCIP02 provides four alternative scenarios of how the climate of the UK might evolve over the course of this century where the changes are relative to the baseline period of 1961 to 1990. For more information regarding UKCIP02, please refer to www.ukcip.org.uk

In this study, the UKCIP02 *medium-high* scenario has been used to derive the weather tapes for year 2050 for both London and Manchester.

2.12 Building Regulation AD:L2A CO_2 emissions

One of the objectives whilst setting up the test building model was to check for compliance with Building Regulations in terms of CO_2 emissions. Table 7 summarised the area weighted average U-values used in the analysis, which are within the limits set by ADL2A. With regards to air tightness of the test building, an infiltration rate of 0.156 ac/hr or an equivalent of $7m^3/h/m^2$ is used, which complies with the limit of $10m^3/h/m^2$, pressure tested at 50Pa. Two of the options considered were checked against the CO_2 emissions targets. Two extremes in terms of thermal mass were used: Scenario 1 is for the test building with SlimDek SD225 floor and light-weight façade, and Scenario 2 is with the 300mm concrete floor and heavy-weight façade.

Construction	U-value [W/m^2K]
Roof	0.25
Ground floor	0.25
External walls	0.30
Glazing (g-value = 0.65)	2.00

Table 7 Building Regulation compliant construction area weighted average U-values

The LTHW radiators are assumed to be supplied via a gas boiler system with 86% seasonal efficiency and 95% distribution efficiency. The domestic hot water is also assumed to be supplied via the same boiler system but with distribution efficiency of 85%.

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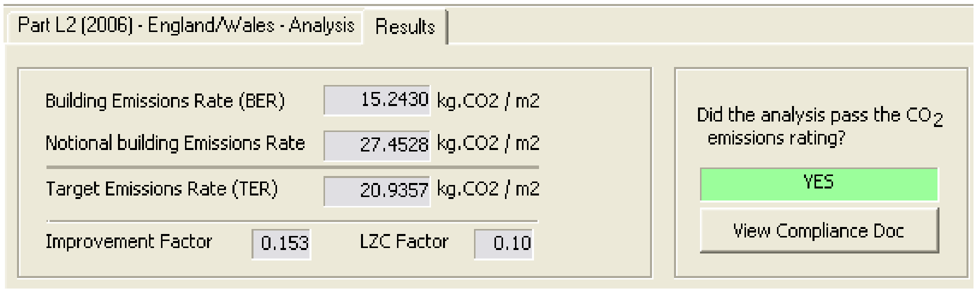
1 CIBSE TM36 Climate change and the indoor environment: impacts and adaptation. *Manchester: Chartered Institution of Building Services Engineers.* (2005) 53p

2 Belcher SE, Hacker JN, Powell DS. Constructing design weather data for future climates. *Building Serv. Eng. Res. Technol.* 26,1 (2005) pp. 49-61

2.12.1 Scenario 1 – light weight construction

The results of the CO_2 emission check is summarised in Figure 2, which shows a comfortable pass margin. The energy consumption for both the *Actual* and *Notional* building are compared in Table 8.



Building Emissions Rate (BER) 15.2430 kg.CO2 / m2

Notional building Emissions Rate 27.4528 kg.CO2 / m2

Target Emissions Rate (TER) 20.9357 kg.CO2 / m2

Improvement Factor 0.153

LZC Factor 0.10

Did the analysis pass the CO_2 emissions rating?

YES

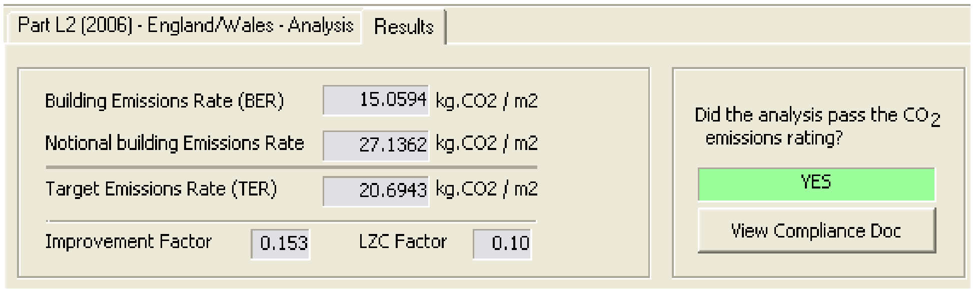
Figure 2 Summary of CO_2 emissions check for scenario 1.

Date	Boilers energy [MWh]		Fans/pumps/ctrls energy [MWh]		Lighting [MWh]	
	Notional	Actual	Notional	Actual	Notional	Actual
Jan 01-31	12.2	6.4	0.43	0.86	11.1	8.9
Feb 01-28	8.3	4.8	0.30	0.73	10.1	6.8
Mar 01-31	6.9	4.1	0.23	0.76	11.1	6.0
Apr 01-30	3.6	1.9	0.12	0.55	9.6	4.1
May 01-31	3.0	1.7	0.11	0.57	10.6	4.1
Jun 01-30	2.8	1.7	0.10	0.57	10.6	3.7
Jul 01-31	2.9	1.8	0.11	0.60	11.1	4.1
Aug 01-31	2.9	1.8	0.11	0.60	11.1	4.4
Sep 01-30	2.9	1.6	0.10	0.55	10.1	4.8
Oct 01-31	4.3	1.9	0.15	0.63	11.6	7.1
Nov 01-30	7.3	2.8	0.27	0.68	11.1	8.8
Dec 01-31	11.6	5.2	0.41	0.70	9.6	8.0
Annual total	68.8	35.8	2.44	7.80	127.5	70.9

Table 8 Energy consumption for both *notional* and *actual* building for scenario 1.

2.12.2 *Scenario 2 – heavy weight construction*

The results of the CO_2 emission check is summarised in Figure 3, which shows a comfortable pass margin. The energy consumption for both the *Actual* and *Notional* building are compared in Table 9.



Building Emissions Rate (BER) 15.0594 kg.CO2 / m2

Notional building Emissions Rate 27.1362 kg.CO2 / m2

Target Emissions Rate (TER) 20.6943 kg.CO2 / m2

Improvement Factor 0.153

LZC Factor 0.10

Did the analysis pass the CO_2 emissions rating?

YES

Figure 3 Summary of CO_2 emissions check for scenario 2.

Date	Boilers energy [MWh]		Fans/pumps/ctrls energy [MWh]		Lighting [MWh]	
	Notional	Actual	Notional	Actual	Notional	Actual
Jan 01-31	11.2	6.1	0.42	0.87	11.1	8.9
Feb 01-28	7.8	4.4	0.29	0.73	10.1	6.8
Mar 01-31	6.5	4.0	0.23	0.77	11.1	6.0
Apr 01-30	3.5	1.8	0.12	0.55	9.6	4.1
May 01-31	3.0	1.7	0.11	0.57	10.6	4.1
Jun 01-30	2.8	1.7	0.10	0.57	10.6	3.7
Jul 01-31	2.9	1.8	0.11	0.60	11.1	4.1
Aug 01-31	2.9	1.8	0.11	0.60	11.1	4.4
Sep 01-30	2.8	1.6	0.10	0.55	10.1	4.8
Oct 01-31	4.2	1.9	0.15	0.63	11.6	7.1
Nov 01-30	7.0	2.5	0.27	0.66	11.1	8.8
Dec 01-31	10.2	4.2	0.39	0.68	9.6	8.0
Annual total	64.8	33.5	2.41	7.79	127.5	70.9

Table 9 Energy consumption for both *notional* and *actual* building for scenario 2.

2.13 Effect of thermal mass on heating energy

The results of the carbon emissions comparison between the light weight and heavy weight building models showed that the annual heating energy for the heavy weight building (i.e. 33.5 MWh from Table 9) was slightly lower than for the light weight building (i.e. 35.8 MWh from Table 8).

When carrying out a design heating load calculation, a heavy weight building will usually have a higher intermittent heating load[8] when compared to the light weight equivalent, and intuitively the difference in annual heating energy would be expected to follow suit, but in both the carbon emissions calculations and the parametric simulations, the results indicate that increasing the thermal mass marginally reduces the annual heating energy.

The intermittent heating load is based on the building being heated up from a nominal setback temperature (i.e. typically 12ºC for un-occupied periods), but in the simulations it was found that greater thermal mass reduced the rate at which the internal air temperature would fall during un-occupied periods. This meant that the start-up temperature would be higher with the heavier weight buildings, and therefore require less heat input. This is demonstrated in Figure 4 with a sample temperature and heating load profile (27th to 31st of December with current London TRY weather) for a south facing perimeter zone on the second floor.

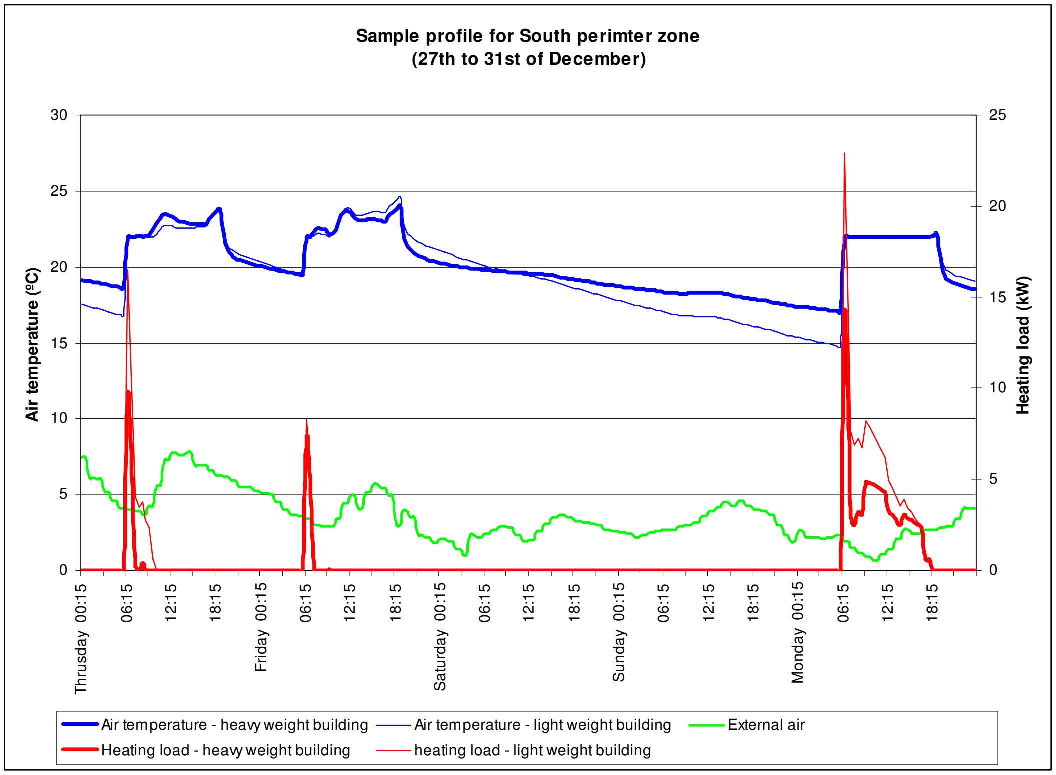


Figure 4 Sample temperature and heating load profile comparing effects of thermal mass.

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[8] Please refer to Appendix 1 for an explanation of intermittent heating.

Results

3 Results

96 simulations were conducted, summarised into sixteen sets as shown in Table 10. From the large compilation of results, there is a series of observation worth noting and they are progressively laid out in the following sub-sections. In order to keep the analysis consistent, only two spaces in the building model were investigated throughout the discussion for the purposed of comparing the frequency of overheating; these are the second floor open plan office perimeter zones north and south, which are referenced as PZN and PZS respectively.

	Simulation set	Sub-set simulations	Description
1	Glazing1_Facade1_ London2005	Floor 1 to 5	normal glazing; light-weight façade; London 2005 weather tape; floor type 1 to floor type 5
2	Glazing1_Facade2_ London2005	Floor 1 to 5	normal glazing; heavy-weight façade; London 2005 weather tape; floor type 1 to floor type 5
3	Glazing2_Facade1_ London2005	Floor 1 to 5	solar control glazing; light-weight façade; London 2005 weather tape; floor type 1 to floor type 5
4	Glazing2_Facade2_ London2005	Floor 1 to 5	solar control glazing; heavy-weight façade; London 2005 weather tape; floor type 1 to floor type 5
5	Glazing1_Facade1_ London2050	Floor 1 to 5	normal glazing; light-weight façade; London 2050 weather tape; floor type 1 to floor type 5
6	Glazing1_Facade2_ London2050	Floor 1 to 5	normal glazing; heavy-weight façade; London 2050 weather tape; floor type 1 to floor type 5
7	Glazing2_Facade1_ London2050	Floor 1 to 5	solar control glazing; light-weight façade; London 2050 weather tape; floor type 1 to floor type 5
8	Glazing2_Facade2_ London2050	Floor 1 to 5	solar control glazing; heavy-weight façade; London 2050 weather tape; floor type 1 to floor type 5
9	Glazing1_Facade1_ Manchester2005	Floor 1 to 5	normal glazing; light-weight façade; Manchester 2005 weather tape; floor type 1 to floor type 5
10	Glazing1_Facade2_ Manchester2005	Floor 1 to 5	normal glazing; heavy-weight façade; Manchester 2005 weather tape; floor type 1 to floor type 5
11	Glazing2_Facade1_ Manchester2005	Floor 1 to 5	solar control glazing; light-weight façade; Manchester 2005 weather tape; floor type 1 to floor type 5
12	Glazing2_Facade2_ Manchester2005	Floor 1 to 5	solar control glazing; heavy-weight façade; Manchester 2005 weather tape; floor type 1 to floor type 5
13	Glazing1_Facade1_ Manchester2050	Floor 1 to 5	normal glazing; light-weight façade; Manchester 2050 weather tape; floor type 1 to floor type 5
14	Glazing1_Facade2_ Manchester2050	Floor 1 to 5	normal glazing; heavy-weight façade; Manchester 2050 weather tape; floor type 1 to floor type 5
15	Glazing2_Facade1_ Manchester2050	Floor 1 to 5	solar control glazing; light-weight façade; Manchester 2050 weather tape; floor type 1 to floor type 5
16	Glazing2_Facade2_ Manchester2050	Floor 1 to 5	solar control glazing; heavy-weight façade; Manchester 2050 weather tape; floor type 1 to floor type 5

Table 10 Summary of options analysed.

3.1 Floor construction

The 5 floor constructions analysed is summarised in Table 11, which shows a trend between increased thermal mass of the floor with a reduction in the frequency of overheating and also a marginal reduction in the heating demand. For London, the effect that the various floor constructions have on the south perimeter zone results in a range of around 18 hours for occupied periods when 25ºC is exceeded (i.e. 144 to 162 hours), which is around 0.7% of the annual occupied period, while for Manchester the equivalent range is around 0.2% of annual occupied period (i.e. 58 to 62 hours). The difference in the annual heating energy for the 5 floor constructions considered is a range of around 5%.

A graphical illustration comparing the difference in temperature frequency distribution over a wider range of operative temperatures during occupied hours is provided for the south facing perimeter zone (PZS) in Figure 5 and Figure 6. A direct comparison over two warm days is also provided in Figure 7.

Simulation	Annual heating demand, £	Percentage of occupied hours when operating temperature exceeded			
		25ºC		28ºC	
		PZN	PZS	PZN	PZS
Glazing1_Facade1_Floor1_London2005	349.75	5.04	6.00	0.48	0.64
Glazing1_Facade1_Floor2_London2005	355.06	5.28	6.48	0.52	0.80
Glazing1_Facade1_Floor3_London2005	340.70	5.20	6.04	0.44	0.64
Glazing1_Facade1_Floor4_London2005	336.65	5.20	5.76	0.44	0.56
Glazing1_Facade1_Floor5_London2005	352.25	5.36	6.48	0.56	0.80
Glazing1_Facade1_Floor1_Manchester2005	480.48	2.36	2.32	0.08	0.04
Glazing1_Facade1_Floor2_Manchester2005	485.47	2.32	2.36	0.12	0.16
Glazing1_Facade1_Floor3_Manchester2005	473.30	2.20	2.32	0.08	0.04
Glazing1_Facade1_Floor4_Manchester2005	467.38	2.12	2.40	0.08	0.04
Glazing1_Facade1_Floor5_Manchester2005	484.85	2.36	2.48	0.16	0.16

Table 11 Effects of floor construction on heating demand and frequency of overheating.

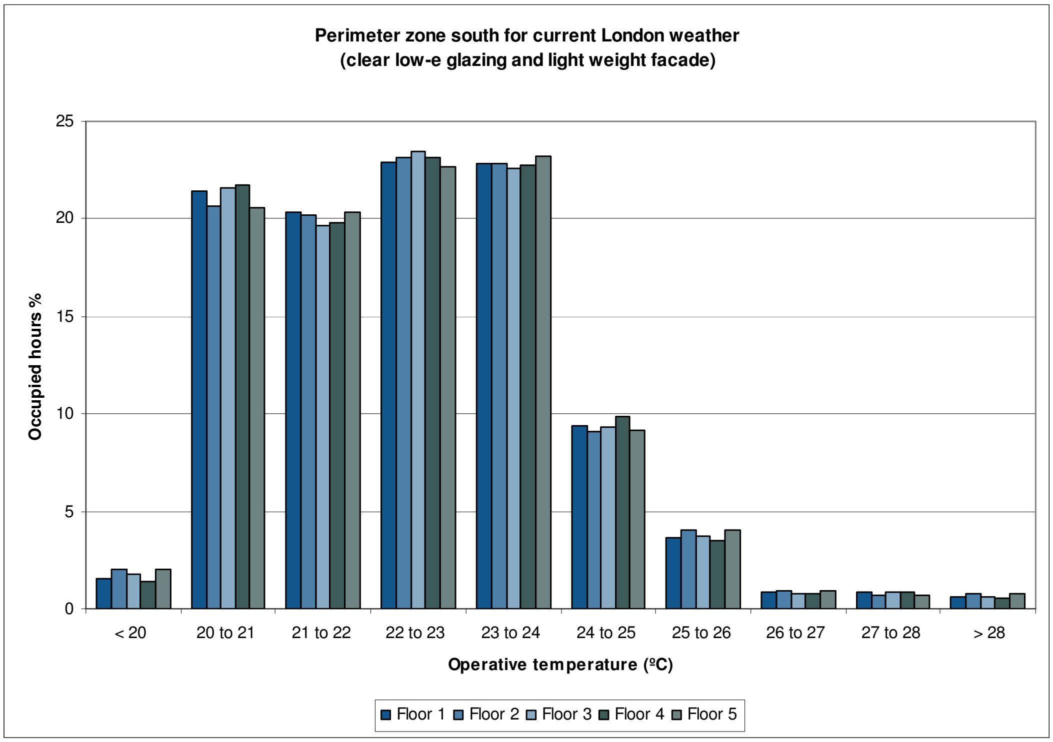


Figure 5 Sample temperature frequency with varying floor construction (London).

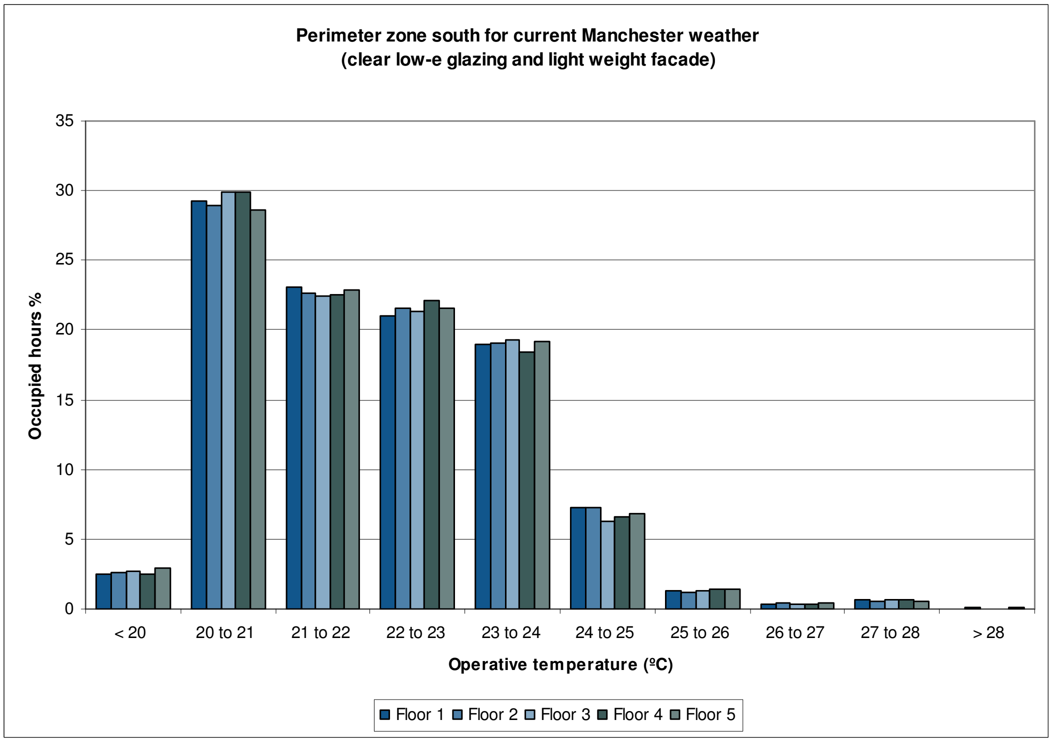


Figure 6 Sample temperature frequency with varying floor construction (Manchester).

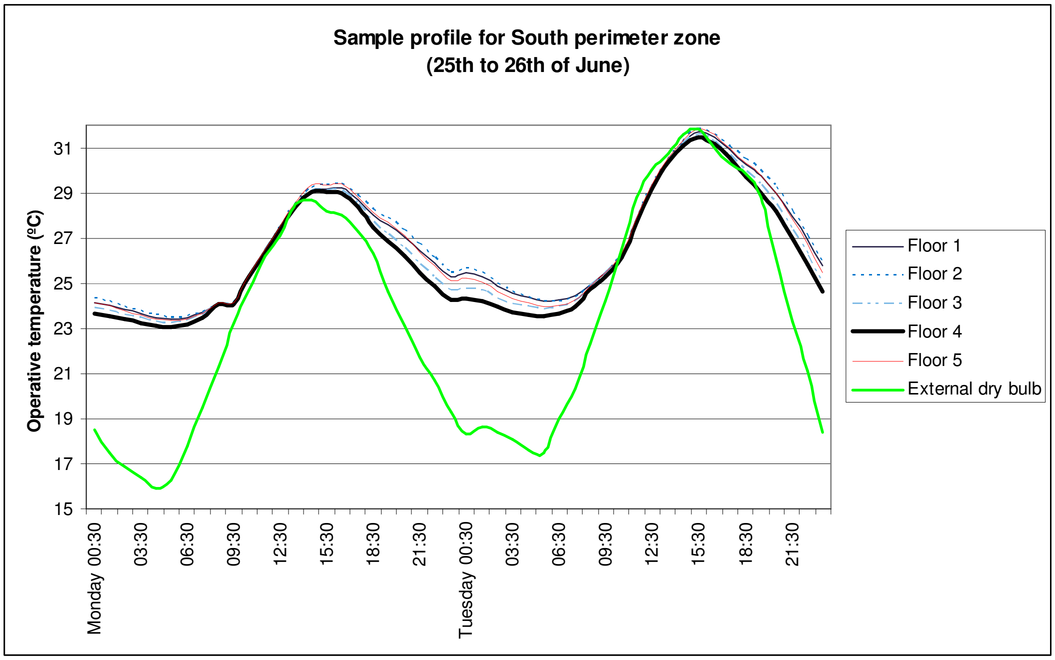


Figure 7 Sample profile for summer based on current London TRY weather.

3.2 Façade

The effect of a light-weight and a heavy-weight façade is summarised in Table 12. This shows a similar trend to that of varying the mass of the floor, where a heavier façade construction results in a small reduction in the degree of overheating as well as the annual heating energy.

Simulation	Annual heating demand, £	Percentage of occupied hours when operating temperature exceeded			
		25ºC		28ºC	
		PZN	PZS	PZN	PZS
Glazing1_Facade1_Floor2_London2005	355.06	5.28	6.48	0.52	0.80
Glazing1_Facade2_Floor2_London2005	349.13	4.84	5.68	0.48	0.60
Glazing1_Facade1_Floor4_London2005	336.65	5.20	5.76	0.44	0.56
Glazing1_Facade2_Floor4_London2005	333.84	4.64	5.12	0.36	0.48
Glazing1_Facade1_Floor5_London2005	352.25	5.36	6.48	0.56	0.80
Glazing1_Facade2_Floor5_London2005	346.94	5.00	5.72	0.48	0.60
Glazing1_Facade1_Floor2_Manchester2005	485.47	2.32	2.36	0.12	0.16
Glazing1_Facade2_Floor2_Manchester2005	481.42	2.28	2.12	0.08	0.00
Glazing1_Facade1_Floor4_Manchester2005	467.38	2.12	2.40	0.08	0.04
Glazing1_Facade2_Floor4_Manchester2005	465.82	1.84	1.88	0.00	0.00
Glazing1_Facade1_Floor5_Manchester2005	484.85	2.36	2.48	0.16	0.16
Glazing1_Facade2_Floor5_Manchester2005	477.05	2.24	2.04	0.08	0.04

Table 12 Effects of façade construction on heating demand and frequency of overheating.

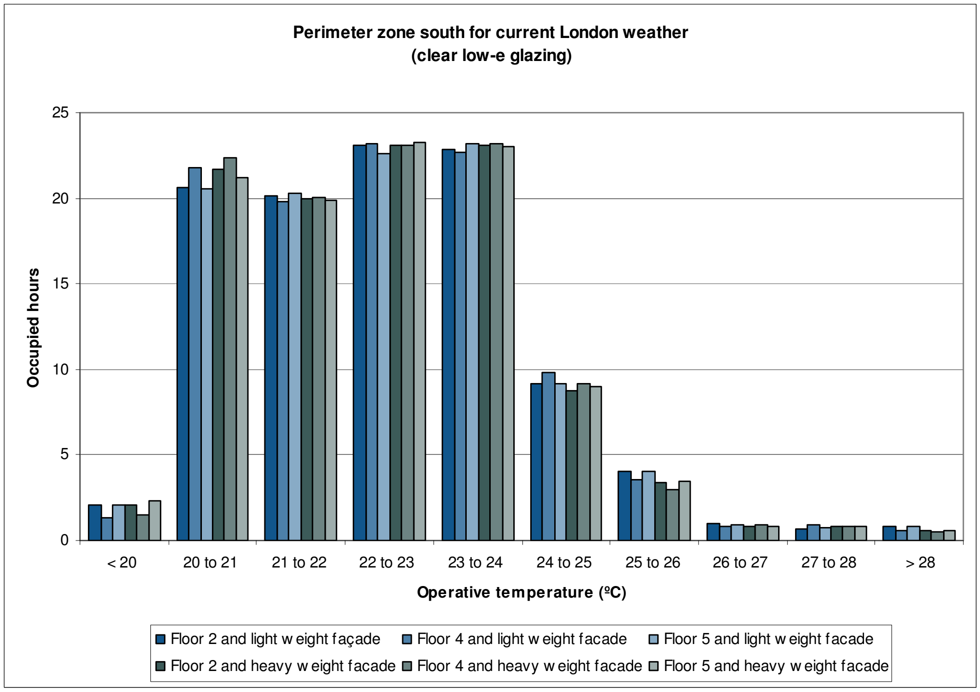


Figure 8 Sample temperature frequency with varying façade and floor construction.

3.3 Glazing

To further mitigate the risk of overheating, the solar performance of the glazing is also investigated and summarised in Table 13. The first observation to point out here is that improving the solar performance of the glazing results in a reduction in the frequency of overheating that is comparable to the combined effects of increasing the thermal mass of both floor and façade. This is also illustrated in the frequency distribution graph for the south perimeter zone (PZS) in Figure 9 where going from clear low-e glazing to high performance neutral solar control glazing results in more occupied hours at the lower end of the desired temperature band (i.e. 20 to 21ºC).

This is of particular interest when considering the possibility of retrofitting high performance glazing to an existing light-weight building where increasing its thermal mass is not readily a viable solution to mitigating overheating.

The second observation to point out is that although improving the solar performance of the glazing very effectively reduces the frequency of overheating it also reduces the amount of passive heating during the heating season, which results in around 20% increase in the annual heating energy. The increase in heating demand from using high performance solar control glazing can be offset by improving the overall U-value of the glazing and building fabric. In practice the issue of overheating is usually more difficult to address than heating in naturally ventilated buildings, which is an issue that may worsen with the potential changes in climate.

Simulation	Annual heating demand, £	Percentage of occupied hours when operating temperature exceeded			
		25ºC		28ºC	
		PZN	PZS	PZN	PZS
Glazing1_Facade1_Floor2_London2005	355.06	5.28	6.48	0.52	0.80
Glazing2_Facade1_Floor2_London2005	460.20	3.72	3.40	0.44	0.44
Glazing1_Facade1_Floor4_London2005	336.65	5.20	5.76	0.44	0.56
Glazing2_Facade1_Floor4_London2005	438.98	3.36	2.92	0.28	0.36
Glazing1_Facade1_Floor5_London2005	352.25	5.36	6.48	0.56	0.80
Glazing2_Facade1_Floor5_London2005	454.90	3.80	3.52	0.44	0.44
Glazing1_Facade1_Floor2_Manchester2005	485.47	2.32	2.36	0.12	0.16
Glazing2_Facade1_Floor2_Manchester2005	611.52	1.56	1.36	0.00	0.00
Glazing1_Facade1_Floor4_Manchester2005	467.38	2.12	2.40	0.08	0.04
Glazing2_Facade1_Floor4_Manchester2005	593.74	1.20	1.32	0.00	0.00
Glazing1_Facade1_Floor5_Manchester2005	484.85	2.36	2.48	0.16	0.16
Glazing2_Facade1_Floor5_Manchester2005	609.34	1.56	1.36	0.00	0.00

Table 13 Effects of glazing performance on heating demand and frequency of overheating.

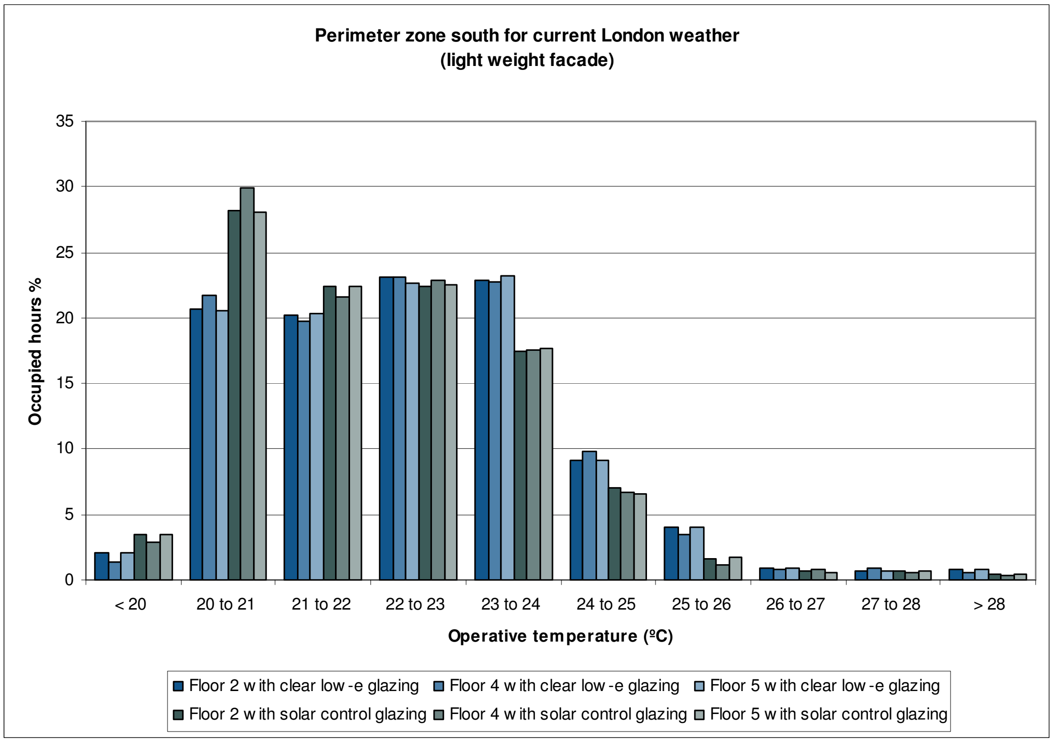


Figure 9 Sample temperature frequency with varying glazing g-value and floor construction.

3.4 Effects of climate change

The predictions for climate changes generally indicate warmer summer conditions, which will have a major effect on naturally ventilated buildings. The comparisons between current Test Reference Year weather and that projected for 2050 are summarised in Table 14. The current CIBSE guidance on overheating recommends that the internal operative temperature should not exceed 1% of the occupied hours, which for typical office working hours would equate to around 26 hours per year.

The effect of floor construction is illustrated for the south perimeter zone (PZS) in Figure 10 and Figure 11, where although there is a significant difference between climate options, the difference between the sample floor constructions is relatively small.

The results show that even with the optimum combination of thermal mass and solar control glazing, the test building fails the overheating criteria for London 2050, while for Manchester 2050 it is very marginal. This indicates that natural ventilation alone will not be a practical method of servicing office buildings if the projected climate changes are correct.

Simulation	Annual heating demand, £	Percentage of occupied hours when operating temperature exceeded			
		25ºC		28ºC	
		PZN	PZS	PZN	PZS
Glazing1_Facade1_Floor2_London2005	355.06	5.28	6.48	0.52	0.80
Glazing1_Facade1_Floor2_London2050	219.96	12.76	13.00	3.36	3.72
Glazing1_Facade1_Floor4_London2005	336.65	5.20	5.76	0.44	0.56
Glazing1_Facade1_Floor4_London2050	202.49	13.68	12.88	2.96	3.40
Glazing1_Facade1_Floor5_London2005	352.25	5.36	6.48	0.56	0.80
Glazing1_Facade1_Floor5_London2050	219.02	13.24	13.04	3.40	3.72
Glazing1_Facade1_Floor2_Manchester2005	485.47	2.32	2.36	0.12	0.16
Glazing1_Facade1_Floor2_Manchester2050	315.74	6.28	6.08	1.56	1.68
Glazing1_Facade1_Floor4_Manchester2005	467.38	2.12	2.40	0.08	0.04
Glazing1_Facade1_Floor4_Manchester2050	298.27	5.76	5.68	1.40	1.52
Glazing1_Facade1_Floor5_Manchester2005	484.85	2.36	2.48	0.16	0.16
Glazing1_Facade1_Floor5_Manchester2050	311.06	6.36	6.12	1.60	1.68

Table 14 Effects of climate change on heating demand and frequency of overheating.

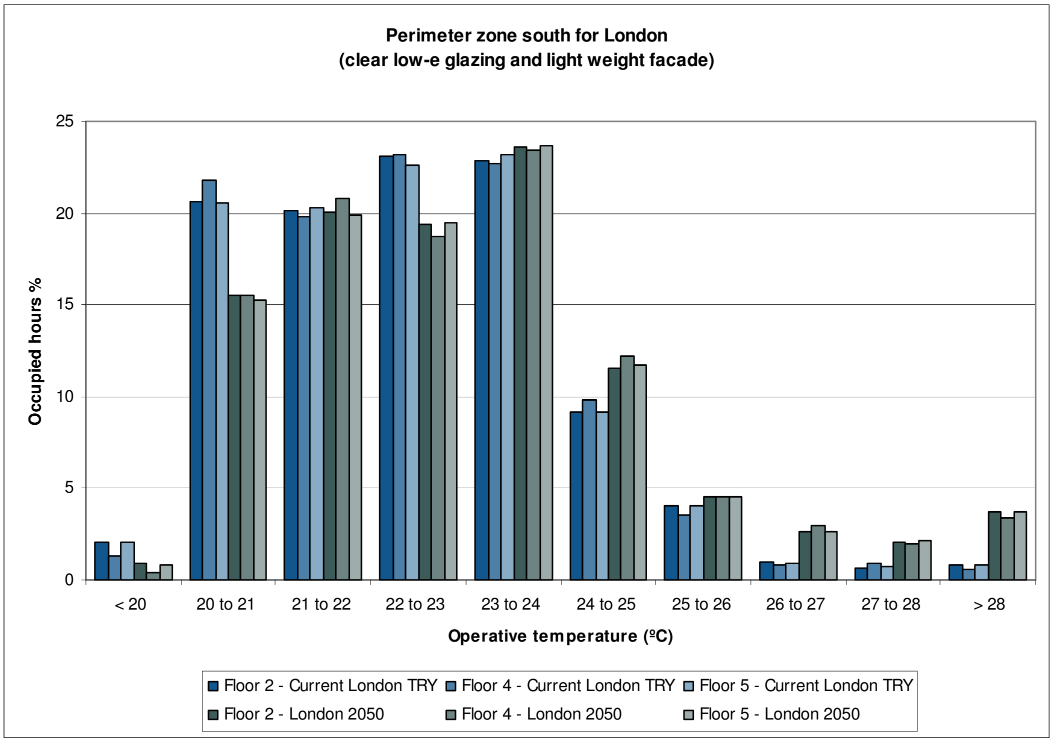


Figure 10 Sample temperature frequency with varying floor construction and climate (London)

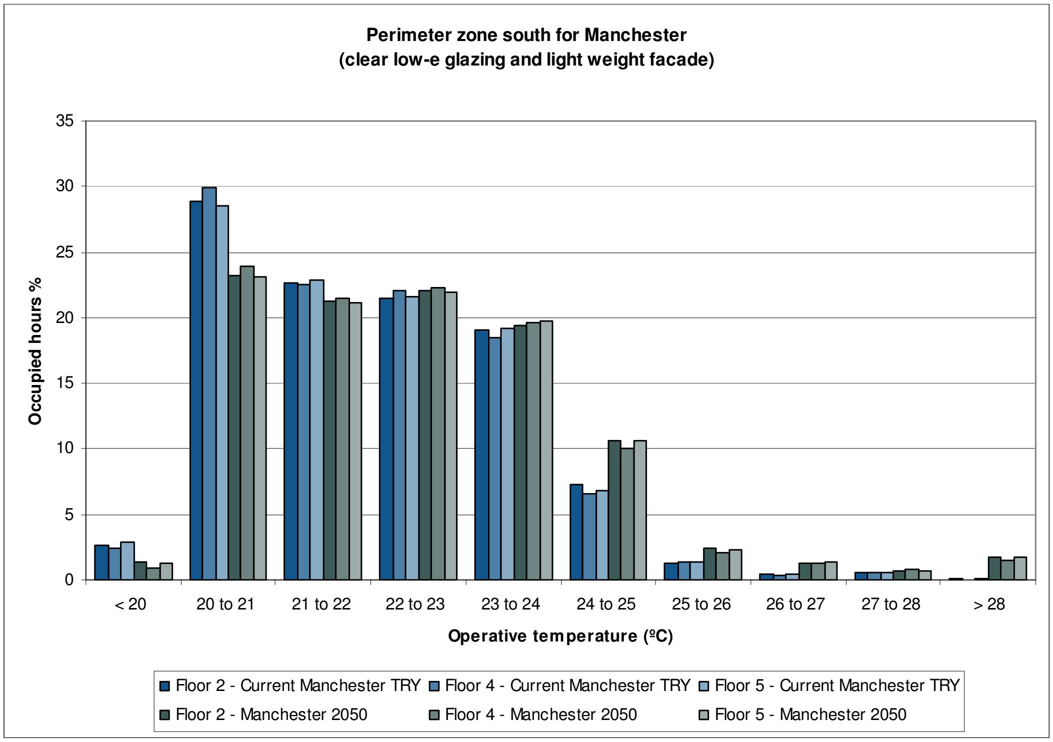


Figure 11 Sample temperature frequency with varying floor construction and climate (Manchester)

3.5 Seasonal mixed-mode

The results of running 3 floor constructions (with clear low-e glazing and light weight facade) with seasonal mixed-mode is compared with the equivalent naturally ventilation and heated only options in Table 15. Please note that because the DX units are controlling to air temperature of 25ºC, the operative temperature still exceeds 25ºC, so for this set of results the frequency overheating hours has been changed from 25ºC to 26ºC operative temperature so as to be able to demonstrate the improvement in comfort conditions.

The results show that with seasonal mix-mode there is still a small difference between the floor constructions (i.e. range of around 10%), which is to be expected because the building would still operate in natural ventilation mode during the heating season and be affected by the available thermal mass. The effect of the floor constructions on the cooling energy is less pronounced with a range of around 5%.

It is worth pointing out that the annual heating energy is higher for the seasonal mix-mode options because of the difference in how the main window is modelled. In the natural ventilation and heated only options the main windows only open when the internal air temperature exceeds 24ºC, but for the seasonal mix-mode option this was changed to modulate 22 and 24ºC.

Simulation	Annual heating demand, £	Annual cooling demand, £	Percentage of occupied hours when operating temperature exceeded			
			26ºC		28ºC	
			PZN	PZS	PZN	PZS
Glazing1_Facade1_ Floor2_London2050	219.96	0	7.72	8.44	3.36	3.72
Glazing1_Facade1_ Floor2_London2050 (mixed-mode)	253.97	297.96	0	4.36	0	0
Glazing1_Facade1_ Floor4_London2050	202.49	0	7.72	8.36	3.4	3.4
Glazing1_Facade1_ Floor4_London2050 (mixed-mode)	236.50	286.10	0	3.72	0	0
Glazing1_Facade1_ Floor5_London2050	219.02	0	7.68	8.52	3.4	3.72
Glazing1_Facade1_ Floor5_London2050 (mixed-mode)	257.71	294.84	0	4.48	0	0

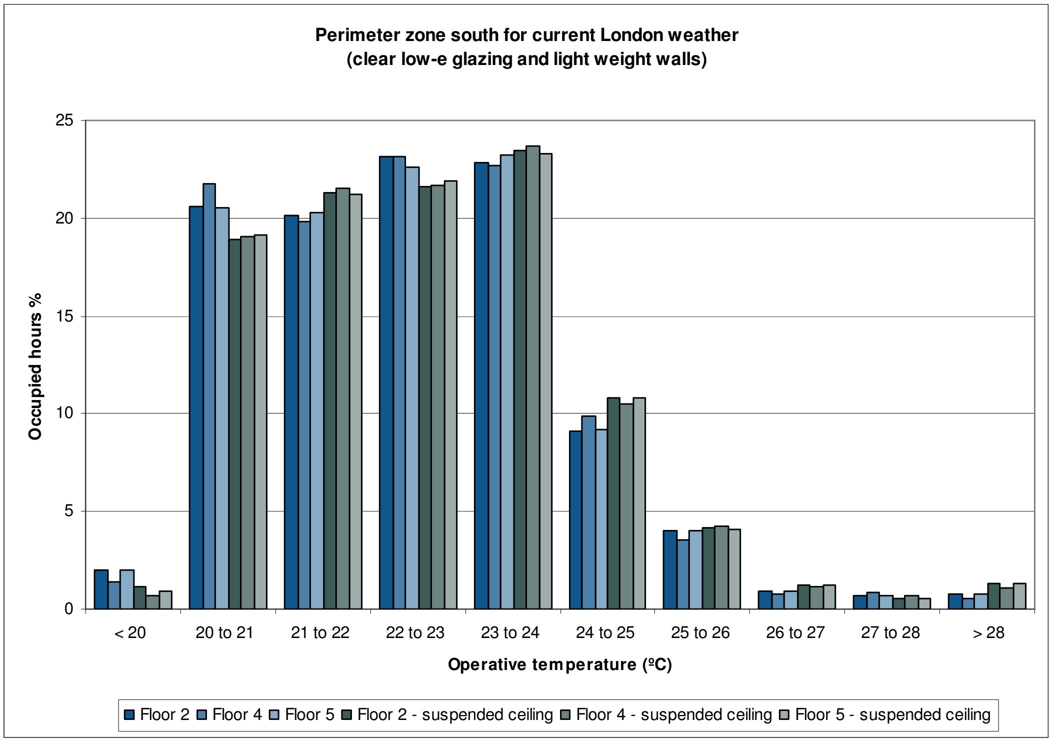
Table 15 Comparison with seasonal mixed-mode.

3.6 Use of suspended ceilings

In many applications it is not always practical or desirable to expose the underside of the floor slab because of the need for noise attenuation and aesthetic issues. Acoustically the BCO[9] guidance sets noise criteria and reverberation times that are difficult to achieve with exposed floor slabs. In current practice, to expose the underside of a floor slab usually requires a good surface finish for aesthetic reasons. Therefore, it is worth considering how this affected the frequency of overheating and annual heating energy.

The results in Table 16 show that with a suspended ceiling the variation in the frequency of overheating between the various floor constructions considered becomes even less pronounced.

The effect of having suspended ceilings is illustrated for the south perimeter zone (PZS) in Figure 12, which shows that the degree of overheating increases significantly with suspended ceilings. This is to be expected as the suspended ceiling effectively insulates the occupied space from the thermal mass of the floor slab.



Simulation	Annual heating demand, £	Percentage of occupied hours when operating temperature exceeded			
		25ºC		28ºC	
		PZN	PZS	PZN	PZS
Glazing1_Facade1_Floor2_London2005	355.06	5.28	6.48	0.52	0.80
Glazing1_Facade1_SusCeil_Floor2_London2005	371.90	6.84	7.20	0.84	1.28
Glazing1_Facade1_Floor4_London2005	336.65	5.20	5.76	0.44	0.56
Glazing1_Facade1_SusCeil_Floor4_London2005	364.10	6.64	7.16	0.76	1.08

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[9] British Council for Offices

Glazing1_Facade1_Floor5_London2005	352.25	5.36	6.48	0.56	0.80
Glazing1_Facade1_SusCeil_Floor5_London2005	371.90	6.84	7.12	0.80	1.28
Glazing1_Facade1_Floor2_Manchester2005	485.47	2.32	2.36	0.12	0.16
Glazing1_Facade1_SusCeil_Floor2_Manchester2005	502.01	2.72	3.40	0.44	0.40
Glazing1_Facade1_Floor4_Manchester2005	467.38	2.12	2.40	0.08	0.04
Glazing1_Facade1_SusCeil_Floor4_Manchester2005	491.40	2.64	3.32	0.28	0.28
Glazing1_Facade1_Floor5_Manchester2005	484.85	2.36	2.48	0.16	0.16
Glazing1_Facade1_SusCeil_Floor5_Manchester2005	500.45	2.80	3.36	0.44	0.36

Table 16 Effects of having suspended ceilings.

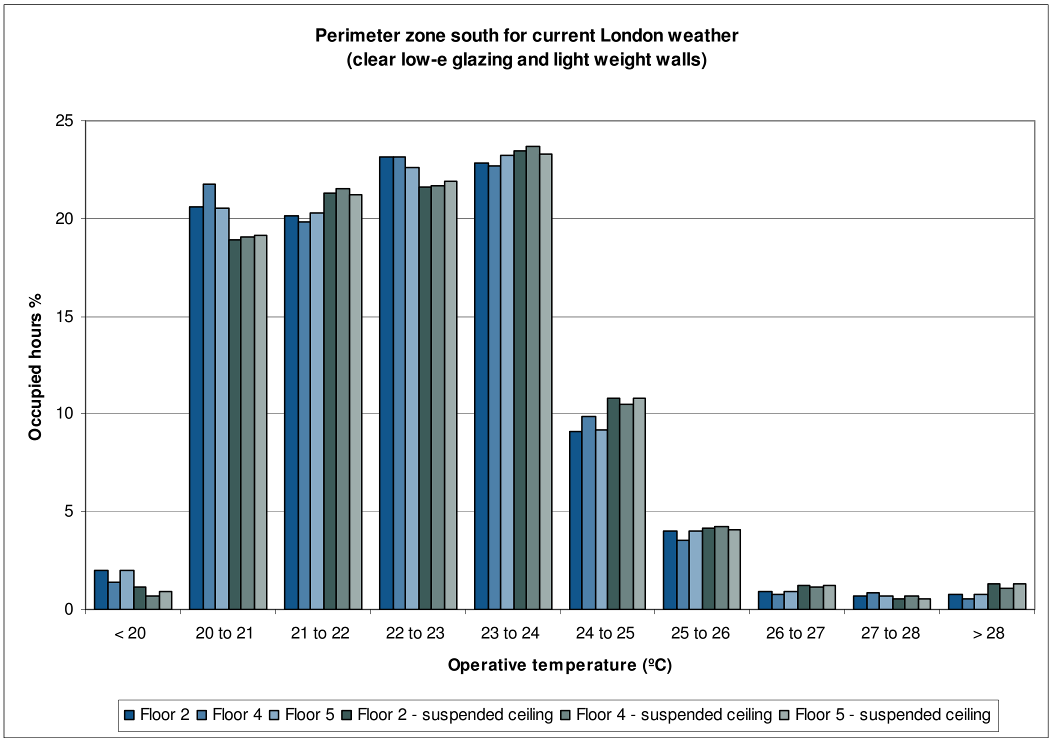


Figure 12 Sample temperature frequency with and without a suspended ceiling (London).

Summary

4 Summary

Increasing the amount of exposed thermal mass in a naturally ventilated office building can have a beneficial effect on the degree of overheating and annual heating energy, but the available thermal mass is not limited to just the floor or façade constructions, and should include the effect of furniture and furnishings. This project has shown that when the thermal mass of a typical office building is adequately modelled, the effect of varying just the floor construction alone is relatively small based on the 5 floor constructions considered.

The relatively small difference in performance between the light weight floor constructions (i.e. SlimDek and ComFlor) and the heavy weight floor constructions is due to the fact that the light weight floor constructions have profiled steel decking to the undersides which increase the heat transfer effect of the available thermal mass.

The effect of improving the solar performance of the glazing was shown to be just as significant as increasing the available thermal mass based on a building with a modest 40% glazing area, when comparing between standard clear low-e glazing and high performance neutral solar control glazing. It was also shown that improving the solar performance of the glazing, reduces the amount of passive heating available during the heating season which resulted in increased annual heating energy of around 20%.

The effect of climate change based on UKCIP medium high scenario for 2050 was modelled and this demonstrated that it could become very difficult to operate naturally ventilated office buildings and still maintain acceptable comfort conditions. This could lead to more offices needing air-conditioning or seasonal mix-mode operation. To address this issue the seasonal mix-mode scenario was considered and this showed that the difference in floor construction resulted in differences in the heating and cooling energy in the order of 10% and 5% respectively.

For acoustic as well as aesthetic reasons, it is not always practical to have the under side of the floor slab exposed. This effectively isolates any mass that might have been available from the floor construction, and resulted in increased frequency of overheating and further reduced the difference in performance between the various floor constructions considered.

Appendices

5 Appendices

5.1 Appendix 1 – Glossary

Admittance (Y-value)

The admittance is the rate of heat flow between the internal surface of the construction and the space temperature, for each degree of swing in space temperature about its mean value. It can be considered as the cyclic u-value for heat flow between the space and the construction. For thin structures, the admittance is equal to the U-value and tends to a limiting value for thickness greater than 100mm. For further information please refer to CIBSE Guide A.

Decrement Factor (*f*)

The decrement factor is the ratio of the rate of heat flow through the structure to the internal space temperature for each degree of swing in external temperature about its mean value, to the steady state rate of heat flow or U-value. For thin structures of low thermal capacity, the decrement factor is unity and decreases in value with increasing thickness and/or thermal capacity. For further information please refer to CIBSE Guide A.

Daylight factor

This is defined as the percentage of internal illuminance (i.e. on a working plane) relative to the illuminance on a horizontal plane due to an unobstructed sky. Daylight factors are normally calculated using a standard CIE overcast sky (Commission Internationale l'Eclairage). The standard CIE overcast sky has a sky luminance that is uniform with respect to azimuth, and varies as a function of the Sine of the altitude only. The maximum luminance occurs at the zenith (altitude of 90º) while at the horizon (altitude of 0º) it is a third of the zenith brightness.

Frame factor (%)

In the IES <VE> software package, the window U-value is defined in terms of an overall U-value which takes account of edge effects and window frame U-value. The building model therefore uses window geometry that includes the frame area, and this needs to be accounted for in terms of solar gain calculations by using a frame factor to set the proportion of frame relative to the total projected window area.

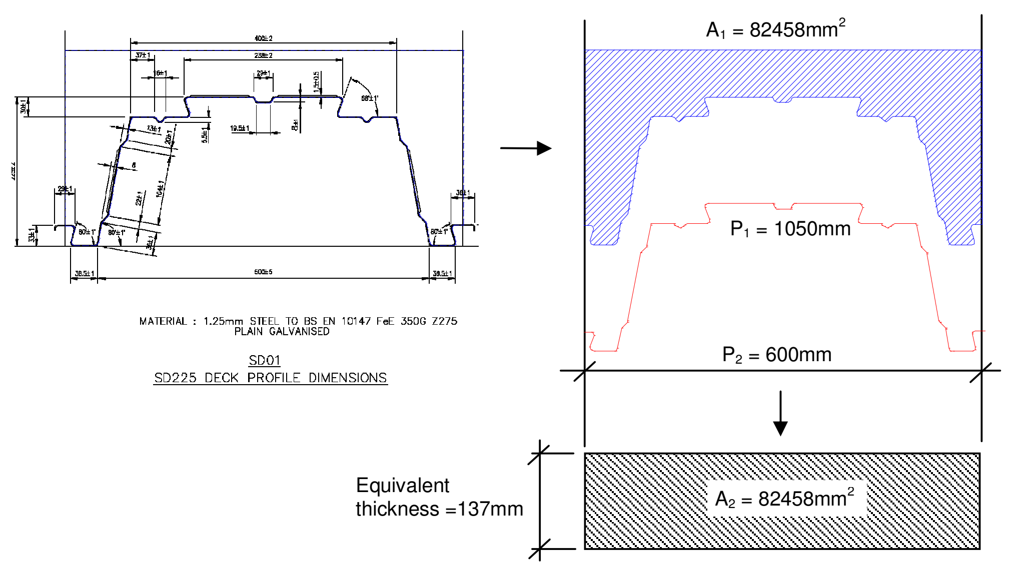
Intermittent heating

This is where plant is switched off at the end of a period of building occupancy/operation and switched on again at maximum output prior to the next period of occupancy/operation in order to get the building to design conditions. The intermittent heating load is usually greater than the steady state heating load (i.e. after the building is brought up to design conditions) because it has to overcome the thermal inertia of the building. Therefore the intermittent heating load is affected by the operating period and the thermal response factor of the building. For further information please refer to CIBSE Guide A.

5.2 Appendix 2 – Modelling of SlimDek SD225 and ComFlor-70

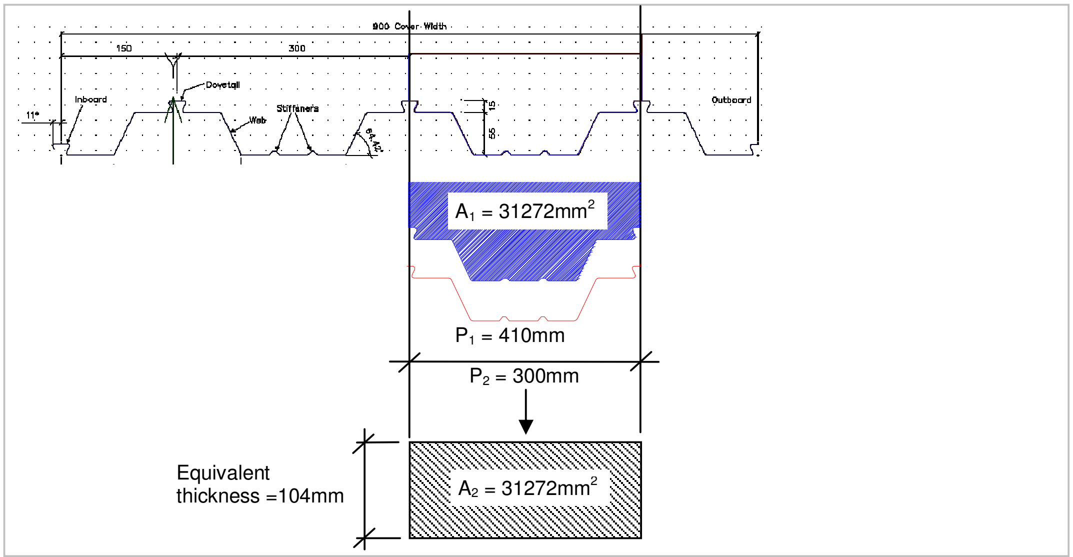
The CAD drawings for the SlimDek SD225 and ComFlor-70 were obtained from Corus online datasheets. An equivalent homogenous thickness was used to model the floors as it is not possible to incorporate the floor surface profile information in the software package. The surface thermal resistance was then derived by adjusting the convective component in proportion to the increase in surface area in the SlimDek SD 255 and similarly for the ComFlor-70 construction relative to the respective equivalent projected surface areas.

SlimDek SD225 equivalent floor model



The modelled floor has 137mm of equivalent thickness and the surface resistance for the underside of the floor slab was adjusted accordingly to 0.0936 m^{2}K/W.

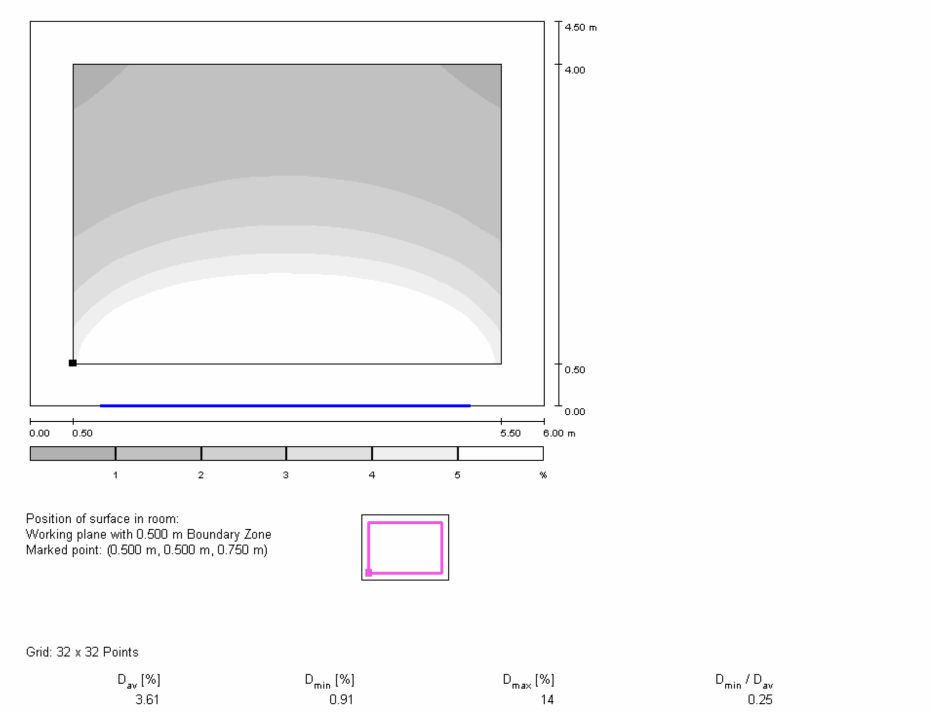
ComFlor-70 equivalent floor model



The modelled floor has 104mm of equivalent thickness and the surface resistance for the underside of the floor slab was adjusted accordingly to 0.1045 m^{2}K/W.

5.3 Appendix 3 – Daylight factors

The daylight factors were calculated using Dialux (version 4.3) and based on a typical perimeter bay (6m wide × 4.5m deep). The glazing is assumed to have light transmittance of 70% before allowing for 10% frame factor and 10% maintenance factor. The daylight factors are calculated on a working plane located 0.75m above floor level with the 0.5m perimeter zone ignored. The internal wall surfaces assumed diffuse reflectance of 70% for the ceiling, 50% for the walls, and 20% for the floor.



Position of surface in room:
Working plane with 0.500 m Boundary Zone
Marked point: (0.500 m, 0.500 m, 0.750 m)

Grid: 32 x 32 Points

D_{av} [%]	D_{min} [%]	D_{max} [%]	D_{min} / D_{av}
3.61	0.91	14	0.25

5.4 Appendix 4 – Furniture mass factor

The furniture mass factor allows the thermal mass of the office furniture to be taken into account. To estimate what furniture mass factor should be used, the assumption was to look at a typical office furniture layout, where the desktops account for around 50% of the floor area. Based on the perimeter bay used for the daylight analysis (i.e. 6.0m×4.5m) this would equate to a desktop area of around 13.5m², which if the desktops were 30mm thick chipboard with density of 800kg/m³ and heat capacity of 2.1kJ/kgK would equate to a thermal capacity of around 719 kJ/K. When compared to the thermal capacity of the air in the perimeter bay (74.25m³×1.2kg/m³×1.01kJ/kgK) of around 90 KJ/K the ratio is already around 7.5, therefore once drawers, chairs, books, etc are taken into account, a furniture mass factor of 10 was considered appropriate.