THERMAL ZONING IN SPECULATIVE OFFICE BUILDINGS: DISCUSSING THE CONNECTIONS BETWEEN SPACE LAYOUT AND INSIDE TEMPERATURE CONTROL

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ABSTRACT

This paper discusses how different office space layouts affect the predicted heating and cooling energy demands in speculative office buildings. The discussion is based on energy simulations of a case study office floor plan layout situated in London. Significant variations in predicted energy demands were found. Examining the free-float inside air temperature profiles led to the conclusion that the thermal behaviour of each zone is mainly influenced by the relationships between different combinations of floor area, window area and internal gains. This means that different ways of describing the building other than its zoning are necessary to assess the potential ranges of thermal behaviour in speculative office buildings.

INTRODUCTION

The aim of this paper is to provoke further discussion into the issue of how different office space layouts affect the predicted heating and cooling energy demands in speculative office buildings.

This issue is notoriously difficult to address because thermal simulation of speculative office buildings carries with it many uncertainties associated to the absence of a specific layout and/or HVAC system distribution. Even though recommendations associated to zoning, internal gains and ventilation rates are in place (iSBEM 2006, Design Builder 2011, to cite a few) to address these absences, the effectiveness of using them, especially concerning zoning strategies, has not been widely explored in the literature.

Generically defined as air volumes at uniform temperatures bounded by heat transfer surfaces (DOE 2011), thermal zones are part of the first set of decisions about how to model a building to assess its thermal performance. They define the boundaries within a thermal model to set up investigations and undertake decisions about building envelope, HVAC systems and temperature controls.

Even though zones are said to be a thermal concept not a geometric one (DOE 2011), the two concepts are related by linking building usage and operation with spatial layout and HVAC distribution. This is why they often appear in the literature either defined in relation to the building usage and operation (Hyde and Pedrini 2002, CIBSE 1998, Platt et al 2010, Autodesk 2011, to cite a few) or as a set of recommendations that take these into account (CIBSE 1998, iSBEM 2006, Design Builder 2011, EQuest 2011, to cite a few).

The most common strategies found in Software, handbooks and standards (CIBSE 1998, EQuest 2011, iSBEM 2006, Design Builder 2011) to zone a building can be summarised as the following:

(i) Zoning based on different spatial activities, spatial performance or building usage;

(ii) Zoning based on different HVAC requirements and/or controls;

(iii) Zoning based on different solar gains;

(iv) Zoning based in temperature stratification.

The first two strategies have highly embedded in them building usage and operation whereas the third and fourth ones, more building design dependant, tend to be the options to simulate speculative office buildings. As more options are in place for buildings in which the internal layout and/or the HVAC system are known or under design, zoning recommendations for speculative office buildings (DOE 2011, Autodesk Vasari 2012, eQuest 2011) end up mainly being the following:

(i) Zoning based on perimeter / core to estimate magnitude of demands rather than demand distribution;

(ii) Zoning by orientation separating solar gains from each different façade to better estimate thermal demand distribution.

This paper questions how far these simplistic zoning strategies, together with some commonly recommended UK settings for internal gains and ventilation rates, are from describing the reality of speculative office buildings in use. It does so by discussing thermal simulation results of a typical office floor plan layout situated in London. As we move towards near zero carbon building design, the paper discusses what are the potential problems involved in using these settings and different zoning strategies and how this issue can be further investigated in future work.

EXPERIMENT – RESEARCH METHODOLOGY

The chosen methodological approach for this study consisted of two phases which combined three different zoning strategies with two different strategies to set up internal gains and ventilation rates suggested by the literature (iSBEM 2006).

The three different zoning strategies investigated were the following (Figure 1):

(i) a 'single zone' model: in which all office spaces are lumped together into one zone;

(ii) a '5 zone' model: in which each different principal orientation of the perimeter of the building is separated from its interior;

(iii) an 'office in use' model: in which the existing case study spatial layout is modelled and *each room is a different thermal zone with a specific type of office activity*

Two different strategies to set up internal gains and ventilation rates were used with two of these three zoning strategies and the study was organised into the following two different phases:

(i)'Speculative' settings phase: Study in which the 'single zone' model and the '5 zone' model are simulated using literature settings (iSBEM 2006) for internal gains and ventilation rates for two 'extreme' types of office use - cellular use and open plan use - and results are compared with the ones from the 'office in use' model.

(ii) 'Existing layout' settings phase: Study in which the 'single zone' model and the '5 zone' model are simulated using literature settings (iSBEM 2006) for internal gains and ventilation rates considering the different office activities from the case study layout. In this phase, all internal gains and ventilation settings used in the case study layout are added together and evenly distributed across the floor areas of the 'single zone' model and the '5 zone model'. Results are compared with the ones from the 'office in use' model.

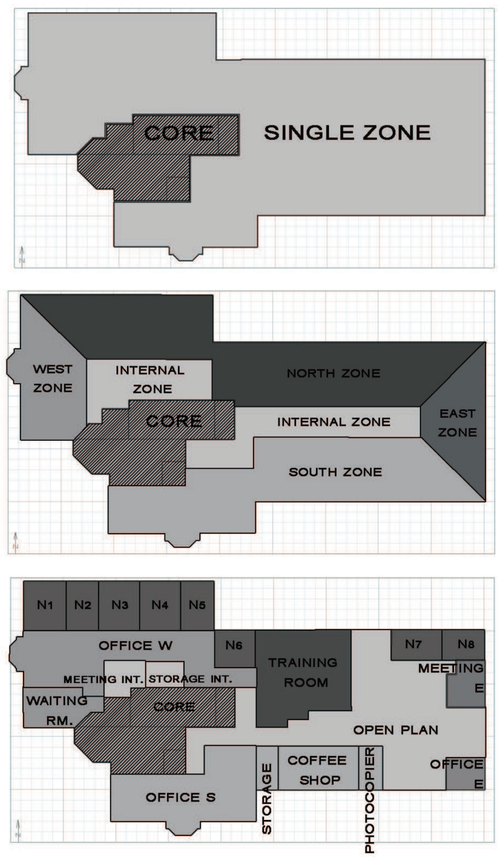


Figure 1 – Three different zoning strategies used in the study.

The case study was modelled and simulated in Energy Plus version 7 with ideal machines to meet heating and cooling requirements. Zones that are part of the building core were excluded from the comparisons. Specifics for the '5 zone' model are the following:

(i) Perimeter zone depths of 6m (iSBEM 2006);

(ii) Interzonal heat transfer surfaces set as infrared transparent with convective heat transfer coefficients of 0.1 W/m2K (DOE 2011);

(iii) Air exchange rate between zones modelled using mixed object with an exchange rate of 2 ach (DOE 2011).

(iv) Building envelope and other simulation details were assumed based on a visual assessment of the building and the age of its construction

RESULTS ANALYSIS:

'Speculative' settings are used to illustrate and discuss the magnitude of uncertainties related to internal layout in simulation results, i.e. to illustrate a potential range of thermal behaviour when a layout is unknown. 'Existing layout' settings are used to have a closer look at the effect of each different zoning strategy in the simulations. Overall heating and cooling demands are analysed and compared for phase 1 and 2 but a more detailed study including free-float inside air temperatures is only presented for phase 2.

Phase one – 'Speculative' settings:

Table 1 displays internal gains and ventilation rates used in the cellular, open plan and 'office in use' models. As the combination of activities from the existing layout has rates for people and ventilation similar to the ones for the open plan office but equipment loads similar to the ones for cellular offices, it is possible to predict this combination should result in the highest heating demand and possibly the lowest cooling demand from all simulations.

	Strategy 1		Strategy 2
	Cellular	Open Plan	Combination of activities from existing layout
People (people/m2)	0.07	0.11	0.11
Lighting (W/m2)	15	15	15
Equipment (W/m2)	10	15	10.54
Ventilation (m3/sec)	0.0007	0.0011	0.0011

Table 1 – Two different strategies to set up internal gains and ventilation rates.

Simulation results confirm the predictions: the 'office in use' model has the highest heating demand and one of the lowest cooling demands compared to the other models (Table 2). The difference between the highest and lowest heating demand is around 8.6kWh/m2 whereas the difference between the highest and lowest cooling demand is around 16.9kWh/m2. In all cases the office is in need of more cooling than heating.

Open plan settings result in higher heating demands than cellular ones probably due to the higher ventilation rates. Highest cooling demands and lowest heating demands appear in the '5 zone' model (with open plan and cellular settings respectively). Meaning the zoning strategy seems to be influencing the results as much as the different internal gains and ventilation rates. Besides that, 'speculative' settings are underestimating the heating demands and overestimating the cooling demands, even when set to their minimum (cellular office use). This means they are not useful to set up potential 'boundaries' (lowest and upper ranges) of combined heating and cooling demands. However, potential 'boundaries' do seem to appear in the total annual demands (sum of heating and cooling demands) (Figure 2) in which the bottom of the range is defined by the 'single zone' model cellular (33kWh/m2), the top of the range is defined by the '5 zone' model open plan (49.2kWh/m2) and all the other models fall right in the middle of it (approximately 41kWh/m2).

Annual HEATING demands for the office area

	Single zone' OPEN PLAN	Single zone' CELLULAR	5 zone' model (sum) OPEN PLAN	5 zone' model (sum) CELLULAR	Office in use' model (sum)
Annual Sum (kWh)	3852	3347	2434	2057	7695
Annual sum (kWh/m2)	**5.85**	**5.09**	**3.70**	**3.13**	**11.69**

Annual COOLING demands for the office area

	Single zone' OPEN PLAN	Single zone' CELLULAR	5 zone' model (sum) OPEN PLAN	5 zone' model (sum) CELLULAR	Office in use' model (sum)
Annual Sum (kWh)	23143	18822	29955	24913	19560
Annual sum (kWh/m2)	**35.17**	**28.60**	**45.52**	**37.86**	**29.72**

Table 2 – Heating and cooling demands from phase one: 'Speculative' settings

Phase two – 'Existing layout' settings:

When isolating the effect of different zoning strategies from potential uncertainties related to unknown office layouts, overall heating and cooling demands should in theory be the same in the three different models. This is because the settings are supposed to affect the distribution but not the magnitude of these demands.

However, this and the few papers that discussed this issue in the past noted that different zoning strategies do have an impact on simulation energy demand results (DeWilde and Tian 2010, O'brien 2011).

Table 3 shows similar trends to Table 2. This office still needs much more cooling than heating. Highest cooling demands and lowest heating demands still appear in the '5 zone' model and the 'office in use' model still has the highest heating demand and one of the lowest cooling demands compared to the other models. However, the magnitude of the differences between the highest and lowest heating and cooling demands, respectively 6.1kWh/m2 and 9kWh/m2, is slightly narrower. The 'single zone' model and the '5 zone' model are still defining potential lowest and upper boundaries of a range when annual demands are analysed (Figure 2). However, the 'office in use' model appears to be much closer to the upper values rather than to the mid-range one.

	Annual HEATING demand			Annual COOLING demand		
	Single zone' model	5 zone' model	Office in use' model	Single zone' model	5 zone' model	Office in use' model
Annual Sum (kWh)	5573	3677	7695	18454	24386	19560
Annual sum (kWh/m2)	**8.47**	**5.59**	**11.69**	**28.04**	**37.06**	**29.72**

Table 3 – Heating and cooling demands from phase two: 'Existing layout' settings

A comparison between Table 2 and Table 3 shows that cooling demands in phase 2 are nearly the same as the corresponding cooling demands with cellular settings in phase 1. However, heating demands in phase 2 are higher than heating demands of corresponding open plan settings in phase 1. In both phases the 'single zone' model (with cellular settings and with 'existing layout' settings) is the one with cooling demands closer to the ones from the 'office in use' model.

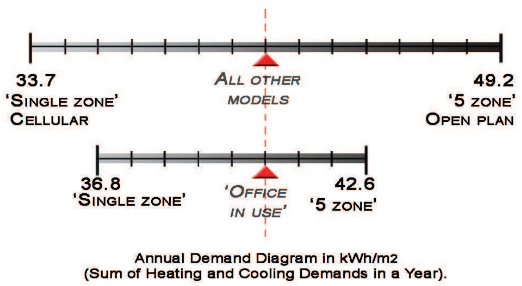


Figure 2 – Annual demand diagram

Detailed results

A closer look into free-float inside air temperature profiles for each specific orientation allows us to see what is causing the differences found in phase 2 of this study. Table 4 summarises and illustrates the scale of temperature variations (magnitude and profile) around the office floor plans on the coldest and hottest day averages which have an impact on peak heating and cooling demands, and therefore on HVAC services sizing. Comments are made for ranges at the maximum and minimum temperatures shown at the graphs. A series of observations which are orientation specific are discussed, followed by a set of overall comments and conclusions.

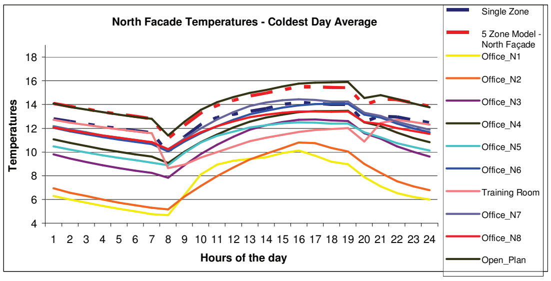
Observations – North Orientation: The afternoon summer peak occurring in 'office N1' zone is probably happening as a result of two West orientation openings. The morning summer peak in 'office N5' zone is probably due to an East orientation opening. 'Office N2' zone summer temperature pattern can be heavily influenced by the adjacent 'office N1' zone. Openings to the South and West orientations do not seem make the air temperature profile of the 'open plan' zone different from the majority of the zones with openings to the North orientation. All zones have roughly the same amount of internal gains (around 25W/m2) but 'office N1' and 'office N5', relatively small rooms (with floor areas of 18m2 and 15m2 respectively), have a larger amount of double aspect transparent surfaces per floor area compared to the other ones (with total window areas of 6m2 and 4.6m2 respectively). This means solar radiation could be a major factor influencing the thermal behaviour of these rooms.

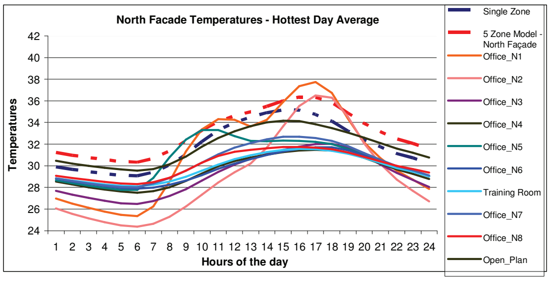
Observations – East Orientation: Peak and dip are quite different in this orientation in the hottest day average.

Peak morning temperatures can be expected for rooms with East facing windows if they are strongly influenced by solar gains. Zones where this happens are the 'meeting E' and the 'office N5' on the hottest day average. The remaining zones all have a temperature peaks in the afternoon, even the 'East facade' one with openings exclusively to the East. Concentrated solar gains in summer might be the explanation to 'meeting E' and 'office N5' morning peak. The first room has two windows to the East (4.6m2 of window area), a relatively small floor area (15m2) and less internal gains compared to the other zones (20.2W/m2). The second room has one opening to the east and one opening to the north, also a relatively small floor area (15m2) but the same amount of internal gains as most rooms (25W/m2).

North Orientation

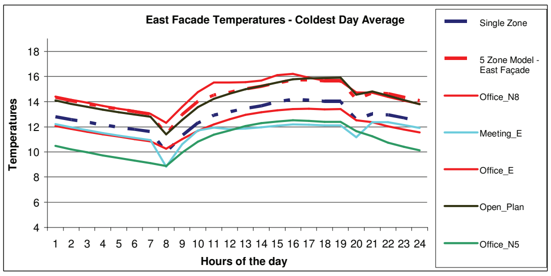
Coldest Day Average			Hottest Day Average		
Range at max 6.7℃ Open Plan zone North Façade Between 4pm - 6pm	Range at min 6.7℃ Office N1 Office N2 8am	*Similar profile shape for most zones* *Exceptions:* Office N1, Office N2, Training Room	Range at max 6.3℃ Office N1 Office N2 North Façade 5pm	Range at min 6.1℃ Office N1 Office N2 8am	*Similar profile shape for most zones* *Exceptions:* Office N1, Office N2, Office N5

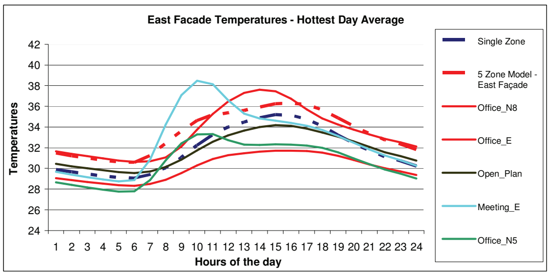




East Orientation

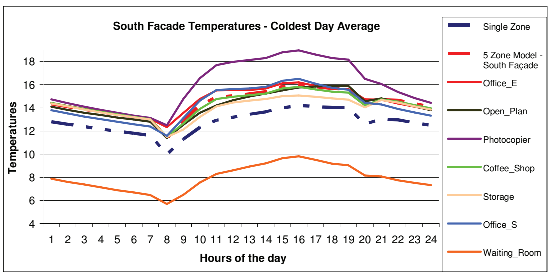
Coldest Day Average			Hottest Day Average		
Range at max 4.0℃ Office E Open Plan Between 4pm - 6pm	Range at min 3.5℃ Meeting E Office N5 8am	*Very similar profiles (1℃ difference):* Office N5 & Office N8 *Very different profiles:* Meeting E (with openings to the East only) & Office E (with openings to the South only)	Range at max 8.1℃ Meeting E - 10am Office E - 2pm	Range at min 2.3℃ Office N5 6am	*Similar profile shape - Morning peak:* Meeting E & Office N5 Peak in middle of the day - Office E Peak in middle afternoon - East Façade

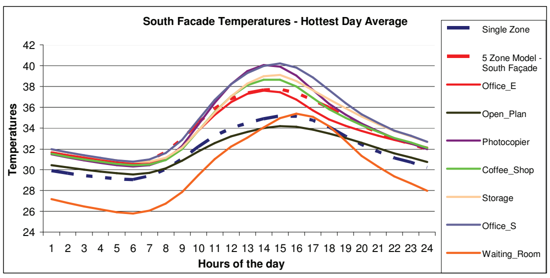




South Orientation

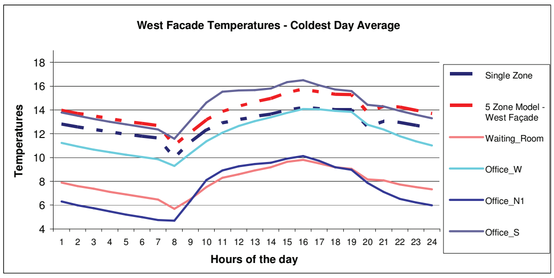
Coldest Day Average		Temperature Profiles	Hottest Day Average		Temperature Profiles
Range at max 9.2℃ Photocopier - whole day Maximum - 4pm	Range at min 6.8℃ Waiting Room - whole day Minimum -8am	*Similar profile shape for most zones* *Exception* - Open Plan *Temp difference across profiles 2℃* *Exception* - Photocopier & Waiting Room	Range at max 6.0℃ Office S - 3pm Photocopier - 2pm	Range at min 5.0℃ Waiting Room 6am	*Similar profile for most zones* *Exceptions:* Waiting Room - with peak delay

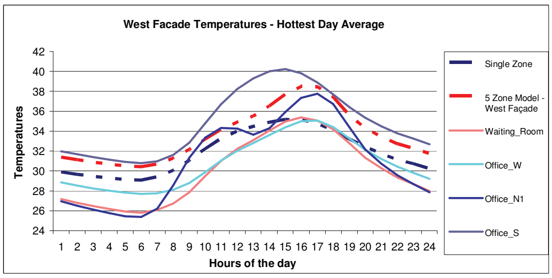




West Orientation

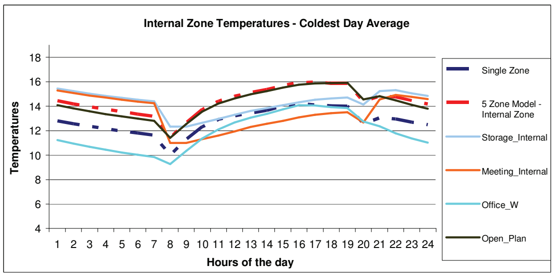
Coldest Day Average		Temperature Profiles	Hottest Day Average		Temperature Profiles
Range at max 6.9°C Office S 4pm	Range at min 6.7°C Office N1 8am	*Similar profile shapes (2°C apart):* West Façade & Single Zone *Similar profile shapes (4°C apart):* Waiting Room & Office W *Similar profile shapes (6°C apart):* Office N1 & Office S	Range at max 5.4°C Office S 3pm	Range at min 5.8°C Office N1 6am	*Similar profile shapes (2°C apart):* Waiting Room & Office W *Similar profile shapes (5°C apart):* Office S & Single Zone at peak Late afternoon peak - rooms with mainly west windows





Internal Zones

Coldest Day Average		Temperature Profiles	Hottest Day Average		Temperature Profiles
Range at max 2.4°C Open Plan Internal Zone Between 4pm - 7pm	Range at min 3.1°C Office W 8am	*Similar profile shapes (0.5°C apart):* Open Plan & Internal Zone *Similar profile shapes (2°C apart):* Meeting Internal & Storage Internal	Range at max 4.5°C Internal Zone 4pm	Range at min 3.1°C Office W 8am	*Identical profiles:* Storage Internal & Meeting Internal *Other zones - similar pattern but different peak time*



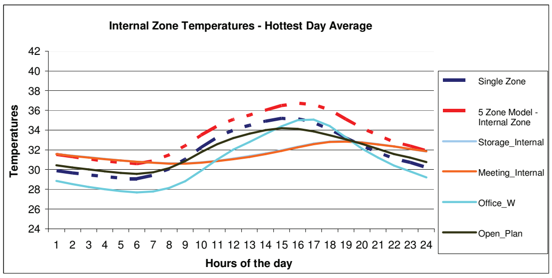


Table 4 – Summary of detailed results

Observations – South Orientation: The very high air temperatures in the 'photocopier' zone are likely to be due to large amounts of internal gains (45W/m2) concentrated on a relatively small floor area (9.5m2). The winter condition seems to make this evident as this zone stands out from the rest. Lower temperatures in the 'waiting room' zone over the winter are coherent with the lower amounts of internal gains this room has (20W/m2) distributed over a 23m2 floor area. Low internal gains with an extra West facing window in this room can result in a late afternoon inside air temperature peak if solar radiation is the major factor influencing the thermal behaviour of this zone.

Observations – West Orientation: The inside air temperature profile of the 'office S' one tends to be higher than all the other zones profiles. This is probably because this zone has the larger amount of openings compared to the others and most of them face the South orientation. Similarities in terms of temperature profiles found in the hottest and coldest day average happen in spite of differences in terms of floor areas, internal gains and amount of openings. Observations on 'office N1' have been made in the North orientation section of this paper.

Observations – Internal Zones: The thermal behaviour of the 'single zone' and the 'internal zone' are quite similar during the coldest day average even though these zones have different floor areas (658m2 and 125m2 respectively). This is probably because they have the same amount of internal gains (25.5W/m2) and the 'single zone' has a very small number of openings per floor area. The same cannot be seen on the hottest day average, when the external surfaces of the 'single zone' seem to be contributing to lower the inside air temperatures. The slightly different floor areas between the 'storage internal' and the 'meeting internal' zones (8.7m2 and 12m2 respectively) as well as their different internal gains (17.1W/m2 and 20.2W/m2 respectively) do not seem to make their hottest day average temperature profiles differ.

Overall comments

Generic findings from the graphs (Table 4) suggest the following:

- Lowest predicted internal air temperatures tend to occur in the 'office in use' model zones.

- Results for the 'single zone' model tend to fall between results for the '5 zone' model and results for the 'office in use' model.

- Temperature profiles with the most similarities in terms of shape can be found in the North and South orientations.

- The majority of zones with west and north facing orientations tend to have their highest internal air temperature in the late afternoon (between 4pm and 6pm). The coldest day average peaks tend to happen earlier than the hottest day average ones

- Peak temperatures for south facing zones tend to happen earlier in the afternoon compared to north and west facing ones. In this orientation, peaks in the hottest day average tend to happen earlier than the ones in the coldest day average.

- Morning peaks only happen in the hottest day average in zones with relatively small floor area and windows facing east. The 'East Façade' zone peaks in the afternoon.

Generic findings from the analysis suggest that zones in the North and West façade have a similar and constant range of inside air temperature variation at peaks and troughs on the hottest and coldest day averages – around 6°C. Sharp differences in inside air temperature peaks and troughs can be found in zones at the East orientation on the hottest day average and in zones at the South orientation on the coldest day average - from 2.3°C up to 8°C and from 6.8°C up to 9.2°C respectively.

Overall, the observations suggest the shape and magnitude of inside air temperature profiles are being affected by different combinations of floor area, window area and internal gains. Table 5 displays the different ranges of window to floor area for the 3 models studied, highlighting internal gains that are higher than 25W/m2 (in red) and lower than 25W/m2 (in blue).

Window / Floor area range	Zone name
0.3 or above	Office N1, Office N5, Office N7, Meeting E
0.2 to 0.3	Office N3, Office E, Photocopier West Façade
0.1 to 0.2	Office N2, Office N4, Office N6, Office N8, Coffee shop, Storage, Office S, Waiting room North Façade, South Façade, East Façade Single Zone
Below 0.1	Training Room, Storage Internal, Meeting Internal, Office W, Open Plan Internal Zone

Table 5 – Ranges of window to floor area with internal gains higher and lower than 25W/m2 highlighted in red and blue respectively.

From Table 5 it is possible to see that the majority of zones with window to floor area ratios of 0.3 or above were likely to have their thermal behaviour most strongly affected by solar radiation (especially if they have windows opening to two different orientations) whereas zones highlighted in red were most likely to have their thermal behaviour mainly affected by their high internal gains. This being the case, it is possible to predict that in this model, zones with window to floor area ratio of 0.3 or above and internal gains of 25W/m2 are likely to be externally driven[1].

In contrast, zones with internal gains of 45W/m2 or above and window to floor area ratio below 0.3 as well as zones with window to floor area ratio below 0.1 and internal gains of 30W/m2 or higher are most likely to be internally driven.

CONCLUSIONS

This study has examined how recommended settings for internal gains and ventilation rates together with the use of different zoning strategies can produce significant variations in the predicted energy demands in speculative office buildings.

Phase 1 of this study has shown that assuming settings for cellular offices as the minimum condition of occupancy may not actually reflect the minimum demands to be found in an existing office layout. However, in spite of underestimating the heating demands and overestimating the cooling demands, 'speculative' settings did produce a

[1] Externally driven zones are zones in which outside weather conditions have a predominant effect on their thermal behaviour. Their opposite, internally driven zones, are situations in which thermal behaviour is predominantly influenced by internal gains. (Waltz 2000)

consistent range of total annual demands with results for the existing case study layout falling on the middle of this range.

Leaving 'speculative' settings aside, it was possible to conclude that different zoning strategies do have an impact on energy demand results. This impact could be seen most clearly by comparing results for the '5 zone' model with the ones from the 'office in use' model. The '5 zone' model underestimated the heating demands and overestimated the cooling demands much more than the 'single zone' model once compared with the 'office in use' layout. However, the '5 zone' model displayed total annual demands quite close to the ones of the case study layout.

A closer look into free-float inside air temperature profiles enabled a series of observations to be drawn leading to the conclusion that the thermal behaviour of each zone is mainly influenced by a relationship between different combinations of floor area, window area and internal gains. Combinations specific to this study were plotted in Table 5 with extremes characterised as internally driven and externally driven behaviours.

From these combinations it is possible to envision that a more relevant way of zoning a building to predict ranges of heating and cooling demands can be derived by working with extremes in terms of window to floor area ratio combined with internal gain settings. This is because in this climate, externally driven zones will tend to have higher heating demands whereas internally driven zones are likely to have higher cooling demands. More simulations and tests are necessary to establish a set of criteria about how to set up zoning strategies that consider these combinations. In addition, more simulations involving a reasonable sample of office buildings in this and other climates are necessary to generalise results concerning combinations of window to floor area ratios and internal gains settings.

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