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Space Planning, Ventilation and Energy Efficiency in Offices

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Abstract

This work investigates the impact of space planning, interior porosity and variable occupancy on the energy use in offices that is attributable to ventilation/infiltration and air movement. TAS, Lightscape, and Excel software packages were used to simulate and analyse airflow and thermal loads in different office layouts. These layouts were created by varying the internal configurations of a base case shell. Constructions of the roof, floor, external walling, windows and vents of the base case shell were based on good practice recommendations, as were the specifications for ventilation, thermal and lighting conditions in the simulations. The results show significant variations of: natural ventilation/infiltration with plan regime; internal air movement with internal porosity; and consequently thermal loads with layouts and occupancy levels. The choices of layouts for given occupancy patterns and the design and control of interior apertures should be carefully made since their impact on ventilation in offices can significantly influence a building's energy consumption.

Key words: natural ventilation, energy use, offices, space planning, interior porosity, United Kingdom.

1. Introduction

Avoidable energy waste in buildings is associated with, among other factors, excessive ventilation (BRECSU, 1995; Ashford, 1997). Buildings that experience varied occupancy or those that are typically under-occupied are especially likely to suffer from energy waste from mismatches between the numbers of occupants and volumes of air supplied. Control of ventilation in such buildings is therefore very important. The argument presented in this paper is that air supply and flow and, consequently, energy use can be influenced by carefully planning space and controlling the interaction/autonomy of air between spaces for varied patterns of occupancy. The conversion of offices from largely cellular spaces to predominantly open spaces would, for example, potentially improve airflow, but may also lead to over-ventilation. On the other hand a naturally cross ventilated office would be undermined by inappropriate insertions of partitions which block the airflow path.

Some evidence and inspiration for further investigation into the links between internal porosity, environmental diversity and energy use is provided by Littler and Thomas (1984). They examine the need to seal a staircase in a two level house to separate the upstairs bedroom temperature zone from the ground floor and to reduce heat losses due to the stack effect. They cite experimental evidence reported by Siviour (1980) to show that energy can be saved if this is done. The experiment was performed, not by sealing the staircase, but by having the internal doors leading to the staircase closed in one case and open in the other. The results showed that a significant saving in energy use (70.2 MJ/day compared to 97.1 MJ/day) may be achieved by closing internal doors and accepting a somewhat lower temperature in the upstairs bedrooms. They also describe an alternative approach - to leave the staircase open and use the ground floor to heat the first floor. In non-domestic buildings, space use is not as clearly distinct as in the above example and the energy that can be saved this way is not clear. The complexity of many functions; the different levels of interaction of users between spaces; the configuration of circulation routes; and the distribution of spaces and users vertically would come into play.

If ventilation air were delivered per user, theoretically the volume of air (to be heated or cooled) would be the same whether the occupants are in an open or cellular plan, or in floor levels that are separated or interacting. In practice, it is more complicated and difficult to deliver air with such precision, especially if natural forces drive the supply air, and if occupancy is varied. Until recently, ventilation has traditionally been specified in air changes per hour based on a design-occupancy rather than the potentially more appropriate expression in volume per person. The shortcomings of sizing for design occupancy have been addressed in recent systems. VAV systems address zone differences but still need prior knowledge of the likely occupancy for each zone to determine how much ventilation to provide. Direct digital controls (DDC) provide control of indoor air quality (IAQ) at the individual zone level.

Occupancy-based delivery of fresh air using zone levels of concentrations of CO_2 as the controlled variable, to some degree overcomes the shortcomings of VAV and DDC in matching ventilation with occupancy. But how does space planning influence the dispersion of CO_2? According to Stipe (2003), the drawback to CO_2 is that sensors may suffer from false sensing. Large spaces allow concentrations of CO_2 to grow more gradually compared to cellular spaces and may suffer from false sensing from local concentrations. Single rooms are the most easily controlled. Another drawback is that it is still applied to total volume (TV) based ventilation. This means that fresh air supply would still be a function of, not only the occupied zone, but also the physics of the total space volume. Personalised ventilation (PV) (Sekhar, 2004), which provides individual ventilation and control at personal desks partly addresses the shortcomings of total volume ventilation by supply of air only where it is required. The airflows, however, still depend on the total space volume and planning. Although previous studies have addressed the effect of internal partitions and porosity on airflow (Allard, 1998) and internal air velocities (Givoni, 1969), the amount of energy that can be saved through the choice between alternative floor layouts is also not usually clear. The physical definition of spaces in office interiors is often partly a function of work patterns. Although layouts are chosen for given patterns of work, it is also true that layouts determine the way a space is used, including density.

The impacts of five common layouts of office spaces, namely: "Hive", "Den", "Club", "Cell" and "Combi" are investigated in this paper. These layouts are described in detail in Section 3. The first four are based on a classification in a study on 'New Environments for Working' (NEW) (Duffy et al., 1998). Although there are more layout types and ways of classifying workspace layouts (Brill, 2001; Saari, et al, 2006), Duffy's types were selected because they are classified based on the degrees of user interaction and autonomy, which can influence occupancy patterns between spaces and airflow – issues that this research focuses on. It is worth noting that there are many ways of defining spaces, such as full or part-height partitions and/or different floor levels. The plans used for the analysis in this paper are defined by full-height partitions.

The "Den" space is an open plan or group room with simple settings and shared facilities. The "Club" has a wide variety of shared task-based settings while the "Hive" has a uniform open-plan and impersonal space. In the "Cell", each individual uses an enclosed space or a highly screened workstation for a wide variety of tasks. Larger Cell spaces may be planned for sharing by two to three users. The Combi office started as a Scandinavian type originally conceived as a retrofit solution to open landscape offices (Wyon, 2000) and "a response to the idea that cellular offices are an obstacle to interaction" (Meel, 2000). According to Wyon, Combi offices incorporate a design concept that places small individual offices, each with a window, on a building's perimeter around a common open space for informal meetings and common facilities such as shelving and printing. The perimeter offices have solid walls between them, but glass walls and glass doors separating them from the common central area in order to share daylight and view-out with the central area. All the walls are floor-to-ceiling height.

Many variations of these setting types exist, and organisations are likely to have varied mixes co-existing within a single layout. The Cell and Combi, and some spaces of the Club, may not adhere to, or make full use of, the passive zone depth of 2 x ceiling height (2h) (Baker and Steemers, 2002; CIBSE Guide F, 1998) for optimising daylight and natural ventilation. This is typically 6 m from the window wall. For single sided ventilation in low heat gain spaces, it could be as deep as 10 m, especially in open-plan offices (BRE, 1994). Commercial considerations for office space-lets result in a typical subdivision depth of 4.5 m (Yeang, 1996), thus not using the passive zone fully.

2. Procedure

The procedure for the simulations, as summarised in Figure 1, involves the following:

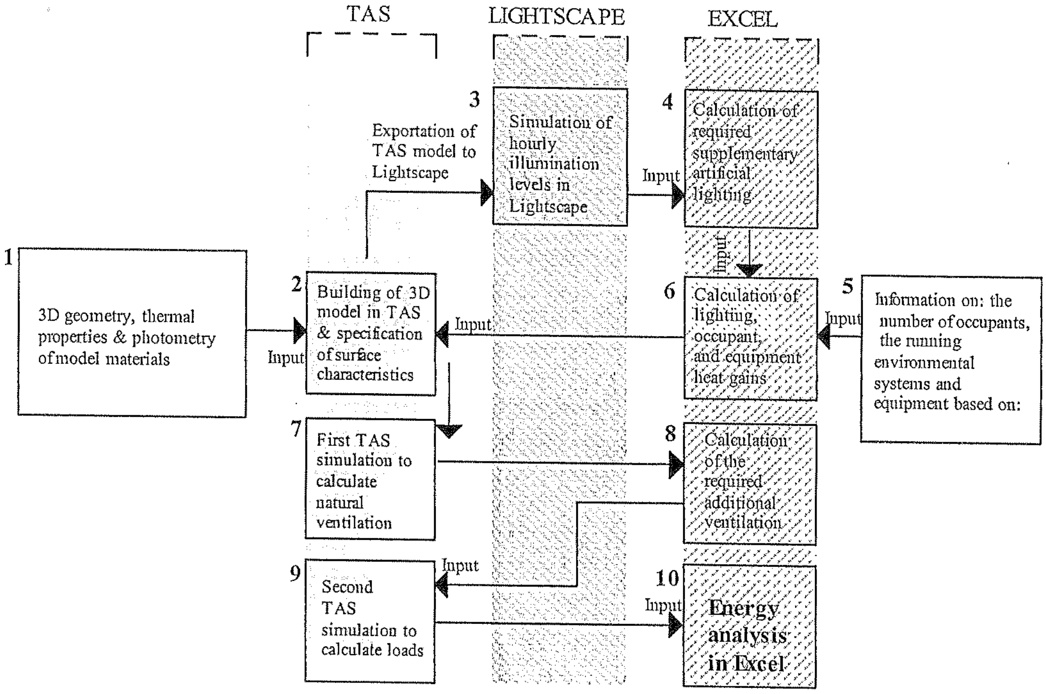


Figure 1. Simulation procedure.

- Creation of a base case 3D envelope model in the thermal simulation model TAS.
- Specification of the characteristics of the construction elements, site location, orientation, and weather conditions. The building elements and constructions are a mixture of some from the TAS libraries (modified where necessary) and others created and attributed with the desired thermophysical and photometric properties.
- Introduction of partitions in copies of the base case to create different plan regimes.
- Exportation of each model from TAS to lighting model Lightscape to calculate illuminance levels for each room, which are then input onto Excel spreadsheets.
- Calculation of the required supplementary artificial lighting (and therefore lighting gains) in the Excel spreadsheets.
- Calculation of occupant gains (sensible and latent) and sensible equipment gains in the Excel spreadsheets.
- Input of the gains to the Internal Conditions Data Editor in TAS.
- Calculation of natural ventilation through the permanent background vents – first TAS run.
- Input of the results of the first TAS run into the Excel spreadsheets to calculate supplementary ventilation where natural ventilation does not meet a recommended minimum fresh air requirement of 8 litres per second per occupant. Where a result indicates over-ventilation, the level of waste is also calculated.
- Input of the hourly mechanical ventilation levels, where required, into the TAS models for each scenario.
- Second TAS run of the final dynamic response of the model to calculate the detailed airflow and volumes, temperature, humidity profiles, and energy load breakdowns for each zone.

3. Simulation Model Characteristics

Figure 2 shows the five plan regimes in an office space slice 12 m wide, in a building 12 m deep. It also shows: positions of windows and vents; layouts of luminaires, switches, auxiliary facilities and workstations; and the likely occupancy capacities across the plan regimes. The model depth is based on the 2h definition of the passive zone (see Section 1), on a ceiling height of 3 m. The Hive (open plan) serves as a base case for the analysis. A uniformly distributed glazing ratio of 30% on the north and south is maintained in all the models. This ratio is the optimum for southern UK office buildings (Baker and Steemers, 2002), and is also the upper limit for avoidance of glare (CIBSE Guide F, 1998;

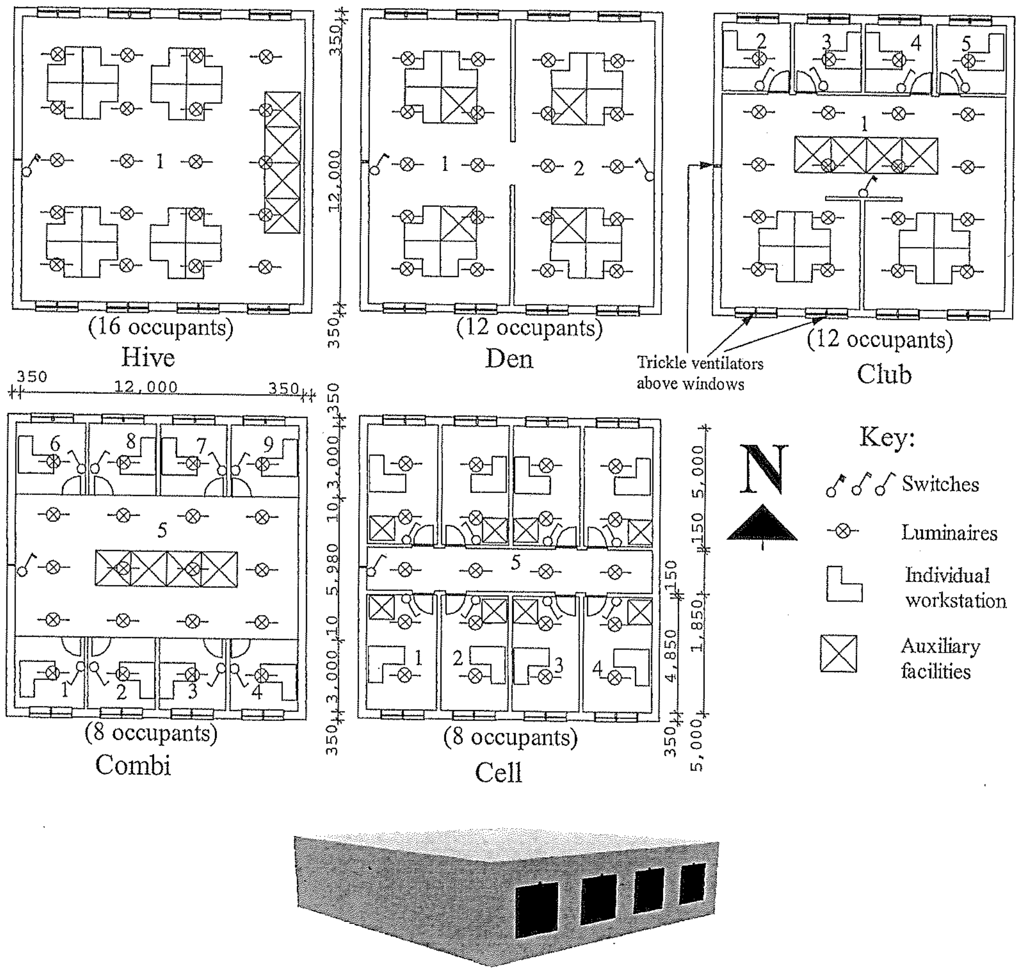


Figure 2. Different plan regimes on a 12 m x 12 m office space and the 3D base case shell used in the simulations.

Leaman et al, 1995). The east and west are windowless. Interior light reflectances in the models are: 0.3 for floors, 0.55 for walls, and 0.7 for ceilings. A 300 mm high fanlight (window) is provided on each internal door. There are no external doors.

Permanent background vents are provided (one above each window and one on the west wall – see Figure 2) based on the Building Regulations - Approved Document AD part F1 (CIBSE Guide H, 1999). It recommends the minimum size for the opening area of vents as 400 mm^2 per m^2 of floor area and 4000 mm^2 in rooms less than 10 m^2. Air infiltration between rooms in the compartmented regimes, when doors are closed, is through 3240 mm^2 gaps at the bottom of each door assuming standard 800 mm wide door shutters. Partitions are placed to ensure that the glazing ratio is maintained and daylight, vents, and luminaires are distributed uniformly in the subspaces.

Table 1 shows the base case construction characteristics of the roof, floor, walling and windows, compared with UK Building Regulations and best practice values. These are kept constant in all the simulations. The only exception is the internal walls in the Combi plan where 10 mm thick glass partitions separate the central common space and the individual peripheral offices but enable them to share daylight and view-out. All the simulations do not take into account the role of furniture and interior fit-outs that may cover exposed slabs and/or walls.

4. Ventilation, Lighting and Thermal Conditions Specified in the Simulations

The ventilation requirements, different internal heat gains, lighting and thermal environments were adjusted to match occupancy patterns. The need to investigate the temporal aspects of occupants and

Table 1. Characteristics of construction elements of the base case model.

Building element	**Description**	**Conductance** (W/m^2 °C) (This study), not including surface resistances.	**Maximum U-value** (W/m^2 K) (UK Bldg. Regs. Part L2, DETR, 2002)	**Best practice U-value** (W/m^2 K) (Best practice, BRE 2002)
Flat Roof	15mm acoustic panel, 200mm air cavity (downward flow), 150mm concrete, 125mm expanded polystyrene sheet & 3mm asphalt	0.266	0.25	0.13
Ground floor	5mm plastic tiles on 50mm screed on 125mm concrete on 75mm crushed brick aggregate on 1000mm sand	0.29	0.25	0.20
External wall	25mm light weight plaster, 100mm aerated autoclaved concrete block, 100mm glass fibre, 50mm air cavity (horizontal flow) 105mm brickwork.	0.256	0.35	0.25
Internal Wall	25mm lightweight plaster, 100mm foamed slag conc. blocks, 25mm lightweight plaster	1.054	–	–
Windows	6mm kappa float – 12mm air cavity (horizontal flow) – 6mm clear float	2.6	2.20 metal, 2.0 timber/PVcu frames	1.8 metal, 1.8, timber/PVcu frames

systems operation requires hourly zone inputs of environmental conditions based on the occupancy in each zone. Simulations were therefore limited to a peak winter day and peak summer day – 21st December and 12th July respectively. For ventilation, in the first set of simulations, windows were assumed to be closed with natural ventilation provided through the background vents – either cross and/or one-sided ventilation. In occupied rooms, where background ventilation did not meet the recommended minimum fresh air requirements of 8 L/s/person the hourly deficit was input and assumed to be met by supplementary mechanical means. In unoccupied rooms, ventilation was only through background vents.

Although the assumption in the first set of simulations is that the air delivery system prevents occupants from opening windows when the system is on and windows are therefore closed, it is not always the case. For naturally ventilated buildings in summer, windows would typically be open if there is adequate wind unless a building's strategy is to deliver air passively through ducting (via a cooling plenum for example) or is air conditioned. Other situations where windows may remain closed include: noisy, dusty, and polluted environments; places where opening of windows would raise security concerns; and places with very strong winds or storms. The second set of simulations looks at the effect of opening windows intermittently or continuously for rapid ventilation. According to Givoni (1998), the decision whether or not to open windows when the outdoor temperature is higher than indoors depends on the personal relative preference for a higher air speed with higher temperatures or lower temperatures with still air. The weather conditions used in the simulations are given in Table 2. These are based on data from Garston (north of London, UK). This site was chosen because it is at the location of the UK Building Research Establishment (BRE) where research on light switching behaviour of occupants was done. The results of the BRE research were used in the lighting loads analysis in this study. During the peak summer simulation hours the air temperature ranged between 25.3 and 32 °C. The wind was predominantly southerly and varied between 1.6 and 3.3 m/s. Conditions are above the comfort zone; users may leave windows either open or closed.

In practice, a majority of buildings have vents for permanent background ventilation. These are usually manually controlled but occupants rarely adjust them. They are typically small in size and are incorporated into the window and/or wall decoration. This camouflages and makes them obscure and it is not obvious whether they are open or closed. Occupants may not even know what they are and would therefore be more likely to open windows than open vents. Automatic dampers are

Table 2. BRE-Garston station (UK) weather data used for peak winter (Day: 354) and peak summer (Day: 193) simulations (Tas Building Designer, 2004).

	Peak Winter							Peak Summer						
Hour	Global Solar Rad. (w/m2)	Diffuse Solar Rad. (w/m2)	Cloud cover (0 - 1)	Dry Bulb Temp (deg.	Relative Humidity (%	Wind Speed (m/s)	Wind Dir. (deg. E of N)	Global Solar Rad. (w/m2)	Diffuse Solar Rad. (w/m2)	Cloud cover (0 - 1)	Dry Bulb Temp (deg.	Relative Humidity (%	Wind Speed (m/s)	Wind Dir. (deg. E of N)
1	0	0	0.33	1.1	96	2.4	265	0	0	0.13	20.1	29	0.2	21
2	0	0	0.33	0.9	96	2.2	270	0	0	0.13	18.2	89	0.4	3
3	0	0	0.33	0.5	95	2.1	242	0	0	0.13	15.6	91	0.2	11
4	0	0	0.33	-0.5	96	1.2	213	0	0	0.13	15.0	92	1.0	30
5	0	0	0.33	0.3	96	2.2	300	0	0	0.13	14.7	93	0.5	3
6	0	0	0.33	1.0	96	2.4	288	21	12	0.18	16.3	92	0.6	15
7	0	0	0.33	-0.3	96	0.8	231	99	79	0.63	20.0	81	0.3	48
8	0	0	0.33	-0.6	96	1.1	279	373	100	0.00	22.8	70	0.4	81
9	8	7	0.33	0.3	96	1.0	321	523	134	0.00	25.3	60	0.9	169
10	71	53	0.54	2.0	96	1.9	309	630	139	0.00	28.1	46	1.6	167
11	153	58	0.00	3.5	94	3.0	310	665	144	0.00	29.3	38	2.4	179
12	261	109	0.00	4.9	85	3.3	307	712	160	0.00	30.4	36	2.4	185
13	250	113	0.02	5.7	80	3.6	309	686	206	0.00	31.3	32	2.7	189
14	183	76	0.00	5.9	78	2.8	307	606	204	0.00	31.8	32	2.9	227
15	105	51	0.07	5.7	78	2.5	294	590	201	0.00	32.0	31	3.3	223
16	21	21	0.99	4.8	83	1.8	255	567	199	0.00	31.9	30	3.2	248
17	0	0	0.23	3.5	88	1.3	244	451	169	0.00	31.7	29	3.3	221
18	0	0	0.23	1.9	91	0.7	236	129	74	0.23	30.2	32	2.9	224
19	0	0	0.23	1.2	94	1.0	216	99	74	0.54	28.8	34	2.3	343
20	0	0	0.23	1.5	95	1.0	221	49	42	0.74	27.3	31	1.1	13
21	0	0	0.23	1.2	96	1.2	197	0	0	0.15	25.8	16	0.8	338
22	0	0	0.23	1.6	96	1.5	230	0	0	0.15	24.3	47	0.7	269
23	0	0	0.23	1.1	96	0.8	227	0	0	0.15	22.8	47	0.7	269
24	0	0	0.23	0.3	96	1.0	229	0	0	0.15	21.5	53	0.7	323

increasingly being installed in some new buildings and refurbishments but the assumption in this simulation is that the vents are manual and remain open throughout. This implies the energy analysis includes some avoidable energy waste in the cases where some spaces are over-ventilated – representing a common phenomenon in practice.

For the thermal environment, internal heat gains were set at 80 W sensible and 50 W latent per occupant; and 150 W per computer. The plant was set with a one-hour preconditioning period to operate between 8:00 and 18:00 hrs in all cases. In occupied spaces, it was set to automatically size the maximum heating/cooling with indoor lower and upper temperature limits of 18 and 24 °C respectively, while the respective relative humidity limits are 40 and 60%. Although the upper temperature limit for the summer was also set at 24 °C as recommended, it is worth noting that higher summer temperatures may be acceptable in buildings that are not air conditioned (CIBSE Guide A1, 1999). According to Givoni (1998), users may feel comfortable in temperatures as high as 27 °C in summer weather as hot as that chosen for peak summer simulations – 12th July (Table 2). In simulating the role of varied occupancy in different spaces, the temperature profiles were allowed to fall outside the comfort limits - below 18 °C and above 24 °C in unoccupied rooms. Where the limit was allowed to fall below the comfort zone, the heating plant was set to provide a minimum temperature of 10 °C to provide protection for the building fabric and its contents (CIBSE Guide H, 1999).

For lighting, the results of daylight distribution from the Lightscape simulations were used to calculate the probabilities of switching on lights in the different rooms based on time of day and the minimum Daylight Factor (Littlefair, 2001). Light gains were calculated assuming an installed lighting capacity of 3 W/m^2 for every 100 lux required. This is considered good practice – between 10-12 W/m^2 to achieve 400 lux (CIBSE Guide F, 1998). Other assumptions made in the determination of lighting gains in the simulations were that: manual switches for general lighting in each room are located in one switch panel as is common in practice (Figure 2);

lights are manually controlled; users would switch on all the lights if switches are in one panel and the lights would remain on until people leave the building – in this case at 17:00 (Baker and Steemers, 2000; Tregenza and Loe 1998; Phillips, 2004). Lights in shared auxiliary facility spaces were assumed to remain on even when occupancy in private spaces around them is not 100%. For the Club plan, interactivity requires that most of the lights remain on even when under-occupied and this was therefore assumed. The lighting assumptions were based on the requirements for Hives, Cells, Dens and Clubs, as outlined by Monica and Grinfeld (2003).

5. Internal Porosity and Interspatial Airflow

This section explores the impact of interior porosity through door apertures on airflow and energy use. In one set of simulations, interior doors were shut throughout and in the other, fully open throughout. In practice, doors may be open to various positions between the fully open and shut extremes depending on the levels of user interactivity and degree of privacy required between rooms. It may be intermittent where privacy is needed or the level of interactivity is low. Doors are more likely to be open in summer, when higher airflow is needed, than in winter. The simulation here was therefore meant to find out the range of energy variations one may expect between the two extremes i.e. continuously fully open and continuously shut.

In practice, fire safety requirements for compartmentalisation often inhibit the use of natural ventilation between zones, especially involving circulation zones (Baker and Steemers, 2000). The assumption in the simulations here was that this may be overcome through the available solutions such as electrically operated fire dampers and window releasers. As a control, the other assumption in this section was that the spaces are fully occupied with equal occupancy density of 18 m^2/person with each occupant's computer running. The exchange of air between the outside and indoor is only through the background trickle vents and the windows are shut. The next two sections explore the influences of variable occupancy and air exchange via open windows respectively.

5.1 Results

The results for the peak winter simulation show that when doors are open, the Combi and Club plans have similar airflow patterns but the Club's total air volume is slightly less (Figure 3). Shutting the doors decreases the total fresh air greatly – by approximately 65% and therefore reduces the heating loads attributable to natural ventilation/infiltration drastically (Figure 5). The interspatial airflow also drops drastically when doors are closed as shown in the case of the Cell in Figure 4. Although percentage variations across plan regimes, in the winter and summer loads, attributable to ventilation/infiltration are comparable (81% and 82% respectively), absolute summer load

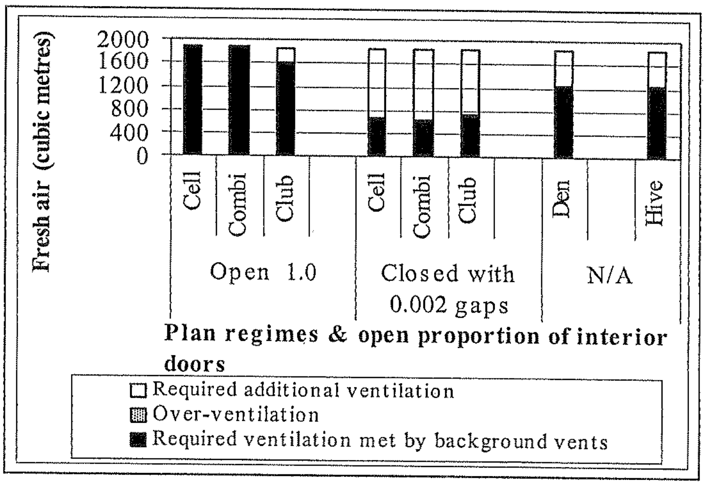
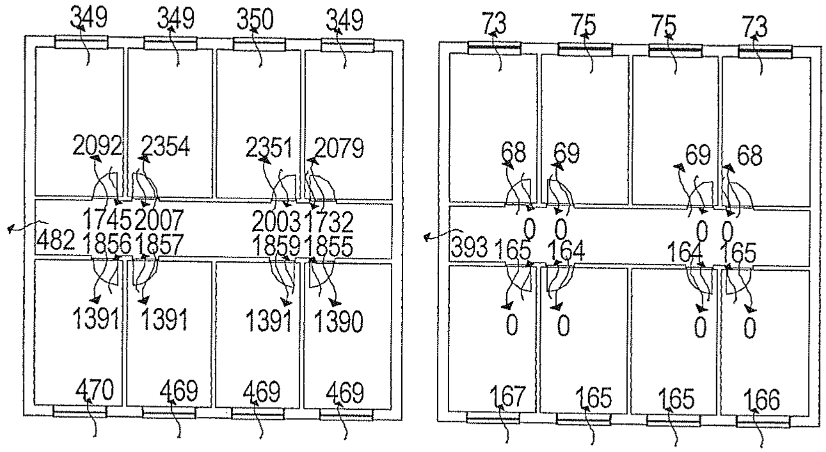


Figure 3. Variation of fresh air supply with interior porosity on 21st December (08:00 to 18:00) assuming that occupancy is 100%, all lights are switched on and each occupant's computer is running.



(Doors fully open) (Doors closed, 0.002 gaps)

Figure 4. Effect of interior aperture opening on total air exchange (volume in m^3) between interior spaces of the Cell plan and the outdoors on 21st December (08:00 to 18:00). These totals have been calculated from the hourly air-change rates. Note the bidirectional flows.

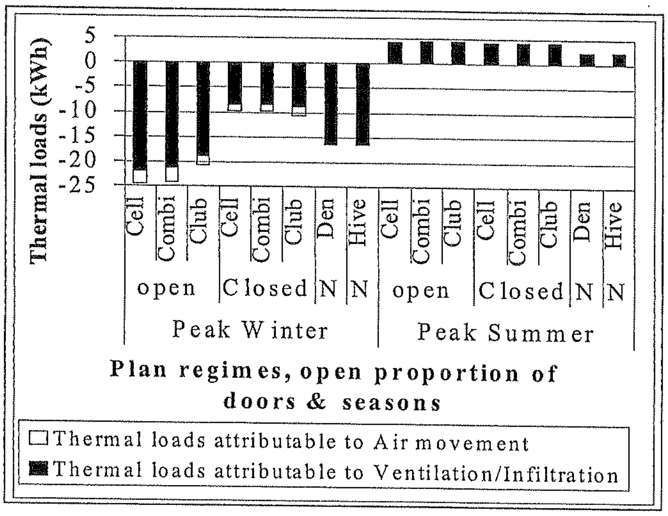


Figure 5. Heating and cooling loads attributable to ventilation/infiltration and air movement in peak winter and peak summer respectively. The negative and positive values represent heat loss and heat gains respectively. N = Not applicable.

variations across plan regimes (Figure 5) are significantly lower – by a factor of approx. 10.

6. The Case of Various Occupancy Levels

In the preceding simulations the assumption was that occupancy is 100 percent. In this section the layout density (space per occupant) remains uniform but occupancy was varied in the first set of simulations. In the second set, the layout densities are what would likely be found in practice in the various plan regimes. These are based on an analysis by the author using typical desk sizes and recommended planning standards (after Tutt and Adler, 1979), and are as follows: Cell – 18 m^2, Combi – 18 m^2, Den – 12 m^2, Club – 12 m^2, and Hive – 9 m^2. The analysis translates to 8 occupants in the Cell and Combi, 12 occupants in the Club and Den, and 16 occupants in the Hive, for the 144 m^2 of floor area in each plan. The simulation also examined the implications of various occupancy levels – 25%, 50%, 75%, and 100%. These were kept constant across the day although in practice

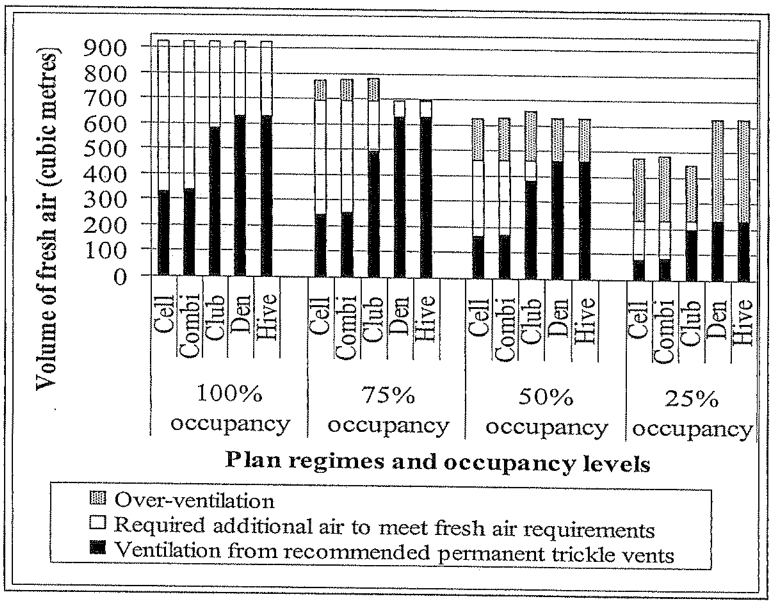


Figure 6. Volume of fresh air supplied through the recommended minimum background vents; supplementary ventilation required to meet occupant fresh air demand; and over-ventilation, in different plan regimes with uniform density (18 m^2 per occupant) but varying occupancy between 8:00 to 18:00 on 21st December.

buildings may have fluctuating occupancy at different times of the day and seasons of the year. The average occupancy in many UK offices is 50% (Duffy, 1998) but it is worth noting that many building systems would normally be designed and specified assuming 100% occupancy. The ventilation inputs in the simulations were based on the various occupancy levels. All the other parameters remained the same as in the previous simulations and interior doors were assumed to be closed. As mentioned in the Introduction, occupants rarely adjust background vents and the assumption in this simulation was that background vents were manual and remained open throughout.

6.1 Results

The results in Figure 6 show the amount of ventilation required in winter that is met by the minimum background vents and the deficits or over-ventilation. The latter presents an indication of the levels of avoidable heating energy waste. Note that in some cases, there is over-ventilation in the windward rooms while there is under-ventilation in the leeward rooms – see the case of the Cell in Figure 4, Section 5. The simulations do not take into account fan power and it would be necessary to do so if the supplementation was through mechanical means. The deficits in ventilation reflect the potential energy levels that would be used for fan power. From the results, the potential for energy waste through over-ventilation increases with the decrease in occupancy while the potential energy demand for fan power in under-ventilated spaces increases with the increase in occupancy. The Hive and Den have the greatest potential for waste while the Cell and Combi have the highest demand for fan power.

Figures 7 and 8 show the combined loads attributable to ventilation/infiltration and air movement to the heating loads in winter and cooling loads in summer for the two sets of simulations respectively. Note that although it is expected that equal occupancy capacities in the first set would result in equal fresh air requirements, the variations in the heating loads attributable to ventilation/infiltration is the result of heat loss variations through outgoing air. The heat loss variations are produced by the different interior configurations and variable heating between the occupied and unoccupied spaces. On the other hand, note that the summer cooling loads match occupancy levels better. This could be attributed to these being better related to incoming air, which is demand controlled for the different layout densities and occupancy levels.

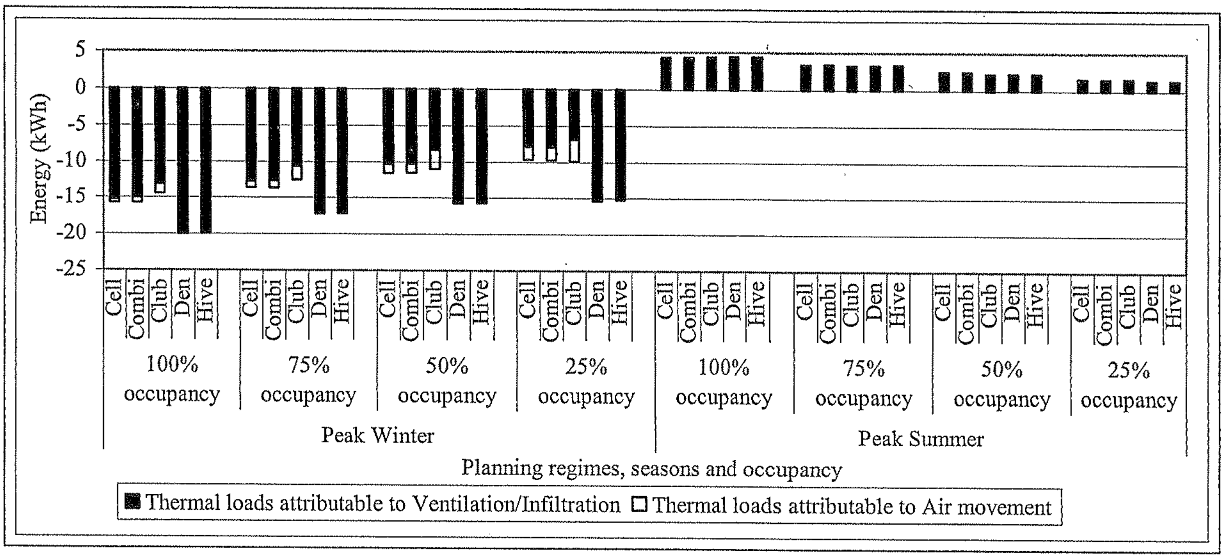


Figure 7. Heating and cooling loads attributable to ventilation/infiltration and air movement in peak winter and peak summer respectively. Occupancy density is uniform. The negative and positive values represent heat loss and heat gains respectively.

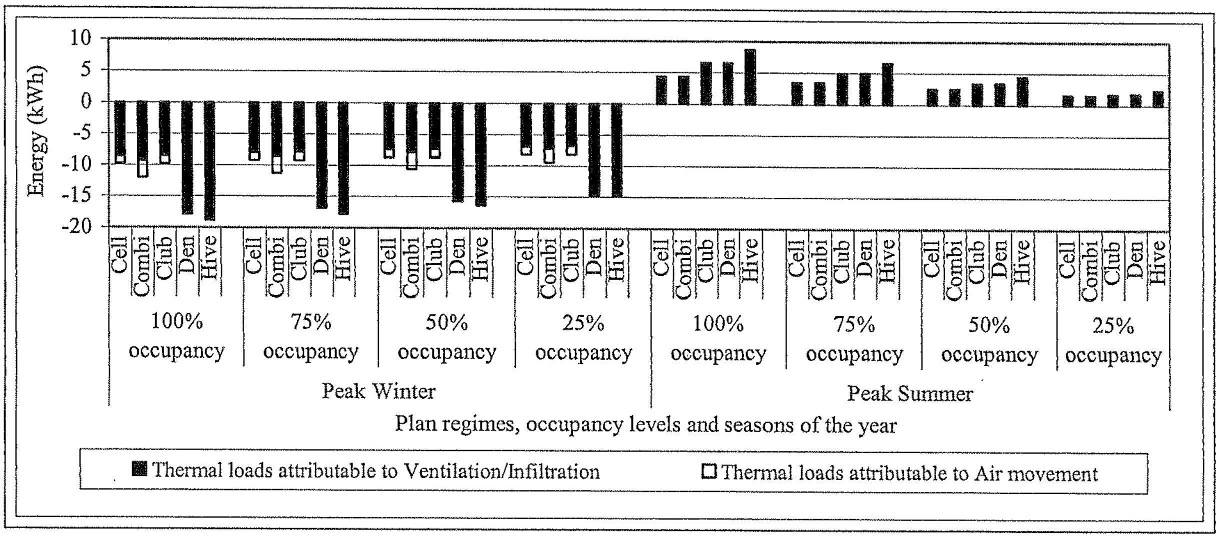


Figure 8. Heating and cooling loads attributable to ventilation/infiltration and air movement in peak winter and peak summer respectively. Occupancy density is varied to the typical densities in practice for each layout. The negative and positive values represent heat loss and heat gains respectively.

7. Intermittent and Continuous Ventilation

During the heating season, large natural ventilation routes such as doors and windows in buildings remain mainly closed as assumed in Section 6. CIBSE recommends that they need to remain closed because of the difficulties of controlling natural ventilation to supply sufficient air without causing excessive heat loss and uncomfortable draughts. Permanent background vents are therefore typically the only natural ventilation routes as assumed in the simulations so far, unless a building has vents from an air plenum, ventilation stacks or ducts.

As pointed out in Section 4, occupants rarely adjust manual background vents. They may instead, choose to open windows or doors to let in rapid fresh air. The opening may be intermittent and wide or continuous but with only small apertures of the windows open. In winter, when occupants come indoors, they may retain the heavy clothing that kept them warm outdoors and open windows for fresh air, while thermostats at the same time operate to maintain the set comfort temperatures. Occupants may also open windows when they perceive fresh air supply through background vents to be inadequate even if it meets the minimum requirements. In hot conditions, on the other hand, they may also adopt the intermittent or continuous patterns of window opening to increase internal air movement. In such circumstances occupants may not be very sensitive to over-ventilation if there are no uncomfortable draughts. The simulations in this subsection look at the implications of the two options of opening windows.

The open size of each window aperture for both sets of simulations was assumed to be 0.03 of the window size. In the intermittent case, windows were scheduled to open for a cumulative time amounting to 25% of the total occupancy time. Although window opening is likely to vary between the higher owned individual offices in the Cell, Combi and Club and the less owned Hive and Den, the assumption here is that windows were open in uniform patterns across plan regimes in the occupied rooms. Measures to control the effect of orientation were also taken, as done in the simulations in Section 6. The results in Section 6

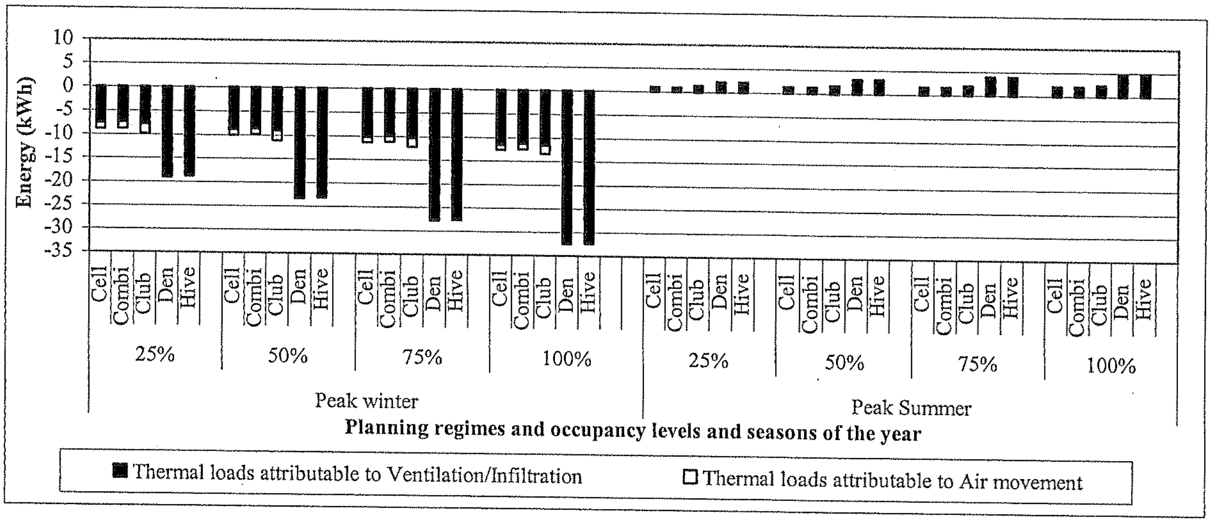


Figure 9. Heating and cooling loads attributable to ventilation/infiltration and air movement in peak winter and peak summer respectively, assuming intermittent opening of windows for rapid ventilation and uniform occupancy capacity. The negative and positive values represent heat loss and heat gains respectively.

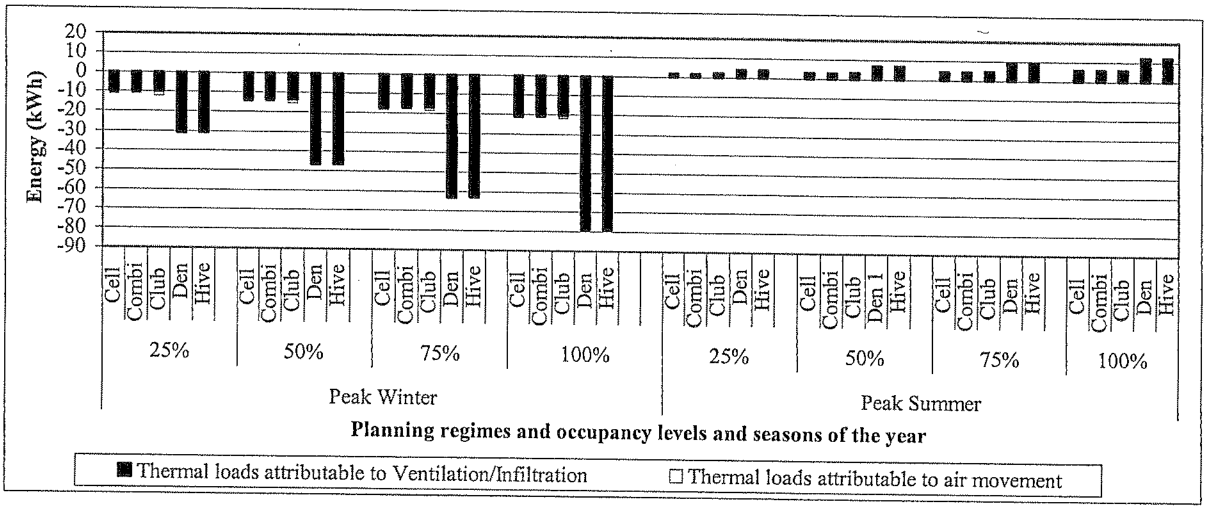


Figure 10. Heating and cooling loads attributable to ventilation/infiltration and air movement in peak winter and peak summer respectively, assuming continuous opening of windows for rapid ventilation and uniform occupancy capacity. The negative and positive values represent heat loss and heat gains respectively.

showed that the rooms on the leeward side in the Cell and Combi received inadequate ventilation through cross ventilation when doors were assumed to be closed. The opening of windows in this simulation also represents situations where the reason to open windows in winter may be to meet ventilation requirements through single sided ventilation in both windward and leeward facing rooms.

7.1 Results

The results in Figures 9 and 10 show the respective peak winter and summer loads attributable to ventilation/infiltration and air movement assuming the two window opening regimes. The combined peak winter loads attributable to ventilation/infiltration and air movement follow a similar pattern to those in the previous Section (6) shown in Figures 7 and 8, where windows are assumed to be closed and vents open. The differences are in the margins of variation. For the intermittently open case, there were drastic differences between the peak winter loads of the partitioned plans and those of the open ones. These vary with occupancy by much smaller margins than when windows remain closed in the previous section of this paper. The summer cooling loads have less drastic variations between the loads of the partitioned regimes and those of the open ones. For the continuously open case, there are also drastic differences between the winter loads of the partitioned regimes and those of the open ones and with wider margins. The summer loads have less drastic variations between the partitioned and open regimes and by slightly smaller margins than the winter loads.

Note that the loads in all the simulations are based on the total air volume of each occupied room being cooled to the comfort limit. It is likely that the use of local fans in summer for localised air movement at the occupied zone would alter the variations. Also note that the cooling effect of airflow on occupants is not factored and would be expected to alter the variations to some degree since the indoor airspeed would potentially vary with plan regime. The summer variation results are more relevant to situations with centralised cooling and automated window opening. They may be less so in cases with local cooling fans and manually operated windows where occupants may open windows and switch on the fans at the same time.

8. Conclusions

The results indicate that the influence of planning and internal porosity on fresh air supply and its interspatial flow are significant determinants of energy use in offices. For the majority of the scenarios, the loads attributable to ventilation/infiltration and air movement in the partitioned cases vary from the open plan base case (hive) loads by between 20% and 70% (Figure 11). The variations in absolute terms in winter loads were much more than those in summer. The results further suggest that natural ventilation strategies

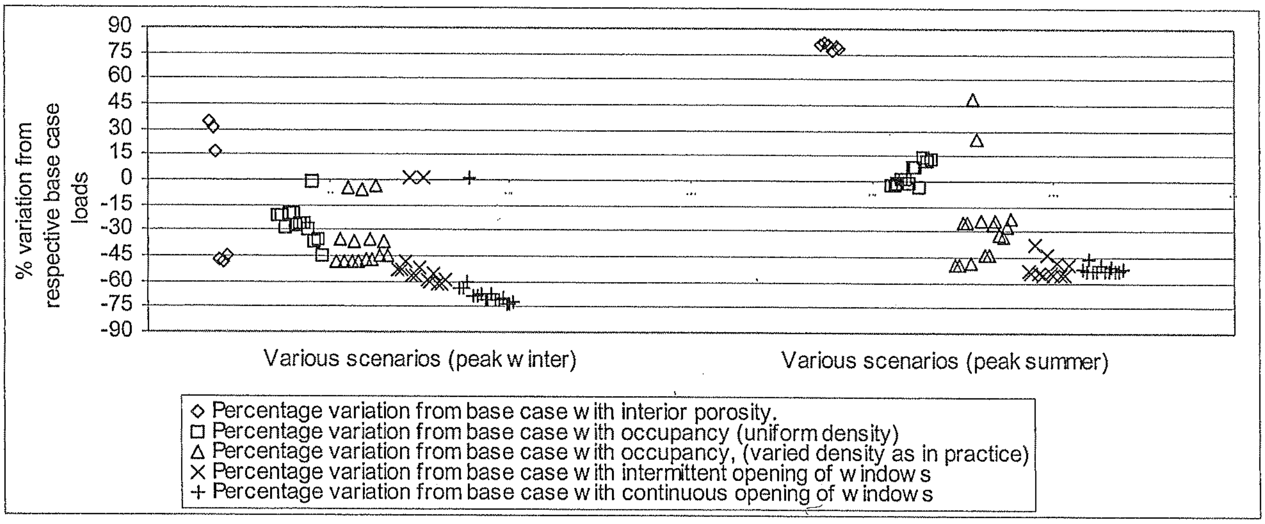


Figure 11. Summary of percentage variations of heating and cooling loads attributable to ventilation/infiltration and air movement from respective base case loads in different scenarios.

should be designed for maximum flexibility to accommodate changes in interior planning and be sensitive to variable occupancy. Distributing vents as much as possible for example, is expected to facilitate localised or sectional natural ventilation for variable occupancy.

The levels of variations with interior porosity imply that the controls for interior apertures are potential energy consumption determinants. Devices such as self-closing door hinges, door closers, door stops and stoppers are therefore not only useful in the control of fire and security, but also for energy use. This also suggests that factors that influence the patterns of opening interior apertures such as whether doors are staggered to increase privacy or whether they open to heavily used passages should be important considerations in interior space planning. Although the simulations assume 100% airtight envelopes excluding permanent vents, this is never the case in practice. They however, indicate that even in an ideal airtight envelope case, energy use can be significantly influenced by space planning and interior porosity.

References

Allard F (ed.): (1998), "natural ventilation in buildings: a design handbook". James & James, London.

Ashford CJ: (1997) "Avoidable waste/base energy budgeting", BRESCU Workshop Document, Watford, UK.

Baker N and Steemers K: (2002) "Daylight Design of Buildings". James & James, London.

Baker N and Steemers K: (2000). "Energy and Environment in Architecture: a Technical Design Guide". E. & F.N. Spon, London.

BRE: (1994) "Natural Ventilation in Non-domestic Buildings: Digest 399". Building Research Establishment, Garston, UK.

BRE: (2002) "General information leaflet no. 72: Energy efficiency standards – for new and existing dwellings". Building Research Establishment, Garston, UK.

BRESCU: (1995) "Controls and Energy Savings, Fuel Efficiency Booklet 10". Building Research Energy Conservation Support Unit, Harwell, UK.

Brill M: (2001) "Disproving widespread myths about workplace design", *International Journal for Corporate Real Estate*, **1**, (2), pp141-153.

CIBSE (1999). "Guide A1, Environmental Design". Chartered Institute of British Services Engineers, London.

CIBSE (1998). "Guide F, Energy Efficiency in Buildings". Chartered Institute of British Services Engineers, London.

CIBSE: (1999) "Guide H, Building Control Systems". Butterworth-Heinemann, Oxford.

DETR: (2002) "Building Regulations, Approved Document L2: Conservation of fuel and power in buildings other than dwellings", 2002 edition. Department of the environment, Transport and the Regions, The Stationery Office, London.

Duffy F, Laing A, Jaunzens D and Willis S: (1998) "New environments for working: the redesign of offices and environmental systems for new ways of working". E. & F.N. Spon, London.

Givoni B: (1969) "Basic study of ventilation problems in hot countries. Building Research Station, Haifa.

Givoni B: (1998) "Climate considerations in building and urban design". Van Nostrand Reinhold, London.

Leaman AJ, Bordass WT and Bromley AKR: (1995) "Comfort, control and energy efficiency in offices". Building Research Establishment, Garston, UK.

Littlefair PJ: (2001) "Photoelectric control: the effectiveness of techniques to reduce switching frequency", *Lighting Research Technology*. **33**, pp43-58.

Littler J and Thomas R: (1984) "Design with energy: the conservation and use of energy in buildings". Cambridge Architectural Press, Cambridge.

Meel JV: (2000) "The european office: office design and national context". 010 Publishers, Rotterdam.

Monica G and Grinfeld A: (2003) "Good lighting in offices", *RIBA Journal*. **110**, (06) ppxvii-xx.

Phillips D: (2004) "Daylighting: Natural Light in Architecture". Architectural Press, London.

Saari A, Tissari T, Valkama E and Seppänen O: (2006). "The effect of a redesigned floor plan, occupant density and the quality of indoor climate on the cost of space, productivity and sick leave in an office building–A case study", *Building and Environment.* **41**, (12), pp1961-1972.

Sekhar SC: (2004) 'Evaluation of energy efficient personalised air units for enhanced ventilation in the tropics', *Healthy Buildings 7th International Conference, National University of Singapore.*

Siviour JB: (1980) "The effect of increasing house insulation on electrical heating equipment design", IEE Conference on Effective Use of Electricity in Buildings, cited in Littler, J. and Thomas, R. (1984) Design with Energy: the Conservation and Use of Energy in Buildings. Cambridge Architectural Press, Cambridge.

Stipe MPE: (2003) with the Oregon Department of Energy, "Demand-Controlled Ventilation: A Design Guide for Architects and Engineers". http://www.energy.state.or.us/bus/DCV/DCVintro.htm (Updated 6/2/04, accessed 05/2008).

Tas Building Designer: (2004) Environmental Design Solutions Limited (EDSL).

Tregenza P and Loe D: (1998) "The design of lighting". E. & F.N. Spon, London.

Tutt P and Adler D (eds.): (1979) "New Metric Handbook, Planning and Design Data". Architectural Press, London.

Wyon PD: (2000) "Individual control at each workplace: the means and the potential benefits" In: Croome D. (ed.) (2000) Creating the Productive Workplace. E & F N Spon, London.

Yeang K: (1996) "The Skyscraper Bioclimatically Considered: a Design Primer". London: Academy Editions.