How adaptive comfort theories might influence future low energy office refurbishment strategies

Stuart Barlow[1)] and Dusan Fiala[2)]

[1)] De Montfort University, Leicester & Reid Architecture, London

[2)] IESD, De Montfort University, Leicester & FBTA, University of Karlsruhe, Germany

---

Abstract

With the UK commercial sector replacing buildings at 1-1.5% per year adaptations to existing buildings are needed to maintain comfort levels, while reducing energy use and carbon emissions.

In this study, occupants of a refurbished office recorded their thermal sensations, assessment of lighting and air movement, perceptions of comfort and their reactions to adaptive opportunities. The observed mean thermal sensation votes and the overall comfort votes correlated best with mean diurnal internal and external temperatures, respectively. The results indicated heat balance models would not fully explain surveyed responses. Occupants reported higher discomfort levels than predicted by the PMV model using on-site measurements.

In the study opening windows was voted to be the most favourite adaptive opportunity followed by controlling solar glare, turning lights off locally and controlling solar gain. Occupants also expressed desires to intervene with heating and ventilation currently operated centrally but they generally did not change their clothing during the day. The study concluded that both passive and active adaptive opportunities are important in future low energy office refurbishment strategies.

Keywords: Field survey; Thermal comfort; Adaptive opportunities; Offices

---

1. Introduction

Non-domestic buildings account for 20% of the UK's carbon dioxide (CO_2) emissions. With 75% of the UK's existing building stock constructed prior to 1980 (*POUT et al 2002*), and with it only being replaced at a rate of 1-1.5% per annum, occupants of existing offices will need to respond to rising temperatures resulting from climate change (*Steemers 2003*). Internal temperatures could exceed comfort levels for over a fifth of the working day by 2050 (*Clarke et al 2002*). The conventional response of installing air conditioning only results in increasing levels of CO_2 emissions and pollution.

Integrating low energy adaptive strategies into the refurbishment cycles of offices could increase their resilience to the effects of climate change (*Hulme et al 2002*). If building occupants were allowed to adapt to a building's environment by adjusting their clothing, location or interacting with it (e.g. by opening windows) they could tolerate environmental conditions considered outside those recommended by the 'steady state' theories, as represented by ISO7730 (*McCartney & Nicol 2002*).

This study's aim was the investigation of occupant perceptions of comfort, their understanding of, and response to, low energy adaptive opportunities. It hoped to draw conclusions on which low energy adaptations of buildings and occupant intervention strategies should be adopted for refurbishment strategies for existing UK offices in the future.

2. Background

Comfort predictive methodologies such as BSEN ISO7730 (1996) relate physical parameters (activity, clothing, environmental parameters etc.) with an average person's thermal sensation. They view occupants as passive recipients of thermal stimuli and assume the effects of a thermal environment are mediated exclusively by the physics of heat and mass exchanges between the body and the environment, being mainly related to the thermal balance of the body.

The use of heat balance models as predictive design tools have been increasingly questioned when compared to occupants' recorded thermal perceptions (*Brager & de Dear 1998*). It was suggested that differences between Predicted Mean Vote (PMV) predictions and occupant comfort temperatures observed in naturally ventilated buildings were due to perceived control and greater diversity of thermal experiences. Discomfort was not just an outcome but also the starting point for initiating an adaptive response (*de Dear & Brager 2002*). Good adaptive opportunities are essential in achieving thermal satisfaction when ambient temperatures fluctuate beyond a predicted neutral zone. Dissatisfaction occurs where the stimulus exceeds the adaptive opportunity or when insufficient adaptive opportunities do not or are perceived not to exist (*Baker & Standeven 1996*).

Humphreys & Nicol (1995) formulated guidance relating UK office 'set temperatures' to the preceeding week's exponentially weighted running mean external temperature. While external temperatures appear to be a principle factor in determining acceptable comfort temperatures, other influences such as the extent of change, the rate of change that is possible and the ability of occupants to take actions to either change their conditions or directly influence what is an acceptable comfort temperature also effect perceptions of thermal sensations (*Nicol & Humphreys 2002*).

3. Adaptive strategies suitable for office building refurbishments

To improve existing buildings' capacities to maintain comfort levels low energy adaptations are required which allow occupants to create their own thermal preferences by interacting with their environment, modifying their behaviour, or gradually adapting their expectations to match ambient thermal conditions (*Brager & de Dear 1998*). When refurbishing office buildings adaptive opportunities can be classified as either *active* (where building occupants intervene to change their thermal environment) or *passive* (where a building's environment or fabric is adapted without active occupant intervention).

Possible active adaptive opportunities that could be considered include:

- Temporal & spatial control - building occupants alter the timing of their work patterns or move to other areas of a building to avoid uncomfortable working conditions.
- Clothing - removed or added when occupants are too hot or too cold.
- Adding occupant controlled solar shading - to reduce solar gains.

- Localized switching to turn off lighting - reduces energy consumption and heat gains.
- Localized control of replacement heating systems - such as thermostatic radiator valves (TRVs).
- Occupant controlled natural ventilation - opening windows providing cross or single sided ventilation.
- Occupant controlled localized assistance to air movement - to offset air stratification.

In addition passive adaptive opportunities can include:

- Adding insulation to walls, roofs & floors, and replacing existing windows - nearly two-thirds of UK offices were constructed prior to requirements for minimum fabric U-values.
- Adding fixed or automatically controlled solar shading - reduces solar gains.
- Centrally controlled replacement heating systems.
- Reducing occupants densities - reduces occupant heat gains.
- Hardware or software solutions to turning equipment off automatically - reduces heat gains.
- Time-off switching, photocell or occupancy sensors to turn of lighting - reduces heat gains.
- Centrally controlled cooling systems – can be required to maintain comfort levels.
- Natural ventilation through centrally controlled grilles - removes heat gains through air movement.
- Mechanical ventilation – can be required due to proximity of external pollution or noise sources.
- Automatic night time ventilation - cools a building's thermal mass.
- Centrally controlled assistance to air movement – automatically controlled ceiling mounted fans can reduce air stratification.

4. The surveys

The surveys were conducted in a Central London architects' office (Reid Architecture), a 1950s building refurbished in 2001/02. Surveys were conducted on 3 floors (1st, 2nd and 3rd) of open plan offices (247m^2) with approximately 32 workstations (in a similar arrangement) at an occupant density of 1 person per 7.7m^2 (*Figure 1*) which is higher than recommended by the British Council of Offices Guide (2005). Each floor has windows along almost the whole length of 2 sides (facing south-east and south-west) onto narrow streets with buildings extending up to a similar height and along 30% of a wall facing north-west into a large light well. Reid Architecture's working day operates between 09:00 to 17:30 (although people often work longer). On average surveys were returned evenly from each floor. 78% of returned surveys were from occupants in areas adjacent to the south-east and south-west facing windows and a greater number came from occupants sitting right next to open-able windows.

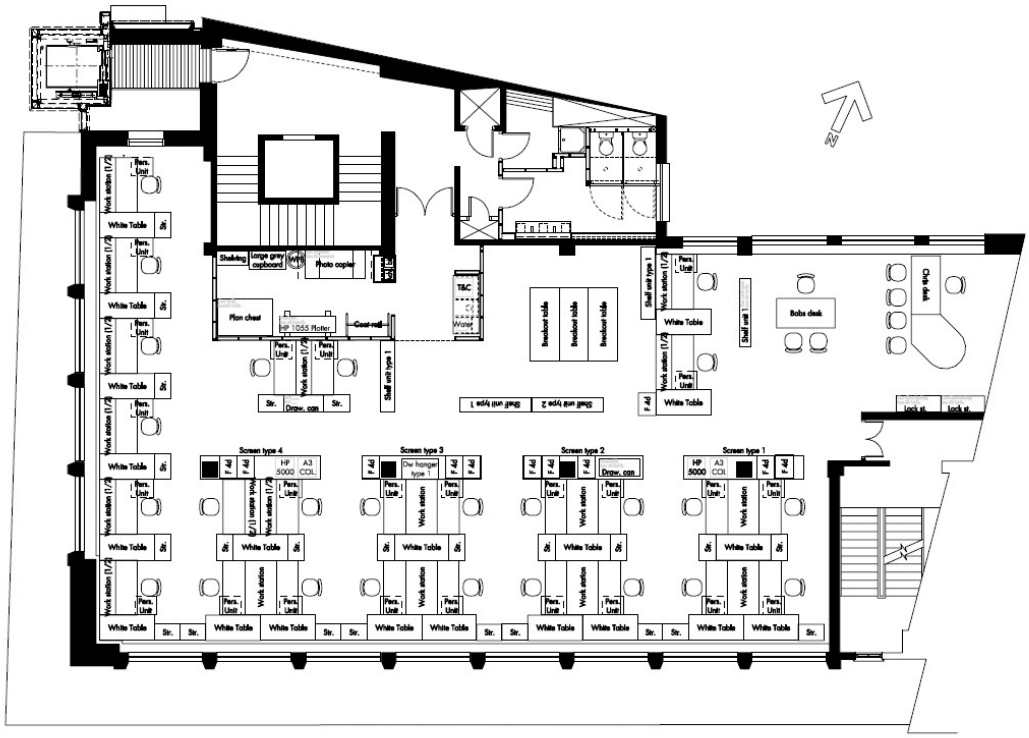

Figure 1: Typical office floor plan of the surveyed building.

The refurbishment was based around a mixed mode strategy for managing the internal environment using natural ventilation (NV) through grilles set under new windows and night time ventilation, but without improvements to either wall or roof insulation. Air enters the office spaces at low level through a plenum within a perimeter casing under the window sills (*Figure 2*).

The NV grilles, controlled by a Building Energy Management System (BEMS), open increasingly while free cooling is available with stack pressure differentials generating air movement across the offices allowing air to be extracted at high level into two vertical stacks (a new glazed entrance tower and escape staircase at either end of the floors). Outside normal working hours NV grilles opened when there was a cooling demand and external temperatures were lower than internal temperatures. Original single glazed steel framed windows were replaced with aluminium double glazed windows, with opening lights providing cross and singled sided ventilation. Some desk top fans and electric heaters were available to assist in maintaining comfort levels.

New external fabric awnings were provided to control solar gains on the south-east and south-west elevations linked to solar sensors controlled automatically by the BEMS. Active occupant intervention was possible as both elevations of awnings could be manually opened or closed separately on each floor by using manual override switches. No internal blinds had been provided for controlling solar glare at the time of the surveys. All occupants had a computer at their workstation and a photocopier, printers, drinks station and network hubs were located on each floor. Lighting was provided by high efficiency T5 tubes, controlled by centralised switching on each floor.

The replacement heating system was a low nitrogen-oxide, gas-fired condensing boiler feeding low pressure hot water fin radiators in the perimeter casings to temper the air entering the building through the NV grilles (*Figure 2*). Controlled by the BEMS, the system operated until the set point temperature was exceeded, but was disabled if external temperatures exceeded 18^0C.

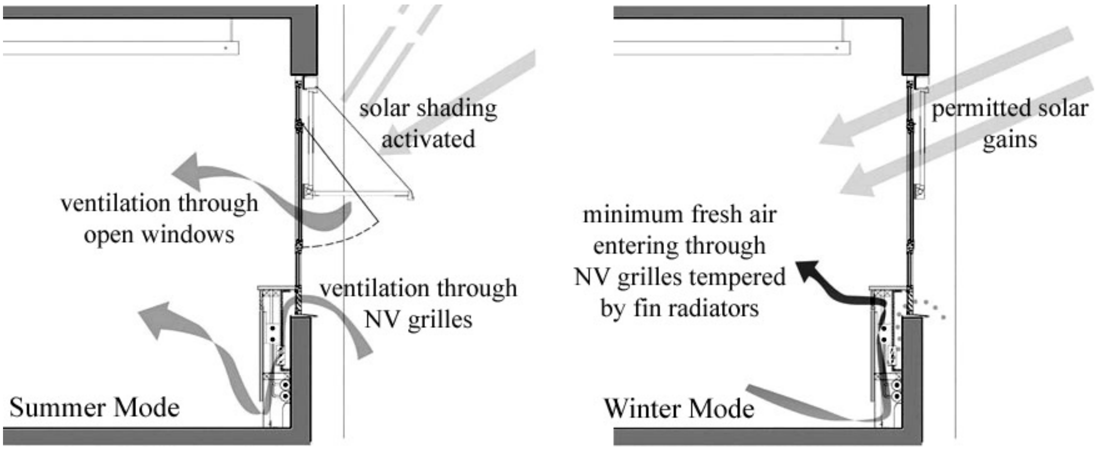

Figure 2: Typical window section in the surveyed building showing ventilation strategy.

The building's orientation, level of glazing, occupancy levels and equipment loads meant a chilled beam cooling system was installed, as it could operate with opened windows. The chilled beams were controlled by the BEMS and no active occupant intervention was possible. When the chilled beams were activated the NV grilles closed down.

Eight surveys were conducted during March, April and June 2005, covering the end of winter, spring and early summer. Survey forms were issued to the occupants of the 3 floors surveyed and occupants were asked to return them at the end of each survey day. In addition to providing demographic, personal (clothing) and locational information occupants were asked to describe their subjective response (for both mornings and afternoons) to a range of thermal conditions that may have influenced their perceptions of comfort. This produced nearly 1500 data responses describing their perceptions of:

- Thermal sensation (measured on the 7 point ASHRAE scale; from *hot* +3, *warm* +2, *slightly warm* +1 *neutral/ comfortable* 0, *slightly cool* -1, *cool* -2, *cold* -3*)*
- Preferred changes to the perceived thermal conditions (5 point scale; *much warmer* +2, *warmer* +1, *no change* 0, *cooler* -1, *much cooler* -2*)*
- Perceptions of air movement (7 point scale; *very stuffy* +3, *stuffy* +2, *slightly stuffy* +1, *no draughts felt* 0, *slightly draughty* -1, *draughty* -2, *very draughty* -3)
- Occupants' perceptions of whether air movement was comfortable within the offices (4 point scale: *comfortable* 0.0; *slightly uncomfortable* 1.0; *uncomfortable* 2.0; *very uncomfortable* 3.0)

– Occupants' perceptions of the combined thermal and visual comfort (4 point scale: *comfortable* 0.0; *slightly uncomfortable* 1.0; *uncomfortable* 2.0; *very uncomfortable* 3.0)

Occupants were asked to vote on their perceptions of cold or hot radiating from surfaces within the spaces (floors, ceilings, walls, windows) and estimate internal temperatures. Additional questions were asked about visual perceptions, to see if perceptions of thermal conditions were the only criteria influencing comfort (McCartney & Nicol 2002). Over 700 data responses were recorded describing occupants' perceptions of lighting levels (7 point scale; *very bright* +3, *bright* +2, *slightly bright* +1, *satisfactory/neither bright or dim* 0, *slightly dim* -1, *dim* -2, *very dim* -3), preferred changes to perceived lighting levels (5 point scale; *much dimmer* +2, *a bit dimmer* +1, *no change* 0, *a bit brighter* -1, *much brighter* -2) and whether occupants suffered from solar glare.

Occupants recorded their interventions in relation to the limited range of available active adaptive opportunities, which included opening windows, manual opening or closing of the external awnings and use of localized heaters or fans. In addition occupants were asked which adaptive opportunities they would support if available. These ranged from opening windows, controlling solar glare, turning lights off locally, increasing levels of ventilation, ability to alter room temperatures, controlling solar gain, increasing levels of cooling, turning lights off automatically and using localized heaters and fans.

In addition to the surveys objective measurements were taken on each survey day. Manual readings were taken from the BEMS covering internal and external temperatures, external solar radiation levels, heating, natural ventilation and cooling systems status. In addition measurements of air and operative temperatures, air movement and relative humidity were recorded using Dantec Dynamics A/S Vivo Operative Temperature, Vivo Humidity and the Vivo Draught/ Low Air Velocity measuring units in similar locations on one floor on each survey day (rotated to ensure all floors were covered). Data was recorded over a 7 hour period, at approximately one minute intervals, and then downloaded onto a computer for analysis, using the Dantec Dynamics A/S Vivo Controller PC (version 1.2) software to calculate PMV/ PPD values, with upper and lower limits for PMV votes calculated from their standard deviation (SD), based on measured parameters, estimated mean Clo values (from occupants' descriptions of their clothing contained in the surveys) and an assumed activity level of 1.2Met, taken from Table A1 – Metabolic Rates in ISO 7730 (1996) for office sedentary activity.

Data from occupants' descriptive votes was logged into an Excel spreadsheet and using the Excel 'data analysis tools' a series of mean, median and mode values were calculated. The upper and lower margin of error in estimating mean values is indicated by the standard error margin (SEM) values. The mean votes were evaluated in relation to the likely distribution of votes recommended in ISO 7730 (1996) for spaces for human occupancy where the Predicted Percentage of Dissatisfaction index (PPD) achieved is lower than 10%, which corresponds to $-0.5<PMV<+0.5$.

An additional objective analysis of the survey data was undertaken to understand if there were any underlying trends between occupants' votes (ordinal data) and measured environmental data. Spearman non-parametric rank correlation tests were used to investigate relationships between dependant and independent variables, establishing the correlation value ‘r_s’ to test the hypothesis whether there were any monotronic relationships between paired values.

5. Results

As a dress code was not operated in the building surveyed, occupants were asked to record their clothing for both the morning and afternoon. Using thermal insulation values from ISO7730 (1996) for the recorded clothing combinations mean Clo values were estimated for calculating PMV values using the Dantec Dynamics A/S Vivo software. Mean Clo values decreased from 0.8Clo to 0.66Clo over all the surveys as working day mean external temperatures increased from 6.7^0C to 27.3^0C (*Figure 3*). Less than 4% of respondents, however, indicated a change of clothing during a survey day.

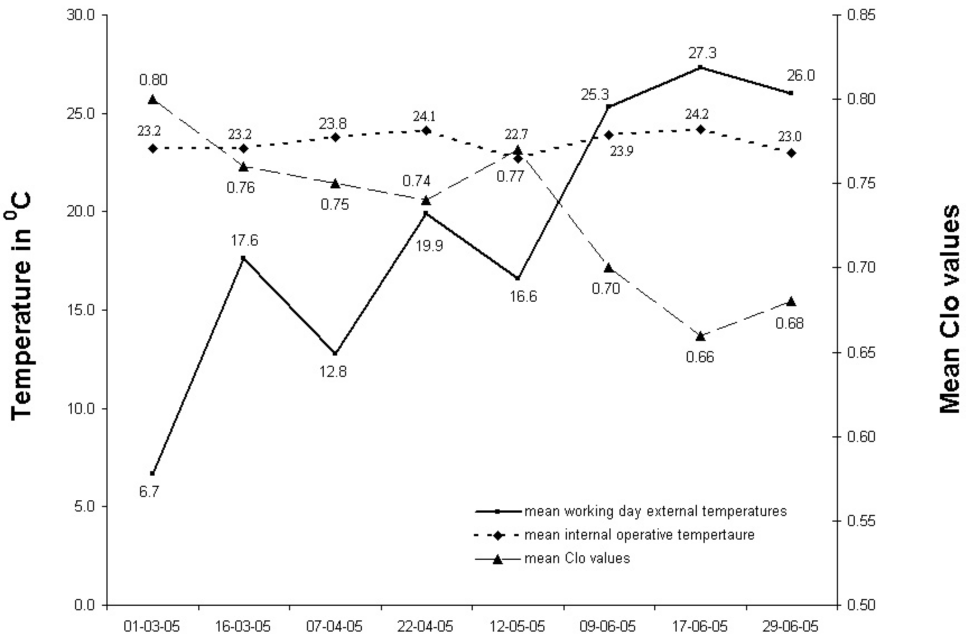

Figure 3: Mean working day external, internal operative temperature & the corresponding mean Clo values.

A comparison of occupants mean thermal sensation votes for the 8 survey days and calculated PMV values is given in *Figure 4*. While all the calculated PMV values fell within the -0.5<PMV<+0.5 parameter for 10% PPD, occupants’ mean thermal sensation votes fell outside this on 3 occasions (16-03-05; 22-04-05; 17-06-05). When SEM values were considered for these 3 occupants’ votes, there was a 68% probability that in one instance (on 22-04-05) the lower SEM value might fall within -0.5<PMV<+0.5. Generally occupants’ votes were evenly distributed around ‘neutral/comfortable (0.0)’, with the most frequent observed vote ‘neutral/comfortable (0.0)’ (mode; 0.0). On the 3 occasions when the mean vote fell outside the -0.5<PMV<+0.5 range median values moved towards ‘slightly warm (+1.0)’. In all instances calculated PMV values were closer to ‘neutral/ comfortable (0.0)’ than the survey votes.

The SD values for the calculated PMV values indicated the values within which 68% of occupants would probably vote. The distribution of the actual votes only approached the calculated SD values on 2 days (66.6% on 01-03-05 & 09-06-05). On 4 other days between 62-54% of actual votes fell within the calculated SD range and on 2 survey days (17-06-05 & 29-06-05) this number fell to 33% and 25%. Yet on each survey day between 55-66% of occupants preferred no change to the thermal conditions, although significant minorities expressed preferences for conditions to be either ‘a bit cooler’ (36% - 22-04-05; 30% - 29-06-05) or ‘a bit warmer’ (33% - 17-06-05). When occupants were asked to estimate internal temperatures they consistently underestimated the measured mean internal air temperatures by -3.2^{0}C.

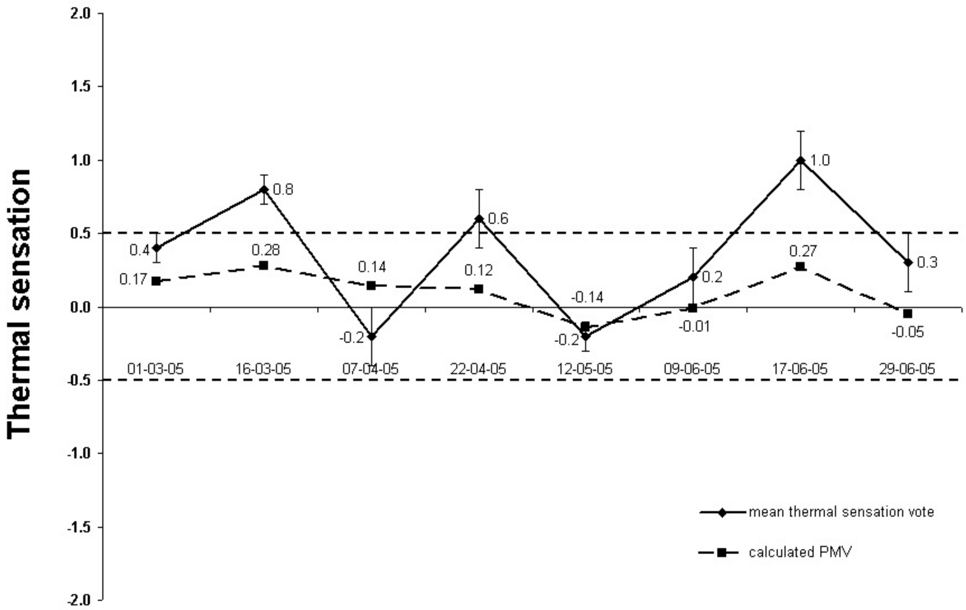

Figure 4: Occupants’ mean thermal sensation vote & calculated PMV values.

The mean votes for occupants’ perceptions of air movement (*Figure 5*) were all close to and evenly distributed around ‘neutral/no draughts felt, 0.0’ (median; 0.0), with the most frequent observation ‘neutral/no draughts felt, 0.0’ (mode; 0.0). While on 5 days the mean vote was located on the ‘slightly draughty’ side of ‘neutral’ occupants’ perceptions of whether they found air movement comfortable indicated mean votes remained relatively consistent in relation to ‘comfortable, 0.0’ and did not exceed 0.5 on any of the survey days and were all well short of ‘slightly un-comfortable, 1.0’. SEM values for occupants’ perceptions of air movement indicated a 68% probability that possible mean vote values would not deviate greatly from the recorded mean values.

Using the environmental measurements (including mean air speed, internal operative temperature etc) taken on survey days Draught Rate (DR) values were calculated using the Dantec Dynamics A/S Vivo Controller PC (version 1.2) software. These indicated a greater variability (*Figure 6*) than occupants’ mean perception of air movement. On three occasions (01-03-05, 22-04-05, 09-06-05) the DR exceeded both the 15% DR indicated in ISO 7730 (1996) as the threshold for causing local thermal discomfort and the 20%, the level suggested by Olesen (2001) for avoiding local thermal discomfort if <10%PPD is to be achieved. Only on one occasion did these higher values coincide with a measured thermal sensation PPD above the 10%PPD (13% PPD on 22-04-05) suggested by ISO 7730 (1996). Higher calculated DR values were generally recorded when occupants opened windows and the BEMS opened NV grilles to increase ventilation. Lower calculated DR values were recorded on days (17-06-05, 12-05-05, 29-06-05) when fewer windows were opened.

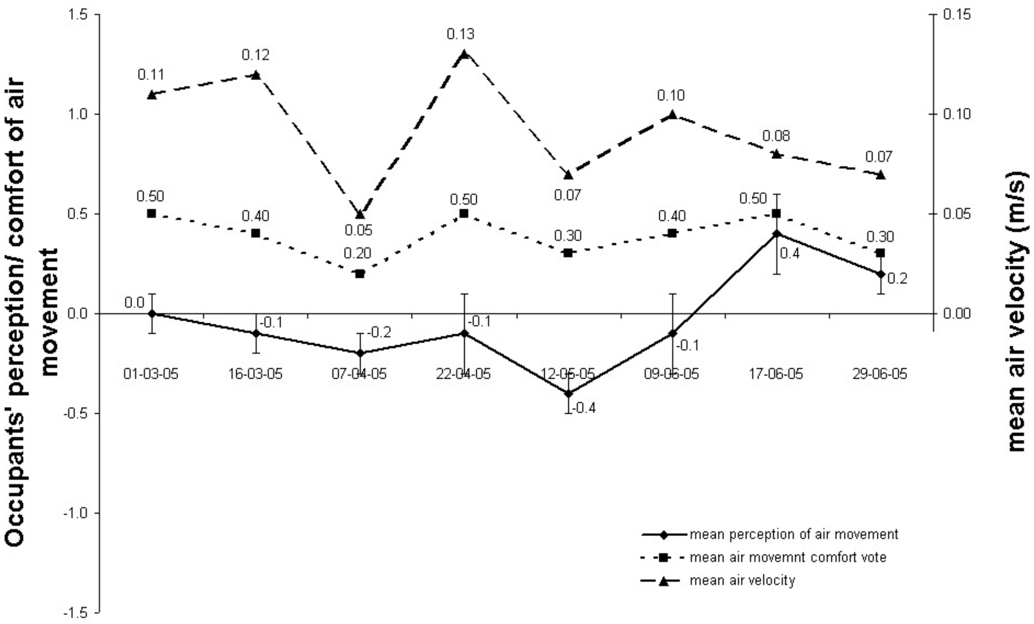

Figure 5: Occupants' mean perception of air movement, air movement comfort vote & mean air speeds.

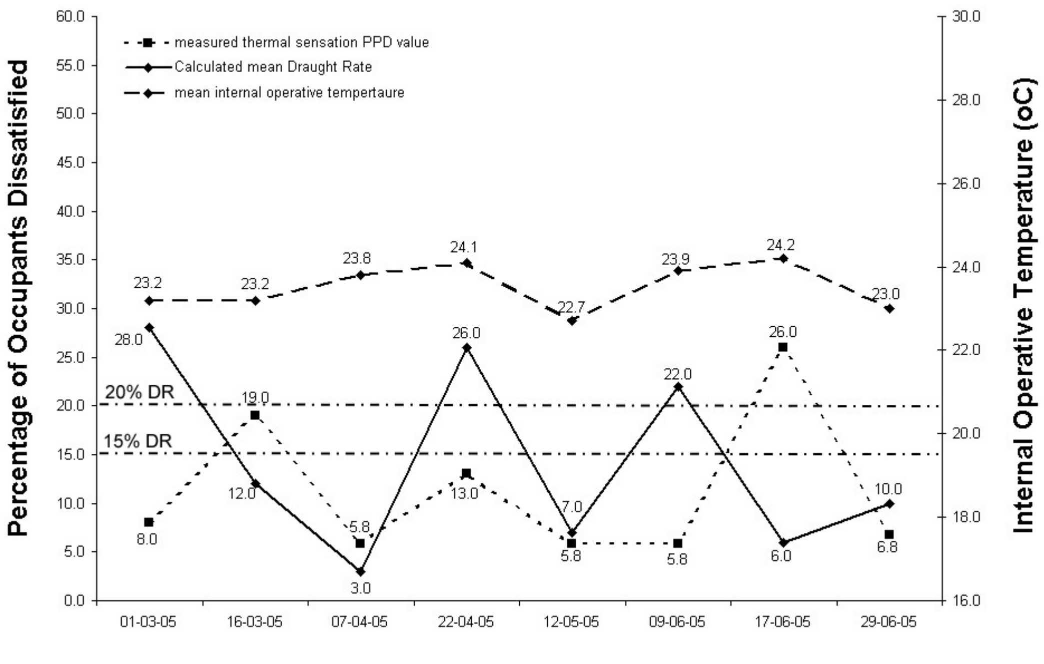

Figure 6: Draught Rate (DR), measured thermal sensation PPD value & internal operative temperature.

On each survey day the mean vote of occupants' perception of lighting levels (*Figure 7*) fell between -0.2 and +0.5. The mean votes were close to and the overall votes were evenly distributed around 'satisfactory/neither bright or dim, 0.0' (median; 0.0), with the most frequent observation 'satisfactory/neither bright or dim, 0.0 (mode; 0.0). SEM values for the mean light assessment vote indicated a 68% probability that on 3 occasions (16-03-05; 07-04-05; 17-06-05) the upper end mean votes values might lie above +0.5. Although most mean votes were on the 'slightly bright, +1.0' side of ‘satisfactory/neither bright or dim’ between 50-75% of occupants voted for ‘no change’ to light levels on 5 occasions and were ‘not at all affected by solar glare’, though not always coinciding with preferences for ‘no change’. Occupants actively opened and closed the external awnings more in March and April than May and June.

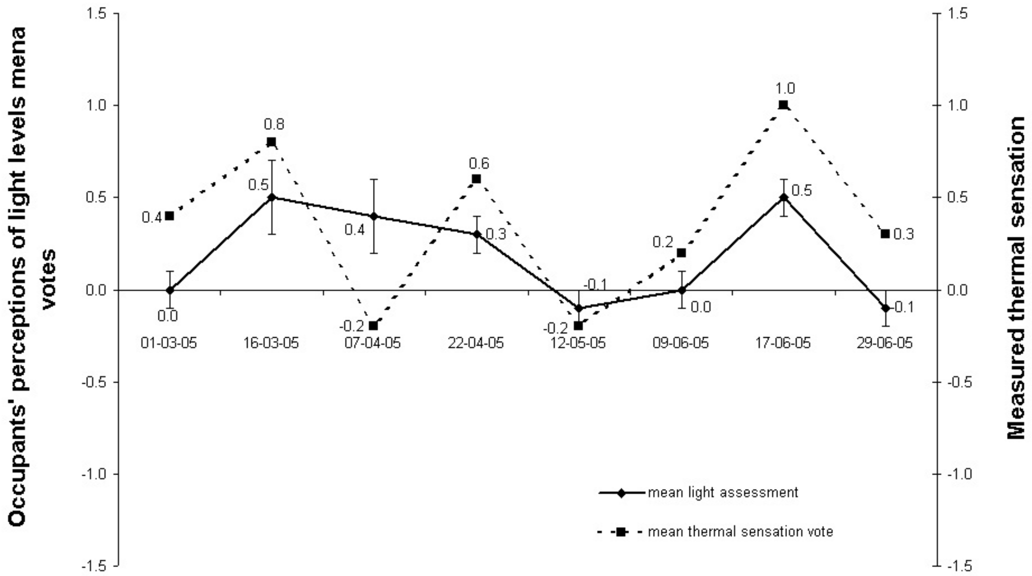

Figure 7: Occupants’ perceptions of lighting levels mean votes & measured thermal sensation.

Occupants were asked to vote on their overall thermal and visual perceptions as a combined thermal & visual comfort vote (*Figure 8*) to see whether other environmental factors (such as lighting levels) were influencing occupants overall perceptions either in negative or positive ways (*McCartney & Nicol 2002*). The combined thermal & visual comfort mean votes ranged from ‘comfortable, 0.0’ to ‘very uncomfortable, 3.0’ appears to produce a ‘flatter’ response with mean votes on all but one occasion (mean = 0.6 on 29-06-05) below 0.5. Even when SEM values were considered only one additional vote (09-06-05) indicated a 68% probability that its upper end mean value might lie above 0.5. Whilst higher levels of solar irradiation were recorded on both of these days they were by no means the highest levels recorded. Votes were evenly distributed around ‘comfortable, 0.0’ (median; 0.0), with the most frequent observation ‘comfortable, 0.0’ (mode; 0.0).

When asked which adaptive opportunities they would support occupants voted by a significant majority for opening windows (74%) which remained constant through all the surveys. 69% voted for controlling solar glare, reflecting anecdotal comments that glare was a problem, even though occupants consistently voted they were ‘not at all’ suffering from solar glare in the surveys. 47% voted for adaptive opportunities to control solar glare. A majority voted for turning lights off locally (56%) which might have been in response to the existing central controls on each floor. A similar number (55%) wanted to be able to increase levels of ventilation, and 50% voted for actively intervening to alter room temperatures, both of which were operated by a centralised BEMS. Similar numbers of occupants voted to support and oppose the use of localized heaters (35%; 31%) and fans (35%; 27%).

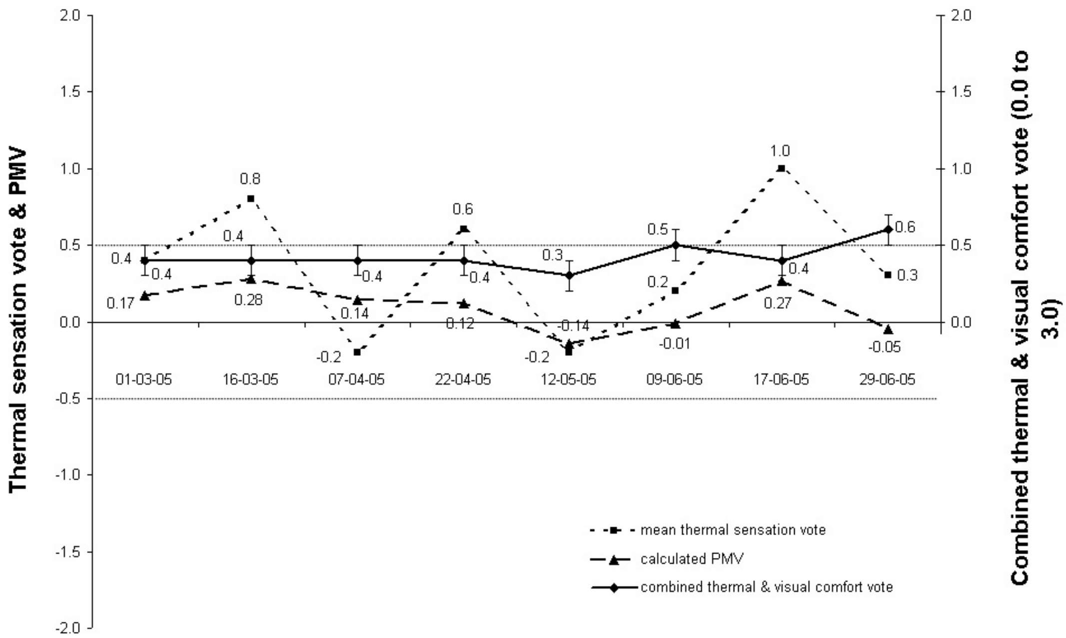

Figure 8: Combined mean thermal & visual comfort vote, mean thermal sensation vote & calculated PMV.

6. Discussion

The culture of fixed working day periods, fixed workstation layout and set team structure meant neither temporal nor spatial adaptive opportunities were available to the occupants surveyed. It appears economic pressures on companies from office overheads (rental, staff costs etc.) is making both temporal and spatial adaptations unlikely within the UK context (*Procter & Fennell 2001*). Although mean Clo values fell across the period of the surveys only 4% of occupants appeared to adapt to changing environmental conditions by changing their clothing during any particular day. This is an interesting observation indicating that cultural influences (fashion trends; wanting to wear the same clothes at different time of the year) might be stronger than the willingness to use this form of adaptation.

While active occupant adaptive opportunities in the building studied were limited, occupants generally took advantage of opening windows, manually opening and closing the external awnings and using the limited number of localized heaters and fans available. Awareness of possible adaptation strategies appeared to be strong as only 9% voted 'don't know' when asked their views on suitable intervention strategies. The surveys indicated significant support (74% of occupants) for the ability to open windows. Generally the greatest number of windows were opened on days with higher external temperatures, suggesting occupants actively intervening to increase ventilation rates (even if NV grilles were being opened by the BEMS) to control internal temperatures. This appeared to reinforce results from other studies in that opening windows have a positive influence on occupants' comfort votes (*Brager & de Dear 1998*).

The ability to open or close the external awnings for controlling glare was also considered important by occupants (68% positive votes). Intervention appeared to decline during summer months suggesting low level winter sun might have proved a greater problem than higher summer sun elevations. This might suggest occupants intervened more frequently as the result of solar glare from lower sun altitudes experienced during the earlier period of surveys.

Interestingly it appeared occupants wanted to actively intervene in those systems centrally controlled through the BEMS. Support was expressed for intervening to increase levels of ventilation through the NV grilles. The desire to alter room temperatures appeared to be another example of occupants wanting to actively control centralised environmental systems. This might have been influenced by the inaccessibility of localized TRVs in the office studied. The control of solar gain is often fixed or controlled through centralized controls, occupant support for active intervention with the external awnings in the surveys might be a reflection of the positive impact this adaptive opportunity in the building surveyed has had on perceptions of comfort. While occupant intervention through the use of localized switching was positively supported, 59% voted against turning lights off automatically. This might be a reflection of occupants' unease with centrally controlled systems (even where they would reduce energy consumption).

One might have expected the opportunity to use localized methods of adapting the environment (such as the use of heaters and fans) to have received greater support than suggested in the survey. There appeared to be a greater desire to actively control centralised heating and ventilation systems rather than using individual items of equipment. 66% voted against the ability to increase cooling which might reflect positive experiences of the chilled beams used in the building studied or that passive control of cooling is more acceptable to occupants.

It has been considered the norm, in relation to adaptive comfort theory, that when occupants of a building have adaptive opportunities they would (as a large group) tolerate greater environmental variations than suggested by predictive heat balance models such as ISO7730 (*Baker & Standeven 1996*). It might thus be expected that the distribution of occupants' mean thermal sensation votes obtained through surveys would result in a mean closer to 'neutral' than would be calculated by the heat balance approach. This did not occur in this study. On each survey day the calculated mean PMV values were closer to 'neutral' than the mean thermal sensation votes statistically derived from the occupant surveys. Whilst this does not follow the classic assumptions concerning adaptive opportunities regarding occupants' mean thermal sensation votes it does, however, support the contention that heat balance models are not fully explaining how people react to their environments. Heat balance model predictive calculations also produced a narrower distribution of votes than occupants' perceptions of acceptable thermal sensations.

On the other hand occupants' perceptions of air movement, which would cause local discomfort, indicated mean votes from surveys closer to 'neutral' than calculated DR suggested on a number of occasions. Occupant mean air movement votes were more consistently similar than DR values. Higher DR values appeared to be the result of adaptive intervention by occupants opening windows or the BEMS opening the NV grilles to increase ventilation in response to increasing internal temperatures. This appears to lend support to the premise that where there are adaptive opportunities occupant perceptions will be closer to 'comfortable/neutral' than calculated values using any static model.

When asked to make an overall assessment of their 'comfort' occupants' response appeared more stable, as the combined mean thermal & visual comfort vote varies less than the mean thermal sensation vote. Although occupants' perceptions of lighting levels mean votes were generally on the ‘slightly bright’ side of ‘neutral’ there is no evidence to suggest this might have influenced the combined thermal & visual comfort votes. An objective statistical analysis indicated no monotronic relationship between occupants’ mean thermal sensation votes with occupants’ perception of lighting levels (r_s = 0.23) or air movement votes (r_s = 0.39). They also appeared to be very weak relationships between the combined thermal & visual votes and perception of lighting levels (r_s = 0.12), air movement (r_s = 0.01) and thermal sensation votes (r_s = 0.16).

The relationship between mean thermal sensation votes and the number of environmental measurements (mean external temperature, mean internal air & operative temperature, mean relative humidity, mean air velocity, mean DR), as independent variables, found the strongest relationship was with mean internal air temperature (r_s = 0.54) rather than internal operative temperatures (r_s = 0.52) and mean diurnal external temperature (r_s = 0.48). It was, however, short of the 5% significance level (when plotted onto a Spearman rank correlation graph). In contrast the objective relationship between mean combined thermal & visual comfort vote and the environmental measurements indicated the strongest relationship was with mean diurnal external temperature (r_s = 0.6). Although this fell just short of the 5% significance level it seams to support results from larger survey sources described in studies such as by Humphreys & Nicol (1995) and McCartney & Nicol (2002). The relationships with mean internal operative temperature (r_s = 0.4), internal air temperature (r_s = 0.39) and mean relative humidity (r_s = 0.4) were weaker.

7. Summary and conclusions

The main finding from this study was the need to make active adaptive opportunities central features of future refurbishment strategies for existing office buildings. They offer the best low energy opportunities for building occupants to remain comfortable in a period of changing of environmental conditions. The building occupants surveyed in this study voted positively for active adaptive opportunities such as opening windows, manually controlled external shading for controlling both soar glare and solar gains. The use of localized switching for turning lights on or off also appeared to be strongly supported. Its use in conjunction with any automatic controls to reduce energy loads and heat gains from lighting should, however, be considered carefully as automatic lighting controls were not supported by the occupants surveyed.

The study found week statistical relationships between the active adaptive opportunities in the building studied and occupants’ comfort votes despite occupants expressing their strong support adaptive opportunities. This suggests further statistical analysis of the above conclusions should be undertaken in order to confirm what appears to be happening. Additional studies will be needed to understand whether the support for not intervening in the cooling system in the study is a reflection of the type of system used (a chilled beam cooling system) specifically or a reflection of cooling systems generally.

Passive interventions will also need to be included in future refurbishment strategies in order to save both energy and reduce carbon emissions during a period facing significant climate change. Passive interventions can also contribute to occupant comfort by possibly reducing localized discomfort from temperature asymmetry. It also appears, however, that changes in clothing could be of less importance to building occupants than generally assumed. More research needs to undertaken into the relationship between the need to adapt ones clothing and cultural influences of fashion on dress codes. If the trend suggested in this study is supported then this would suggest refurbishment strategies need to concentrate on the active adaptive opportunities mention above.

The results from this and other studies appear to indicate that both building designers (architects and service engineers) will need to pay attention to providing active adaptive opportunities within their refurbishment design proposals in the future. This will not only include provide opportunities referred to above but also meet the expressed support for occupant active adaptation of heating and ventilation systems (whether natural or mechanical) which are currently centrally controlled by BEMS. This will need to include how these environmental systems can be controlled by small groups of people, how this form of adaptation would interact with individual desires in a practical way and how this would feed into the overall perception of occupants' comfort levels as a large group.

References

Procter A and Fennell B (2001), A National Survey of Total Office Costs. City University Business School, London.

Baker N & Standeven M (1996), Thermal comfort for free-running buildings. Energy and Buildings, Vol. 23, No. 3. pp 175-182.

Brager G S & de Dear R J (1998), Thermal adaptation in the built environment: a literature review. Energy and Buildings, Vol. 27, No. 1, pp 83-96.

BSEN ISO7730 (1996), Moderate thermal environments - Determination of the PMV and PPD indices and specification of the conditions for thermal comfort (Incorporating Amendment No. 1). British Standards Institute, London.

Carmona I (2004), Feedback User Group Case Study: West End House, 11 Hills Place, London. Usable Buildings Trust, Feedback Portfolio Results Website

http://www.usablebuildings.co.uk/rp/index.html

Clarke S, Kersey J, Trevorrow E, Wilby R, Shackley S, Turnpenny J, Wright A, Hunt A & Crichton D (2002), London's Warming: The Impacts of Climate Change on London - Summary Report. The London Climate Change Partnership.

de Dear R J & Brager G S (2002), Thermal comfort in naturally ventilated buildings: revisions to SAHRAE Standard 55. Energy and Buildings, Vol. 34, No. 6, pp 549-561.

Energy Consumption Guide 19 (2000), Energy use in offices. Energy Efficiency Best Practice Programme. BRESCU, BRE, Watford.

Hulme M, Jenkins G J, Turnpenny J R, Mitchell T D, Jones R G, Lowe J, Murphy J M, Hassell D, Boorman P, McDonald R, & Hill S (2002), Climate Change Scenarios for the United Kingdom: The UKCIP02 Scientific Report. Tyndall Centre for Climate Change Research, Norwich, UK.

Humphreys M.A & Nicol J.F (1995): "An Adaptive Guideline for UK Office Temperatures". In Standards for thermal Comfort: Indoor Air Temperature Standards for the 21st Century, Edited F Nicol, M Humphreys, O Sykes and S Roaf. Chapman & Hall, London

Humphreys M.A & Nicol J.F (2002), The validity of ISO_PMV for predicting comfort votes in everyday thermal environments. Energy and Buildings, Vol. 34, No. 6, pp 667-684.

McCartney K.J & Nicol J.F(2002), Developing an adaptive control algorithm for Europe. Energy and Buildings, Vol. 34, No. 6, pp 623-635.

Nicol J.F & Humphreys M.A (2002), Adaptive thermal comfort and sustainable thermal standards for buildings. Energy and Buildings, Vol. 34, No. 6, pp 563-572.

Olesen B W (2001), Introduction to the new revised draft of EN ISO7730. Proceedings of Moving Thermal Comfort Standards into the 21st Century Conference**,** Windsor, United Kingdom, 5-8 April, 2001.

Pout C.H, MacKenzie F and Bettle R (2002), Carbon dioxide emissions from non-domestic buildings: 2000 and beyond: BR442. CRC Ltd, London.

Steemers K (2003), Establishing research directions in sustainable building design: Technical Report 5. Tyndall Centre for Climate Change Research, Norwich, UK.