

Case Study: Method of Investigation of a Commercial Building's Comfort Levels: Highlighting Energy Efficiency Concerns

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ABSTRACT: An investigation of the thermal comfort issues of a building was carried out to identify areas for improving the building's energy efficiency.

A qualitative investigation of perceived comfort in a building acted as a foundation to highlight any patterns of indoor comfort that could help identify critical areas requiring a more detailed study: which includes a series of measurements and site surveys combined with computational fluid dynamics (CFD) modelling to help generate a more detailed understanding of the comfort control and associated energy concerns of the building.

The investigation shows the office building displaying inadequate control of the internal environment; resulting in poor thermal comfort and energy inefficiency. The studied building was built under building regulations in force in 1990; where Part L energy conservation regulations were in existence. This study suggests that assessments of thermal control systems of all existing commercial buildings should be considered a vital, initial step in helping to reduce the CO₂ emissions associated with commercial buildings. It should also be considered as a repeatable process to help maintain and continually improve a building's energy efficiency.

Keywords: energy efficiency, CO₂, thermal comfort, commercial building

1. INTRODUCTION

Efficient energy use by buildings is a relatively modern concern that became of great importance during the oil crisis of the 1970's. Over the past 30 years the management of energy use by a building has increased in importance. Equally tighter controls on expected levels of comfort in the

working environment have been introduced as a greater understanding of its effects on our health are understood.

The large stock of existing buildings in developed countries such as Britain play a significant role in the carbon emissions of those countries. An IPCC report [1] showed buildings in the UK to be contributing 30% of the total CO₂ emissions of the country. Commercial property was thought to count for

10% of total emissions, the other 20% coming from domestic buildings. Studies carried out by BRE [2] give much higher figures with 20% of total CO₂ emissions coming from commercial property.

Stipulation for tighter control of internal conditions has led to greater energy demands associated with commercial property in particular. Control of thermal comfort within a building is thought to make up as much as 60% of a building's energy demands; relying on installed Heating, Ventilation and Air Conditioning (HVAC) Systems to meet the heating and cooling loads placed on a building [3-5].

Occupants of an existing commercial building reported poor levels of thermal comfort to the building management team. It was decided that the building could act as a test case for improving thermal comfort whilst reducing the carbon load associated with the building.

In order to achieve these improvements detailed investigation of the building has been carried out to identify and assess the potential causes of the reported comfort problems.

This paper presents the process used to identify the causes of thermal discomfort as an important step in ensuring effective energy efficiency improvements can be made.

2. BUILDING FORM

The building under investigation is a steel framed, lightweight cladding structure; built in 1990. The cladding used is made of interlocking composite metal panels and double glazed units, with a window-to-wall ratio of approximately 40%.

None of the windows can be opened so the building is reliant on mechanical ventilation. The HVAC system consists of a Heat Pump supplying low temperature hot water and chilled water to a network of fan-coil units: used to distribute the required cooling and heating.

The building consists of 3 floors with the stairwell, lift and toilets enclosed in a solid

concrete core of the building. The first and second floors consist of open plan offices where the environment is managed to ensure human comfort.

For this study a focus was given to the office areas of the building.

3. METHOD

3.1 Questionnaire

A questionnaire was developed to try and validate physical measurements taken regarding the building's comfort levels. By providing a carefully planned questionnaire a qualitative measure of the occupants subjective opinion on the internal environment helped to provide insight into the thermal comfort of the building.

Fanger Theory [6] allows a predicted mean vote (PMV) of thermal perception to be given for known values of environmental parameters. A scale based on the PMV scale was decided upon as a useful measure of occupant comfort. The scale ranged from -2 to +2 with 0 signifying ideal conditions.

Comfort can be effected by three physical factors: air, lighting and thermal quality as well as certain psycho-social factors such as job satisfaction and personal control of your environment [7]. As the projects aim is to reduce the carbon load associated with the building whilst maintaining a comfort level within the recommended building standards only the physical aspects were considered in the investigation.

3.2 Monitoring

Strategic placement of the monitoring equipment was carried out to provide more detailed investigation of poorly performing areas identified by the questionnaire results. Monitoring was carried out over a year and was combined with local weather data to highlight patterns of behaviour in the thermal parameters of the building.

Investigation (via spot checks and long term monitoring) into the behaviour of the fan-coil units that control air flow and temperature

supplied to the office space helped to provide accurate boundary conditions to a CFD model representation of the building. Point measurements of air temperature across the office space were also used to validate the accuracy of this model.

In order to improve the energy efficiency of the building it is necessary to observe its current energy performance. Monitoring parameters that effect comfort levels should highlight inefficient behaviour within the internal building space. Analysis of collected data combined with computer modelling, should lead to an understanding of current energy inefficiency so possible methods for improving energy regulation can be suggested, tested and implemented (if financially viable and practical).

3.3 Modelling

Monitoring and questionnaire data could only be confidently used in determining general patterns of thermal behaviour and distribution within the studied building. Disruption to the building occupants and cost of equipment place restrictions on the type and level of monitoring carried out.

Use of an air conditioning system often results in localised non-uniform conditions. The sensitivity of an occupant to thermal conditions will depend on which part of the body is most exposed to those conditions[8]. Positioning of workstations relative to the HVAC systems air vents could therefore influence perceived thermal comfort. This could result in unexpected levels of dissatisfaction for an otherwise efficient system.

Developing a computational fluid dynamic (CFD) model provided a means by which detailed analysis of the buildings thermal performance could be carried out.

A basic model was developed based on investigation of the building structure, orientation and internal loads. Verification of the model was carried out using monitoring data.

4. RESULTS

4.1 Questionnaire

Table I and II show the averaged results and standard deviation in each office space for the physical parameters assessed in the questionnaire (temperature t, humidity h, air flow a and insolation i). The averaged responses suggest a good degree of satisfaction with a mean vote very close to ideal conditions.

Table I: Mean Vote (m) and Standard Deviation (sd) of assessed comfort issues of Heating Season

Comfort Issue	t		h		a		i	
	m	sd	m	sd	m	sd	m	sd
Ground Floor	-1	1.1	-0.2	0.5	-0.3	1.0	-0.3	0.9
First Floor	0	1.2	-0.6	0.9	-0.4	1.3	-0.2	0.9
Second Floor	0	1.1	-0.7	0.8	-0.3	0.9	0	1.1

Table II: Mean Vote (m) and Standard Deviation (sd) of assessed comfort issues of Cooling Season

Comfort Issue	t		h		a		i	
	m	sd	m	sd	m	sd	m	sd
Ground Floor	0.2	1.1	-0.2	0.4	-0.4	0.8	0.1	1.6
First Floor	0.1	1.0	-0.4	0.9	0	1.4	0.5	1.2
Second Floor	0.2	1.1	-0.5	0.9	-0.4	1.2	0.2	1.0

The mean votes are near to 0 (on given scale) with a relatively large standard deviation, representing the conflicting perception of thermal discomfort reported by occupants.

For occupants reporting thermal discomfort 75% also report some level of discomfort within the other physical parameters assessed.

There was no clear relationship, however, between the physical parameters and the level of thermal comfort.

Comments given on the questionnaires showed staff reporting levels of discomfort were providing their own means of combating the issue. Staff that found conditions too hot had installed their own desk fans to improve cooling. Staff that were too cold would request cooling units to be switched off in their area, placing greater demand on other units and resulting in other discomfort issues within that area.

4.2 Monitoring

Internal temperature showed strong correlation to external conditions. Figure 1 shows the observed relationship between external and internal temperatures. The increase in external temperature from the 05/06/06 to the 07/06/06 is also seen in the internal temperature (though not as large).

The Building Management System (BMS) is designed to maintain internal temperature within a range of $\pm 2^{\circ}\text{C}$ around a set point of 21°C . Figure 1 represents the common daily temperature profile noted in the building over the cooling season. It was often seen that temperatures would exceed the upper limit set by the BMS; suggesting cooling loads exceeded the HVAC systems cooling capacity.

Figure 1 already represents an influence of external conditions on the level of internal temperatures. It is important to establish whether the bell shaped profile results from internal or external influences.

Comparing the internal temperature profile between two days where external loading is very similar whilst internal loads differ, helped to develop a greater understanding of the relationship these loads had with internal conditions.

Figure 3 shows the internal and external temperature profiles over a working and non-working day. On both days outside conditions were very similar. The HVAC system was left on over the weekend. It is clearly seen that the bell shaped internal temperature profile over a

working day is lost at the weekend.

Two conclusions could be made from the monitoring so far:-

(i) Internal heat sources result in a cooling load too large for the current HVAC system and

(ii) External conditions influence the base temperature from which the working day temperature profile starts.

The HVAC systems expected cooling capacity was calculated as greater than the peak loads. Further monitoring showed the thermal distribution system in the building to have malfunctioning components, reducing the system to less than 75% of it expected capacity.

A distribution of thermocouple groupings showed an uneven temperature distribution across the office space that remained consistent over the monitoring periods (see figure 2).

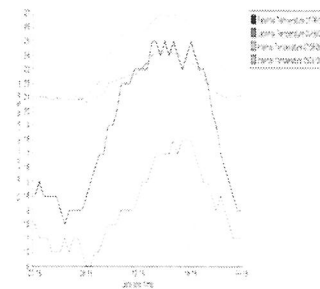


Figure 1: Temperature relationship between external and internal environment

Areas where air temperature reached the highest values during the cooling season corresponded to malfunctioning fan-coil units.

Conflicting behaviour of thermal distribution units within the same control zones were recorded.

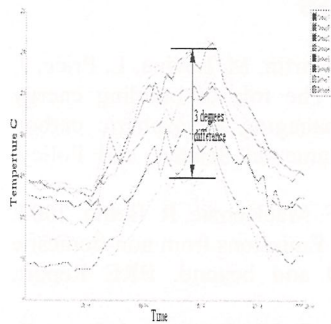


Figure 2: Distribution of averaged office air temperature for groupings over one day

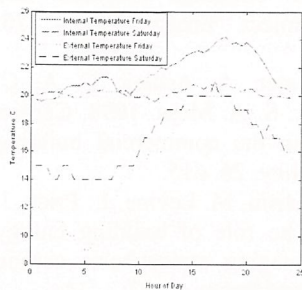


Figure 3: Demonstration of effects of internal heat sources on internal temperature profile

Simultaneous cooling and heating is an obvious system inefficiency. As the differing behaviour was noted in the same control zone this can be attributed to malfunction within the HVAC system or the controlling BMS.

The imbalance in thermal distribution across the office areas lead to further energy wastage as a result of staff behaviour.

4.3 Modelling

The model's verification points were within $\pm 2.5^\circ\text{C}$ of the monitored results.

Figures 4 and 5 show planar cuts of the simulation results for air speed and air temperature, respectively. The modelling work proved useful in highlighting causes for conflicting response of thermal comfort between neighbouring workstations. This is highlighted by the circled areas in figures 4 and 5.

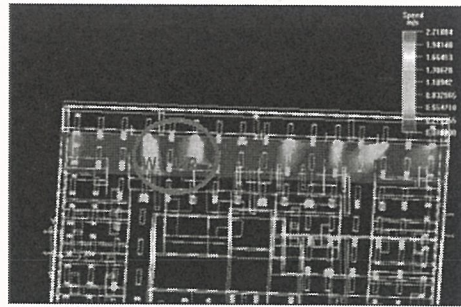


Figure 4: Planar cut of air speed

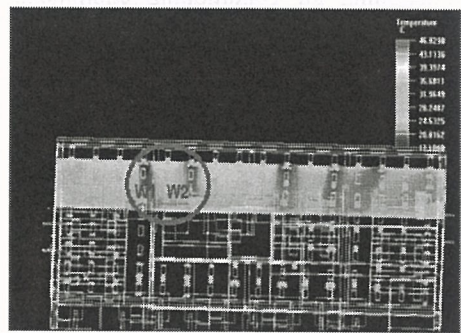


Figure 5: Planar cut of air temperature

The modelling work showed that vent design and position, along with conditioned air inlet speeds can lead to localised conditioning. This causes pockets of uncomfortable zones that lead to conflicting levels of thermal comfort. It has already been discussed how this will effect occupant behaviour to add further energy demands on the building.

5. DISCUSSION AND CONCLUSION

Determining levels of thermal comfort within a building and investigating issues potentially responsible for the perceived thermal comfort is complex. Questionnaires provide a useful means for assessing the perceived level of thermal comfort as well as identifying occupant behaviour that increases the buildings energy demands.

Long term monitoring is required to identify relationships between thermal loads and

building conditions. Monitoring will highlight inefficient behaviour in a building's HVAC system.

Building modelling provides a detailed description of the thermal conditions experienced by building occupants. It can help highlight areas requiring improved thermal distribution; so improving HVAC system efficiency and preventing occupants providing subsidiary conditioning systems.

In this case study an inadequate level of thermal comfort could be related to malfunctioning air conditioning equipment, poor design of the air conditioning distribution system and some external influences, such as solar loading.

With 60% of a buildings energy demands attributed to thermal control, ensuring a high level of efficiency in the system is essential in reducing the carbon footprint of a building.

Thermal discomfort is often excepted within commercial buildings as a result of differing physical and psycho-social factors of its occupants. It is demonstrated in this case study, however, that the reported thermal discomfort represents a level of energy inefficiency both in the HVAC system and the resulting behaviour of the occupants.

This process should prove to be an important initial step in reducing the carbon load associated with all commercial property.

Increased control of the Built Environment and reducing the energy use of buildings are potentially contradicting demands placed on a building. It is important that the building structure and infrastructure are designed to minimise the energy demands of a building. Good management, maintenance and regular upgrading are therefore also essential to a building performing in the desired manner.

6. ACKNOWLEDGMENTS

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