Quantitative vs. Qualitative Methodologies to Investigate Environmental Control in the Workplace:

Neutral Thermal Sensation and Thermal Environmental Intention

SALLY SALOME SHAHZAD[1], JOHN BRENNAN[2], DIMITRIS THEODOSSOPOULOS[3]

[1,2 & 3]Edinburgh School of Architecture and Landscape Architecture, University of Edinburgh, Edinburgh, UK

ABSTRACT: This study compares the application of qualitative and quantitative methods to investigate user comfort and environmental control in the workplace. This is examined by environmental measurement and user satisfaction in two workplaces with respectively low and high levels of individual environmental control. An open plan office in Scotland is selected with automatic displacement ventilation, where users have access to limited windows. In contrast, a cellular plan office in Norway is chosen that provides every user with control over a window, in addition to the ability to adjust heating and cooling. Complimentary quantitative and qualitative methodologies are applied with particular emphasis on Grounded Theory methods. Questionnaire, environmental measurements and semi-structured interviews are used. A new visual recording method is applied to analyse the subject in its context qualitatively. Information regarding all users and their environment is applied as colour codes to floor plate layouts. The results are compared with the quantitative analysis. The study examines the significance of applying a qualitative method to question the 'Neutral Thermal Sensation' and expand on the importance of the 'Thermal Environmental Intention'. This paper suggests that the quantitative appraisal could be associated with a risk of misjudgement.
Keywords: methodologies, analysis, thermal comfort, individual control, workplaces

INTRODUCTION

This paper compares the application of a quantitative and a qualitative methodology to research the thermal environments of two buildings with high and low levels of environmental control. The aim is to discover differences and misjudgements of these two approaches. Through this comparison, the 'Neutral Thermal Sensation', which is the basis of thermal comfort studies, is questioned. In addition, the qualitative analysis highlights the importance of the 'Thermal Environmental Intention, which is the user's intention to change and apply control over the thermal environment.

NEUTRAL THERMAL SENSATION

ASHRAE presents a seven-point scale for thermal sensation surveys as hot, warm, slightly warm, neutral, slightly cool, cool and cold [1]. The ASHRAE standard and defining the comfort zone are based on the neutral thermal sensation [2]. For instance, the ASHRAE handbook explains that 'acceptability is determined by the percentage of occupants who have responded as neutral or satisfied with their thermal environment' [2]. Other studies of thermal comfort including the experimental chambers and adaptive comfort are also based on the neutral thermal sensation. For example, Fanger's experiments to find the optimum temperature are on this basis. Bluyssen explains that Fanger 'strongly believes that comfort can be reached when the heat balance of the human body is neutral' [3]. He discovered that 'for practical purposes the neutral temperature is invariant [4].

Based on a study in 2007, Humphreys found that many people were comfortable when they did not feel neutral regarding the surrounding thermal conditions. In the UK, where the temperature is generally cold, people were comfortable when experiencing sensations, such as neutral, slightly warm, warm and occasionally hot [5]. Hitchings explains that 'instead of talking about what temperatures feel neutral in particular places when we have already accepted this to be dynamic, the ambition may now be to reveal which techniques people are willing to employ to get through particular periods more sustainably' [7]. Although this was recognised in 2007, adaptive comfort studies are still based on the neutral thermal sensation [6 & 8]. For example, Nicol's 'scatter of neutral temperature', which is presented in figure 1, shows how neutral temperature changes according to outdoor temperatures in free running buildings [6].

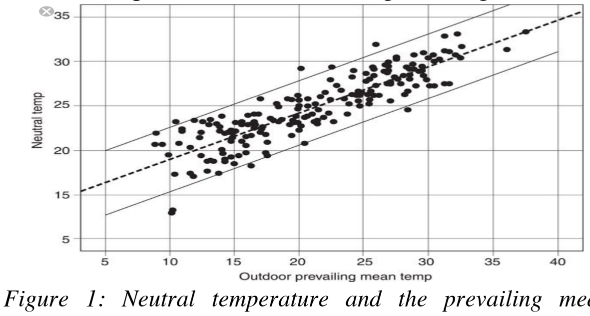


Figure 1: Neutral temperature and the prevailing mean outdoor temperatures in free-running buildings [6]

ENVIRONMENTAL CONTROL

Different studies explain the impact of environmental control on user comfort [9, 10, 11 and 12]. Nevertheless, the prevalence of deep open plan layouts and the speculative nature of workplace development prevent the direct influence of users on the indoor thermal environment and replace it with centralised facilities management [13]. In addition, there is a strong preference for centralised automatic systems to eliminate users' influence on the system to streamline the facilities management [14]. Different studies have been conducted regarding the pattern of use of environmental controls, such as windows [5, 15]. This paper compares environments with high and low levels of individual control over the thermal environment. It compares cellular and open plan offices with respective high and low levels of environmental control.

Anglo-Saxon Open Plan vs. Scandinavian Cellular Plan Offices. The working culture, legislation and building traditions of Anglo-Saxon and Scandinavian countries are very different. This is followed by a difference in the design of workplaces as well as individual environmental control [16]. In Scandinavia, every worker has the right to access natural light and ventilation [16]. In order to maximise these two aspects, offices are located around the perimeter of the floor plates, in the form of traditional personal offices. In this case, every individual is provided with a high level of environmental control. In contrast, the open plan layout has become common in Anglo-Saxon countries. The high level of communication and very efficient use of space are the benefits of an open plan office [17, 18]. In the deep open plan offices, many occupants are allocated far from windows and openings, and they are provided with very limited environmental control.

METHODOLOGY

Traditionally, in thermal comfort studies, quantitative methodologies have been used, however the application of the qualitative methods has recently been encouraged [7]. In this study, a combination of quantitative and qualitative methods is employed with particular emphasis on the qualitative part, which is the Grounded Theory. The latter is a cycle process of designing, collecting and analysing the information to develop hypotheses into a theory [19]. In this research, different pilot studies were conducted to formulate a research plan to be employed at the site. Measurements of the thermal environment and questionnaires are used simultaneously at every workstation as the traditional techniques. The questionnaire is based on the ASHRAE seven-point scale. In addition, semi-structured interviews are applied as a qualitative tool to investigate environmental control and comfort in depth. The quality of the thermal environment at every workstation is compared to the commonly used worldwide standard, ASHRAE Standard 55-2010, by using the second version of the ASHRAE Thermal Comfort Tool.

CASE STUDY BUILDINGS

This research includes two good practice examples of workplaces with low and high levels of individual environmental control. An open plan office with centrally controlled displacement ventilation in Aberdeen, Scotland, is researched with low levels of individual environmental control. In contrast, an air conditioned cellular plan office in Oslo, Norway, is investigated with high levels of individual environmental control. The plans are presented in figure 9 and the sections in figure 2. In the open plan office, only people seated around the perimeter of the building have access to limited openable windows and blinds to control their thermal environment. The majority of the people are allocated to workstations at the centre of the open plan with no means of control. However, in the cellular plan office every individual has access to an openable window, internal and external blinds and a control device to adjust the temperature, see figure 2. In the open plan practice 81 votes and in the cellular plan office 97 votes are considered in this study. Approximately equal numbers of men and women with a variety of ages have participated in the research.

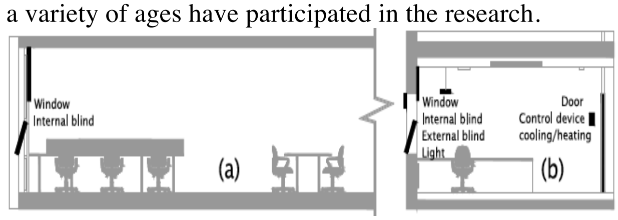


Figure 2: Sections: Environmental control in (a) British open plan and (b) Scandinavian cellular plan office

BUILDING PERFORMANCE

Energy Consumption. The energy use of the two buildings is compared with the CIBSE TM 22 energy benchmark [20]. As shown in figure 3 the cellular plan office has a much higher energy use, 552.80 KWh/m^2, compared to the open plan office, 159.39 KWh/m^2.

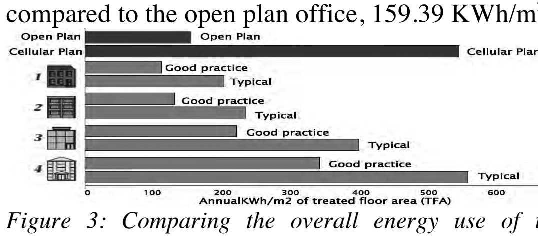


Figure 3: Comparing the overall energy use of the two buildings against the CIBSE energy benchmark (simplified)

CO2 Level. As shown in figure 4a, the cellular plan office has slightly lower CO_2 levels, but both of the buildings are within the acceptable range.

Environmental Control. The availability of control over temperature and ventilation in the two buildings is compared in figure 4b. In the open plan, 77% of the participants have no access to any means of environmental control as they sit close to the centre, in contrast to 91% of the participants in the cellular plan who have full personal control over a window, door, corridor blind, internal and external blinds, as well as a control device to adjust cooling and heating.

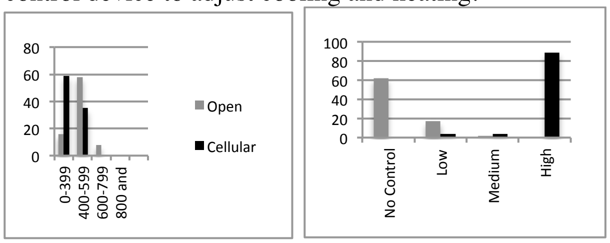


Figure 4: Comparing the two buildings in terms of (a) CO_2 levels; and (b) availability of environmental control

Predicting Thermal Comfort. The thermal environments of the two buildings during the period of a day are compared with the ASHRAE Standard 55-2010 comfort zone, both adaptive and PMV models, see figures 5a and 5b. The basis of both models is the 'Neutral Thermal Sensation'. The adaptive model predicts that 94% of the people in the open plan layout and 100% in the cellular plan office are thermally comfortable. The PMV model predicts that 48% of the people in the cellular plan office have a neutral thermal sensation, while only 9% of the people in the open plan workplace have the same neutral feeling.

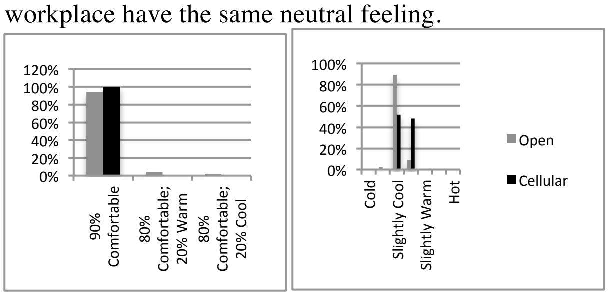


Figure 5: Thermal environments (a) adaptive (b) PMV models

The building performance analysis of the two buildings shows that both buildings provide relatively a good quality of an indoor thermal environment, although the performance of the cellular office is slightly better. Both buildings perform well according to the energy benchmark, in this case the open plan is more efficient. The cellular office provides significantly a higher level of individual environmental control compared to the open plan office.

QUANTITATIVE VS. QUALITATIVE ANALYSIS

Although steady state and adaptive comfort theories oppose each other, both of them use quantitative methods and analysis. The former takes place in experimental chambers with a few controlled variables, while the latter is measured in the real life context of workplaces [21].

Quantitative Analysis. In the open plan office, 40% of the participants reported having a neutral thermal sensation, 49% reported having no desire for a change in temperature, 40% reported being satisfied, and 64% reported being thermally comfortable, see figure 6. The number of respondents who reported neutral, no change and satisfied is very similar. In addition, the level of comfort reported by participants in the open plan office is much higher than the PMV prediction, while much lower than the adaptive model. Furthermore, the number of respondents who reported a neutral thermal sensation is much lower than the adaptive model and much higher than the PMV model. In the cellular plan office, 46% of the occupants reported having a neutral thermal sensation, 46% reported having no desire for a change in temperature, 71% reported being satisfied, and 81% reported feeling thermally comfortable, see figure 6. The number of respondents who reported neutral and no change is very close. The level of comfort reported by participants in the cellular plan workplace is much higher than the PMV prediction, while lower than the adaptive model. In addition, the neutral sensation reported in the cellular office is much lower than the adaptive prediction, but very close to the PMV model. With the exception of the latter, the actual survey results are significantly different from either the adaptive or PMV predictions in both buildings.

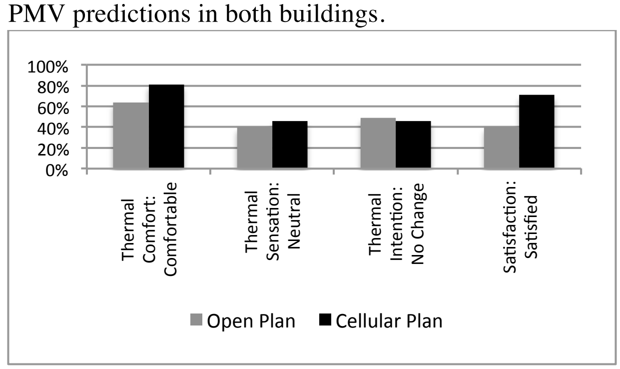


Figure 6: Comparing the two buildings regarding the desired thermal comfort, sensation, intention, and satisfaction

In addition, the survey statistics in both buildings suggest a close relationship between the 'Neutral Thermal Sensation' and 'No Change' thermal intention, as the results are very close. However, they also suggest that more people reported being thermally comfortable than those with a neutral thermal sensation or no change intention in both buildings.

Qualitative Analysis. Although the architecture of a building directly influences the indoor thermal environment, architects have passed the responsibility to provide thermal comfort to engineers [6]. The results of thermal comfort studies, such as Fanger's heat balance equation, although very useful, are often expressed in a language that may not be convenient for architects.

Visual Analysis Tool. Visual tools are commonly used in the field of architecture to apply information on plans and sections. They add a different value and perspective by putting together different information regarding a specific aspect in a visual way. In this paper, a visual recording technique shown in figure 9 has been used, in which the information has been expressed by applying different colours to the floor plates. Figure 7 shows the analysis of an individual workstation, which is a top view of a seated person. The colours inside the squares show the PMV and adaptive predictions based on the ASHRAE tool and environmental measurements. The colours inside the ellipses symbolising the person's body, indicate the person's reported survey at the time of the measurements at the particular workstation. The green colour shows an acceptable situation, while blue, red, and orange are respectively cold, warm, and an unacceptable situation.

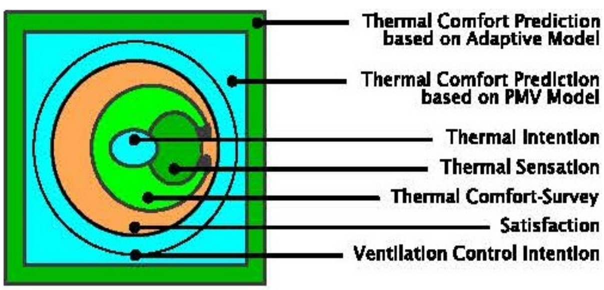


Figure 7: Qualitative demonstration of the information regarding a workstation, top view

Neutral Thermal Sensation. The qualitative analysis shows that 48% of the participants in the cellular plan and 46% in the open plan prefer to have other thermal sensations than neutral. Many respondents want no change in the temperature when they feel slightly warmer or cooler, while others prefer a change in the temperature when they have a neutral thermal sensation, see figure 8. Occasionally respondents may have an extreme temperature desire, such as a slightly cooler intention when they already feel cool.

Figure 8: Sample of participants who do not prefer a neutral thermal sensation, top view

Neutral Thermal Sensation and Comfort. Qualitative analysis shows that 50% of the respondents in the cellular plan office and 53% of the participants in the open plan are comfortable when they do not have a neutral thermal sensation. In addition, the interview results confirm that the majority of participants desired temperatures other than neutral for working; 40% of the participants preferred to work feeling slightly cool and occasionally cool, in order to feel fresh and not sleepy, while 30% of the participants desired slightly warm and occasionally warm working conditions since they were not physically active at work. Only 30% of the participants preferred to work feeling neutral.

Environmental Thermal Sensation and Satisfaction. Quantitative analysis shows lower levels of satisfaction compared to thermal comfort in both buildings, see figure 6. Qualitative analysis shows that in the cellular plan, 100% of the participants who reported satisfied are also comfortable, while only 62% of the participants who reported being comfortable are also satisfied. In the open plan office, 86% of the respondents who reported being satisfied are also comfortable, while only 35% of the people who reported being comfortable are also satisfied. This suggests that satisfaction is more of a delicate matter compared to comfort and that user satisfaction has a strong relationship with their thermal comfort so that satisfied people are more likely to be thermally comfortable.

No particular pattern or relationship was found between the use of environmental control and user satisfaction or comfort. However, the qualitative analysis shows a strong relationship between satisfaction and thermal environmental intention, including user intention to change the temperature and ventilation. In the cellular plan office, 93% of the respondents with a less than satisfied also reported having a thermal intention other than 'No Change'. In addition, 90% of the people with a 'No Change' thermal environmental intention reported being satisfied. In the open plan setting the number of respondents who reported being satisfied as well as no change is 62%, which is lower than the cellular plan. However, the number of respondents with a ventilation intention, who would like to apply a change to the air quality or air movement is 90%.

In addition, 96% of respondents with a 'No Change' thermal environmental intention reported satisfied. The satisfaction of the participants in the cellular plan with easy access to a window is more related to their desire to change the temperature, while people's satisfaction in the open plan with no access to any window or environmental control is more related to their desire for ventilation, such as the air movement and air quality. Conclusively, the qualitative analysis suggests a significant influence of overall thermal environmental intention on user satisfaction.

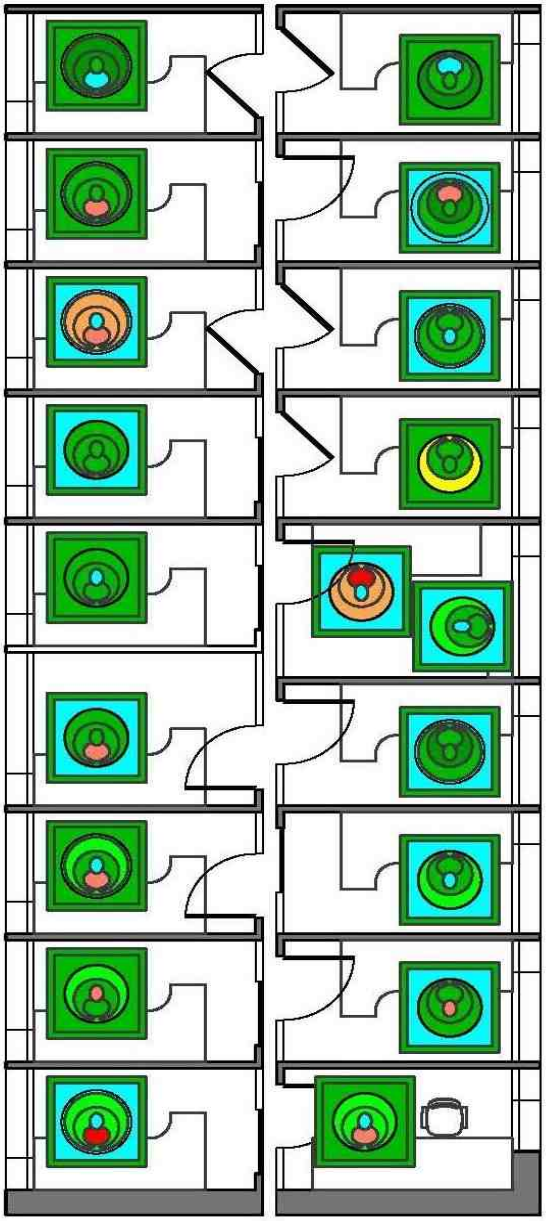


Figure 9 (a): Plan: Sample of the qualitative analysis of the Scandinavian cellular plan office, morning of 22 May 2012

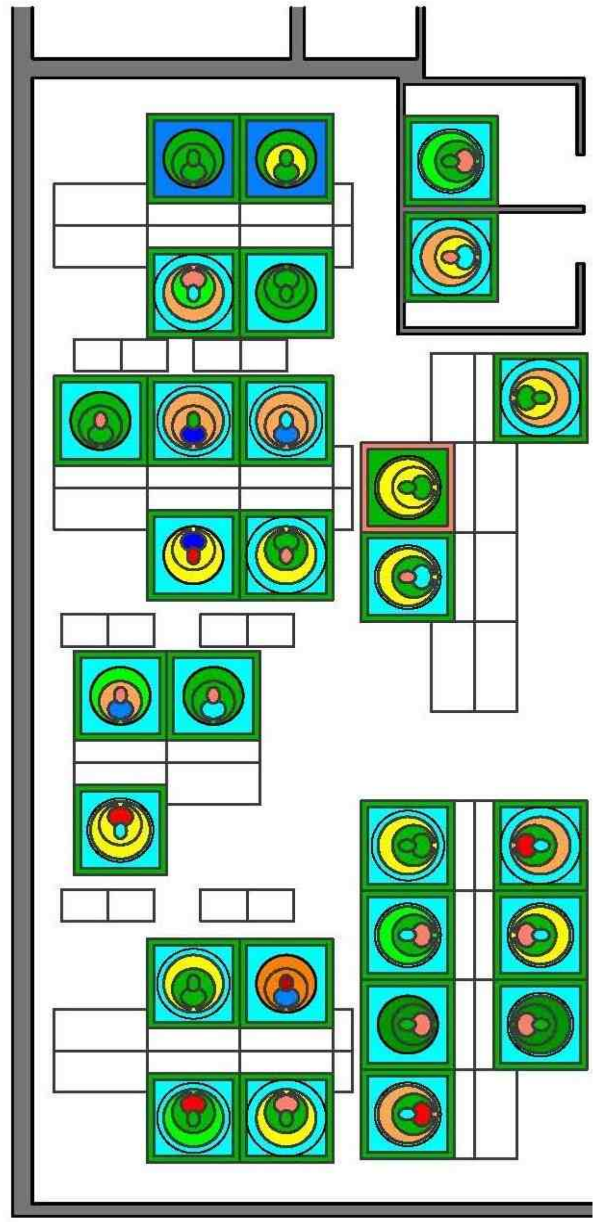
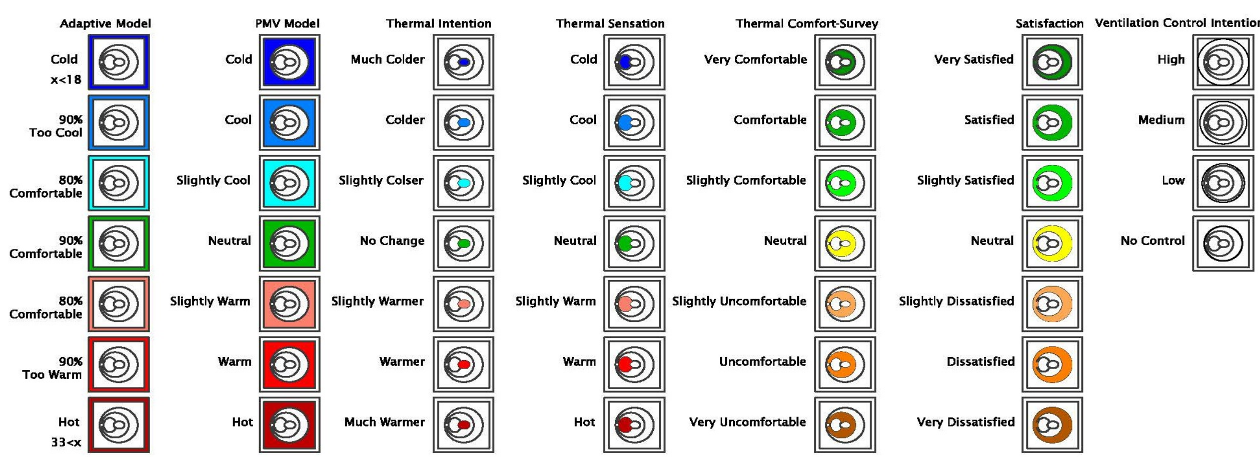


Figure 9 (b): Plan: Sample of the qualitative analysis of the British open plan office, morning of 28 August 2012



CONCLUSION

This paper compares a quantitative and a qualitative approach to research thermal comfort. These two approaches have different applications. It suggests that the quantitative approach is more suited for general understanding of a situation such as the overall satisfaction. However, the interpretation of the connection between information through a quantitative approach could drive to a misjudgement. Here, 'the significance of often straightforward mathematical relationships becomes almost talismanic' [22]. Therefore, user competence is required as to where to apply the quantitative or qualitative method. The qualitative analysis of the collected information reveals connections between the data regarding a particular person that changes the meanings and influences the findings of the research. The qualitative analysis in this paper suggests that the 'Neutral Thermal Sensation' does not guarantee thermal comfort as the quantitative analysis of the same data suggests as well as being presumed in the previous studies of thermal comfort. This confirms Humphreys' findings regarding the 'Neutral Thermal Sensation' that many people prefer thermal sensations other than neutral to feel comfortable [5]. In addition, qualitative analysis suggests that satisfaction is significantly influenced by the 'Environmental Thermal Intention', such as temperature and ventilation. Satisfied respondents have limited intention to change the temperature, ventilation rate or air quality. Finally, occupants of the cellular plan office with a high level of individual environmental control report much higher levels of thermal comfort and satisfaction compared to the occupants of the open plan workplace with limited access to environmental control, such as openable windows.

Field studies of thermal comfort have been criticised for the complexities of the context and diversity of variables influencing the comfort conditions [3]. In addition, Nicol et al. suggest that the findings of a field study may not be applicable to other buildings since the context changes, thus generalising the findings of a field study is difficult [6]. In addition, in this study, due to the constraints on time and resources in a doctoral study period, as well as collecting the data in a qualitative way, such as interviews, the sample size is fairly small. However, this research suggests that the qualitative analysis reduces the risk of misjudging the information, so the results are more likely to be accurate and applicable. In addition, Nicol et al. explain that the way forward is through more research in a variety of contexts to gain a better understanding of this complicated field to both clarify and generalise the findings [6].

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