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Energy Dependant Behaviour and Thermal Comfort: Home and Office Based Workspaces

Ibrahim Halil Ozdemir[1], Sally Shahzad[1*]

1 School of Architecture, Arts Tower, Western Bank, University of Sheffield, Sheffield, S10 2TN, UK

(*Corresponding Author: s.shahzad@sheffield.ac.uk)

ABSTRACT

How does paying energy bills impact occupants' comfort regarding the thermal environment? Are they more comfortable, when all energy bills are paid for them, as compared to when they are responsible for their energy bills? 40% of the energy use is spent for space heating and cooling. The recent energy crisis and the increase of the energy bills significantly impacted the affordability of space heating. Also, post COVID-19, working from home became part of the working arrangements for many people, which also signifies the impact of heating affordability. This work investigates the impact of paying energy bills on the behaviour and thermal comfort of occupants. Three work settings were explored, including office settings and two home environments, one with all bills included in the rent and one, in which the occupants paid their own energy bills. Only in the latter, participants paid the energy bills. Field test studies of thermal comfort were applied in the UK in the winter of 2021. 57 participants responded to thermal comfort surveys three times a day during five days, while the environmental measurements were recorded. Additionally, ethnographic behavioural video recordings were applied using a thermal camera to capture environmental and personal adjustments, as well as surface temperatures of the surroundings, while occupants were working. Overall, 601 datasets were included in this work. The results did not suggest any significant differences in the comfort of the occupants in the three environments. However, significant differences were found between the energy uses of the three environments. The home, in which all bills were included in the rent used 9.2 times more energy, as compared to the home environment, where the occupants were responsible for paying their own energy bills, and 2.4 times more energy use, as compared to the office settings.

Keywords: energy, adaptive behaviour, thermal comfort, office, home, workspace

1. INTRODUCTION

People typically spend 90% of their time either at home or in office spaces [1]. The commercial and real estate sector is responsible for 40% of global energy consumption annually and contributes to over a third of carbon emissions [2]. In the EU, heating and cooling spaces account for 40% of energy usage [3], necessitating a balance between energy consumption and comfort [4]. A satisfying indoor environment is crucial for both office and home settings, accommodating various activities including computer-intensive work [5].

The past decade has witnessed a gradual global rise in the practice of working from home (WFH), with a pronounced surge in spring 2020 due to the COVID-19 pandemic [6-8]. This shift to remote work has led to a transition from conventional office setups to home-based work arrangements. Some companies are considering extending remote work options beyond the pandemic [9], highlighting the need to enhance home-based work environments. Despite substantial research on office spaces, there's limited exploration of the thermal conditions and energy use in home-based workspaces. Homes were originally designed for domestic activities; and thus, turning them into an office setting has challenges, such as having a dedicated workspace, ensuring proper indoor environmental conditions to work efficiently due to socioeconomic reasons [10,11]. Along these lines, the design of the home-based work environment and accordingly occupant satisfaction are highly important [12].

Considering the significant influence of human behaviour on building performance and energy consumption [13], understanding the thermal comfort and adaptive behaviours of individuals in this new era of remote working is vital for managing energy use. This

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work investigated the thermal comfort and energy use in three environments, including an office building and two home-based work environments when all bills were included and excluded from the rent

2. RESEARCH METHODS

Field test studies of thermal comfort were conducted in 26 environments, including office and home environments in the UK in the winter of 2021. The heating in the office building was centrally operated and openable windows were available for the occupants, who did not pay any energy bills. The set up of all home environments were similar, except the payment for energy bills, as in half of the houses all bills were included in the rent (home with bills included) while the occupants of the other half were responsible to pay their own energy bills (home). 601 responses were collected from 57 participants who were young adults in the 21-35 age category, including 23 females and 34 males who worked for 5 to 8 hours each day. The participants responded to a thermal comfort survey three times a day during five days, while environmental measurements were recorded. Also, ethnographic behavioural video recordings were applied by using a thermal camera while they were working. The ASHRAE seven-point scale [14] of thermal sensation (TSV), thermal preference (TP), overall comfort (OC), and satisfaction (SA) were the key survey questions.

3. ANALYSIS

Table 1 compares the indoor temperature (Ti) and relative humidity (RH) in the three working environments demonstrating significant differences. The temperature range in the office environment was more limited, as compared to both home environments. Home with bills included showed a wider range of indoor temperatures (i.e. 10°C). However, its minimum temperature was up to 4°C higher than the other home environment, where occupants paid their bills. Also, the highest temperatures were recorded in homes with all bills included, reaching as high as 30.75°C during the winter, due to the availability of free space heating. The highest humidity levels were recorded in homes, where occupants paid their bills. Also, they had the lowest indoor temperature recording of 17.77°C.

Workspace Type		N	Minimum	Maximum	Mean	Std. Deviation
Office	Ti	285	19.32	26.67	23.08	1.62
	RH	285	28.48	51.88	39.75	4.97
Home	Ti	130	17.77	26.11	23.41	1.76
	RH	130	32.64	64.56	48.90	7.04
Home All bills included	Ti	186	21.34	30.75	25.95	1.91
	RH	186	24.99	61.24	40.85	6.69

Table 1. Indoor temperature and humidity ranges

The average mean indoor air temperature across all measurements was recorded at 24.04°C. Meanwhile, the mean comfort temperature, determined through the application of Griffiths method [15] and a regression slope of 0.50 [16] was established at 23.76°C. The mean indoor temperatures for the office, home, and home with bills included were 23.08°C, 23.41°C, and 25.95°C, respectively. Correspondingly, the mean comfort temperatures for these three environments were 23.06°C, 22.72°C, and 25.57°C, as illustrated in Figure 1. This was higher than CIBSE Guide A [17]. The comfort temperatures worked better with the ASHRAE Standard 55-2013/2017 [18,19]. When comparing occupants' responses while working, it was observed that the comfort temperatures in the office and the home were similar. However, the comfort temperature in the home with all bills included was 2.51°C higher than that of the office and 2.85°C higher than that of the home.

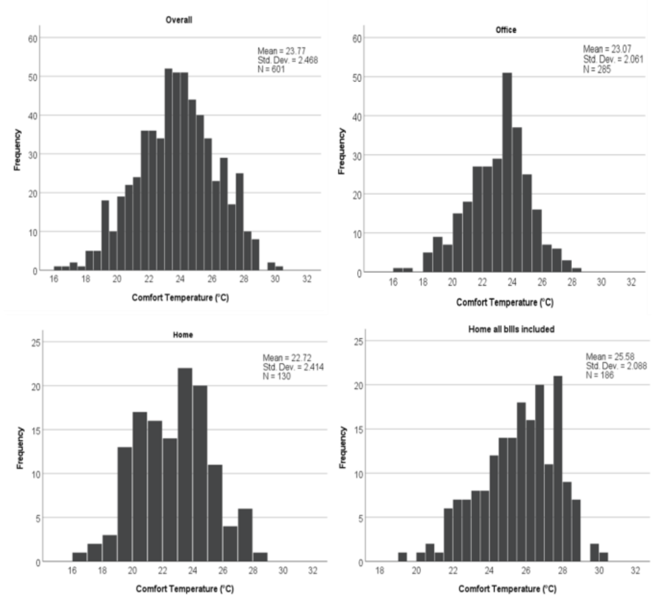

Fig. 1 Comparing Griffiths` comfort temperatures between the three environments

The survey responses were analysed using an ANOVA test. The analysis revealed no statistically significant differences in OC, TP, and TA responses. However, significant differences were found in TSV and SA responses among the groups. Specifically, a statistically significant difference in TSV responses ($p = 0.024$) was observed between occupants working at

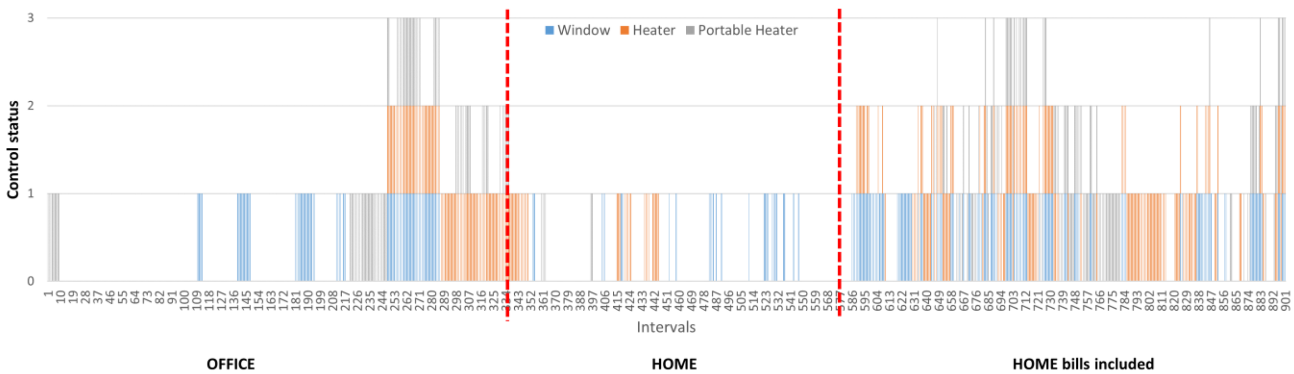

Fig. 2 The Use of Thermal Control Systems

home and in office. Additionally, SA survey responses showed significant differences ($p = 0.007$ for home environments, and $p = 0.033$ for home environments with bills included) compared to those working in offices.

Various thermal control systems, such as openable windows, central heating, wall-mounted electrical heaters, and portable heaters, were identified in three office environments. Thermal video recordings were analysed to assess their thermal control usage patterns. Figure 2 illustrates 30-minute intervals showing when these controls were on.

The availability of thermal control options was limited in the office and home where occupants paid their bills. In the office building, central heating was provided, but occupants did not have access to any thermostats. In both home environments, wall-mounted electric heaters were available. In office and home environment, the percentages of having a portable heater were 33% and 16% respectively. Similarly, in both environments, portable heaters were not that available. On the contrary, 86% of the occupants in the home with bills included environments had portable heater and they used a variety of thermal control systems more often and for more prolonged periods, as compared to the occupants of the other two environments. In Figure 3, a pie chart was used to represent the proportions of various energy usage combinations observed in the research, gathered through thermal video recording while occupants were working. As an example, the brown segment illustrates that the heater and portable heater were on when the window was open. While this situation was observed in 7% and 9% of the observation period in the office and the homes with all bills included respectively, this situation was not observed in the home.

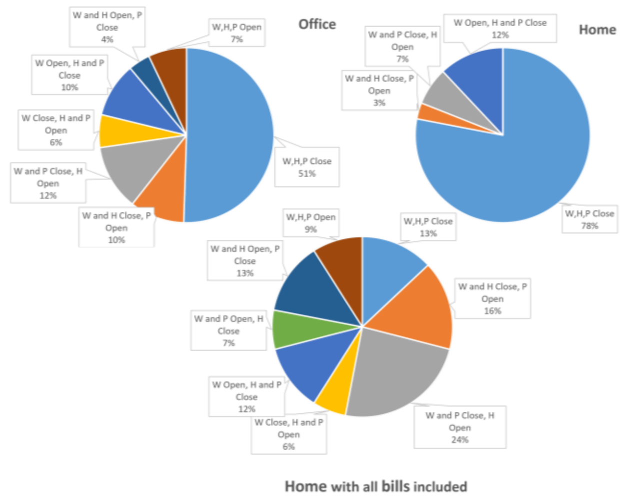

Fig. 3. Percentage of thermal control usage
W=Window, H=Heater, P=Portable Heater

To calculate energy consumption, determinations were based on the specifications of all wall-mounted heaters and portable heaters, using manufacturer manuals, which indicated an energy consumption of 2 kWh. The information regarding the energy consumption of the central heating in the office building was sourced from another study [20]. In this work, energy calculations per person was required to compare the environments and to consider the role of the occupants. The mean average energy consumption per person in an hour in the case studies for the office, home, and home with bills included were calculated as 0.74 kWh/pp, 0.19 kWh/pp, and 1.8 kWh/pp, respectively. This indicated that energy consumption for space heating in the home with all bills included is significantly higher (up to 9 times) than the other environments. In homes where bills are included in the rent, occupants' energy consumption for heating is 9.22 times higher than occupants who pay their own bills.

Likewise, office workers who don't pay the bills consume 3.77 times more energy than home residents, who pay their own bills. As a result, it has been found that users who are not responsible for energy bills consume much more energy than respondents, who pay their own energy bills

4. DISCUSSION AND CONCLUSION

The results indicated the following key findings:

- The differences between the comfort level of participants in the three office environments were not statistically significant, despite the significant differences in the indoor temperatures.
- Home with all bills included in the rent had a much wider range of indoor temperatures (i.e. 10°C) reaching up to 30.75°C and a much higher mean comfort temperature (i.e. 25.57°C).
- The occupants of the home environment with all bills included used a variety of thermal control systems more often and for more prolonged periods. The occupants in the home environment where occupants paid their bills used much less thermal control systems and for shorter periods.
- Energy usage in the case studies for the office, home, and home with all bills included were calculated as 0.74 kWh/pp, 0.19 kWh/pp, and 1.8 kWh/pp, respectively. This suggests there was up to 9 times higher energy use in home, when all bills were included in the rent. The lowest energy use was found in homes, where occupants paid their energy bills.
- The results indicated that energy bills is an important driver for energy use. The occupants used more active and energy-intensive control systems to achieve thermal comfort when they were not responsible for paying their energy bills. However, their comfort level was not much different from that of occupants, who paid their energy bills.
- The results also revealed that in the office and especially in the home with all bills included, an excessive amount of energy is consumed and wasted to ensure thermal comfort. In such settings, the approach to achieving thermal comfort often involves spending more energy rather than using it efficiently. On the contrary, in the home environment, the occupants aimed to attain thermal comfort while conserving energy.

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