The Effects of Lowering Temperature Setpoints on Perceived Thermal Comfort – An experimental study in office buildings

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ABSTRACT

This study investigates the impact of lowering temperature setpoints on occupants' thermal comfort in office buildings, prompted by government initiatives in Europe, including the Netherlands, to reduce energy consumption. The research methodology involved a case study conducted in three office buildings in The Netherlands. Data on occupants' perception, motivation, clothing thermal insulation, activity level, discomfort, and thermal control options were collected through interviews conducted for thermal comfort surveys and building surveys. Statistical analysis revealed the importance of providing diverse control options to accommodate individual preferences, specially under temperatures outside the comfort zone. Occupants with more control options reported higher satisfaction. Variations in thermal sensation and comfort were observed among gender, age, and BMI groups, with females experiencing more discomfort and cold sensations at lower temperatures. The study emphasizes the need to consider individual differences in thermal comfort and the importance of adequate thermal control in office design and energy-saving measures. The findings contribute to the development of effective strategies for lowering temperature setpoints while maintaining occupant comfort and satisfaction.

KEYWORDS

Temperature setpoints, occupant thermal comfort, energy-saving measures, office buildings

1 INTRODUCTION

The pursuit of energy efficiency and reduction of greenhouse gas emissions has become a global priority, driven by the Russian invasion of Ukraine in 2022. Governments and building managers are exploring ways to reduce energy consumption. One widely proven approach to achieving energy savings in buildings is through human-based retrofits, specifically by adjusting HVAC temperature setpoints, which can be implemented at minimal cost (Haniff et al., 2013). Given this situation, in the beginning of April 2022, the Dutch government launched a campaign titled "Zet de knop om" ("turn the knob"), outlining plans to reduce energy consumption for room air conditioning in the short term (Rijksoverheid, 2022). The government proposed adopting a "2 degrees lower" winter setpoint of 19ºC in all governmental buildings, as according to the European Commission HVAC systems in buildings account for approximately 40% of the EU's energy consumption and 36% of CO_2 emissions. However, it has also been observed that increasing the dead band results in decreased occupant thermal comfort (Jafarpur & Berardi, 2021). Neglecting comfort for energy efficiency may lead to issues like discomfort, fatigue, and reduced productivity (Ortiz et al., 2017). Humans are constantly reacting and adapting to indoor thermal surroundings. Previous studies have highlighted the role of adaptive behaviours in achieving thermal comfort and energy savings, including physiological, behavioural, and psychological responses (Sun & Hong, 2017). However, the adoption of such behaviour measures can be influenced by various factors, including occupant awareness, motivation, perceived effectiveness, convenience, and the availability of feedback and incentives (D'Oca et al., 2017; Hu et al., 2020). Moreover, granting occupants the ability to exert control over the thermal environment has been shown to enhance their satisfaction. Leaman & Bordass (1993) found that greater occupant control access leads to higher tolerance for thermal variations in buildings. These findings highlight the complex and subjective nature of the relationship between energy-saving measures and occupants' perceived thermal comfort. Empirical studies are crucial to understanding the effects of lowering temperature setpoints on occupant comfort. This paper presents a case study in three Dutch office buildings to explore the trade-off and provide insights on lower temperature setpoints and thermal comfort. The main research question is: *"What are the effects of lowering the temperature setpoints, in Dutch office buildings, on the occupant's thermal comfort?"*. The study used thermal comfort surveys to collect data on occupant comfort levels at different temperature setpoints, focusing on behavioral responses, occupant satisfaction, and personal motivation.

2 METHODOLOGY

2.1 Design and Procedure

A thermal comfort study was conducted in three office buildings in the Netherlands to assess the impact of lowering temperature setpoints on occupant thermal comfort. The study involved conducting individual interviews, lasting around 7 minutes on average, in a dedicated room. The interviews were conducted in English and incorporated a combination of closed-ended and open-ended questions to gather extensive data. The interview process spanned approximately two days per building, resulting in a total duration of six days for the entire survey. The same questionnaire and methodology were used across all three buildings in the study.

2.2 Participants

A total of 121 participants, 65 males and 56 females, took part in the field study. Building A had 51 participants, while Buildings B and C each had 35 participants. The study focused on office workers only, excluding janitors and maintenance staff. Participants were randomly selected and provided with a brief introduction to the study and interview process. Participants who met the inclusion criteria, which included a minimum of one year of work experience in the building for winter comparisons, were invited to participate.

2.3 Buildings

The study examined three office buildings in the Netherlands: two high-rise buildings (Buildings A and C) with glass facades and air heat distribution systems, and one 3-floor office building (Building B) with air and water heat distribution systems, and a balanced window-to-wall ratio. In winter 2022-2023, all three buildings lowered their temperature setpoints, but the extent of reduction varied. Additional information on the buildings' characteristics is provided in Table 1.

Table 1: Brief description of the studied buildings

Building	Height	Location	TSet- before (ºC)	TSet- after (ºC)	Investigated floors	Interviews
A	149.1 m	Rotterdam	22.7	19	15	51
B	10 m	Utrecht	22	20	3	35
C	141.9 m	The Hague	21	19	10	35

3 RESULTS

The respondent group included 121 individuals, aged 18 to over 60. In Buildings A and B, the main age group was 50-59 years, while in Building C, it was 30-39 years. The majority of respondents reported being in the healthy BMI range. The following analysis combines data from all three buildings.

The analysis found that occupants adopt compensatory behaviours in response to lower indoor temperatures, such as adjusting clothing thermal insulation or using radiators. The preference for using radiators to enhance comfort raises implications for energy-saving control.

Figure 1 shows the impact of lower temperatures on thermal comfort. The analysis indicates that occupants generally experience higher comfort levels with higher temperature setpoints. A chi-square test (χ^2 (4, N = 242) = 35.63, p < .001) demonstrates a significant effect of lower temperature setpoints on perceived comfort. This suggests an association between indoor temperatures and thermal comfort.

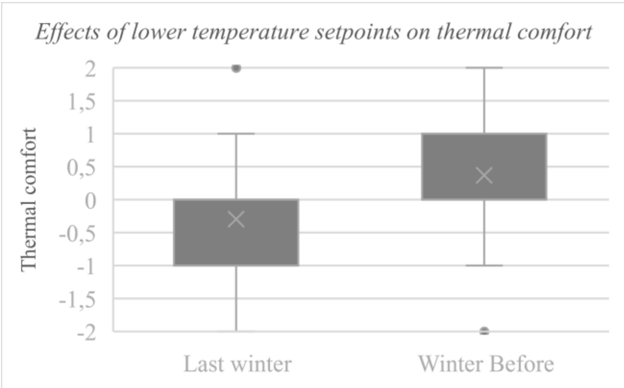


Figure 1: Box-plot illustrating the influence of lower temperature setpoints on thermal comfort. Where -2 signifies discomfortable and 2 signifies comfort. The X represents the mean.

Additionally it was found that, the majority of building occupants displayed a high motivation level (level 4) to save energy. Building B had the highest motivation (65.7%), closely followed by Building A (56.9%). Building C had a relatively lower motivation level (40%). All buildings showed an increase in motivation compared to the previous winter, with Buildings B and C having the highest percentage of occupants with changed motivation. An analysis of motivation to save energy identified sustainability as the primary driving factor across all three buildings. The second most reported motivation factor in all buildings was high energy bills.

Remarkably, the percentage of individuals motivated by the war in Ukraine was relatively low: 13.7% for Building A, 5.7% for Building B, and 9% for Building C. Despite this, when comparing the willingness to maintain low temperature setpoints across the three buildings, Building B had the highest level of willingness, with 89% of occupants committed to maintaining the setpoints even after energy prices return to regular values. Building C showed a moderate level of willingness, with 66% of occupants expressing their intention to maintain the setpoints. Building A had a lower level of willingness, with only 43.1% of occupants committed. Notably, within Building A, 31.4% of individuals explicitly stated their willingness to maintain the lower temperature setpoints only if they remained within acceptable levels of thermal comfort.

Figure 2 shows the evaluation of the "Zet de knop om" campaign in the three buildings. Building B had the most favourable evaluation, Building C had a mix of satisfied and dissatisfied occupants, and Building A had a significant percentage of occupants leaning towards being very dissatisfied, dissatisfied, or neutral in their evaluation of the campaign.

These results highlight the varying perceptions of the campaign's implementation across the buildings, with Building B displaying the highest satisfaction level.

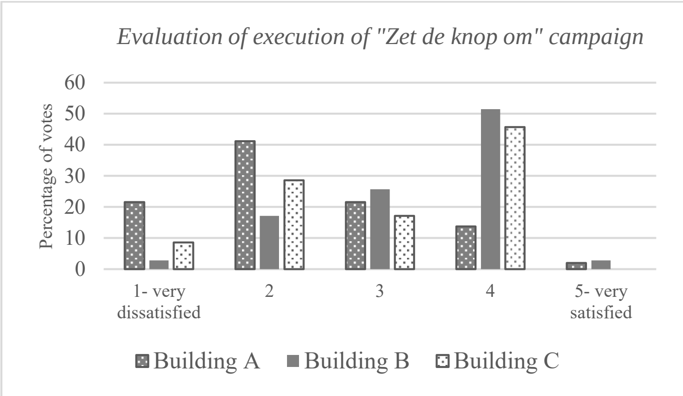


Figure 2: Evaluation of execution of "Zet de knop om" energy-saving campaign across the three buildings

A qualitative analysis identified common complaints in the three buildings: absence of feedback solicitation and perceived disregard for occupants' comfort, lack of control over the thermal environment, and unacceptable comfort levels.

Figure 3 shows the relationship between the number of control options for the thermal environment and occupant satisfaction. A chi-square test (χ^2 (8, N = 121) = 66.65, $p < .001$) revealed a significant difference in satisfaction based on the number of control options. The data suggests that occupants with more control options reported higher satisfaction levels compared to those with limited or no options.

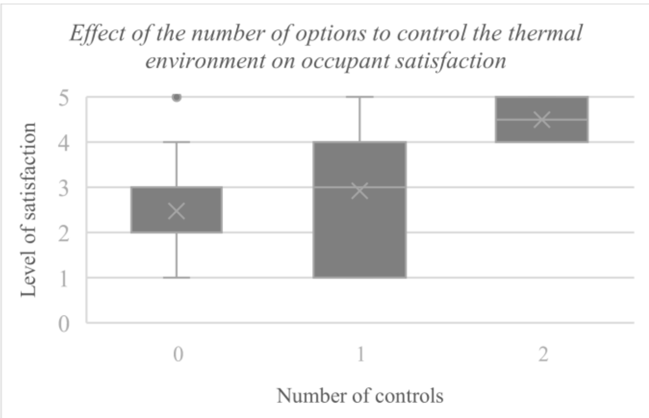
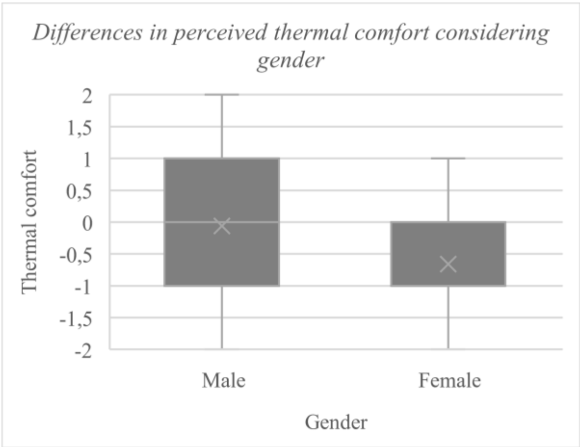
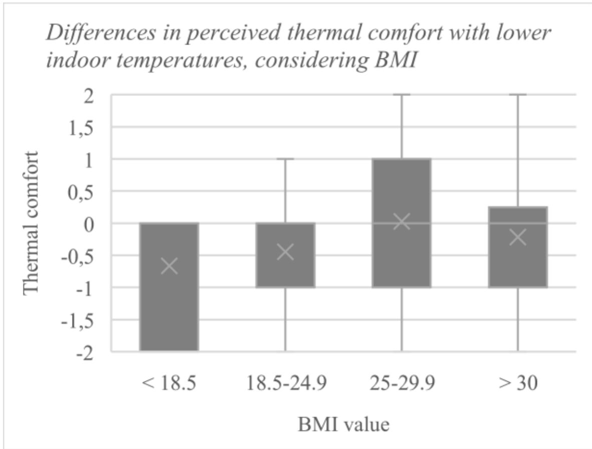


Figure 3: Box-plot depicting the effect of the number of options to control the thermal environment and occupant satisfaction. Where 0 signifies dissatisfaction and 5 signifies satisfaction. The X represents the mean.

Figure 4 illustrates the influence of gender, BMI, and age on perceived thermal comfort. A statistical analysis showed significant differences in perceived thermal comfort with lower indoor temperatures based on gender (χ^2 (4, N = 121) = 13.67, p = 0.00843), BMI (χ^2 (12, N = 121) = 105.6, $p < .001$), and age (χ^2 (12, N = 121) = 57.5, $p < .001$). Suggesting that females experienced more discomfort and cold sensations at lower temperatures compared to males. Moreover, no clear patterns were found for BMI and age.



a)



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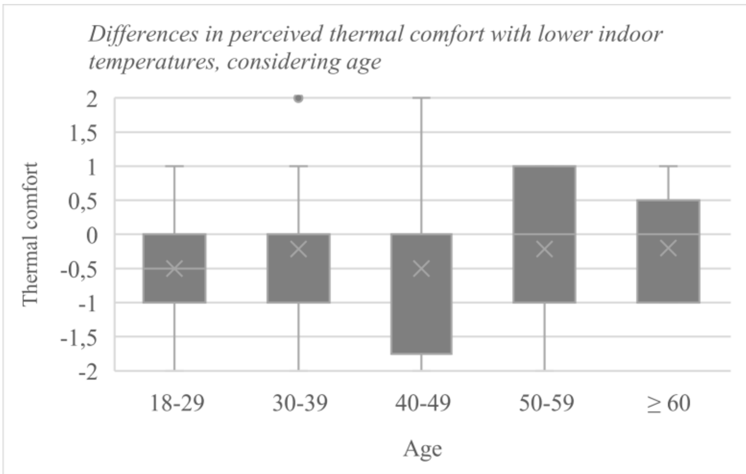

c)

Figure 4: Box-plot illustrating the differences in perceived thermal comfort with lower indoor temperatures, considering gender (a), BMI (b) and age (c). Where -2 signifies discomfortable and 2 signifies comfort. The X represents the mean.

4 DISCUSSION

The case study yielded important findings on occupant behaviour, coping strategies, perceptions, and the impact of temperature setpoints on thermal comfort. Occupants employed compensatory behaviours like adjusting clothing thermal insulation and using radiators in response to lower temperatures, highlighting considerations for energy savings. Previous research emphasizes the role of adaptive behaviours in achieving comfort and energy savings (Butera, 1998; Sun & Hong, 2017). In line with the literature (Chun et al., 2008; Wang et al., 2018), higher temperature setpoints generally led to increased comfort, but individual experiences varied, emphasizing the importance of understanding individual preferences.

Occupants' motivation to save energy primarily stems from high energy bills rather than environmental concerns, as the majority of occupants motivation to save energy has increased since last winter, and there were variations in motivation between different settings (office vs. home), possibly due to personal responsibility for utility bills. Despite this, occupants expressed willingness to maintain lower temperature setpoints, as long as minimum comfort levels were ensured, particularly in Building A. Satisfaction with energy-saving campaigns differed across buildings, emphasizing the importance of feedback and communication. Providing diverse control options improved satisfaction, aligning with existing literature on the positive impact of user control on comfort, satisfaction, energy savings, and productivity.

Gender, age, and BMI influenced thermal comfort, with females experiencing more discomfort in lower temperatures, consistent with previous studies by Indraganti et al., (2015) and Chaudhuri et al., (2018) highlighting women's higher dissatisfaction and sensitivity to temperature variations. Variations in comfort among different BMI and age groups call for tailored considerations. Additionally, exploring whether highly motivated individuals who actively lowered the temperature at home perceived more comfort would have been interesting. However, the data collected in this study, which consisted of participants with uniformly high levels of motivation towards energy conservation, did not allow for definitive conclusions. Without a suitable control group or participants with varying motivation levels, establishing a direct link between motivation, temperature adjustment behaviour, and perceived comfort becomes challenging. Further research with diverse participants is necessary to delve deeper into this question and obtain meaningful insights.

5 CONCLUSION

This study explored the impact of lower temperature setpoints on thermal comfort in Dutch office buildings, revealing significant effects on occupants' comfort perception. Adaptation to lower temperatures varied among individuals based on factors such as age, gender, clothing, and activity level. Control over the thermal environment and clear communication positively influenced comfort, while acceptance of lower setpoints differed across buildings. Higher comfort ratings were associated with greater acceptance, highlighting the link between comfort and energy-saving measures. The study underscores the importance of a holistic approach considering occupant preferences, energy efficiency goals, and adaptive strategies for optimal comfort. Ongoing communication and engagement are crucial for occupant satisfaction and support for sustainable, energy-efficient buildings.

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