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COIMBRA

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THE EFFECTS OF LOWERING TEMPERATURE SETPOINTS ON PERCEIVED THERMAL COMFORT

AN EXPERIMENTAL STUDY IN OFFICE BUILDINGS

Dissertação no âmbito do Mestrado em Engenharia Mecânica na especialidade de Energia e Ambiente orientada pelo Professor Doutor Adélio Rodrigues Gaspar e Engenheira Froukje van Dijken e apresentada ao Departamento de Engenharia Mecânica da Faculdade de Ciências e Tecnologia de Universidade de Coimbra.

Julho 2023

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The Effects of Lowering Temperature Setpoints on Perceived Thermal Comfort

An Experimental Study in Office Buildings

A dissertation submitted in partial fulfilment of the requirements for the degree of master's in Mechanical Engineering in the speciality of Energy and Environment

Os Efeitos da Redução dos Pontos de Regulação de Temperatura no Comforto Térmico

Um Estudo Experimental em Edifícios de Escritório

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Coimbra, July 2023

"Para ser grande, sê inteiro: nada teu exagera ou exclui. Sê todo em cada coisa. Põe quanto és no mínimo que fazes"
- Fernando Pessoa

“To be great, be whole; exclude nothing. Be whole in everything”
- Fernando Pessoa

To Froukje and Atze

Acknowledgements

I am deeply grateful to everyone who contributed, no matter how small their role, to the creation and completion of this master's thesis. Your smiles, kind words, and thoughtful gestures have certainly brightened my days and made this journey more meaningful.

First and foremost, I would like to express my deepest appreciation to my university supervisor, Adélio Gaspar, for his unwavering guidance, valuable insights, and continuous support throughout this journey.

I am also indebted to my internship supervisor, Froukje van Dijken, for her guidance, encouragement, daily inspiration and care during my master’s project. Her mentorship and practical insights provided a crucial real-world perspective that enriched the content of my thesis. I would also like to extend my sincere appreciation to Atze for granting me the opportunity to flourish and acquire profound knowledge within such an exceptional work environment. Additionally, I would like to express my heartfelt gratitude to the entire team I had the privilege of working with during my internship, Arjen, Janneke, Juliët, Mark, Marije, Stan, Stijn, and Tim. Your collective expertise, constructive feedback, and collaborative spirit contributed significantly to the development of this research. A special thanks to Parikshit, Soujanya and Floris for their delightful companionship.

To all the individuals who generously spared their time to participate in the interviews conducted for this study, I am sincerely grateful. Your willingness to share your experiences and insights has been pivotal in providing a rich and comprehensive understanding of the topic. A special thanks to Martine, Rico and Edwin for being so helpful and collaborative.

I would also like to mention Professor Manuel Gameiro for being the spark engine of this journey. Thank you.

Finally, I would also like to acknowledge the projects that supported and provided resources for this research. Your financial assistance, data, and access to relevant materials have been essential in conducting the necessary analysis and reaching meaningful conclusions. The presented work was supported by:

Plurianual - UIDB/50022/2020 and CLING - PTDC/EME-REN/3460/2021

Abstract

This study examines the effects of lowering temperature setpoints on occupants' thermal comfort in office buildings. The motivation for this research stems from the recent initiatives by governments across Europe, including the Dutch government, to reduce energy consumption and address energy security concerns. Lowering temperature setpoints in buildings has been proposed as a potential strategy to achieve these goals. However, it is crucial to understand the impact of such measures on occupants' thermal comfort and satisfaction.

The research methodology involved an experimental case study conducted in three office buildings in the Netherlands. Data was collected through building surveys and thermal comfort surveys conducted via interviews. The building survey provided information on the buildings' characteristics, which could influence occupants' thermal comfort. The thermal comfort survey collected data on occupants' thermal comfort perception, clothing thermal insulation, activity level, type of discomfort felt, and options to control the thermal environment. The collected data was analyzed and statistical analysis techniques were employed to identify patterns and relationships between variables.

The findings highlight the importance of offering diverse control options to accommodate individual needs and preferences, particularly when the setpoints are outside the comfort zone. Occupants provided with a greater number of control options reported higher levels of satisfaction. The study also revealed notable variations in perceived thermal sensation and comfort among different gender, age, and BMI groups. Females tend to experience greater discomfort and cold sensations when exposed to lower temperatures compared to males, suggesting gender-related differences in thermal perception and sensitivity. These results underscore the significance of accounting for individual variances in thermal comfort and highlight the crucial role of ensuring adequate thermal control for users when designing office environments and implementing energy-saving measures. The findings contribute to the development of effective strategies to lower temperature setpoints in office buildings while maintaining occupant thermal comfort and productivity.

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

Resumo

Este estudo explora os efeitos da redução dos valores nominais de temperatura no conforto térmico dos ocupantes em edifícios de escritórios. A motivação para esta investigação decorre das recentes iniciativas dos governos de toda a Europa, incluindo o governo neerlandês, para reduzir o consumo de energia e responder às preocupações com a segurança energética. A redução dos valores nominais de temperatura nos edifícios tem sido proposta como uma estratégia potencial para atingir estes objectivos. No entanto, é crucial compreender o impacto de tais medidas no conforto térmico e na satisfação dos ocupantes.

A metodologia de investigação envolveu um estudo de caso experimental realizado em três edifícios de escritórios nos Países Baixos. Os dados foram recolhidos através de levantamento das características dos edifícios e avaliação do conforto térmico através de entrevistas. Do levantamento das características dos edifícios obteve-se informação sobre as características dos edifícios, tais como os tipos de sistemas AVAC e a envolvente do edifício, que poderiam influenciar o conforto térmico dos ocupantes. Das entrevistas sobre conforto térmico recolheram-se dados sobre a percepção de conforto térmico dos ocupantes, o isolamento térmico do vestuário, o tipo de desconforto sentido e as opções de controlo do ambiente térmico. Os dados recolhidos foram analisados utilizando análises descritivas e estatísticas para identificar padrões e relações entre variáveis.

Os resultados destacam a importância de oferecer diversas opções de controlo para acomodar as necessidades e preferências individuais, particularmente quando os pontos de regulação estão fora da zona de conforto. O estudo revelou variações notáveis na percepção da sensação térmica e do conforto entre género, idade e índice de massa corporal (IMC). Adicionalmente, as mulheres tendem a sentir maior desconforto e sensação de frio quando expostas a temperaturas mais baixas do que os homens, o que sugere diferenças relacionadas com o género na percepção e sensibilidade térmicas. Estes resultados mostram a necessidade de considerar as diferenças individuais no conforto térmico e a importância do controlo do utilizador na concepção de ambientes de escritório. Os resultados contribuem para o desenvolvimento de estratégias eficazes para baixar os pontos de regulação da temperatura em edifícios de escritórios, mantendo o conforto térmico e a produtividade dos ocupantes.

Palavras-chave: Pontos de regulação da temperatura, conforto térmico dos ocupantes, medidas de poupança de energia, controlo térmico, edifícios de escritórios

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LIST OF ACRONYMS/ABBREVIATIONS

ASHRAE - American Society of Heating, Refrigerating and Air-Conditioning Engineers
BMI - Body Mass Index
CAV - Constant Air Volume
CO_2 - Carbon Dioxide
DR - Demand Response
FSP - Fixed Set-Point
HVAC - Heating, Ventilation and Air conditioning
MPC - Model Predictive Control
MBPC - Model-Based Predictive Control
PMV - Predicted Mean Vote
PPD - Predicted Percentage Dissatisfied
TSet - Temperature Setpoint
VAV - Variable Air Volume
WWR - Window-to-wall ratio

CHAPTER

ONE

Introduction

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1. CHAPTER 1 - INTRODUCTION

1.1. Introduction

The pursuit of energy efficiency and reduction of greenhouse gas emissions has become a priority for governments worldwide, particularly in the wake of the energy crisis caused by the Russian invasion of Ukraine in early 2022. In this context, many governments and building managers are exploring ways to reduce energy consumption while keeping occupants comfortable. 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 19 ºC and a "2 degrees higher" summer setpoint of 25 ºC 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. Similar measures were taken by other European countries such as Spain (The Guardian, 2022a), France (The Local, 2022), Germany (DW, 2022), the United Kingdom (The Guardian, 2022b), and Portugal (TSF, 2022).

Lowering temperature setpoints offers a cost-effective and immediate opportunity to reduce energy consumption in buildings, particularly in relation to HVAC systems. However, it has also been observed that increasing the dead band results in decreased occupant thermal comfort (Antoniadou & Papadopoulos, 2017; Aryal & Becerik-Gerber, 2018; Kazanci et al., 2013). Thermal comfort, defined by Fanger (1973) as the sensation experienced by individuals as a function of the physiological strain imposed by the environment, is a crucial aspect of indoor spaces, particularly in office buildings where occupants spend a significant amount of time (Mannan & Al-Ghamdi, 2021). According to Zhou et al. (2014), the concept of thermal comfort considers “the thermoregulatory responses of all body segments, which can be affected by the thermal storage capacity of the human body”. Thermal sensation is defined by Zhou et al. (2014) as “the integrated response of signals emitted from the cutaneous thermoreceptors across all body segments”.

Distinguishing between the two concepts, thermal comfort and sensation, is crucial at this point. Despite the potential benefits of lowering temperature setpoints, many commercial buildings rely on HVAC systems operating within a narrow temperature range, often failing to meet occupants' comfort requirements (Hoyt et al., 2009; Huizenga et al., 2006: Roussac et al., 2011). Neglecting human health and comfort in the pursuit of energy efficiency may result in various issues such as discomfort, fatigue, headaches, and musculoskeletal problems among occupants, potentially leading to absenteeism and reduced productivity (Bluyssen, 2009, 2013; Ortiz et al., 2017; Rashid & Zimring, 2008). Several studies have examined the influence of temperature setpoints on energy consumption and occupant thermal comfort. Ghahramani et al. (2016) found that the choice of setpoints becomes influential when outdoor temperatures are slightly outside specific ranges, resulting in significant energy savings. Aryal & Becerik-Gerber (2018) explored the energy consumption of office buildings based on personal thermal comfort preferences, showing potential energy savings by selecting zone-level setpoints. Kazanci et al., (2013) concluded that increased dead-band results in lower energy consumption but decreased thermal comfort. Additionally, Arens et al. (2010) found that a narrow dead band increases HVAC system operation and energy demand without improving occupants' satisfaction. Jafarpur & Berardi, (2021) studied the effects of extending temperature setpoints under future climate conditions, observing variations in cooling and heating loads across different climate zones.

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 (Butera, 1998; R. De Dear & Brager, 1998; Hong et al., 2018; Humphreys, 1998; Sun & Hong, 2017). These adaptations, such as changing clothing thermal insulation or opening windows, play a significant role in quickly achieving perceived thermal comfort (R. De Dear & Brager, 1998). 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; D. Li et al., 2017, 2019; Tekler et al., 2022). Engaging occupants through different interventions, such as information sharing, feedback, and social marketing, can enhance the effectiveness of energy-saving interventions (Li et al., 2017). The study by Yang et al., (2014) suggests that individuals with a pro-environmental mindset are more likely to accept their indoor environments within green buildings and highlights the importance of adaptive thermal comfort and altering occupant expectations. Moreover, granting occupants the ability to exert control over the thermal environment has been shown to enhance their satisfaction. Leaman & Bordass (1993) conducted a study revealing that buildings with greater occupant access to building controls tend to exhibit a higher tolerance for variations in the thermal environment. Boerstra (2016) examined the influence of perceived control over the indoor climate on health and comfort in Dutch office buildings. The study found that when occupants are provided with functional operable windows and adjustable thermostats, they experience increased comfort and productivity while also reporting fewer symptoms associated with sick building syndrome.

These findings emphasize the intricate relationship between energy-saving measures and the thermal comfort perceived by occupants, shedding light on the complex and subjective nature of the latter. To gain a deeper understanding of the effects of lowering temperature setpoints on occupants' thermal comfort, it is crucial to conduct empirical studies in real-world office building environments. Therefore, this master's thesis presents an experimental case study conducted in three office buildings located in The Netherlands. The primary objective of this research is to investigate the effects of lowering temperature setpoints on occupants' thermal comfort and to provide insights into the trade-off between energy savings and occupant satisfaction. The study was carried out via thermal comfort surveys, to collect data on occupant comfort levels at different temperature setpoints. The study focused on various aspects, including behavioural responses, occupant satisfaction and personal motivation of the occupants to the altered thermal conditions.

This master’s thesis is organized in five chapters. Chapter 1 focuses on the introduction and sets the stage for the entire thesis, providing the necessary background information and research context. Chapter 2 delves into the methodology employed, including the research design and procedure, participant recruitment, building and data analysis techniques. Chapter 3 presents the results obtained from the research, while Chapter 4 offers a comprehensive discussion and interpretation of these findings, discussing their limitations, and suggesting avenues for future research. Finally, Chapter 5 concludes the thesis by summarizing the key findings.

1.2. Research Objective

The goal of this master thesis is to examine the impacts of reducing temperature setpoints on occupant thermal comfort in real-world office building environments located in The Netherlands. The main research question addressed in this study is: *"What are the effects of lowering the temperature setpoints, in office buildings in The Netherlands, on the occupant's thermal comfort?"*. Various factors including occupant satisfaction, adaptive behaviours, and personal motivation will be examined to comprehensively understand the occupant's experience of implementing energy-saving measures. Hence, various sub-questions have been organized to address different topics and aspects related to occupant thermal comfort in response to lower temperature setpoints.

1. *How building occupants cope with lower indoor temperatures and whether there is any compensatory behaviour that affects energy savings?*
2. *Are there effects of lower temperature setpoints on perceived thermal comfort and sensation?*
3. *How motivated are the building occupants to save energy? And is there a correlation between motivation to save energy change, with the political-social crisis?*
4. *To what extent are people willing to maintain these temperature setpoints even after the political-social situation that led to their implementation has resolved?*
5. *How did the occupants perceive the "Zet de knop om" campaign and its implementation?*
6. *Is there an effect of building factors, such as the number of options to control the thermal environment and the type of heat distribution system, on occupant satisfaction?*
7. *What are the differences in perceived thermal comfort and sensation with lower indoor temperatures, taking into consideration factors such as gender, age and BMI?*

CHAPTER

TWO

Methodology

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2. CHAPTER 2 - METHODOLOGY

Thermal comfort is a subjective experience, and personal preferences can play a significant role (Ma et al., 2021; Mansi et al., 2021). Measuring subjective experiences can be difficult as they are based on individual assessments and judgements. However, it is possible to do quantitative measurements to assess the thermal environment and its impact on occupants. In this experimental field study, a methodology was employed to assess thermal comfort by collecting data through building surveys and conducting thermal comfort surveys via interviews. The building survey gathered information about the buildings' characteristics, such as the type of HVAC system and the building envelope, which could impact the occupants' thermal comfort. The thermal comfort surveys collected data on the occupants' thermal comfort perception in the office, clothing thermal insulation, activity level, type of discomfort felt and options to control thermal environment. Additionally, questions about occupants' thermal comfort at home, motivation to save energy and agreeability with “Zet de knop om” campaign were included. The data collected from the thermal comfort surveys was analysed using descriptive analysis and statistical analysis to identify patterns and relationships between the variables. The data was collected during the period from mid-March until beginning of May 2023. Thermal comfort surveys were conducted in three buildings - that had lowered the temperature setpoints in winter 2022-2023, during the same time frame, and the data collected was analysed to determine the effects of the temperature setpoint change on occupant’s thermal comfort and sensation.

The following sections will provide a comprehensive overview of the design and procedure (Section 2.1), participants and recruitment (Section 2.2), building characteristics (Section 2.3) and data analysis (Section 2.4). It outlines the systematic approach used to gather and analyse data, including the structure of the study, participant selection process, building characteristics, methods of measuring thermal comfort, and statistical techniques employed.

2.1. Design and Procedure

To assess the effects of lowering the temperature setpoints on perceived thermal comfort of the building occupants a thermal comfort survey was conducted. The thermal comfort survey was performed via interviews. This survey was specifically designed to answer the main research question and the sub-research questions, additionally exploratory questions were also included. The development of the survey also took in consideration important topics in the literature related to thermal comfort and the effects of lowering temperature setpoints and standard thermal comfort surveys (Dhaka et al., 2015; Djamila, 2017; Zhang et al., 2017). For the questions asked during the interviews for the perceived thermal comfort survey, please refer to Appendix A and B. The questions were intentionally designed to generate both close-ended and open-ended responses. Although some questions may require specific answers, sufficient space is given to the interviewee to provide detailed and nuanced responses, this way some participants gave short-closed answers while other preferred to elaborate their answers. This approach aimed to capture participants' perspectives in their own words, ensuring rich and varied data collection. The same questions were used in the three buildings, and the same methodology was applied. The interview was divided into three parts: subject profile, perceived thermal comfort, and motivation and adaptation. The subject profile gathered information on the occupants' age, gender, BMI and clothing thermal insulation. The perceived thermal comfort section asked about the occupants' thermal sensation (cold/hot) and comfort (comfortable/uncomfortable) level at work and at home, type of temperature control in the office, "Zet the knop om" campaign. The motivation and adaptation section explored occupants' willingness to save energy and adapt to the lower temperature setpoints.

The interviews were conducted in English in a separate room as a one-on-one interview, having an average duration of about 7 minutes. First the interviewee was given a small introduction and explanation about the research and the questions, after that, the interviewer asked for permission to record the interview and started the interview. At the beginning of the interview, the interviewee was given an answer sheet while the interviewer had the questions' sheet, only some specific questions would require the interviewee to write down the answer, most of the questions will be answered orally and the interviewer will write down the answer in her sheet. The interview phase of the study, which involved conducting interviews in each of the three buildings, took an average of two days per building. Thus, a total of six days were dedicated to conducting the thermal comfort survey.

2.2. Participants and Recruitment

In total 121 occupants (65 male and 56 female) participated in this field study of which 51 worked at Building A, 35 worked at the Building B and 35 at Building C. While the building accommodates various types of personnel, including janitors and maintenance staff, this study concentrates solely on the experiences and behaviours of office workers. The occupants were randomly asked to participate in the interview, while they were given a small introduction of the study and the interview. Potential participants who matched the inclusion criteria were selected from those. The inclusion criteria for participation was that the participant had been working in that building for more than one year, so they could make a comparison between winters. To ensure that the presence of the researcher was expected, an introduction email was sent to potential participants prior to the interview day. This email served to provide background information about the research and the interview process, increasing interest and engagement among the potential participants. By establishing clear expectations and generating interest, the introduction email helped to ensure a successful and productive interview process.

2.3. Buildings

The studied buildings comprise a group of three office building in The Netherlands where occupants mostly have low-intensity physical activity and standard working hours (9:00-17:00). Building A and C have similar characteristics, these are high-rise buildings with over 100m high with a façade mainly made of glass and with only air heat distribution systems. The office Building B is a 3-floor office building with both air and water heat distribution system and a more balanced window-to-wall ratio (WWR). All the studied buildings lowered the temperature setpoints during the winter of 2022-2023, furthermore the difference within the temperature setpoints from before and now was different in all the buildings. Table 1 briefly shows more details about the buildings location, temperatures setpoints before and after “Zet de knop om” campaign, the number of investigated floors and the number of interviews done. Please refer to Appendix C for more information about the buildings.

Table 1: Brief description of the studied buildings

Building	*Name*	*Height*	*Location*	*TSet- before (ºC)*	*TSet- after (ºC)*	*Number of investigated floors*	*Number of interviews*
A	De Rotterdam	149.1 m	Rotterdam	22.7	19	15	51
B	Building D	10 m	Utrecht	22	20	3	35
C	The Hoftoren	141.9 m	The Hague	21	19	10	35

Table 2 provides additional information regarding building features obtained from the building survey. This includes details such as the window-to-wall ratio, sunshades, openable windows, HVAC terminal units, HVAC system running hours, temperature set-points, setting of thermostat and types of thermal controls.

Table 2: Physical buildings information

Building information	*Building A*	*Building B*	*Building C*
WWR	80	40	60
Types of Sun Shading	Interior vertical screen	Exterior vertical screen	Interior vertical screen
Openable Windows	No	Yes	No
HVAC Terminal Units	Induction CAV unit (Chilled beams)	Induction VAV box	Induction VAV box
Type of heat distribution system	Air heat distribution system	Air + water heat distribution systems	Air heat distribution system
HVAC system running hours	Per week: 75h Week days 6:30-19:00 Holidays and weekends: not working	Per week: 72h Monday: 4:00-20:00 Other days 6:00-20:00 Holidays and weekends: not working	_ *
Temperature set-points and Thermal control	Heating: 19 ºC Local thermostats off	Heating: 20 ºC Local thermostats off	Heating: 19 ºC Local thermostats off
Type of space	Mainly open	Open and closed	Mainly closed
Personal environmental control	Sun shadings	Radiators + sun shadings	Sun shadings

* no information was provided

2.4. Data Analysis

The data was analyzed using Excel. The main analyses will be presented first, followed by an exploratory analysis.

Quantitative analysis

subRQ 1 - How building occupants cope with lower indoor temperatures and whether there is any compensatory behaviour that affects energy savings?

The first sub-research question was analysed by plotting the percentage of votes, across the three buildings, of different coping strategies employed by building occupants when faced with lower indoor temperatures, surveyed during the collection data phase. Furthermore a comparison within the three buildings was made.

subRQ 2 - Are there effects of lower temperature setpoints on perceived thermal comfort and sensation?

To investigate the effects of lower temperature setpoints on perceived thermal comfort/sensation and overall satisfaction, first a descriptive statistic analysis is performed to summarize the data; this involved the calculation of measures such as mean, standard deviation, median, maximum and minimum values. This will provide an overview of the effects of lower temperature setpoints on perceived thermal comfort and sensation. To test if there are statistically significant ($p < .05$) effects of lower temperature setpoints on perceived thermal comfort and sensation, a statistical analysis was conducted, using a chi-square statistical analysis of independence test and a comprehensive analysis was conducted by combining data from the three buildings.

subRQ 3 - How motivated are the building occupants to save energy and did their mindset or motivation to save energy change, with the political-social crisis, and if so, how?

To explore the fourth sub-research question, three column graphs were utilized. The first depicts the percentage of votes pertaining to the level of motivation to save energy, the second aims at understand the specific motivations for energy conservation, the last seeks to comprehend any changes in occupant motivation since the previous winter. These graphs were then subjected to further analysis, allowing for a comparative examination among the three buildings.

subRQ 4 - To what extent are people willing to maintain these temperature setpoints even after the political-social situation that led to their implementation has resolved?

To address this question, a comparative plot was created to explore the willingness of occupants across the three buildings to maintain low temperature setpoints despite the return of energy prices to regular (lower) values. This plot, with the data from the three different buildings, was subsequently analysed to gain further insights.

subRQ 5 - How did the occupants perceived the "Zet de knop om" campaign and its implementation?

To answer this question, two graphs were generated. The first graph presents the percentage of agreement with the "Zet de knop om" campaign across the three buildings, while the second graph illustrates the evaluation of the campaign within the same buildings. Subsequently, a thorough analysis was conducted to delve deeper into the findings.

subRQ 6 - Is there an effect of building factors such as the number of options to control the thermal environment and the type of heat distribution system on occupant satisfaction?

To evaluate if there is an effect of the number of options to control the thermal environment on occupant satisfaction, firstly a descriptive statistic analysis is performed to provide an overview of the data and its central tendencies; this involved the calculation of measures such as mean, standard deviation, median, maximum and minimum values. Additionally, a statistical analysis was conducted, combining the data from the three buildings, in order to understand if there is a statistically significant ($p < .05$) effect of the number of options to control the thermal environment on occupant satisfaction, using a chi-square statistical analysis of independence test. To evaluate if there is a difference in the thermal comfort and sensation felt, during last winter and the winter before, using radiators and only forced-air systems first a descriptive analysis is done. Afterwards, to evaluate if there is a statistically significant ($p < .05$) effect, a statistical analysis was performed using a chi-square statistical analysis of independence test, combining the data from the buildings.

subRQ 7 - What are the differences in perceived thermal comfort and sensation with lower indoor temperatures, taking into consideration factors such as gender, age and BMI?

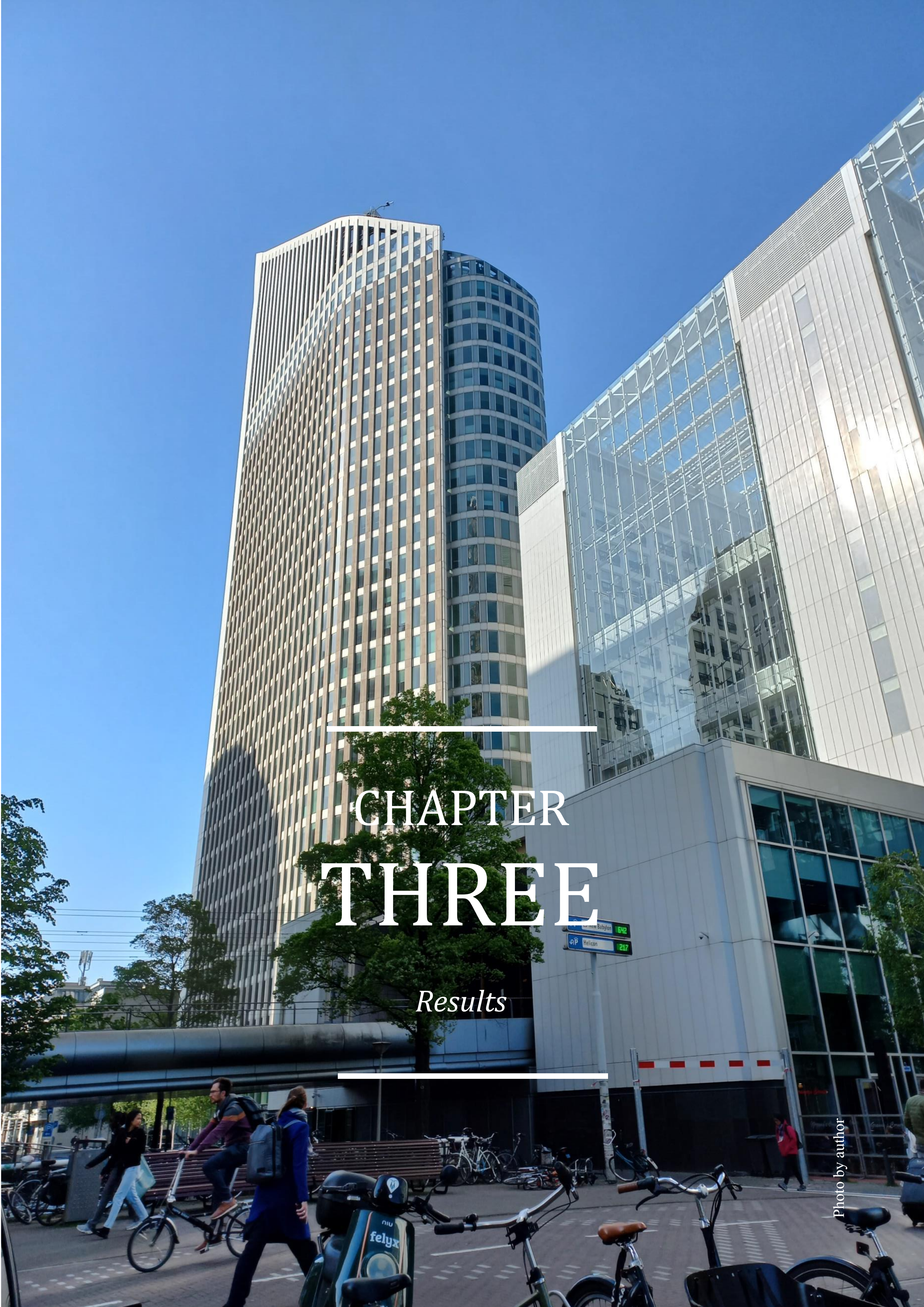
To understand whether there are differences in perceived thermal comfort and sensation with lower indoor temperatures, taking into consideration factors such as gender, age and BMI, first a descriptive analysis, that provided an overview of the data and its central tendencies, was done. Furthermore, a statistical analysis was also conducted using a chi-square statistical analysis of independence test. Three separate chi-square tests were performed, combining the data from the building being studied, these aimed to test the statistically significant ($p < 0.05$) differences in perceived thermal comfort and sensation with lower indoor temperatures, taking into consideration (1) gender, (2) age and (3) BMI.

Qualitative analysis

A qualitative analysis was conducted by examining the open-ended responses from the interviews and identifying patterns. This was accomplished by utilizing the interviews' recordings and systematically screening the three most frequently mentioned topics related to their experience of the energy-saving campaign, within each building. By doing so, it was possible to obtained a more comprehensive and realistic understanding of the situation, taking into account the frequency of these mentions.

(Exploratory) Is there a difference in the thermal comfort and sensation felt at home or at the office during last winter and the winter before?

To evaluate if there is a difference in the thermal comfort and sensation felt at home or at the office during last winter and the winter before first a descriptive analysis is done. This will help to summarize the data for each variable and provide an overview of the data and its central tendencies. Additionally, a statistical analysis was conducted, using a chi-square statistical analysis of independence test, with a combination of the data from all the buildings. This test aimed to test the statistically significant ($p < .05$) differences in perceived thermal comfort and sensation felt at home or at the office during last winter and the winter before.



CHAPTER
THREE

Results

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3. CHAPTER 3 - RESULTS

3.1. Quantitative results

The subsequent sections present the findings of the exploratory field study. Initially, a description of the respondents' demographics and characteristics is provided, followed by an overview of the descriptive statistics. Afterwards, the results of the main analyses are presented, and finally, a description of the results of the exploratory analysis is provided.

Respondents demography and characteristics

The group of respondents comprised 121, with 65 (54%) of males and 56 (46%) of females, both aged 18 to over 60. In Building A and Building B the main age group consisted of 50–59 years old employees, followed by 30–39-year employees, with 31% and 24%, and 34% and 29%, respectively. In Building C, the main age group consisted of 11 (31%) 30–39 years old employees, followed by 8 (23%) 40–49-year employees. Figure 1 and 2 depict the respondent demography in detail.

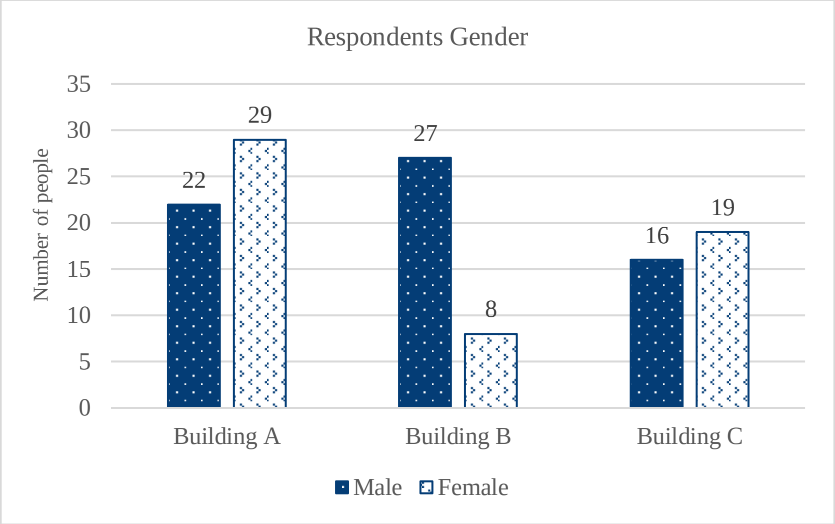


Figure 1: Respondents gender for each building

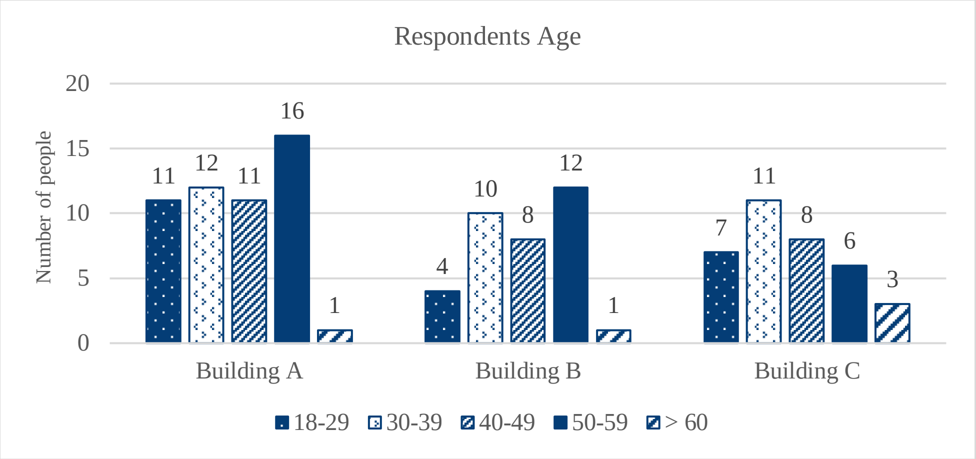


Figure 2: Respondents age for each building

The majority of the respondents considered themselves (self-reported) as being in the healthy zone (18.5-24.9) regarding their BMI, as shown in Figure 3.

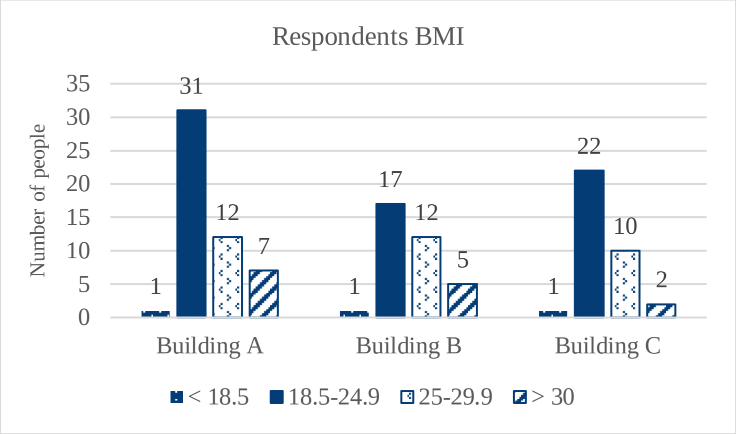


Figure 3: Respondents BMI range of values for each buildings

Descriptive Analysis

A general description of the dependent variables in the experimental field study is presented in Table 3. It includes the mean and median values, standard deviations, minimum and maximum scores.

Table 3: Descriptive statistics of the dependent variables. $\bar{x}$ = sample mean, SD = standard deviation, Min= minimum, Max= maximum.

Variable	*Condition I*	*Condition II*	*Building*	$\bar{\mathbf{x}}$	*SD*	*Median*	*Min*	*Max*
Thermal comfort (-2 to 2) (uncomfortable - comfortable)	*Office*	*Last winter*	*Building A*	-.76	.84	-1	-2	1
			Building B	.14	.77	0	-2	2
			Building C	-.06	1.05	0	-2	2
		Winter before	*Building A*	.46	.66	0	-1	2
			Building B	.39	.63	0	-1	2
			Building C	.26	1.01	0	-2	2
	Home	*Last winter*	*Building A*	.39	.66	0	-2	2
			Building B	.46	.78	0	-1	2
			Building C	.11	.79	0	-1	2
		Winter before	*Building A*	.98	.76	1	-1	2
			Building B	.86	.69	1	-1	2
			Building C	.74	.78	1	-1	2
Thermal sensation (-3 to 3) (cold-hot)	*Office*	*Last winter*	*Building A*	-2.08	1.15	-2	-3	1
			Building B	-.63	.77	-1	-3	1
			Building C	-1.06	1.45	-1	-3	2
		Winter before	*Building A*	.02	.91	0	-2	2
			Building B	.26	.70	0	-1	2
			Building C	-.40	1.33	0	-3	2
	Home	*Last winter*	*Building A*	-.20	1.10	0	-3	2
			Building B	-.34	1.19	0	-2	3
			Building C	-.69	1.13	-1	-3	2
		Winter before	*Building A*	.67	1.12	1	-3	2
			Building B	.83	.82	1	0	3
			Building C	.20	.96	0	-2	2
Level of satisfaction with controls (1 to 5) (very dissatisfied-very satisfied)			*Building A*	2.16	1.06	2	1	5
			Building B	4.09	.85	4	2	5
			Building C	3.00	1.31	3	1	5
Level of motivation to save energy (1 to 5)			*Building A*	3.84	.86	4	1	5
			Building B	4.00	.77	4	1	5
			Building C	3.57	.92	4	1	5
Evaluation of execution of Zet de knop om (1 to 5)			*Building A*	2.33	1.03	2	1	5
			Building B	3.34	.91	4	1	5
			Building C	3.00	1.06	3	1	4

Despite requesting temperature data, it was not obtained. Consequently, to ascertain whether it indeed became colder or more uncomfortable after the temperature setpoints were lowered, the researchers had to depend solely on the information provided by the occupants, as indicated in Table 3.

Adaptation

Figure 4 illustrates the utilization of water heat distribution systems as form of radiators as a coping mechanism for lower indoor temperatures specifically in Building B. It is important to note that Buildings A and C only have air heat distribution systems, as indicated in Table 2. The graph uncovers that a significant percentage of building occupants relied on radiators to manage the challenges posed by lower indoor temperature setpoints. Figure 5 showcases the distribution of individuals resorting to higher clothing thermal insulation as a coping mechanism in response to lower indoor temperatures. Notably, a substantial proportion of occupants from Building A (84.3%) opted for personal thermal clothing, such as sweaters or blankets, to enhance their comfort levels. In contrast, the majority of occupants in Buildings B (71%) and C (57.1%) maintained their existing clothing thermal insulation without making alterations.

Overall, the analysis of these graphs indicates a predominant reliance on specific coping strategies among building occupants when confronted with lower indoor temperatures. Rather than employing a diverse range of approaches, occupants primarily resorted to higher clothing thermal insulation or the use of radiators (when available) as their primary coping mechanisms.

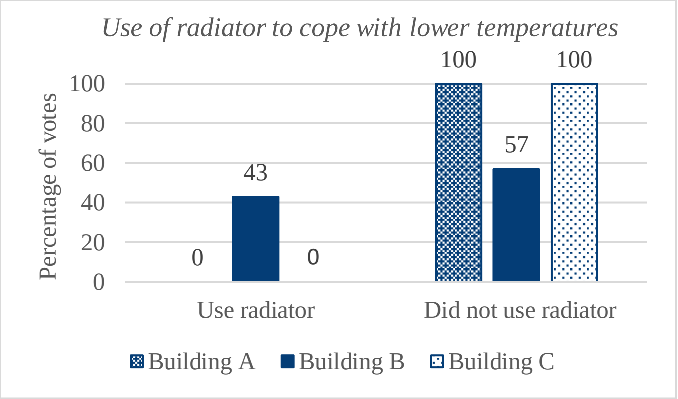


Figure 4: Percentage distribution of votes for using radiator as a coping mechanism across Building A, Building B and Building C , where Building A and C do not have radiators.

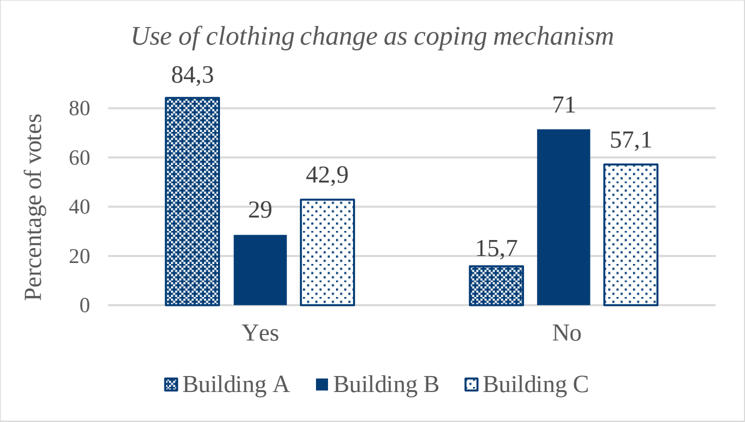
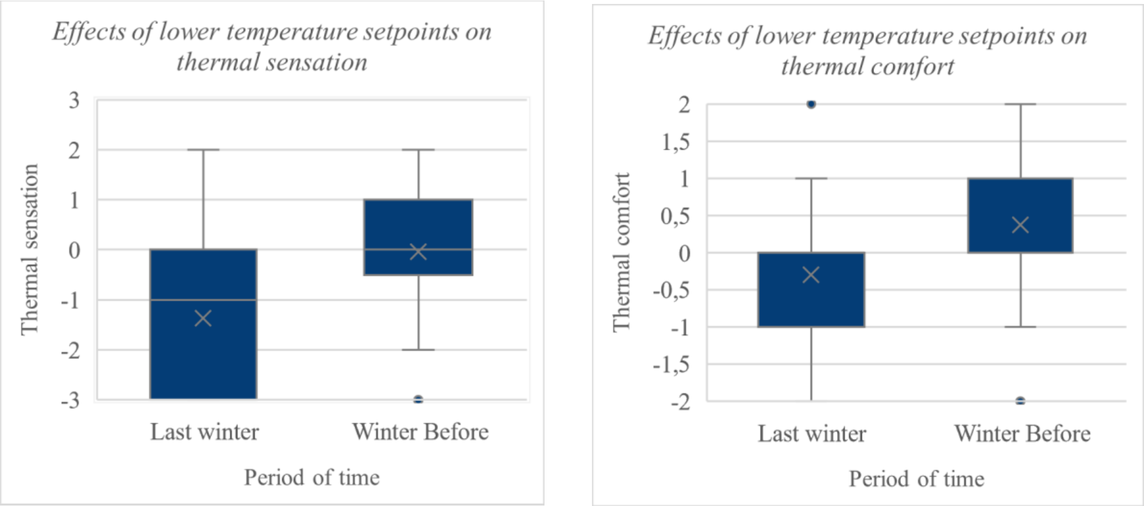


Figure 5: Percentage distribution of clothing change as a coping mechanism, Building A (first), Building B (second), Building C (third)

Perception

In order to address the overall impact of lowering temperature setpoints on thermal sensation (cold/hot) and comfort (comfortable/uncomfortable), a comprehensive analysis was conducted by combining data from the three buildings. Figure 6a) depicts a box plot comparing the thermal sensation ratings under two different conditions: last winter- lower temperatures and winter before- higher temperatures. Figure 6b) illustrates the influence of lowering temperature setpoints on thermal comfort. The box plot analysis provides valuable insights into the distribution of thermal sensation and comfort among the occupants of the buildings under the two explored conditions. By observing the means in Figure 6a) and b), a clear pattern emerges, indicating that the means are consistently higher in the winter before (WB) compared to the lower indoor temperatures conditions of last winter (LW). This suggests that, on average, building occupants are more comfortable and thermally satisfied under conditions with higher temperature setpoints. Looking at the interquartile ranges (IQR), in Figure 6a), it becomes evident that the box representing the last winter condition exhibits a wider distribution and less concentration. This is evident from the larger size of the box, suggesting a higher degree of variability in the evaluation of thermal sensation during that period. In contrast, the box corresponding to the winter before condition appears narrower, indicating a more limited range of scores and lower variability among the respondents. Additionally, both in Figure 6a) and b) there are a few outliers, represented by individual data points beyond the whiskers of the box plot. These outliers indicate scores that deviate significantly from the majority of the data points. These exceptional scores exemplify particular evaluations of thermal comfort (comfortable/uncomfortable) and sensation (cold/hot), emphasizing the subjective nature of this measure. A chi-square statistical analysis of independence test showed a statistically significant effect of lower temperature setpoints on perceived thermal sensation (χ^2 (5, N = 242) = 61.61, $p < .001$) and comfort (χ^2 (4, N = 242) = 35.63 , $p < .001$), hence the data suggests that there is an association between the indoor temperatures and thermal comfort and sensation. The overall findings demonstrated that conditions with lower temperature setpoints, clearly, resulted in lower levels of thermal comfort and sensation.



a) *b)*

Figure 6: Box plot illustrating the influence of lower temperature setpoints on thermal sensation (a) and comfort (b). The X represents the mean. a) $\bar{x}_{LW} = -1.36$; $\bar{x}_{WB} = -.03$ and b) $\bar{x}_{LW} = -.30$; $\bar{x}_{WB} = .37$. The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data

Motivation

The graphs presented below provide valuable insights into the level of motivation and its dynamics within the three buildings under analysis. The first graph, Figure 7, focuses on the level of motivation of the occupants to save energy in the three buildings. It illustrates that in all three building the occupants are in general motivated (level 4) to save energy. Furthermore, considering level 4, Building B exhibits the highest motivation (65,7%) among occupants, followed closely by Building A (56,9%). Building C, however, shows a relatively lower motivation level (40%). It is noteworthy to observe that a significant proportion of occupants exhibit a neutral (level 3) level of motivation, indicating a lack of active consideration in this regard. The second graph, Figure 8, delves into the percentage of occupants with changed motivation to save energy since the previous winter. Expectedly, the level of motivation has increased across all the buildings, with Building B and C demonstrating the highest percentage of occupants with changed motivation (85%), while Building A reports a slightly lower percentage (78%). The third graph, Figure 9, explores the various types of motivation to save energy across the three buildings. It reveals that sustainability and the environment are the dominant factor driving occupants across the three buildings (84,3% Building A, 80% Building B and C). In terms of the second most commonly reported motivation factor across the three buildings, a substantial proportion of occupants expressed concerns about high energy bills (45,1% in Building A, 48,6% in Building B, and 34% in Building C). Remarkably, there was a comparatively low percentage of individuals whose motivation stemmed from the war in Ukraine, with figures of 13,7%, 5,7%, and 9% across Buildings A, B, and C, respectively. These results suggest that since last winter there was a widespread increase of motivation to save energy among the building occupants, without significant variations within the buildings.

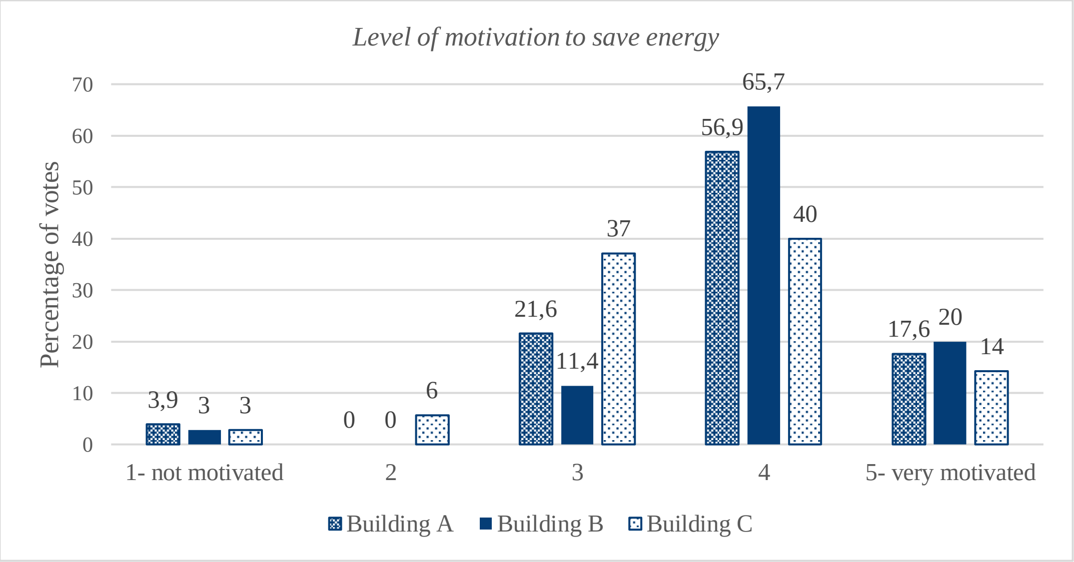


Figure 7: Plot comparing the level of motivation to save energy across Building A (first), B (second), and C (third)

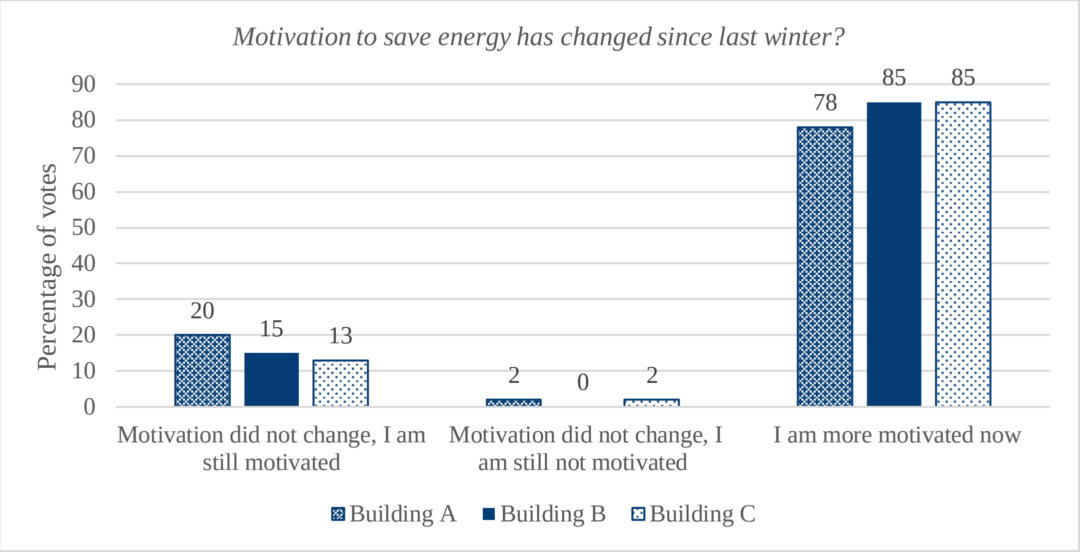


Figure 8: Plot illustrating the percentage of occupants with changed motivation to save energy and the nature of the change since last winter, across Building A (first), B (second), and C (third)

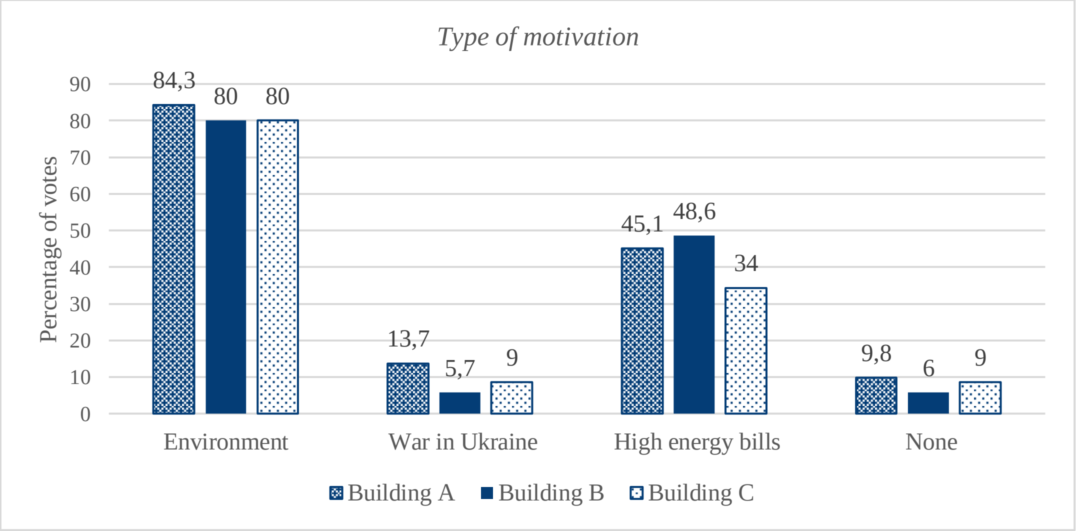


Figure 9: Plot depicting the various types of motivation to save energy across Building A (first), B (second), and C (third)

Willingness

Figure 10 provides valuable insights into the extent of individuals' commitment to maintaining low temperature setpoints, despite the normalization of energy prices. This graph focuses on comparing the willingness to maintain low temperature setpoints across the three buildings. It reveals that Building B exhibits the highest level of willingness, with 89% of occupants expressing their commitment to maintaining the setpoints even after energy prices return to regular (lower) values. Building C shows a moderate level of willingness, with 66% of occupants indicating their intention to maintain the setpoints. Building A, however, displays a lower level of willingness, with only 43,1% of occupants expressing their commitment. Additionally, it is noteworthy that within Building A, a significant proportion (31,4%) of individuals explicitly stated their willingness to maintain the lower temperature setpoints only if they fell within acceptable levels of thermal comfort (comfortable/uncomfortable). Furthermore, Building A and Building C had the highest proportions of occupants expressing their unwillingness to maintain the temperature setpoints, with 25,5% and 26% respectively. These findings highlight variations in the degree of willingness among the three buildings, suggesting that factors specific to each building's context may influence occupants' decisions.

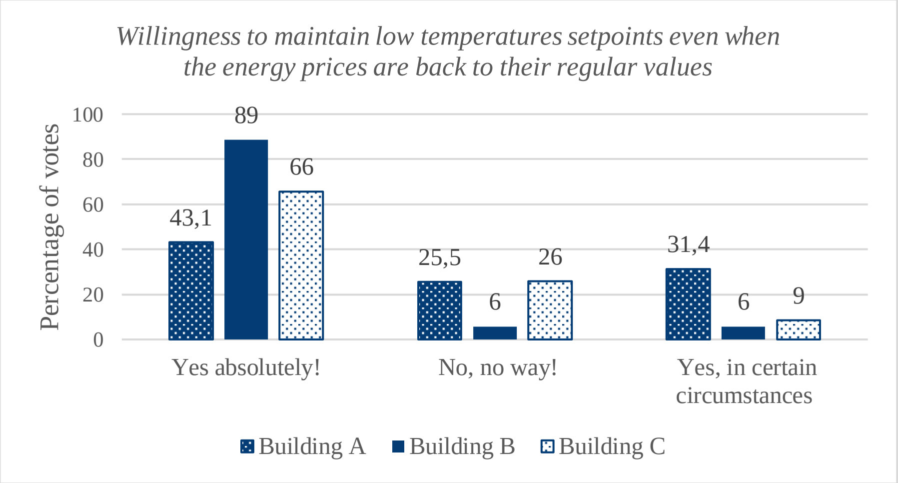


Figure 10: Plot comparing the willingness to maintain low temperature setpoints despite energy prices returning to regular (lower) values, across the three buildings A (first), B (second), and C (third)

Reception

Figure 11 and 12 provide insights into the level of agreement and evaluation of the campaign across the three buildings. The first graph illustrates the percentage of agreement with the "Zet de knop om" campaign. It reveals that the level of agreement with the "Zet de knop om" campaign is unanimous across the buildings. Building B had the highest level of agreement, with almost all the occupants (97%) expressing their support for lowering the temperature setpoints. Building C follows closely, with 86% of occupants in agreement. Building A shows a slightly lower level of agreement (although still a big majority) with 80,4% of occupants supporting the campaign. These findings indicate a generally positive reception of the campaign across the building's occupants, with Building B displaying the highest level of support.

The second graph depicts the evaluation of the "Zet de knop om" campaign across the buildings. Building B demonstrates the most favourable evaluation, with 51% of occupants expressing positive sentiments towards the campaign and an additional 3% demonstrating very high satisfaction with the execution of the mentioned policy. Building C demonstrates a combination of satisfied and dissatisfied occupants, with 46% expressing satisfaction, 17% maintaining a neutral stance, and a notable 29% expressing dissatisfaction with the execution of the campaign and an additional 9% evaluating the execution of the "Zet de knop om" campaign as very dissatisfied. In Building A, a significant percentage of occupants lean towards being very dissatisfied (21.6%), dissatisfied (41.2%), or neutral (21.6%) in their evaluation of the campaign. These results highlight the different perceptions of the campaign's implementation, across the three buildings, with Building B, again, exhibiting the highest level of satisfaction.

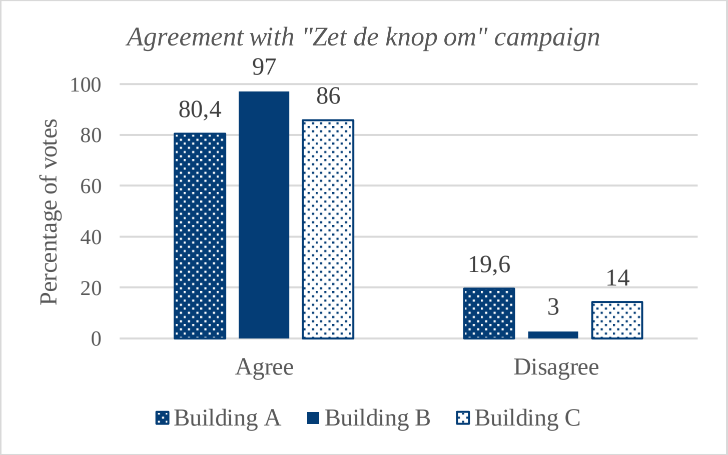


Figure 11: Plot illustrating the percentage of agreement with the "Zet de knop om" campaign across the three buildings A (first), B (second), and C (third)

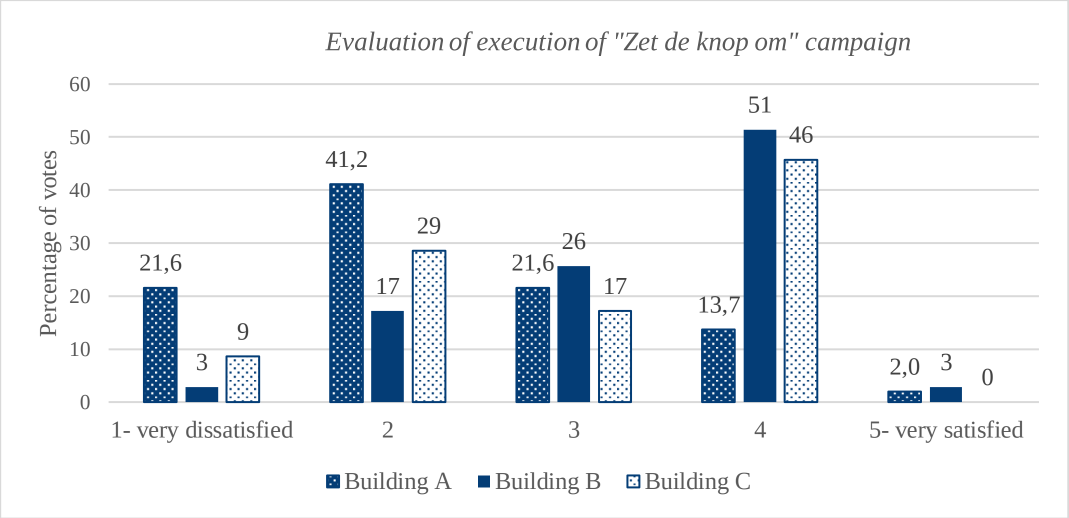


Figure 12: Plot depicting the evaluation of the "Zet de knop om" campaign across Building A (first), B (second), and C (third)

Building

To examine the impact of the number of options available to control[1] the thermal environment on occupant satisfaction, a comprehensive analysis was conducted by combining data from the three buildings. Figure 13 presents a box plot comparing occupant satisfaction ratings and the number of control options. Analysing the means in Figure 13 reveals an interesting trend, indicating that as the number of control options increases, occupant satisfaction also increase. This suggests that having more options to control the thermal environment positively influences occupant satisfaction. Furthermore, examining the interquartile ranges (IQR) in Figure 13, it becomes evident that the boxes representing 1 control option exhibit wider distributions, indicating more variability in occupant satisfaction. Conversely, Figure 13 shows a narrower distribution for higher numbers of control options or no options, implying less variability in satisfaction ratings. Notably, one outlier is observed in Figure 13, this represents a data point that significantly deviates from the majority of the data points in a dataset, indicating a satisfaction rating of the options to control the thermal environment particularly positive when no options are provided. Moreover, to better understand the statistical significance of this effect a statistical analysis of independence test was performed. A chi-square test demonstrated a significant difference

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[1] Because there is no clothing regulation (e.g., uniform) in the studied buildings, changing clothing is not considered one option for controlling the thermal environment.

in occupant satisfaction (χ^2 (8, N = 121) = 66.65, $p < .001$) based on the number of control options available. These findings underscore the influence of the number of control options on occupant satisfaction in the thermal environment. The data results suggest that occupants who are provided with a greater number of options for thermal control reported higher levels of satisfaction compared to those with limited options, or no options.

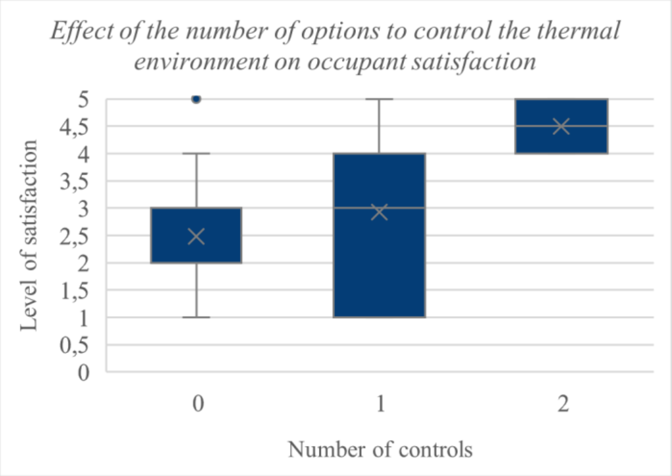
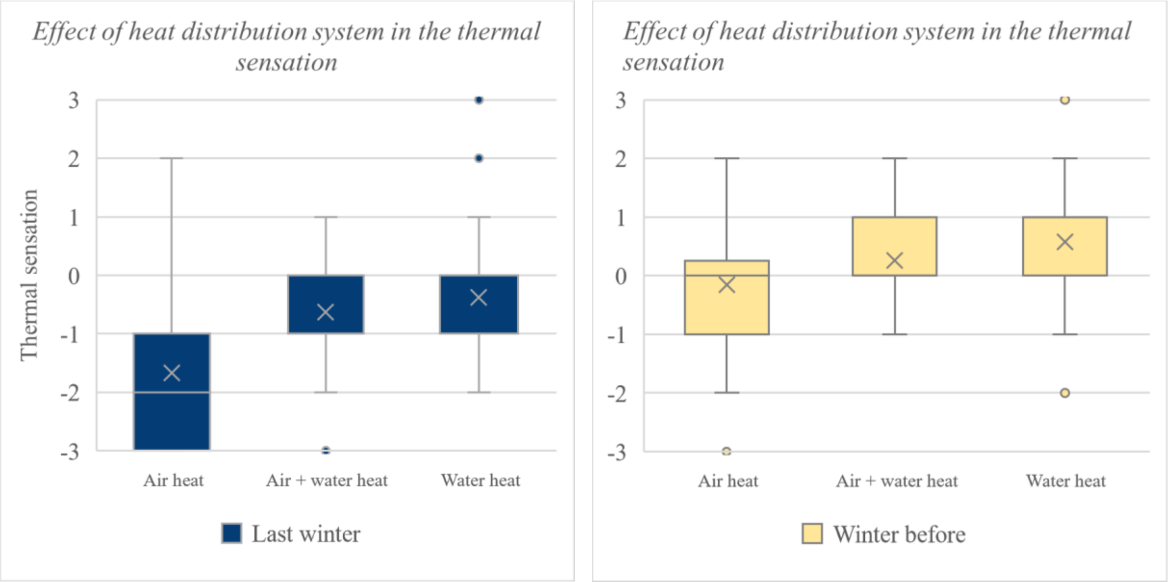


Figure 13: Box plot illustrating the impact of number of thermal environment control options on occupant satisfaction. The X represents the mean. $\bar{x}_{\text{no controls}} = 2.47$, $\bar{x}_{\text{one control}} = 2.92$, $\bar{x}_{\text{two controls}} = 4.5$. *The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data*

Figure 14 and 15 present box plots comparing the thermal comfort (comfortable/uncomfortable) and sensation (cold/hot) ratings, respectively, under two different conditions: last winter, with lower temperatures and winter before, with higher temperatures, using three different heat distribution systems combinations (only air heat distribution systems, only water heat distribution systems and a combination of both). The box plot analysis offers valuable insights into the distribution of thermal sensation and comfort among the building occupants across the explored conditions. Upon observing the means in Figure 14 and 15, a clear and consistent pattern emerges, indicating that the means are consistently higher when water heat distribution systems are used when compared to using only air heat distribution systems. This suggests that, on average, occupants experience higher levels of comfort and satisfaction when using water heat distribution systems. Notably, the difference in means is more pronounced during the last winter compared to the previous winter. Focusing on the interquartile ranges (IQR) in both Figure 14 and 15 it becomes evident that only the box representing the evaluation of last winter's thermal sensation in the condition of using air heat distribution systems exhibits a wider distribution and less concentration. This is manifested by the larger size of the box, indicating a higher degree of variability in the evaluation of thermal sensation during that specific period. On the other hand, all the other boxes (both in Figure 14 and 15) appear narrower, in general, with a range of only one level (of satisfaction), suggesting a more limited range of thermal evaluation and lower variability among the respondents. Furthermore, both Figure 14 and 15 display a few outliers, represented by individual data points beyond the whiskers of the box plot. These outliers signify personal evaluations that significantly deviate from the majority of data points, exemplifying unique evaluations of thermal comfort (comfortable/uncomfortable) and sensation and highlighting the subjective nature of this measure. A chi-square statistical analysis of independence test showed a statistically significant effect of the heat distribution system on thermal sensation (Last winter: χ^2 (12, N = 242) = 274.2, $p < .001$; Winter before: χ^2 (12, N = 242) = 145.1, $p < .001$) and comfort (Last winter: χ^2 (8, N = 242) = 223.3, $p < .001$; Winter before: χ^2 (8, N = 242) = 133.1, $p < .001$). The data suggests that there is an association between the heat distribution system and thermal comfort (comfortable/uncomfortable) and sensation, it is evident that people tend to feel more comfortable and thermally satisfied, with lower temperatures, when water heat distribution systems are provided rather that when air heat distribution systems are used, additionally when the temperature setpoints are higher the gap between the thermal comfort/sensation provided by these two types of heat distribution system is narrower.

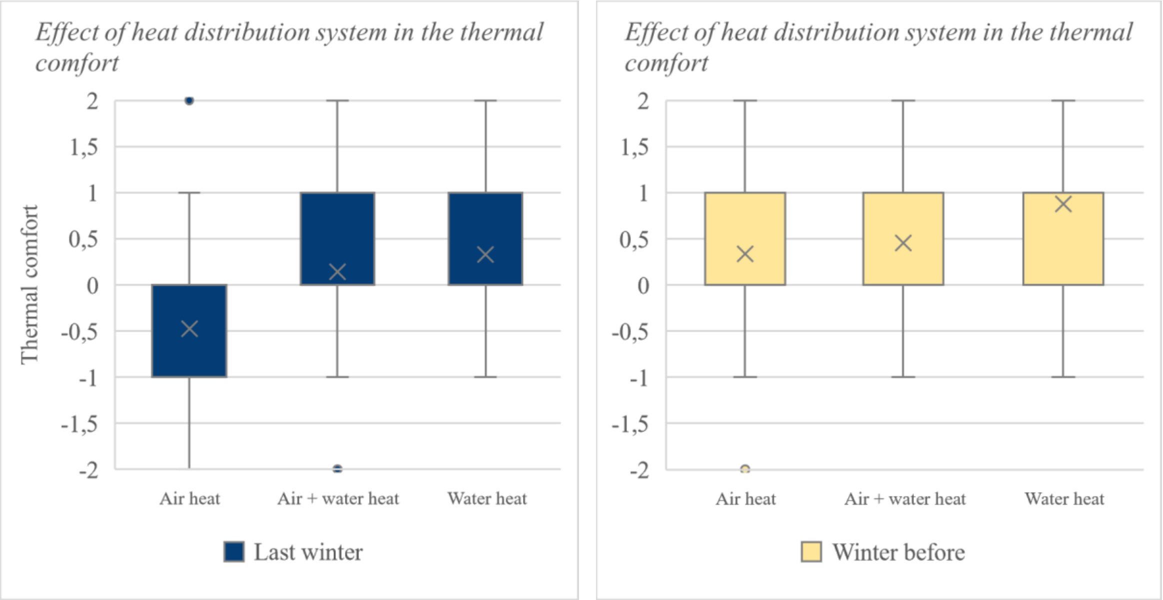


a)

b)

Figure 14: Box plot illustrating the effect of the heat distribution system on thermal sensation under two conditions: (a) last winter and (b) winter before. The X represents the mean. a) ($\bar{x}_{Air\ Heat}$ = -1.66, $\bar{x}_{Air\ +\ Water}$ = -

.62, $\bar{x}_{Water\ Heat}$ *= - .38) and b) (*$\bar{x}_{Air\ Heat}$ *= - .15,* $\bar{x}_{Air\ +\ Water}$ *= .26,* $\bar{x}_{Water\ Heat}$ *= .58). The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data*

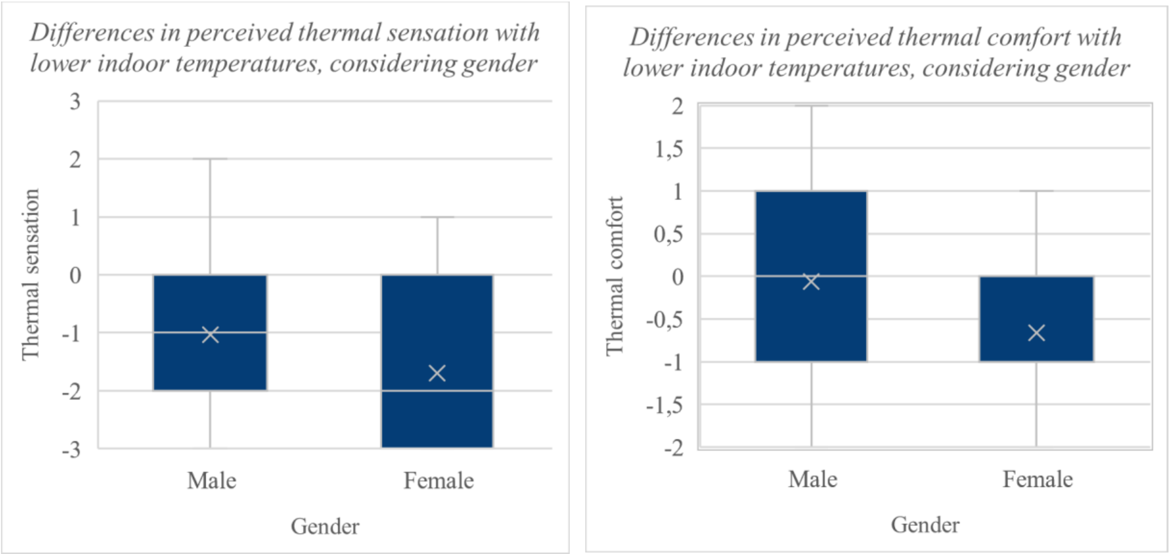


a) *b)*

Figure 15: Box plot illustrating the effect of the heat distribution system on thermal comfort under two conditions: (a) last winter and (b) winter before. The X represents the mean. a) ($\bar{x}_{Air\ Heat}$ = -.48, $\bar{x}_{Air\ +\ Water}$ = .14, $\bar{x}_{Water\ Heat}$ = .33*) and b) (*$\bar{x}_{Air\ Heat}$ = .34, $\bar{x}_{Air\ +\ Water}$ = .46, $\bar{x}_{Water\ Heat}$ = .87*). The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data*

Inclusivity

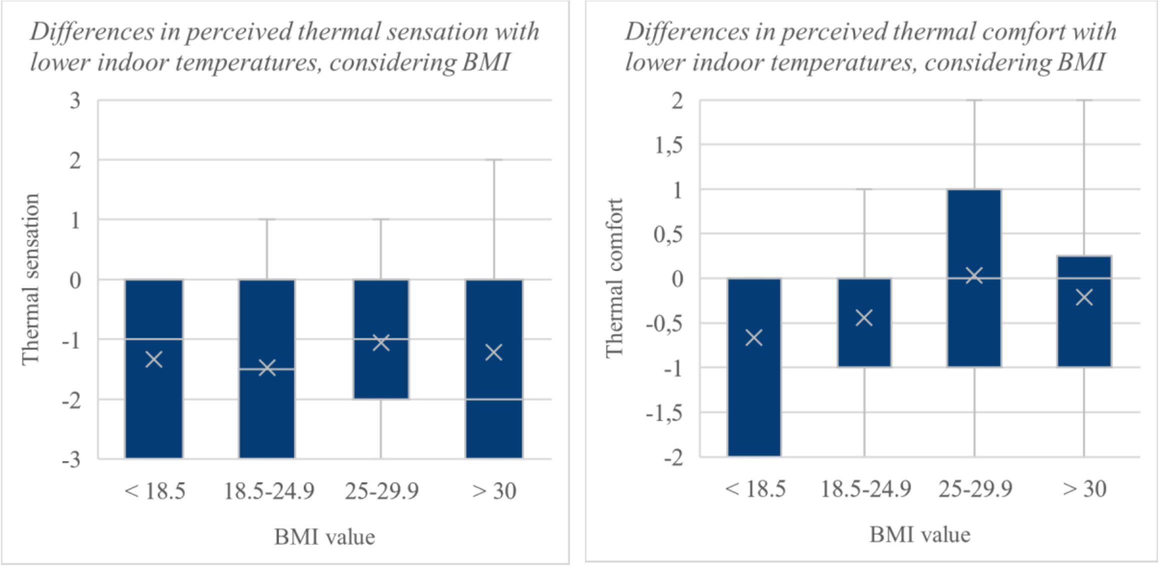
To assess the differences in perceived thermal sensation and comfort with lower indoor temperatures, considering gender, the data from the three buildings were combined to provide a comprehensive understanding. Figure 16 present one box plot comparing thermal sensation (cold/hot) (a) and comfort (comfortable/uncomfortable) (b) ratings, respectively, according to gender. Analysing the means in Figure 16 reveals a consistent pattern, indicating higher average thermal comfort (TC) and sensation (TS) evaluation for males, compared to the females' evaluations. This suggests that, on average, male occupants experience greater comfort and satisfaction under lower temperatures. Furthermore, focusing on the interquartile ranges (IQR) in Figure 16 a), it becomes evident that the box representing females' thermal comfort rating exhibits a wider distribution and less concentration, in contrast Figure 16 b) shows the same happening for male occupants. This is evident from the larger size of the box, indicating higher variability in the men's evaluation of thermal sensation. No outliers are observed in Figure 16. Additionally, a chi-square statistical analysis of independence test demonstrated a significant difference in perceived thermal sensation (χ^2 (5, N = 121) = 14.69, p = 0.0117) and thermal comfort (χ^2 (4, N = 121) = 13.67, p = 0.00843) with lower indoor temperatures, for males compared to females. These findings suggest an association between gender and thermal comfort and sensation. Specifically, upon comparing genders, it was observed that females exhibited a higher degree of discomfort and cold sensations when exposed to lower temperatures.



a) *b)*

Figure 16: Box plot illustrating the differences in perceived thermal sensation (a) comfort (b) with lower indoor temperatures, considering gender. The X represents the mean. $\bar{x}_{\text{TS male}} = -1.03$; $\bar{x}_{\text{TS female}} = -1.69$; $\bar{x}_{\text{TC male}} = -.06$; $\bar{x}_{\text{TC female}} = -.66$. *The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data.*

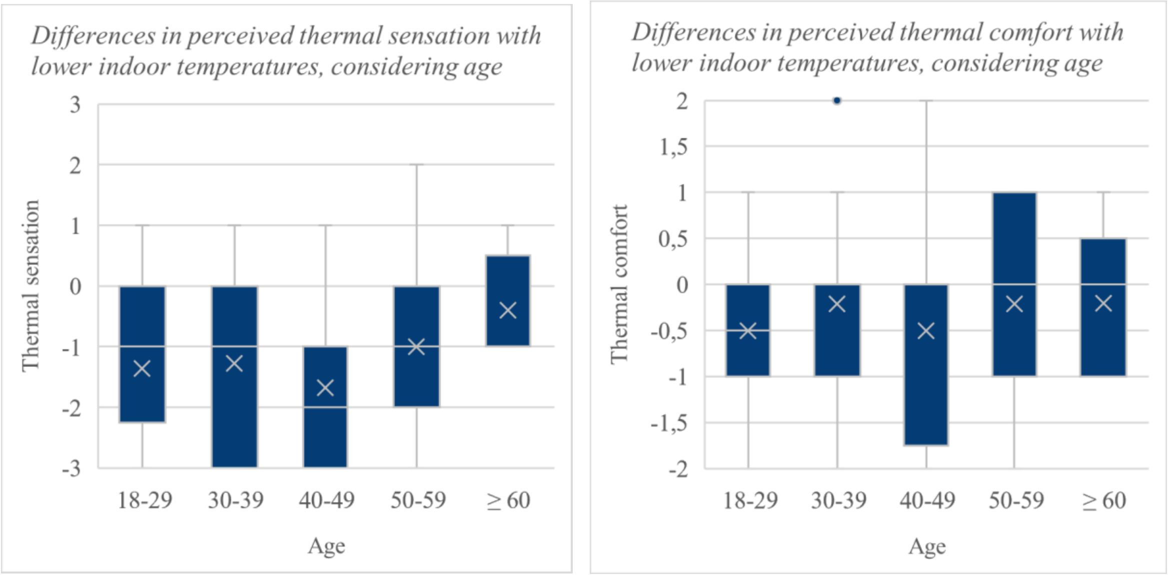
To explore the impact of BMI on perceived thermal sensation and comfort with lower indoor temperatures, a comprehensive analysis was conducted, combining data from the three buildings. Figure 17 presents two box plot comparing thermal sensation (a) and comfort (b) ratings according to the BMI values. Analysing the means in both Figure 17a) and b) reveals a lack of consistent trend, indicating wide variations across all BMI values. This observation emphasizes the subjective nature of the thermal comfort and sensation measure, where individual responses vary significantly within each BMI category. Moreover, examining the interquartile ranges (IQR) in Figure 17a), also indicates higher variability in the evaluation of thermal sensation and comfort among all BMI values. Notably, no outliers are observed in Figure 17. Additionally, to provide further insights and a better understanding of the observed behaviour of this parameters a more statistical analysis was performed. Hence a chi-square statistical analysis of independence test was conducted, revealing a significant difference in perceived thermal sensation (χ^2 (15, N = 121) = 102.4, $p < .001$) and thermal comfort (χ^2 (12, N = 121) = 105.6, $p < .001$) with lower indoor temperatures, with BMI values. These findings highlight an association between BMI and thermal comfort and sensation, although no pattern was found.



a) *b)*

Figure 17: Box plot illustrating the differences in perceived thermal sensation (a) and comfort (b) with lower indoor temperatures, considering BMI. The X represents the mean. a) $\bar{x}_{<18.5}$ = -1.33, $\bar{x}_{18.5\text{-}24,9}$ = - 1.47, $\bar{x}_{25\text{-}29,9}$ = -1.05, $\bar{x}_{>30}$ = -1.21 *and b)* $\bar{x}_{<18.5}$ = - .66, $\bar{x}_{18.5\text{-}24,9}$ = - .44, $\bar{x}_{25\text{-}29,9}$ = - .03, $\bar{x}_{>30}$ = - .21. *The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data*

In order to investigate the influence of age on perceived thermal sensation (cold/hot) and comfort (comfortable/uncomfortable) under lower indoor temperatures, a comprehensive analysis was undertaken, utilizing data from the three buildings. Figure 18 depicts two box plots that compare the thermal sensation (a) and comfort (b) ratings across different age groups of the occupants. Upon examining the means in both Figure 18a) and b), it becomes clear that no consistent trend can be observed, indicating substantial variations across all age groups. Furthermore, an assessment of the interquartile ranges (IQR) in Figure 18 reveals higher variability in the evaluation of thermal sensation and comfort across all age values. Notably only one outlier is observed in Figure 18b), this outlier reflects scores that significantly deviate from the majority of data points, highlighting very different evaluations of thermal comfort and sensation. Consequently, a chi-square statistical analysis of independence test was performed, revealing a significant difference in perceived thermal sensation (χ^2 (15, N = 121) = 64.6, p < .001) and thermal comfort (χ^2 (12, N = 121) = 57.5, p < .001) under lower indoor temperatures with respect to age. These findings underscore an association between age and thermal comfort and sensation, although no pattern was found.



a) *b)*

Figure 18: Box plot illustrating the differences in perceived thermal sensation (a) and comfort (b) with lower indoor temperatures, considering age. The X represents the mean. a) ($\bar{x}_{18\text{-}29}$ = - 1.36, $\bar{x}_{30\text{-}39}$ = - 1.27, $\bar{x}_{40\text{-}49}$ = - 1.67, $\bar{x}_{50\text{-}59}$ = - 1.0, $\bar{x}_{\geq 60}$ = - .4*) and b) (*$\bar{x}_{18\text{-}29}$ = - .5, $\bar{x}_{30\text{-}39}$ = - .21, $\bar{x}_{40\text{-}49}$ = - .5, $\bar{x}_{50\text{-}59}$ = - .21, $\bar{x}_{\geq 60}$ = - .2*), The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data*

3.2. Qualitative results

This section presents the findings derived from an exploratory qualitative analysis of the responses given by the interviewees during the thermal comfort survey. By analysing the interviews data, the aim is to gain a comprehensive understanding of the occupants' perspectives and uncover common themes that emerge from their accounts. This exploratory qualitative analysis allows for a deeper exploration of the perceived thermal comfort experiences in the context of lowered temperature setpoints. Figure 19 provides a schematic overview of the exploratory qualitative analysis, followed by a brief analysis of the findings.

Energy-saving campaign experiences	*Communication*	*Comfort*	*Controls*	*Motivation*
Building A (51)	(33/51): - Expressing dissatisfaction with the absence of soliciting feedback from occupants; - Perceiving a disregard for occupants' comfort;	(35/51): - Unacceptable comfort levels; - Willingness to accept lower temperatures, but not at the expense of comfort; - Opting to work from home more often due to discomfort in the office;	(38/51): - Dissatisfaction with lack of control of thermal environment;	(44/51): - High motivation to save energy; - Agreement with energy-saving campaign;
Building B (35)	No complains	(25/35): - No change of clothing; - Acceptable comfort levels; - Willingness to maintain lower temperature setpoints;	(16/35): - Satisfaction with options to control thermal environment; - Use of radiator;	(31/35): - High motivation to save energy; - Agreement with energy-saving campaign;
Building C (35)	(10/35): - Expressing dissatisfaction with the absence of soliciting feedback from occupants; - Perceiving a disregard for occupants' comfort;	(15/35): - Unacceptable comfort levels; (15/35): - Dissatisfaction with having to wear bulky clothes to maintain comfort levels; (19/35): - No change of clothing;	(23/35): - Dissatisfaction with the absence of controls;	(29/35): - High motivation to save energy; - Agreement with energy-saving campaign:

Figure 19: Schematic overview of the exploratory qualitative analysis. Each category is inerent to each building, the numbers near the category represent the frequency of reporting that theme out of the total number of participants in that building

Regarding Building A, among the most frequently mentioned themes, several key concerns emerged. Firstly, participants expressed a significant decline in their comfort levels. This concern was highlighted by 35 out of 51 participants, who reported feeling less enthusiastic to work at the office due to the discomfort and perceived sacrifice of their own comfort. A snippet from participant 40 illustrating this theme is: *"The comfort I felt in the office this winter was a reason to stay home"*. When questioned about the willingness to maintain these temperature setpoints 35 out of 51 interviewees mentioned that they were willing to do that but not at the expense of their comfort. In terms of agreement with the energy-saving campaign, a majority of participants (44 out of 51) demonstrated a high level of agreement. A snippet from participant 23 illustrating this topic is: *"Yes, I agree with this measure, I believe we have to start somewhere".* However, it is worth noting that a portion of participants expressed scepticism and raised concerns about the effectiveness of the campaign. They felt that the imposition of lowered temperature setpoints lacked consideration for their comfort needs and preferences. The absence of effective communication and failure to seek feedback exacerbated this issue, resulting in a prevailing perception among occupants that their comfort was being disregarded (33 out of 51). Consequently, this perception contributed to a general atmosphere of discontent and dissatisfaction with thermal comfort at the office, among the occupants. An example snippet from participant 11 illustrating this is: *"I would also like to have had some feedback sessions in the middle of the winter, because there are a lot of complains so you should fix that now not next winter".* Furthermore, most of the occupants reported dissatisfaction with having to change their clothing as the only control their had to cope with the thermal environment, a snippet from participant 33 shows that: *"I felt I had to use too many layers, my hands and feet were cold and I was always tense because of the general feeling of low temperature"* or participant 10*: "I had to bring sweaters everyday, since it is the only option we have".* Additionally, participants expressed dissatisfaction (38 out of 51) with the lack of control over the thermal environment. They felt frustrated by the inability to adjust temperatures according to their personal preferences and comfort requirements. An example snippet from participant 24 illustrating this is: *"I would be fine with the fact that I have no option to control my workplace, if the temperature was comfortable"*, or from participant 47: *"They can not simply expose us to such conditions without providing any means to cope with it".*

With respect to Building B there was a slight variation in the situation, as 25 out of 35 occupants reported finding the comfort levels acceptable and did not feel the necessity to change their clothing thermal insulation level, as mentioned by participant 56: *" I was comfortable so I did not change my clothing".* Moreover, there was a notable willingness among occupants to maintain the lower temperature setpoints. Many expressed their readiness to endure slightly cooler environments in order to contribute to energy-saving efforts, highlighting a commendable commitment to sustainability, a snippet from participant 62 illustrates that: *"I guess now we are adapted to these temperatures, so we should keep it".* The use of radiators emerged as a notable theme, with occupants frequently mentioning (16 out of 35) them as a means to compensate for the lowered temperature setpoints. This suggests that individuals were taking (and were given the opportunity to take) proactive measures to enhance their personal comfort in response to the environmental adjustments. Furthermore, occupants also reported satisfaction with the options provided to control the thermal environment. The availability of radiators was perceived as a favourable aspect, enabling individuals to customize the temperature according to their personal comfort preferences. However, it is important to mention that some occupants expressed their disagreement with having such options to adjust the temperature, as they believed it could lead to greater challenges in controlling energy consumption, a snippet from participant 70 that illustrates this is: *"I don't think it is wise to let people use the radiators, because then we no longer control the temperature inside"*. Furthermore, a high level of motivation to save energy was reported among occupants. They expressed a strong desire to actively participate in energy-saving practices, recognizing the importance of their individual contribution to overall sustainability goals. Lastly, occupants generally demonstrated agreement with the energy-saving campaign. They acknowledged the necessity of reducing energy consumption and expressed support for the initiatives undertaken, aligning their values with the overarching goal of conserving resources, a snippet from participant 74 illustrates that: *"As a company committed to sustainability, we should align our actions with our principles, I believe it is essential for us to practice what we preach"*.

Building C presented another distinct perspective on the experience of the energy-saving campaign. The findings revealed a nearly equal division in terms of satisfaction with the thermal comfort levels among the occupants. Specifically, 15 out of 35 individuals reported unacceptable comfort levels and expressed dissatisfaction with the necessity of wearing bulky clothes to maintain a comfortable environment, a snippet from participant 99 illustrates this: *"The comfort I felt this winter in the office was unacceptable, I would like to feel better in my workplace"*. Conversely, 19 out of 35 participants indicated that they did not alter their clothing thermal insulation level, suggesting a level of comfort that did not require additional measures. Furthermore, occupants voiced their dissatisfaction with the absence of controls over the thermal environment. A common complaint (23 out of 35) was the inability to adjust or regulate the temperature settings according to personal preferences. Moreover, some occupants (10 out of 35) perceived a disregard for their comfort, further contributing to their discontent. Participant 97 vividly captured this sentiment, highlighting the frustration experienced by many: *"It is not really nice to work with cold hands. There is a line were you should start care more about the comfort of the occupants than energy* *savings"*. Despite this, there was a high level of motivation among occupants to save energy. Many expressed a strong desire to contribute to energy-saving efforts and expressed agreement with the energy-saving campaign, recognizing the importance of changing behaviours regarding the use of energy and having a more sustainable mindset, an example of that is this snippet from participant 117: *"I believe it's essential for all of us to contribute to energy-saving efforts. It's more than just adjusting temperatures or switching off lights; it's about adopting a sustainable mindset and making mindful decisions"*.

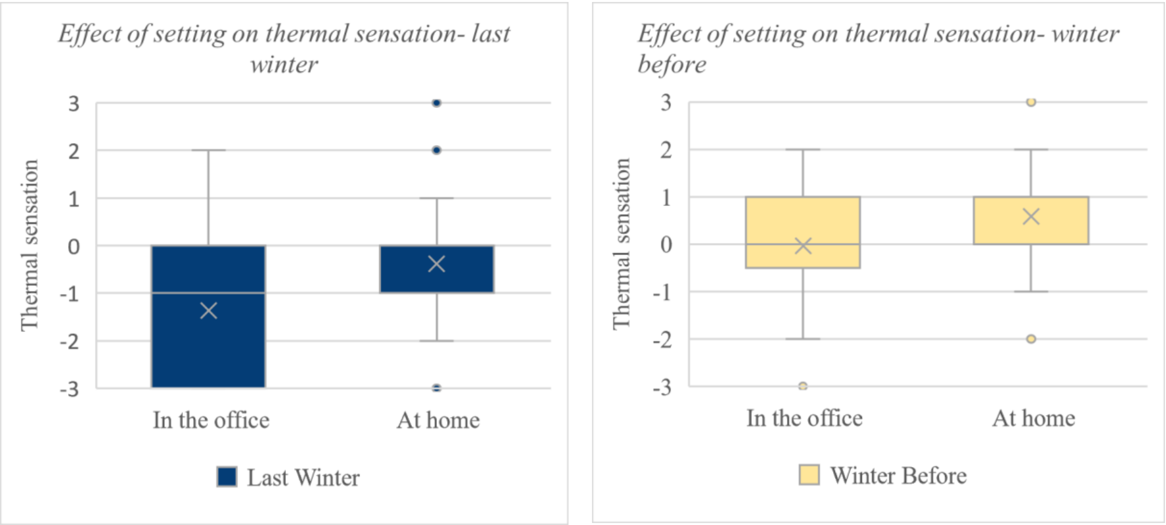
This exploratory qualitative analysis highlights the importance of considering occupant feedback and preferences when implementing temperature adjustments. By actively involving occupants in decision-making processes and addressing their concerns, it is possible to strike a balance between energy conservation and maintaining occupants' comfort and satisfaction.

Below some noteworthy snippets that provide additional insights are presented:

Subject 22: *" I think they should make the building more energy efficient, I understand that the organizitions save costs, but I think in the long run the efficiency of the building is more important"*
Subject 45: *"The occupants are those who suffer from this measure so I think they should feel empowered and envolved as well, otherwise you'll create resistance"*
Subject 4: *"It is definitely unacceptable, some colleagues of mine wore gloves this winter in the office"*
Subject 9: *"This winter, sometimes I used the stairs to warm up"*

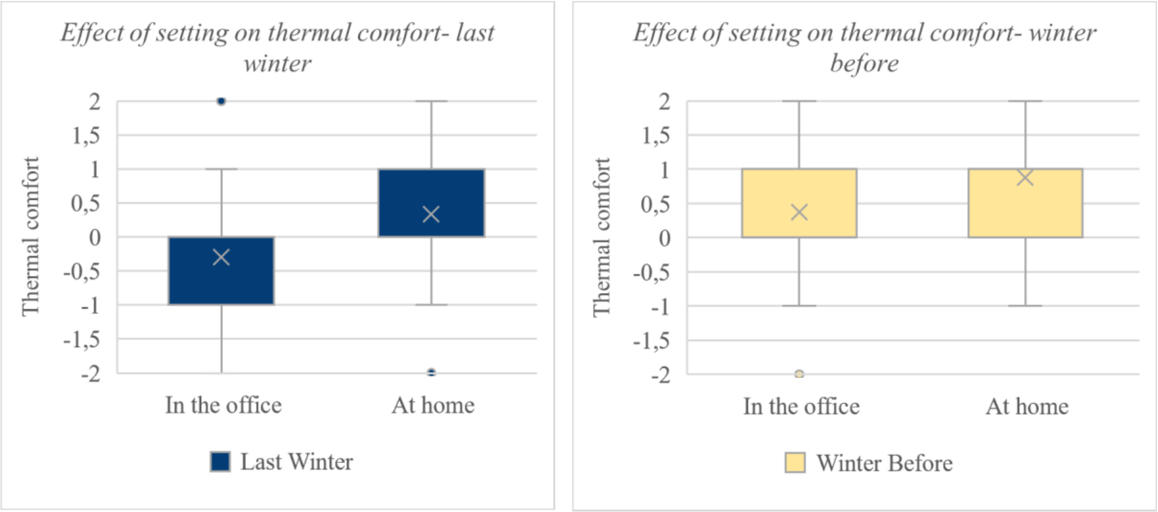
Exploratory: Is there a statistically significant difference in the thermal comfort and sensation felt at home or at the office during last winter and the winter before?

Figure 20 and 21 present box plots comparing the thermal sensation and comfort ratings, respectively, under two different conditions: last winter, with lower temperatures and winter before, with higher temperatures, in two different settings. The box plot analysis offers valuable insights into the distribution of thermal sensation and comfort among the building occupants across the explored conditions. Upon observing the means in Figure 20 and 21, a clear and consistent pattern emerges, indicating that the means are consistently higher at home when compared to that at the office. This suggests that, on average, occupants experience higher levels of comfort and satisfaction within their homes. Notably, the difference in means is more pronounced during the last winter compared to the previous winter. Focusing on the interquartile ranges (IQR) in both Figure 20 and 21 it becomes evident that only the box representing the evaluation of last winter's thermal sensation in the office exhibits a wider distribution and less concentration. This is manifested by the larger size of the box, indicating a higher degree of variability in the evaluation of thermal sensation during that specific period. On the other hand, all the other boxes (both in Figure 20 and 21) appear narrower, in general, with a range of only one level (of satisfaction), suggesting a more limited range of thermal evaluation and lower variability among the respondents. Furthermore, both Figure 20 and 21 display a few outliers, represented by individual data points beyond the whiskers of the box plot. These outliers signify personal evaluations that significantly deviate from the majority of data points, exemplifying unique evaluations of thermal comfort and sensation and highlighting the subjective nature of this measure. A chi-square statistical analysis of independence test showed a statistically significant effect of the setting on thermal comfort (Last winter: χ^2 (4, N = 242) = 34.2, $p < .001$; Winter before: χ^2 (4, N = 242) = 24.7, $p < .001$) and sensation (Last winter: χ^2 (6, N = 242) = 41.6, $p < .001$; Winter before: χ^2 (6, N = 242) = 21.4, $p < .001$). The data suggests that there is an association between the setting and thermal comfort and sensation, it can be observed that people tend to feel more comfortable and thermally satisfied at home, rather than at the office.



a) b)

Figure 20: Box plot illustrating the effect of setting on thermal sensation under two conditions: (a) last winter and (b) winter before. The X represents the mean. a) ($\bar{x}_{\text{office}} = -1.36$, $\bar{x}_{\text{home}} = -.38$) and b) ($\bar{x}_{\text{office}} = -.03$, $\bar{x}_{\text{home}} = .57$). The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data



a) *b)*

Figure 21: Box plot illustrating the effect of setting on thermal comfort under two conditions: (a) last winter and (b) winter before. The X represents the mean. a) ($\bar{x}_{\text{office}} = -.30$, $\bar{x}_{\text{home}} = .33$) and b) ($\bar{x}_{\text{office}} = .37$, $\bar{x}_{\text{home}} = .87$). The horizontal line within each box represents the median, while the box represents the interquartile range (IQR) encompassing the middle 50% of the data

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CHAPTER FOUR

Discussion

4. CHAPTER 4 – DISCUSSION

4.1. Interpretation of results

The results from this experimental case study revealed several key insights regarding occupants' behaviour, coping strategies, and perceptions, as well as the impact of temperature setpoints on thermal comfort and sensation.

Firstly, the analysis of coping strategies revealed that occupants employed compensatory behaviours, such as increasing clothing thermal insulation or utilizing radiators, in response to lower indoor temperatures. Further analysis suggests that occupants show a preference for adjusting thermal comfort by using radiators rather than altering their clothing thermal insulation levels. This suggests that occupants adapt their behaviours to enhance their comfort, but also raises considerations for energy savings control. Extensive research in the literature has explored the role of adaptive behaviours in the pursuit of thermal comfort. Moreover, a consensus prevails within the literature, highlighting the significant contribution of adaptive behaviours in achieving both thermal comfort and energy savings. (Butera, 1998; R. De Dear & Brager, 1998; Hong et al., 2018; Humphreys, 1998; Sun & Hong, 2017).

Regarding the impact of lowering temperature setpoints on thermal comfort and sensation, variations were observed. In line with numerous studies in the literature (Chun et al., 2008; Cui et al., 2013; Frontczak & Wargocki, 2011; Wang et al., 2018), it has been consistently observed that during winter period, higher temperature setpoints, within the range of 20-24ºC, lead to higher levels of thermal comfort and sensation. However, individual experiences of comfort varied, with some expressing acceptable comfort levels and others reporting dissatisfaction. Another noteworthy conclusion is that when the temperature setpoints are high, there is a close similarity between the thermal sensation and comfort assessments. However, as the temperature is lowered, the evaluation of thermal sensation among occupants becomes more diverse compared to thermal comfort. This observation indicates that when the setpoints are within the comfort zone temperature range, the number of dissatisfied occupants remains relatively controlled. Conversely, when the temperature setpoints fall outside the comfort zone, occupants experience a wider range of thermal sensations, highlighting the need for comprehensive understanding and consideration of individual preferences. In such cases, it becomes crucial to provide flexible options for thermal control to accommodate the diverse comfort needs of occupants, such as Personal Control Systems (Lou., 2023).

Regarding occupants' motivation to save energy, the majority exhibited high levels of motivation, driven by factors such as high energy bills and environmental concerns, with the political-social crisis having limited direct impact on occupants' motivation. The findings indicate that a significant majority of occupants across the three buildings reported an increase in motivation to save energy since last winter. This suggests that the primary driving force behind their motivation was the impact of high energy bills rather than environmental concerns, as revealed during the interviews. During the interviews, an interesting observation emerged as some participants inquired about their motivation in different settings, specifically distinguishing between their motivation at the office and at home. This distinction implies that their level of motivation may vary depending on the setting, with a potential explanation being that individuals are more motivated to save energy at home due to their personal responsibility for utility bills. Extensive research has been conducted on the psychology of energy use (Abrahamse & Steg, 2009; Poortinga et al., 2004; Poortinga et al., 2002; Steg et al., 2016), highlighting the importance of understanding the motivations behind pro-environmental behaviour. These studies reveal that successful interventions in workplaces and households, which consider socio-demographic and psychological factors, as well as incorporate values and quality of life considerations, can effectively promote energy savings.

Addressing the question of whether highly motivated individuals who actively lowered the temperature at home perceived more comfort would have been an intriguing aspect to explore. However, due to the nature of the data collected in our study, it was not possible to draw definitive conclusions in this regard. The participants included in this study exhibited a uniformly high level of motivation towards energy conservation, making it challenging to compare them with individuals who may not possess the same level of motivation. Without a suitable control group or a sufficient representation of individuals with varying motivation levels, it becomes difficult to establish a direct link between motivation, temperature adjustment behavior, and perceived comfort. Further research that includes a diverse range of participants with varying motivation levels would be necessary to delve deeper into this interesting question and derive meaningful conclusions.

The evaluation of occupants' willingness to maintain lower temperature setpoints revealed a heterogeneous response, although a majority expressed interest in maintaining the lower temperature setpoints. A notable finding regarding this question is the significant emphasis by occupants of Building A on their willingness to maintain lower temperatures, contingent upon ensuring minimum comfort levels. This observation suggests that occupants of this building, characterized by lower thermal comfort and sensation ratings, are now less willing to compromise their comfort. Interestingly, in the building with the highest thermal comfort and sensation ratings (Building B), occupants exhibited a greater willingness to maintain lower indoor temperatures.

The "Zet de knop om" campaign was generally well received by occupants, although satisfaction with its implementation varied across buildings. Building B received more favorable evaluations, while Buildings A and C demonstrated a mixture of satisfaction, neutrality, and dissatisfaction. These findings emphasize the importance of considering occupants' feedback and continuous communication when designing and implementing energy-saving campaigns. A potential explanation for this could be attributed to the presence of more controls over the thermal environment in Building B. Unlike Building A, which experienced a temperature reduction of 3.7 ºC, Building B implemented a smaller decrease of only 2 ºC. Moreover, Building B is equipped with a water heat distribution system via radiators in addition to the air heat distribution system, allowing for the maintenance of comparable comfort levels at lower temperatures. Additionally, during the winter period, occupants of Building B relied on radiators, potentially resulting in higher perceived temperatures than the initially set target. Furthermore, the findings from previous studies conducted by Leygue et al., (2017), Orland et al., (2014), and Staddon et al., (2016) offer valuable insights for the implementation of energy-saving measures. These studies have provided evidence of the effectiveness of behaviour change interventions in office-type workplaces in reducing energy consumption. Such interventions, which involve creating social and physical opportunities for employees to save energy through support, control, and technology restructuring, have consistently yielded positive outcomes. Additionally, the use of serious games that simulate energy-saving behaviours has shown promise as an effective approach (Orland et al., 2014). The motivations underlying energy-saving behaviour include altruism, warm-glow rewards, and organizational support. Notably, environmental concern and organizational motivations have been found to have a positive influence on energy-saving intentions, while motivations focused on reputation have been found to have a negative impact (Orland et al., 2014).

The findings from this experimental case study also demonstrated that the number of options for thermal control significantly influenced occupant satisfaction. Occupants who had access to a greater variety of control options reported higher levels of satisfaction. This highlights the importance of offering diverse controls to accommodate individual needs and preferences, particularly when the setpoints are outside the comfort zone mentioned earlier. This finding aligns with the research conducted by Leaman & Bordass (1993), which demonstrated that buildings where occupants have more access to building controls tend to exhibit higher tolerance towards the thermal environment. Additionally, Lou., (2023) shown that "(...) the indoor temperature can be lowered (...) while respecting thermal comfort on an individual level using a Personal Control Systems". Numerous studies have investigated the influence of user control in work environments. The majority of these studies have consistently concluded that greater direct personal control leads to higher levels of thermal comfort (Brager et al., 2004; Fountain et al., 1996; Karjalainen & Koistinen, 2007), increased satisfaction (Huizenga et al., 2006b; Lee & Brand, 2005), energy savings (de Bakker et al., 2017; Nagy et al., 2015; Wagner et al., 2007), and improved productivity (Leaman & Bordass, 2001). Too low temperatures can also negatively affect the performance/productivity of office workers (van Dijken & Boerstra, 2015). Seppanen et al., (2006) found (below 20 °C) a linear relationship between the operative temperature and the performance in office situations. Ye et al., (2005) conducted a field study in an office building and found that the objectively measured productivity of the office workers was 8-10% lower on days when office workers perceived the environment to be perceived as cool or cold on average (8 to 10% lower compared to the score for a neutral situation where people perceived the environment on average as not hot / not cold). Lan et al., (2011) also showed during a laboratory study that low ambient temperatures have an effect: performance at 18 °C was found to be about 4% less than at 22 °C. These findings emphasize the positive impact of providing occupants with control over their thermal environment. Understanding the importance of user control and its relationship to thermal comfort is crucial when considering the implementation of lower temperature setpoints in office buildings, as it underscores the need to empower occupants and cater to their individual preferences for optimal comfort and well-being.

The analysis examining the influence of gender, age, and BMI on perceived thermal comfort with lower indoor temperatures yielded valuable insights into the complex nature of occupant responses. One notable finding is that females tend to experience greater discomfort and cold sensations when exposed to lower temperatures compared to males. This observation suggests a gender-related difference in thermal perception and sensitivity, potentially influenced by physiological factors such as variations in body composition, metabolic rates, and thermoregulatory responses. This finding is consistent with the majority of literature, including studies by Indraganti et al., (2015), Karjalainen & Koistinen, (2007) and Chaudhuri et al., (2018) which concluded that women express more dissatisfaction than men under similar thermal conditions and that females are more sensitive than males to variations from an ideal temperature and express more dissatisfaction, particularly in cooler conditions. Studies such as the one conducted by Indraganti et al., (2015) explored the possibility of predicting human thermal state (comfort/discomfort) based on gender-specific physiological parameters. The main conclusions of this study highlighted that women exhibited greater adaptability, while men were more sensitive yet tolerant to thermal conditions. On the other hand, research by Chaudhuri et al., (2018) reported that women have higher thermal acceptability, more comfortable temperature preferences, and a greater inclination to use windows compared to men. These findings indicate that gender can play a significant role in determining individual preferences and responses to indoor thermal conditions. Foster et al., (1976) found that aging men exhibited decreased sweating activity and an increased threshold for the onset of sweating compared to younger men. These differences were even more pronounced in aged women. Lan et al., (2008) studied the thermal comfort of Shanghainese individuals and found that females had a comfortable temperature of 26.3 °C, which was 1 °C higher than that of males. Recently, a study by Rupp et al., (2023) concluded that cold susceptibility is not simply a matter of perception, but relates to a measurable difference in endogenous heat production, the author adds that "currently mandated temperatures setpoints (...) do therefore not seem to discriminate between sexes as a result of sex-related differences in physiology, but they might have negative implications for cold sensitive individuals" (Rupp et al., 2023).

Furthermore, the analysis revealed significant variations in perceived thermal sensation and comfort among distinct BMI and age groups. However, it is important to note that further studies are necessary to establish the direction and causality of these observed differences. For instance, Indraganti et al. (2015) found that younger subjects (age $\leq$ 25 years) expressed comfort at a slightly but significantly higher temperature than older subjects (age > 25 years). Additionally, individuals with a low Body Mass Index (BMI < 18.5 kg/m^2) reported comfort at 27.1 ºC, while those with a high BMI (BMI > 25 kg/m^2) expressed comfort at 0.7 K lesser temperature. Collins & Hoinville, (1980) demonstrated that, in general, older adults were satisfied at lower temperatures than younger individuals, primarily due to higher clothing thermal insulation. Field research conducted by Cena et al., (1986) found that the elderly in Canada were comfortable at temperatures considered too low according to the PMV/PPD model. This discrepancy could be attributed to the incapacity to effectively heat their homes, a problem also observed in over half of elderly households in Ireland (Healy & Clinch, 2002). These findings highlight the need for age and BMI-specific considerations in thermal comfort assessments and the design of indoor environments. Further research is essential to deepen our understanding of these variations and to develop strategies that can accommodate the diverse comfort requirements of different population groups.

The exploratory analysis revealed significant differences in perceived thermal comfort between home and office settings, with individuals experiencing higher levels of comfort at home. The impact of physical settings on occupants' comfort was evident, revealing an intriguing finding during the interviews. It was observed that individuals tend to maintain lower temperature setpoints at home, below 19 degrees Celsius, while still experiencing higher thermal satisfaction. Further investigation indicated that this disparity could be attributed to the type of heat distribution systems employed and the level of control associated with being at home. Notably, water heat distribution systems, using radiators, commonly found in residential settings allow for lower temperatures to be maintained while achieving similar comfort levels, as previously discussed. Furthermore, the freedom individuals have at home to personalize their comfort, such as using blankets or adjusting clothing layers, contrasts with the limited options available at the office where occupants rely solely on the clothes they bring from home. This increased freedom and adaptability contribute to heightened satisfaction and alleviate the feeling of being trapped in discomfort throughout the day. Although this analysis sheds light on the topic, a more comprehensive examination of the factors contributing to the disparity between home and office thermal experiences is warranted.

The extensive literature on the impact of adjusting temperature setpoints on energy savings has consistently shown positive results. However, it is crucial to consider the potential consequences on occupants' comfort when implementing lower temperatures, which requires further investigation. While ongoing studies are exploring this aspect, alternative energy-saving measures are also being explored. The following paragraph delves into some of these measures examined in the literature.

Fadzli Haniff et al. (2013) conducted a study comparing different HVAC scheduling techniques for energy-efficient and cost-effective building operations. The advanced scheduling technique was found to have the highest potential for energy and cost savings. Another approach, demand response (DR), involves adjusting temperature setpoints to reduce energy consumption during peak demand periods (Jafarpur & Berardi, 2021).

However, Aghniaey & Lawrence (2018) highlight that DR measures can impact building occupants physically and psychologically, leading to thermal discomfort, decreased productivity, mood swings, and health issues. To strike a balance between energy efficiency and occupant comfort, optimization algorithms and predictive control strategies have been explored (Afram et al., 2017; Aftab et al., 2017; X. Li & Malkawi, 2016; Salakij et al., 2016). Afram et al. (2017) investigated the effectiveness of model predictive control (MPC) in generating dynamic temperature setpoint profiles, resulting in reduced operating costs without compromising thermal comfort. The study found that compared to fixed set-points, MPC saved operating costs between 6% and 73% depending on the season. Similarly, Salakij et al. (2016) studied the application of Model-Based Predictive Control (MBPC) and demonstrated nearly 43% thermal energy savings compared to traditional constant temperature setpoint control. Furthermore, the studies conducted by Luo et al., (2023) and te Kulve, (2018) investigated the influence of correlated colour temperature (CCT) of light on various aspects, including thermal comfort. Contrary to the hue-heat hypothesis, their findings revealed that CCT did not have a significant impact on thermal sensation in mild cold conditions.

4.2. Limitations

This study, conducted from mid-March to May 2023, is not without its limitations, which should be duly acknowledged. Firstly, the "last winter" examined in this study, referring to the winter of 2022-2023, was relatively mild compared to previous winters, which were characterized by colder temperatures. This disparity in weather conditions may have influenced the occupants' experiences and perceptions of thermal comfort.

Additionally, the term "winter before" does not specifically refer to the winter of 2021-2022. Due to the COVID-19 pandemic, many individuals did not work at the office during that period, making it impractical to collect data solely from that winter. Therefore, the "winter before" is considered an average of previous years when the temperature setpoints were not lowered. Furthermore, it is essential to consider the changes in working habits resulting from the COVID-19 pandemic. During the "last winter," a majority of individuals adopted a hybrid working model, alternating between working from home and the office. In contrast, during the "winter before," most people worked at the office five days a week. These shifts in working arrangements could have influenced occupant behaviours and thermal experiences. It is worth noting that the interviews were conducted between

March and April, extending into the beginning of May. It is recognized that people may have a tendency to recall events that occurred further in the past with less accuracy or detail. This effect is know as the “rosy view” and it suggests that our memory of an event is more positive than our evaluation at the moment (Mitchell et al., 1997). Additionally, the Hawthorne effect studied by Schwartz et al. (2013) and Tiefenbeck (2016) might have some influence on the occupants' behaviour, in the way that individuals may consciously adopt energy-saving practices and exhibit greater energy-saving motivation when they are aware of being monitored or observed. This awareness of being observed can create a temporary shift in behaviour, leading to a potentially greater adherence to energy-saving measures during the period of observation.

Moreover, the absence of setpoint, temperature, and energy data could potentially compromise the validity and reliability of the study's findings, since no information is given about that. The use of interviews may introduce certain limitations associated with human psychology. For instance, individuals may have a tendency to provide responses that align with their desired image rather than reflecting their true behaviours or experiences. This phenomenon, is known as social desirability bias, Nederhof, (1985) describes it as “the most common sources of bias affecting the validity of experimental and survey research findings. From a self-presentational perspective, social desirability can be regarded as the resultant of two separate factors: self-deception and other-deception (...)” (Nederhof, 1985).

These limitations should be taken into account when interpreting the findings of this study, and future research should strive to address these factors for a more comprehensive understanding of occupant thermal comfort in different contexts.

4.3. Recommendations

Expand the methodological scope: To enhance the research findings, consider adding both qualitative and quantitative assessments. Qualitative methods like interviews and group discussions can provide insights into occupants' subjective experiences of thermal comfort. Additionally, conduct a quantitative study using thermal sensors and physiological monitoring devices to gather objective data on occupants' thermal comfort and physiological responses to different temperature setpoints. This approach will provide a comprehensive understanding of the impact of lowering temperature setpoints.

User feedback and engagement: Incorporate user feedback and engagement strategies into future research. Implement real-time feedback mechanisms and occupant engagement initiatives to foster active participation and understanding of energy-saving measures. This would help evaluate the effectiveness of different strategies and promote sustained energy-saving behaviours among building occupants.

Long-term study: Extend the duration of the study to include multiple heating seasons. By studying long-term effects of lowering temperature setpoints, we can capture seasonal variations and understand occupants' adaptive behaviors and evolving thermal comfort over time.

Comparative analysis: Perform comparative analysis to assess variations in occupants' thermal comfort responses to lowering temperature setpoints across different building types. By addressing these areas in future research, a deeper understanding of the effects of lowering temperature setpoints on occupants' thermal comfort can be gained, leading to more informed decision-making in building design, operation, and energy-saving initiatives.

CHAPTER
FIVE

Conclusion

Photo by author

5. CHAPTER 5 – CONCLUSION

In conclusion, this master's thesis explored the effects of lowering temperature setpoints on occupants' thermal comfort in office buildings in The Netherlands, by conducting a comprehensive analysis of existing literature, collecting empirical data, and evaluating occupants' experience of the energy-saving campaign.

The key finding is that lowering temperature setpoints in office buildings can have a significant impact on occupants' perception of thermal comfort. While some individuals may adapt well to lower temperatures and perceive them as comfortable, others may experience discomfort, especially those who are more sensitive to colder environments. Factors such as age, gender, clothing, activity level, and personal preference can influence how occupants perceive and respond to lower temperatures. Furthermore, over time, occupants can adapt to lower temperatures, but the adaptation process may differ for each individual, and some may take longer to acclimate to the new conditions. The findings also demonstrated that allowing occupants to have control over their immediate thermal environment and providing clear communication regarding temperature adjustments can positively influence their perception of thermal comfort. While a majority of occupants expressed interest in maintaining lower temperature setpoints, the willingness to compromise comfort varied depending on individual factors and building characteristics, such as the type of façade and available controls. One important observation from the research is that occupants of office buildings with lower thermal comfort and sensation ratings are generally less willing to accept lower temperature setpoints due to concerns about their personal comfort. However, in buildings with higher thermal comfort and sensation ratings, occupants demonstrated a greater willingness to maintain lower indoor temperatures, indicating a positive correlation between comfort levels and acceptance of temperature reduction measures. Additionally, this study identified a high level of motivation to save energy, along with a consensus regarding the energy-saving campaign. Capitalizing on this enthusiasm, is important to maintain effective communication and continue fostering a culture of energy conservation.

This thesis emphasizes the need for a holistic approach that integrates occupant preferences, energy efficiency goals, and adaptive strategies to optimize thermal comfort in buildings. Ongoing communication and engagement with occupants are crucial for their satisfaction and support for energy-saving measures. Overall, this research makes a valuable contribution to the goal of creating sustainable and energy-efficient buildings while simultaneously preserving optimal levels of thermal comfort.

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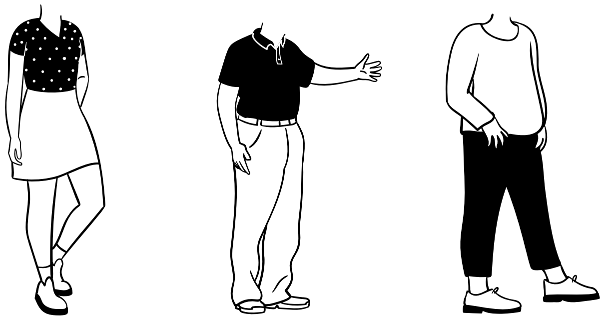
APPENDIX A- THERMAL COMFORT SURVEY

Perceived Thermal Comfort Survey:



A	B	C	D

Figure 22: Clothing thermal insulation (1 clo = 0.155 m²K/W), based on ASHRAE Standard 55 (Dear & Brager, 2002)

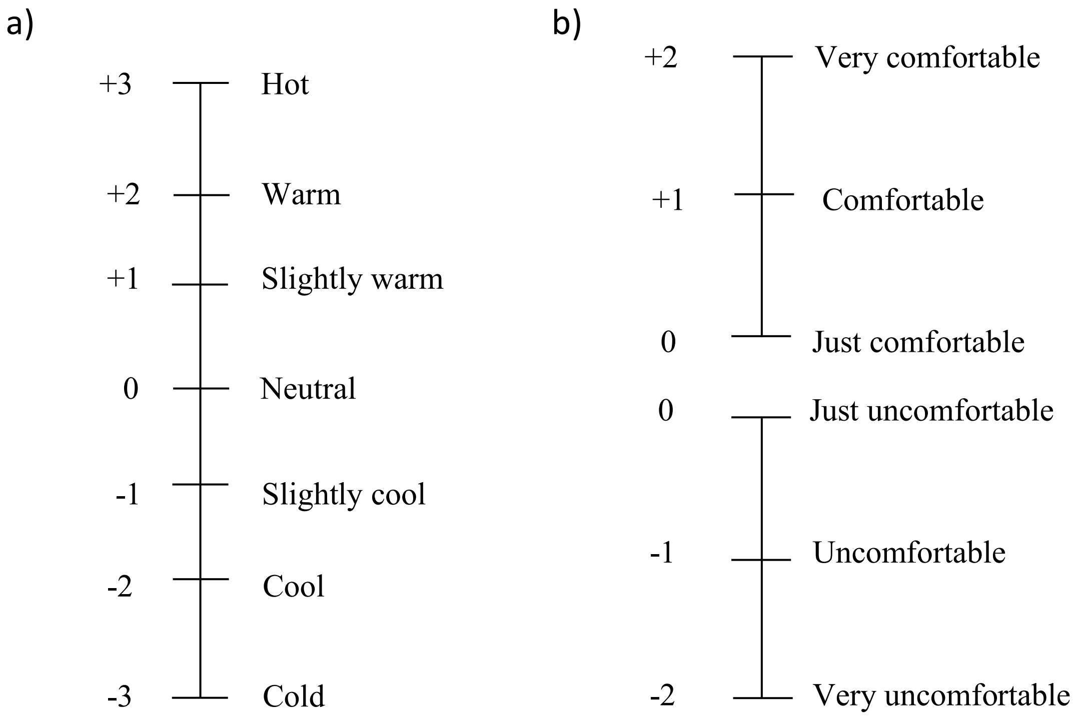
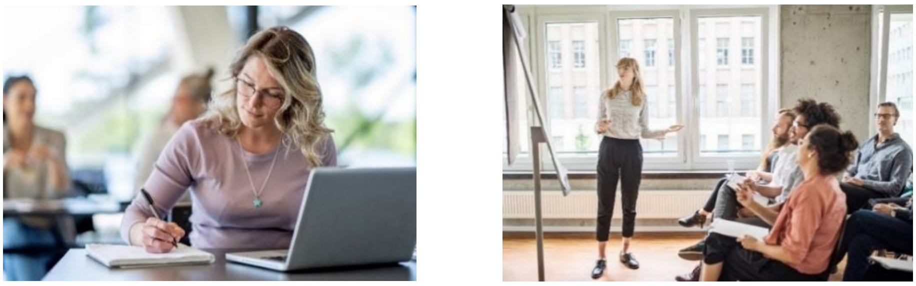


Figure 23: (a) Thermal sensation ASHRAE 7-point scale (b) thermal comfort scale, retrieved from (Y. Zhang & Zhao, 2009)



Mainly seated at the desk	Mainly moving around (e.g. doing presentations, having meetings)
A	B

Figure 24: Metabolic rate of different activities (1 met = 58 W/m²), based on (Gut & Niedermann, 1993) and ASHRAE Standard 55

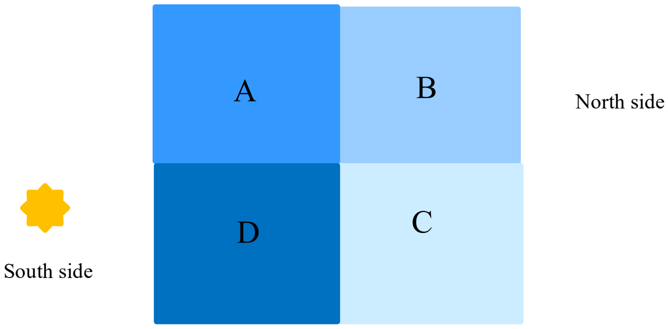


Figure 25: Building working spaces

BMI value range				$\text{BMI} = \frac{Weight}{(Height)^2} = \frac{Gewicht}{(Lengte)^2} = \left[\frac{kg}{m^2}\right]$
< 18.5	18.5-24.9	25-29.9	>30	

Figure 26: BMI values range and formula

Gender			Age value range				
Female	Male	Prefer not to say	18-29	30-39	40-49	50-59	≥ 60

Figure 27: Gender and age value range

APPENDIX B- INTERVIEW QUESTIONS

Table 4: Interview questions

Perceived thermal comfort	
1.	Based on Figure 22, which is the correspondent clothing you usually had in the office, on average, last winter, and the winter before? What is the winter you are considering as "winter before"?
2.	Based on Figure 23, how would you describe the (a) thermal sensation and (b) comfort at your workplace, last winter and the winter before?
3.	Do you think the comfort you felt in the office, this winter, was acceptable or unacceptable?
4.	What type of discomfort did you feel?
5.	What options do you have to control the temperature of your environment?
6.	On a scale from 1-5, where 1 is dissatisfied and 5 is satisfied, how satisfied are you with the options you have to control the temperature in your workspace?
Motivation & Adaptation	
7.	On a scale from 1-5, where 1 is not motivated and 5 is motivated, how motivated are you to save energy?
8.	What is your motivation?
9.	Did you lower the temperature setpoints at home, this winter? To which value?
10.	How did you adapt to these lower temperature setpoints, at home?
11.	Based on Figure 23, how would you describe the (a) thermal sensation and (b) comfort at your home, last winter and the winter before?
12.	How did your mindset/motivation to save energy change since the last winter?
13.	What do you think about the policy of lowering the temperature setpoints?
14.	On a scale from 1-5, where 1 is not satisfied and 5 is satisfied, how would you describe your level of satisfaction with this measure?
15.	How did you adapt to the lower temperature setpoints, at the office?
16.	Would you be willing to maintain these temperature setpoints even when energy prices are back to their regular values?
17.	Do you have any additional comments about the temperature at your workplace?
Subject profile	
18.	Based on Figure 24, how would you describe your work at the office?
19.	How many hours do you spend working in the office per week, on average?
20.	Do you usually work in an open or a closed space – an "office box"?
21.	Based on Figure 25, on which side of the building do you usually work?
22.	Have you been working in this building for more than one year?
23.	Using Figure 26, can you indicate with a X in which range of values is your BMI?
24.	Using Figure 27, can you indicate with a X what is your gender and in which range of values is your age?

APPENDIX C- BUILDINGS INFORMATION

Name	Building A
Size	44-storey and 149.1-metre-high
Location	Rotterdam
Description	This building was designed for residency, labour and leisure. The largest part is intended as office space and residency. The building-parts within the scope of this study are parts that are inside the municipality sphere of influence.
Explored floors	8th, 9th, 10th, 12th, 13th, 14th, 16th, 18th, 24th, 26th, 27th, 32th, 33th, 36th, 38th
Number of interviews	51 interviews
TSet before	22.7 ºC
TSet after	19 ºC
Type of HVAC system	All-air system
WWR	80
Openable windows	No
Types of Sunshading	Interior vertical screen

Figure 28: Building A, photo by author

Name	Building B
Size	3 floors and 10-metre-high
Location	Utrecht, Bunnik
Description	This building was designed to be an office space. The building-parts within the scope of this study are parts that are inside the building B, and correspond to office space (no canteens or coffee corners).
Explored floors	1st, 2nd and 3rd
Number of interviews	35 interviews
TSet before	22 ºC
TSet after	20 ºC
Type of HVAC system	All-air system + radiators
WWR	40
Openable windows	Yes
Types of Sunshading	Exterior vertical screen

Figure 29: Building B, photo by author

Name	Building C
Size	29-storey and 141.86-metre-high
Location	The Hague
Description	This building is home to the Ministry of Education, Culture and Science. The scope of this case study will only focus of the 4th -11th floors.
Explored floors	4th, 5th, 6th, 7th, 8th, 9th, 10th and 11th
Number of interviews	35 interviews
TSet before	21 ºC
TSet after	19 ºC
Type of HVAC system	All-air system
WWR	60
Openable windows	No
Types of Sunshading	Interior vertical screen

Figure 30: Building C, photo by author