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DETERMINANTS OF THERMAL COMFORT: ANALYSIS OF PUBLIC BUILDINGS IN A POST-TRANSITION CONTEXT

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Abstract

Due to an ongoing energy crisis and fluctuating energy prices, the prerequisites for maintaining optimal indoor environmental quality (IEQ), a critical determinant of productivity, cognitive performance, and overall well-being, have been significantly disrupted. This study focuses on examining determinants of thermal comfort, a subjective evaluation of the thermal environment and a key component of IEQ. Through a survey of employees and users of public buildings in Bosnia and Herzegovina, the research employs a four-stage regression analysis to identify the main predictors of thermal comfort. Although 71.33% of respondents report satisfaction with the heating system, only 43.13% find the heating to be adequate, with the optimal perceived temperature averaging 21.66°C. The results show that key factors influencing thermal comfort include thermal sensation, thermal memory, gender, and respondent type (employee versus user). These seminal results could offer valuable productivity and financial implications for energy savings, especially for budgetary policymakers aiming to reduce energy consumption as well as for public sector management and public institutions seeking to improve well-being and productivity.

JEL classification: Q40, Q480
Keywords: Thermal Comfort, Thermal Sensation, Energy Crisis

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Introduction

Even though the topic of indoor environmental quality (IEQ) and its aspects is primarily related to engineering, a multidisciplinary approach that might include productivity gains with financial and economic aspects of such an important topic remains scarce. Hence, available literature and academic research and interest in indoor environmental quality (IEQ) and thermal comfort have continuously examined both traditional predicted mean vote (PMV) models and adaptive thermal comfort models across various countries, climates, and indoor environments over the past few decades. Although research into aspects of the adaptive hypothesis regarding building occupants' thermal expectations and preferences began as early as Bedford's work (1936) and continued through the seminal contributions on adaptive thermal comfort by Humphreys (1978), de Dear and Brager (1998), Humphreys and Nicol (1998) as well as Nicol et al. (2012), academic interest in adaptive thermal comfort through participant surveys remains scarce. Over decades of study, several measurement scales for 'warmth and preferences' have been developed, as summarized by Humphreys et al. (2012), who emphasize that thermal comfort is often viewed from the perspective of thermal physiology (Humphreys et al., 2012). Furthermore, de Dear and Brager (1998) identified three categories of thermal adaptation: behavioural adjustment (subdivided into personal, technological, and cultural responses), physiological adaptation (including genetic adaptation across generations and acclimatization within an individual's lifetime), and psychological adaptation (altered perception and response to sensory information due to past experiences and expectations).

Given the ongoing challenges of climate change and energy price volatility, the aim is to investigate perceived adaptive thermal comfort in public buildings in Bosnia and Herzegovina (BiH) for the first time. Recent years have shown a steady increase in academic interest in different aspects of adaptive thermal comfort in BiH from the engineering perspective, as seen in Peulić et al. (2021), who compares thermal comfort in energy-retrofitted buildings in Slovenia and BiH, Díaz-López et al. (2022), who evaluates thermal comfort in Mediterranean educational settings and in southern BiH and Blažević et al. (2023), who assesses heating design temperature standards in Sarajevo in response to climate change. While the primary focus of this study is to examine predictors of thermal comfort in public institutions, the broader policy and operational implications also include further impacts on energy efficiency in terms of potential energy savings and workplace productivity gains. Hence, as the research topic has not been investigated sufficiently in the public sector, the results of this primary research may have practical implications and more importantly, financial implications that could initiate financial savings of the increasing energy costs in the public sector with their broader implications on public expenditures and therefore public budgets.

Through a recent participant survey conducted among employees and users of public buildings in BiH on perceived thermal comfort in BiH's public buildings, the objective is to contribute to the relatively scarce academic discourse on this topic. The results could have broader applicability and interest for audiences across other European countries, and may yield substantial financial benefits through energy savings, particularly relevant for policymakers engaged in budget planning aimed at reducing energy costs.

Literature review

Although the seminal research underpinning this study was conducted in the engineering sciences, the multidisciplinary objective of the research is to contribute towards adaptive thermal comfort theory as opposed to PMV models in the investigation of perceived thermal comfort in a small post-transition country (BiH). Furthermore, since the research focuses on the determinants of thermal comfort in public buildings in BiH, the research should also contribute towards the identification and significance that thermal comfort may have on productivity gains with clear financial and economic aspects. Hence, the literature review section combines the identification of thermal comfort as a multidisciplinary approach.

Academic interest in the investigation of adaptive thermal comfort has been evolving over time from the seminal works of Bedford (1936), Humphreys (1978), de Dear and Brager (1998), Humphreys and Nicol (1998), Nicol et al. (2012) or de Dear et al. (2020) just to name a few. In fact, parallel to the recognition of the importance of categories of thermal adaptation and development of thermal physiology, theory recognizes constant development and the upgrade of measurement scales that try to capture comprehensiveness of the subject, as developed in the scales of Nicol et al. (2012).

Thermal comfort, which is the focus of this research, is considered a condition of mind that expresses satisfaction with the thermal environment (ASHRAE, 2013) and is one of the most studied IEQ factors (Chen et al., 2020; Wang et al., 2021). Furthermore, an exhaustive Scopus literature review on terms including adaptive thermal comfort as key words resulted in over 1,200 journal and conference proceedings highlighting the ongoing significance of the topic (Parkinson et al., 2020; de Dear et al., 2020). IEQ and its factors influence the occupant's cognitive functions and, consequently, their productivity, learning performance, and well-being. Understanding the predictors and consequences of IEQ is a specific area of research since occupants spend substantial time indoors (Klepeis et al., 2001), especially with the most recent trends of working from home or pandemic lockdowns (Wang et al., 2021). The complexity of the association between IEQ factors and cognitive functions, such as attention, memory, perception, and sensation, has been exhaustively examined in the literature (Wang et al., 2021), but improvements are required in the refinement of categories of IEQ and cognition.

Authors such as Frontczak and Wargocki (2011), Al Horr et al. (2016), Wang et al. (2021) classify IEQ factors as indoor air quality, thermal environment, light, acoustic, office and layout, biophilia and views, look and feel and location and amenities. The systematic literature review that examines the relationship between five IEQ factors (indoor air quality, thermal environment, lighting, noise, and non-light visual factors) and five categories of cognition (attention, perception, memory, language function, and higher-order cognitive skills) concludes that "poor IEQ conditions are but not always associated with reduced cognition" (Wang et al., 2021).

Apart from the measurement scales as developed by Nicol et al. (2012), thermal comfort might also be measured using Likert scales. For example, Velt and Daanen (2017) used a 5-point scale, measuring thermal comfort from comfortable (0) to extremely uncomfortable, while Chun et al. (2008) used a 7-point Likert scale, from -3 (cool) to +3 (hot). Thermal sensation represents a mental process to access the immediate external thermal simulation, typically measured on the scale from 'cold' to 'hot'. In fact, ASHRAE thermal sensation scale uses a 7-point Likert scale, ranging from -3 (cold), 0 (neutral) to 3 (hot). However, as noted by Shahzad et al. (2018), many researchers continue to use the single measure of thermal sensation to express thermal comfort, even though the thermal sensation scale does not reveal whether the respondent prefers or likes the perceived indoor temperature. As noted by Langevin et al. (2013), the thermal comfort of building occupants has long been considered a key performance indicator, but other concepts (such as thermal sensation, thermal acceptability, and thermal preference) emerged out of the existing body of thermal comfort research. It is worth noting that ASHRAE introduced four different scales: thermal sensation scale (cold vs. hot), thermal preference scale (cooler vs. warmer), comfort scale (uncomfortable vs. comfortable) and satisfaction scale (dissatisfied vs. satisfied).

Recent systematic literature review (Wang et al., 2021) indicates that the IEQ factor of the thermal environment and the subjective evaluation of it expressed as thermal comfort has been influenced by four physical parameters (air temperature, mean radiant temperature, air velocity, and relative humidity). In academic research, physical parameters are concentrated with personal variables (clothing insulation and activity level; Standard, 1992) but also investigated and affected by other socio-demographic factors, such as gender (Griefahn & Künemund, 2001; Karjalainen, 2012), age (Griefahn & Künemund, 2001; Indraganti et al., 2015), and physiological adaption (Luo et al., 2016). Schweiker et al. (2020a), in their literature review section, argue that past thermal experiences, or thermal memory, influence occupants' expectations in the built environment. These might also be perceived as aspects of behavioural adjustment, physiological adaptation and psychological adaptation (de Dear & Brager, 1998). In terms of the effects of a specific IEQ factor on different cognitive functions, it is important to state that authors (e.g. Wang et al., 2021), in the comprehensive manual review and co-occurrence analysis, find that the associations or relationships are diverse. In addition to the increasing number of studies and methods being applied, as reported by Wang et al. (2021) as well as Yao et al. (2022), the co-occurrence analysis highlights the importance of interdisciplinary collaboration in identifying new categories IEQ and cognition factors. Authors such as Kim et al. (2018a), Kim et al. (2018b) or Liu et al. (2019) also deploy machine-learning models to assess thermal comfort.

The study conducted by Tanabe et al. (2015) concluded that greater individual thermal satisfaction could lead to an increase in the performance of the worker during simulated office work. However, the relationship between thermal comfort and its predecessor and antecedent is a complex system and, as noted by Putra (2017), "the relationship amongst indoor environmental quality to produce occupant satisfaction is a complex system that needs to be assessed comprehensively". Regarding adaptive thermal comfort models and their positive role in the sustainability of buildings, a most recent comprehensive literature review suggests three representative thermal environment assessment approaches: the heat balance approach, the adaptive regression-based approach, and the adaptive heat balance approach (Yao et al., 2022). The research results identify the strengths and constraints of each approach, whereby the adaptive heat balance approach bridges the gap between the two classical approaches and provides a promising potential increase in predictive performance.

Considering climate change and the growing energy crisis throughout the world, understanding thermal comfort, sensation and satisfaction could provide multiple positive effects on the economy as policy recommendations that could address barriers of having higher than the optimal indoor temperature, which might lead to higher energy consumption. Furthermore, academic multidisciplinary research has attempted to contribute towards a better understanding of adaptive thermal comfort models and related economic and social activities. These are specifically related to green building, energy efficiency, and sustainability (Yao et al., 2023). Hence, understanding the relationship and consequences of inadequate IEQ can have multiple other effects. As summarized by Chen et al. (2020), the following consequences result from inadequate IEQ: headaches and difficulty in concentration, negative moods, decreased work motivation, reduced cognitive capacity, poor work performance, perceived discomfort, indoor environmental dissatisfaction, and job dissatisfaction. A better indoor environment can improve health and productivity (Fisk, 2000; Geng et al., 2017). According to Fisk (2000), improving indoor environments and building energy efficiency in the United States may result in significant health and productivity benefits, including benefits such as reduced respiratory disease, reduced allergies, and asthma, reduced sick-building syndrome symptoms, and direct improvements in worker performance unrelated to health with estimated financial gains from these benefits range from billions to tens of billions of dollars. Furthermore, potential financial estimates rely on cost-benefit analysis whereby estimates reveal that even a “1% increase in productivity should be sufficient to justify an expenditure equivalent to a doubling of energy or maintenance costs, or that productivity increases for a worker of 1% correspond to reduced sick leave of two days per year, reduced breaks from work or increased time at work of 5 minutes per day, or a 1% increase in the effectiveness of physical and mental work” (Fisk, 2000).

Hence, the possible policy implications of researching determinants of thermal comfort in public buildings might lead to the reduction of unnecessary energy costs, improve employees’ productivity, improve service delivery, and enhance employee well-being.

Methodology

Model development

As previously discussed, thermal comfort might be evaluated from PMV models (e.g. Shahzad et al., 2018; Dyvia & Arif, 2021 or Kawakubo et al., 2023) or adaptive thermal comfort models (e.g. de Dear, 1998; de Dear & Brager, 1998; Halawa & Van Hoof, 2012; de Dear et al., 2020). In this study, the purpose is to contribute towards the latter. Following the results from Nicol (2011) that a comfortable temperature in the building “has a range of temperatures that people find comfortable”, or most recent literature review results from de Dear et al. (2020) that “no reliable evidence supports overcooling buildings to 22°C to enhance cognitive performance”, there is no uniform conclusion or ‘one size fits all’ approach when evaluating adaptive thermal comfort (de Dear et al., 2020). This is especially true for small post-transition countries such as BiH where research on adaptive thermal comfort is negligible.

When considering indoor environmental perception as an outcome variable, the following categorization of predictor variables is useful to consider physical variables (physical properties of the thermal, visual, acoustic and air quality environment), contextual variables, and personal variables (Schweiker et al., 2020b). As noted by de Dear (1998), contextual factors can moderate the extent to which building occupants behaviourally interact with their indoor climate. As noted by Halawa and Van Hoof (2012), cultural and social contextual dimensions typically refer to “dress code and clothing habit/behaviour of occupants of a particular building, workplace culture, having a siesta in the heat of the day, local and vernacular architecture, traditional means of construction and demographics”, and these factors have not been the subject of special investigation. For example, as noted by Andersen et al. (2016), the window opening behaviour and thermostat adjustments can influence the indoor environmental quality in residential buildings.

Having this in mindand the fact that thermal comfort as a concept has not yet been investigated in public buildings in BiH context, the purpose of the research is to investigate the determinants of thermal comfort. By using a four-step regression analysis, the research introduces the following steps: thermal sensation, thermal memory, characteristics of respondents being employees or users and socio-demographic characteristics of the respondents. The following hypotheses were developed:

H_1: An increase in perceived thermal sensation is associated with a lower likelihood of reporting dissatisfaction with thermal comfort.

H_2: Having a thermal memory of previous poor heating seasons is associated with a higher likelihood of reporting dissatisfaction with thermal comfort.

H_3: Greater awareness or knowledge of energy efficiency is associated with a lower likelihood of reporting dissatisfaction with thermal comfort.

H_4: A favourable perception of the importance of energy efficiency measures is associated with a lower likelihood of reporting dissatisfaction with thermal comfort.

H_5: Perceiving the quality of windows as extremely poor is associated with a higher likelihood of reporting dissatisfaction with thermal comfort.

H_6: Perceiving lighting conditions as adequate is associated with a lower likelihood of reporting dissatisfaction with thermal comfort.

H_7: Compared to users, employees are more likely to report dissatisfaction with thermal comfort.

Research design

In this research, thermal comfort represents the dependent variable and is measured by the question: "In your personal experience, how would you rate the heating in this building?", on a scale from 1 (very weak), 2 (somewhat weaker than it should be), 3 (adequate), 4 (somewhat stronger than it should be) and 5 (significantly stronger than it should be). The question constructed in this way measures how comfortable respondents are with the indoor temperature, compared to their ideal situation (stronger or weaker than it should be). A similar approach was used to measure "thermal comfort" by Chu et al. (2008) whereby the participants were asked to rate thermal sensation on the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) scale from -1 (slightly cool) to +1 (slightly warm).

The independent variables are presented and described in Table 1. Most variables represent dummy variables while thermal sensation is a continuous variable, measuring the perceived average temperature in the premises of the institution during the winter.

Table 1: Description of the variables used in the model

Variable and type	Type	Description
Thermal comfort (COMF)	Outcome variable (dummy)	Whether a participant rated the heating in this building as very weak.
Temperature (SENS)	Independent variable (continuous)	The perceived average temperature in the premises of the institution during the winter period (Thermal sensation).
Thermal memory (MEM)	Independent variable (dummy)	Whether a participant rated the heating during the entire previous heating season as poor regardless of the outdoor temperature or with major fluctuations.
Awareness/Knowledge (AW)	Independent variable (dummy)	A self-assessed awareness of energy efficiency, i.e., a participant knows the term and has general knowledge about it; or is well-informed about it.
The importance of energy efficiency measures (IMP)	Independent variable (dummy)	Whether a participant perceived the impact of energy efficiency on the quality of life and living standards of ordinary citizens as favourable/positive.
Lighting (LIGHT)	Independent variable (dummy)	Whether a participant rated the lighting as adequate while staying in the institution.
Windows (WIN)	Independent variable (dummy)	Whether a participant assessed the quality of windows as extremely poor.
Type of participants (TYPE)	Independent variable (dummy)	Whether a participant is a user.
Institution (INST)	Independent variable (dummy)	The variable indicates which institution an individual interacted with or worked for.
Gender (FEM)	Independent variable (dummy)	Whether a participant is a female or male.
Age (AGE)	Independent variable (dummy)	The age of a respondent.
Education (EDU)	Independent variable (dummy)	The highest education level achieved.

Source: Authors' own work.

Data used in this research was collected as a part of the project "Social Monitoring and Evaluation for the Implementation of the Energy Efficiency Improvements in Public Buildings". The selected random stratified sample of public buildings is representative in terms of geographical location, type of object, number of users and amount of investment. Data were collected both from employees and users. Employee respondents represent doctors, professional staff, administrative staff, technical staff (hospitals), teachers, administrative staff, technical staff (schools) and employees (other buildings). Building users are patients (those who have visited healthcare institutions in the past six months), students aged 15+ (schools) and service users (other buildings). Surveys were collected using CAPI interviewing procedure with up to 130 tablets. The procedure included: pilot testing, selection and training of interviewers, detailed methods for recording non-response rates and steps necessary to take if the checks revealed a problem, and quality control steps. Table 2 indicates sample characteristics.

Table 2: Sample characteristics

		Frequency	Percentage (% of total)
Total	Total sample size	364	100.00%
Status	Employee	171	46.98%
	User	193	53.02%
Gender	Male	144	39.56%
	Female	220	60.44%
Age	16-24	97	26.65%
	25-34	82	22.53%
	35-44	88	24.18%
	45-54	47	12.91%
	55+	50	13.74%
Education	No education	2	0.55
	Elementary school	32	8.79
	High school	154	42.31
	College or university	176	48.35
Institution	Faculty 1	50	13.74%
	Faculty 2	31	8.52%
	High school 1	58	15.93%
	Police Academy	53	14.56%
	Clinic 1	44	12.09%
	Clinic 2	44	12.09%
	Clinic 3	39	10.71%
	Clinic 4	45	12.36%

Source: Authors' own work.

The total sample size consists of 364 respondents, out of which 46.98% are employees and 53.02% are service users. Male were of 39.95% of the total sample. Participants in all age groups are represented above 20%, except age group 45-54 (12.91%) and older than 55 years (13.74%). The most prevailing group in terms of education is related to college or university (48.35%), followed by high school (42.31%). Finally, there are eight institutions involved in the data-collecting process – two faculties, one high school, one policy academy and four clinics. The proportion of participants from those institutions is almost equally distributed, except for Faculty 2 which consists of 8.52% of the total sample.

The data for this study was collected from four different cities in BiH between March and June 2021, so mainly during the heating season in BiH. The cities included in the study were Mostar, Sarajevo, Tuzla, and Zenica. Air humidity and temperature are important factors in understanding the climatic conditions of the study. Table 3 shows the average monthly values for both air humidity (measured in percentage) and air temperature (measured in degrees Celsius) for each of the specified months and cities. During the period from March to June 2021, there was a noticeable increase in temperatures across Mostar, Sarajevo, Tuzla, and Zenica. In March, temperatures ranged from 4.6°C in Sarajevo to 10.0°C in Mostar, gradually increasing to peak in June, reaching from 20.5°C in Sarajevo to 25.3°C in Mostar. On the other hand, air humidity exhibited a fluctuating pattern, generally increasing from March to May before slightly declining in June. Mostar consistently had higher temperatures compared to the other cities, while Tuzla consistently registered the highest air humidity levels.

Table 3: Average monthly air humidity and air temperatures

Average monthly air humidity	March 2021	April 2021	May 2021	June 2021
Mostar	58.0	64.0	68.0	61.0
Sarajevo	63.0	61.0	55.0	56.0
Tuzla	69.0	67.0	68.0	66.0
Zenica	62.0	61.0	59.0	60.0
Average monthly air temperatures	**March 2021**	**April 2021**	**May 2021**	**June 2021**
Mostar	10.0	12.3	18.4	25.3
Sarajevo	4.6	8.0	15.5	20.5
Tuzla	5.1	8.6	14.6	20.6
Zenica	5.7	9.3	16.1	21.8

Source: Federal Hydrometeorological Institute (2021).

Results and discussion

In this section, the results of the analysis have been presented. First, a brief overview of thermal comfort, thermal sensation and thermal satisfaction has been provided. Afterwards, the results of regression analysis with several different models have been presented.

The perception of adequate temperature

The research provides several interesting results. Firstly, the majority of respondents perceived the temperature to be weak or very weak (56.87%). These participants reported that their perceived average temperature is 17.21°C. Even though those participants reported weak or very weak thermal comfort, 7.25% of participants in this category indicated that they were satisfied with the heating system. Secondly, most of the participants who reported adequate thermal sensation (43.13%) reported that they were satisfied, i.e. 71.33% of participants reported that they were satisfied with the heating system. Their perception of average temperature was 21.66 °C, which is 25.9% higher compared to those respondents that reported weak or very weak thermal comfort. Finally, only a small proportion of participants (1.92%) reported strong or significantly stronger heating in their building, while most of these participants were satisfied with the heating system. In the experiment environment, Tanabe et al. (2015) analyzed the significance that individual thermal satisfaction has on productivity gains in five different scenarios. Similarly, Geng et al. (2017) found that 75% of the thermal satisfaction votes concentrate on "neutral", while none of the subjects felt dissatisfied under the experimental condition of 24°C. Their experiment showed that with deviation from 24°C more subjects felt thermal dissatisfaction; thermal dissatisfaction was more significant under cooler conditions, compared to warmer conditions. When thermal comfort, thermal sensation and thermal satisfaction are compared, there is an evident difference between employees and users (i.e. visitors). A large proportion of employees reported weak or very weak thermal comfort (66.08%) compared to users (48.80%). Table 4 summarizes the results of thermal comfort, thermal sensation, and thermal satisfaction.

Table 4: The perception of adequate temperature results

Q_1: In your personal experience, how would you rate the heating in this building?	Frequency	Percentage	Q_2*: Perceived average temperature in °C		Q_3: Percentage of individuals satisfied with the heating system
			Mean	St. Dev.	%
Weak or very weak	207.0	56.87%	17.21 (n = 177)	3.41	7.25%
Adequate	150.0	43.13%	21.66 (n = 111)	2.31	71.33%
Strong or significantly stronger	7.0	1.92%	22.67 (n = 6)	3.41	71.43%
Employees					
Weak or very weak	113.0	66.08%	17.36 (n = 100)	3.67	8.85%
Adequate	55.0	32.16%	21.52 (n = 54)	2.51	78.18%
Strong or significantly stronger	3.0	1.75%	24.67 (n = 3)	2.52	66.67%
Users					
Weak or very weak	94.0	48.70%	17.01 (n = 77)	3.05	5.32%
Adequate	95.0	49.22%	21.81 (n = 57)	2.01	67.37%
Strong or significantly stronger	4.0	2.07%	20.67 (n = 3)	1.16	75.00%

* In your estimation, what is the average temperature in the premises of the institution during the winter period?

Source: Federal Hydrometeorological Institute (2021).

The results of the regression models

Table 5 presents the main results of the study in four steps. In step 1, thermal sensation, measured as the perceived temperature in °C, has a statistically significant influence on thermal comfort. In other words, a 36% decrease in the odds of rating the heating in a building as very weak for one °C increase in the perceived temperature will be seen, ceteris paribus. As other variables in the remaining three steps have been introduced, the odds ratio remains constant, i.e., between 24% and 27%. Shahzad et al. (2018) noted that the relationship between thermal sensation and thermal comfort is not straightforward. The research confirms that for every degree increase in the air temperature, there is an expected decrease in thermal comfort. Thermal sensation alone explained 28.19% of the variance in the comfort level of respondents, which is somewhat higher than in Shahzad et al. (2018), where thermal sensation explains 13.2% of the variance. However, the results show a percentage decrease in the odds of reporting poor thermal comfort, while Shahzad et al. (2018) established the relationship using a Likert scale. It should be noted that thermal sensation in the developed model is measured simplified as perceived air temperature, not including relative humidity, or the level of activity of a user.

Another variable that has a significant impact on thermal comfort in all steps is thermal memory. The odds for the participants that rated the heating during the entire previous heating season as poor regardless or with major fluctuations are 459% (step 2), 554% (step 3) and 403% (step 4) higher than the odds for those who rated the heating system adequate or appropriate. These results are in line with the existing literature, showing that past thermal experiences, or thermal memory, influence occupants' expectations in the built environment (Schweiker et al., 2020a). However, as concluded by Halawa and Van Hoof (2012), "the expectation hypothesis introduced by some of the adaptive approach researchers is lacking a solid foundation." The Theory of Planned Behaviour assumes that attitudes, subjective norms and perceived behavioural control are important predictors of an individual's intentions; and intention is considered to correlate strongly with behaviour in certain contexts (Conner & Armitage, 1998). Limiting the understanding of the behaviour as the way in which individuals behave in response to a particular situation or stimulus, reporting the poor heating system could be the result of attitudes formed in the past. As such, it is argued that thermal memory could influence thermal comfort by defining expectations through attitudes.

In the third step, individual characteristics as control variables have been added. Similarly, in the fourth step, the research differentiates between employees and users of public buildings as control variables. The results indicated that the odds for females are about 225% (step 3) and 146% (step 4) higher than the odds for males to report poor thermal comfort. These results confirm that gender also plays an important role, which could be due to the different metabolic processes of men and women. While not referring to gender, Akimoto et al. (2010) concluded that the measured metabolic rate could be one of the useful basic design values. The study of Akimoto et al. (2010) also found that the amount of clothing was different between male and female participants, which could offer a potential explanation for the difference between men and women. While only significant at 10%, the results show that on average, if the respondent is a service user, the odds of reporting poor thermal comfort was 62% lower than the odds for employees. This implies that service users are less prone to reporting poor thermal comfort, perhaps as they only spend limited time in the public building.

Table 5: Regression model results

Independent Variable	Odds ratio (standard error)			
	Step 1	Step 2	Step 3	Step 4
Temperature (SENS)	0.64 (0.04***)	0.73 (0.05***)	0.72 (0.05***)	0.76 (0.05***)
Thermal memory (MEM)	-	5.59 (2.02***)	6.54 (2.66***)	5.03 (2.20***)
Awareness/Knowledge (AW)	-	1.26 (0.45)	1.30 (0.57)	1.15 (0.54)
The importance of energy efficiency measures (IMP)	-	0.48 (0.27)	0.41 (0.27)	0.42 (0.29)
Lighting (LIGHT)	-	0.86 (0.32)	0.80 (0.32)	0.80 (0.34)
Windows (WIN)	-	1.71 (0.73)	1.74 (0.79)	2.02 (1.09)

Independent Variable	Odds ratio (standard error)			
	Step 1	Step 2	Step 3	Step 4
Type of participants (TYPE)	-	-	0.34 (0.22*)	0.38 (0.25*)
Female (FEM)	-	-	3.25 (1.28***)	2.46 (1.06**)
Age (AGE) Ref. group (16-24)				
25-34	-	-	2.30 (1.65)	2.89 (2.30)
35-44	-	-	0.84 (0.65)	0.81 (0.69)
45-54	-	-	1.26 (1.00)	1.53 (1.36)
55+	-	-	0.89 (0.72)	1.14 (1.01)
Education (EDU) - Ref. Elementary school or less				
High School	-	-	0.41 (0.26)	1.48 (1.34)
College/University	-	-	0.37 (0.31)	1.21 (1.26)
Institution (INST) - Ref. group Clinic 1				
Clinic 2	-	-	-	0.90 (0.87)
Clinic 4	-	-	-	0.26 (0.24)
Clinic 3	-	-	-	0.53 (0.47)
Faculty 1	-	-	-	0.64 (0.49)
Faculty 2	-	-	-	0.70 (0.57)
Police academy	-	-	-	0.10 (0.11**)
School 1	-	-	-	2.68 (2.55)
Constant	1360.40 (1361.21***)	72.44 (99.19***)	141.35 (228.15***)	31.62 (65.12*)
Pseudo R^2	28.19%	37.15%	42.92%	46.53%

Dependent variable: Thermal comfort (COMF)

Source: Authors' own work.

Discussion

Table 6 presents the summary of hypotheses testing based on the regression analysis results presented in Table 5 and Figure 1. Table 6 highlights predictors of thermal comfort in public buildings in BiH that were tested, while also providing justification for each case. For hypotheses that were not confirmed, the table includes plausible explanations grounded in existing research, indicating that while statistical significance was lacking in this dataset, previous studies and theoretical frameworks suggest these factors may still play a meaningful role in shaping perceptions of thermal comfort.

Table 6: Summary of Hypotheses Testing

Hypothesis	Variable	Status	Result Summary	Explanation
H_1	Thermal sensation	Confirmed	Each 1°C increase in perceived temperature reduces odds of poor comfort by 24-36%	Consistent with Shahzad et al. (2018) and Geng et al. (2017), aligns with adaptive thermal comfort theory that links thermal sensation closely to comfort outcomes.
H_2	Thermal memory	Confirmed	Participants with past poor heating experiences are 403-554% more likely to report discomfort	Aligned with Schweiker et al. (2020a), thermal memory influences current expectations and perceptions, consistent with Psychological Adaptation Theory.
H_3	Knowledge of energy efficiency	Not confirmed	Odds ratios not statistically significant in any step	Although not confirmed, literature (e.g., Day & Gunderson, 2010) suggests that greater awareness may increase tolerance; knowledge may foster acceptance, as predicted by the Theory of Planned Behavior.
H_4	Perception of energy efficiency importance	Not confirmed	Odds ratios not statistically significant in any step	Expected to reduce dissatisfaction, as suggested by Value-Belief-Norm Theory. Monfared and Sharples (2011) have shown that individuals who identify with a building's green features, termed as 'green identity', tend to report fewer comfort-related complaints. This suggests that favourable attitudes toward sustainability may influence how occupants experience thermal discomfort.
H_5	Perceived quality of windows	Not confirmed	Odds ratios not statistically significant in any step	Perception of quality of windows as extremely poor was expected to increase discomfort; poor window quality linked to drafts and radiant heat loss. Although not statistically significant in this study, literature suggests that window characteristics, such as size, shape, and the quality of view, can influence both visual and non-visual perceptions, including thermal comfort (Alsaad et al., 2021). Poor window design may therefore contribute to discomfort by affecting psychological and physiological responses to the indoor environment.
H_6	Perceived quality of lighting	Not confirmed	Odds ratios not statistically significant in any step	Literature suggests visual comfort can influence overall indoor environmental quality (Frontczak & Wargocki, 2011). Positive lighting may reduce perceived discomfort via cross-modal comfort effects (Guo et al., 2025). Previous research shows that proximity to windows enhances visual qualities (e.g., daylight and views), which can positively influence thermal perception and satisfaction, suggesting cross-modal environmental effects that shape overall comfort. The study of Guo et al. (2025) suggests that visual stimuli, such as the color temperature of light, can influence thermal sensation, but the reverse effect, i.e. temperature influencing visual perception, does not occur.

Hypothesis	Variable	Status	Result Summary	Explanation
H_7	Type of participant (Employee vs User)	Confirmed	Users (i.e. visitors) are less likely to report discomfort by 62-66%	Prolonged exposure experienced by employees might increase sensitivity to discomfort. As shown by Hwang et al. (2008), visitors tolerate a wider range of temperatures and prefer cooler conditions after entering from outdoors, while staff in steady indoor environments report more discomfort.

Source: Authors' own work.

This study examined thermal comfort and its determinants within public buildings in BiH, contributing uniquely to the existing body of knowledge on indoor environmental quality and adaptive thermal comfort, particularly in a post-transition context. The significance of the findings is evident given the current global energy crisis, which has heightened the urgency of balancing thermal comfort with energy efficiency. These results underscore the critical interplay between perceived temperature, past thermal experiences, and demographic factors in shaping thermal comfort within public buildings. Specifically, they reveal that higher perceived indoor temperatures significantly enhance occupant comfort, reducing negative assessments by approximately 24% to 36% for each degree Celsius increase. Moreover, past negative thermal experiences profoundly impact current comfort evaluations, substantially increasing dissatisfaction rates. Notably, gender differences emerged prominently, with women significantly more likely to report discomfort. These findings highlight crucial considerations for policymakers and facility managers aiming to optimize indoor environments, balancing occupant comfort, energy efficiency, and well-being. The results highlight the significance of aligning heating strategies more closely with user-perceived comfort thresholds, rather than overcompensating to meet arbitrary temperature targets, that could in turn reduce energy consumption and energy costs, especially in institutional settings with large, heated areas and extended operating hours (e.g. clinics).

The results revealed that while 71.33% of respondents expressed satisfaction with their heating system, only 43.13% perceived the indoor temperature as adequate. This indicates a critical discrepancy between general satisfaction and specific perceptions of thermal adequacy, suggesting that while heating systems might technically perform well, subjective expectations of comfort might differ considerably. This discrepancy may be explained by the fact that satisfaction often reflects a broader, more tolerant evaluation influenced by habit, social norms, or lowered expectations in resource-constrained environments, whereas perceptions of adequacy are more precise, immediate judgments tied to personal thermal comfort thresholds and physiological needs.

A key finding from the regression models is that thermal sensation, measured as the perceived temperature, significantly influences thermal comfort. Specifically, each increase in perceived indoor temperature by one degree Celsius reduces the odds of negatively rating thermal comfort by approximately 24% to 36%. This result aligns with Shahzad et al. (2018), reinforcing the understanding that thermal sensation and thermal comfort, though related, have a complex, nonlinear relationship. Furthermore, the study highlighted the role of thermal memory, indicating that respondents with negative experiences from past heating seasons are considerably more likely (up to 554%) to report poor thermal comfort. This aligns with Schweiker et al. (2020a) and suggests that historical thermal experiences strongly influence current comfort perceptions, supporting the psychological and behavioral dimensions of adaptive comfort theory. These results can be explained by the fact that individuals do not assess thermal conditions in isolation, but rather in relation to their past experiences and expectations; a previous season marked by discomfort can heighten sensitivity and lower tolerance thresholds, leading to a more critical perception of current conditions - even when objective improvements have been made.

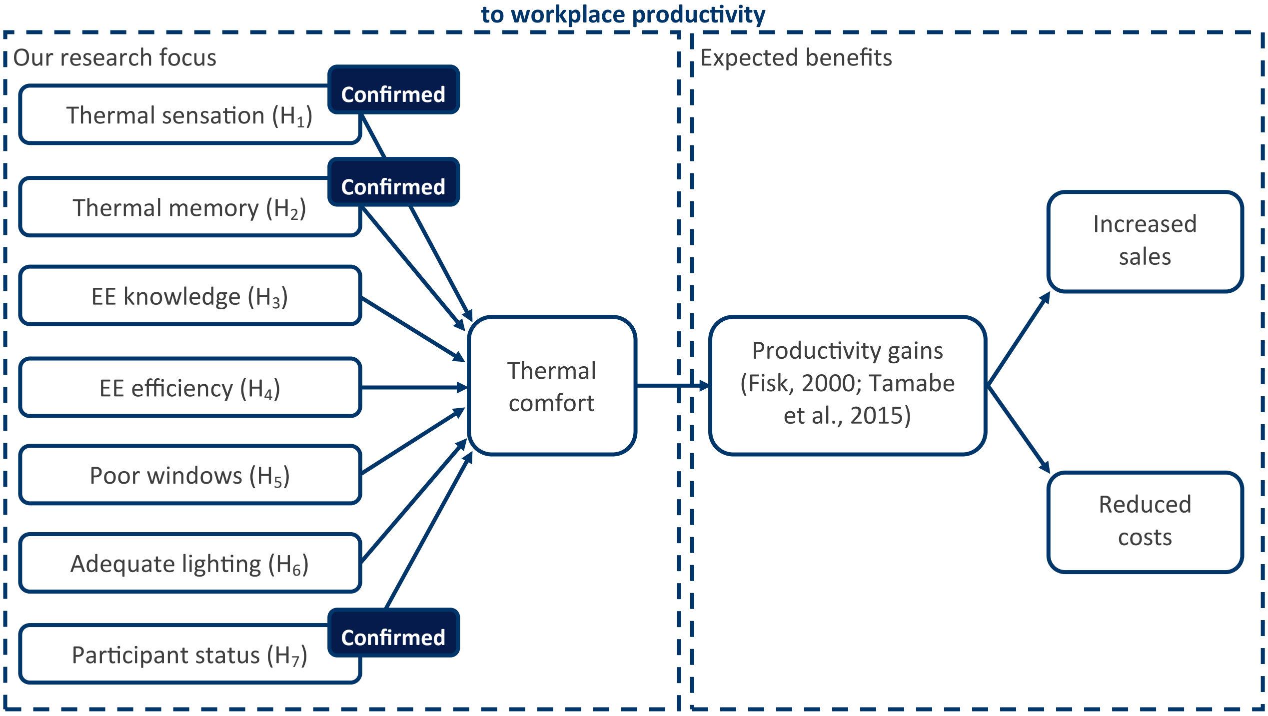
Gender differences were notably significant, with women more likely to report discomfort. This supports findings from previous studies (Griefahn & Künemund, 2001; Karjalainen, 2012), emphasizing physiological differences in thermal perception between genders, likely related to metabolic rates and clothing preferences. This difference may be explained by the fact that women generally have lower metabolic heat production and may adhere to different dress codes or layering practices in institutional settings, making them more sensitive to cooler indoor environments and thus more likely to perceive discomfort under the same thermal conditions.

Although several variables were not statistically significant in predicting thermal comfort, the literature recognizes its possible mechanism of influence on the thermal comfort. Awareness of energy efficiency (H_3) and favorable perceptions of its importance (H_4) did not show significant effects, yet prior research suggests they may shape tolerance for thermal variations through how people feel or think about energy use. For instance, individuals who possess higher awareness may increase tolerance (Day & Gunderson, 2010). Monfared and Sharples (2011) have shown that individuals who identify with a building's green features, termed as 'green identity', tend to report fewer comfort-related complaints. Similarly, the perception of window quality (H_5), although not statistically associated with reported discomfort in this study, has been linked in literature to both physiological (e.g. cold drafts, radiant heat loss) and psychological effects on comfort. Alsaad et al. (2021) emphasize that window characteristics, including shape, size, and view quality, can influence non-visual perceptions like thermal satisfaction. Lighting (H_6) also was found to be significant predictor of thermal comfort, but existing research indicates that pleasant lighting and visual access to daylight can enhance the perception of thermal comfort through cross-modal effects (Guo et al., 2025). These findings suggest that while these factors may not have emerged as strong predictors in this context, they should not be excluded from future models or design considerations, particularly given their potential to interact with other elements of indoor environmental quality.

Drawing from Fisk (2000) and Tanabe et al. (2015), improvements in individual thermal satisfaction have been linked to productivity gains in office settings and may have significant financial and economic implications (Figure 1). Given that employees reported poor thermal comfort in this study, targeted improvements to thermal conditions, based on adaptive preferences rather than fixed standards, could yield significant economic implications. With a more profound control of thermal comfort, these findings reinforce the argument that thermal comfort should not be treated as a secondary design goal, but rather as a strategic component of public sector performance and energy management. Public institutions may therefore reduce unnecessary energy costs, improve productivity through better service delivery, and enhance employee well-being. Future building retrofitting or heating management strategies should explicitly incorporate adaptive thermal comfort feedback loops, allowing institutional managers to adjust heating regimes based on actual comfort metrics, rather than rigid technical parameters alone.

The distinction between employees and users in reporting thermal comfort was another insightful finding. Employees, spending extended periods within these environments, reported significantly poorer comfort compared to users, reflecting potentially different adaptive opportunities or expectations. This is in line with the results as shown by Hwang et al. (2008), as visitors tolerate a wider range of temperatures and prefer cooler conditions after entering from outdoors, while staff in steady indoor environments report more discomfort. These differences can be explained by the duration and nature of exposure - employees, who spend long hours in the same thermal environment, are more likely to notice and be affected by subtle temperature fluctuations, while users, with shorter and more transient visits, may not experience the same level of discomfort or may not prioritize thermal conditions in their overall evaluation.

Figure 1: Summary of results and conceptual framework linking thermal comfort predictors to workplace productivity



Source: Authors' own work.

Conclusions

This paper deals with thermal comfort and thermal satisfaction and investigates the possible antecedents of perceived thermal comfort. The results of this study are based on the data collected in the process of “Social Monitoring and Evaluation for the Implementation of the Energy Efficiency Improvements in Public Buildings”. The descriptive statistics indicate that some respondents report adequate thermal comfort but are dissatisfied with the temperature. The results show that 43.13% of respondents perceived the heating in the building as adequate, yet merely 71.33% of those participants are satisfied with the heating system. The average perceived temperature to be adequate is 21.66°C. The regression model reveals that thermal sensation, thermal memory, gender, and type of respondents (i.e., being users or employees) might play important roles in predicting thermal comfort. The study adds value to the existing literature by implementing a more complex model with a wide range of predictors and demonstrating the odds of reporting poor heating based on these predictors. As noted by Shahzad et al. (2018) that the relationship between thermal sensation and thermal comfort is not straightforward, some empirical evidence to support the relationship between these constructs has been provided. In addition to this, understanding what impact perceived indoor temperature might contribute to improved energy efficiency measures is of interest. Findings are important for a range of stakeholders, including governments advocating for reduced energy consumption, as well as public and private companies seeking to enhance employee performance and well-being. The multidisciplinary nature of the research especially highlights the need that through investigation of determinants of thermal comfort, broader productivity, financial and economic implications ought to be considered. Guided by both employee and user perceptions and behavioural patterns, public sector decision-making officials and corresponding public institutions may conduct cost-benefit analyses that would reduce unnecessary energy costs, improve service delivery, and enhance employee well-being which all may have implications for public expenditures and public budgets.

This study significantly contributes to the sparse literature on adaptive thermal comfort in transitional countries, particularly within the Western Balkans context. It introduces a robust regression analysis integrating a variety of predictors, notably thermal memory and socio-demographic variables, to provide a deeper understanding of thermal comfort dynamics. Furthermore, the differentiation between employees and casual users provides additional insights into user-specific adaptation mechanisms. The significance of these findings is multifaceted. By clearly identifying factors affecting thermal comfort, this research provides actionable insights for policymakers aimed at enhancing energy efficiency without compromising occupant comfort. These findings can inform the design of targeted policy measures that go beyond technical upgrades to include behavioural and perceptual dimensions of energy efficiency. Additionally, understanding thermal comfort parameters can mitigate health issues associated with inadequate indoor environments, such as headaches, poor concentration, and decreased productivity, aligning with findings from Fisk (2000) as well as Chen et al. (2020). In doing so, the study strengthens the case for integrating thermal comfort metrics into broader occupational health and productivity frameworks. Finally, the results highlight areas for improvement in managing heating systems and productivity and possible financial implications of such, potentially reducing energy consumption and contributing to broader sustainability goals. Such insights are essential for developing cost-effective energy management strategies that align institutional practices with long-term sustainability commitments.

One key limitation of the research relates to the inability to collect actual financial statements and corresponding energy costs of the investigated public buildings in BiH over time since they are not publicly available. Hence, further investigation in the field ought to include cost-benefit analyses with clear financial implications of identified determinants of thermal comfort in public buildings in BiH.

Another limitation of this study lies in the operationalization of thermal sensation, which was measured solely through respondents' self-reported perceptions of air temperature. This approach excludes important environmental parameters such as relative humidity, air movement, and radiant temperature, as well as physiological variables like clothing insulation and activity levels, which together form the basis of more comprehensive thermal comfort indices such as PMV (Predicted Mean Vote). As a result, the explanatory power of the model may be constrained by the simplified representation of thermal conditions, limiting its generalizability in environments with more dynamic or complex indoor climates. Additionally, the thermal memory variable, although conceptually important and statistically robust in the analysis, is based on respondents’ recollection of heating quality over the previous season. This introduces a potential recall bias and temporal ambiguity, as individuals may conflate more recent experiences with older ones, especially in the absence of objective records. The inability to disentangle short-term dissatisfaction from long-term memory may have introduced noise into the measurement, potentially affecting the precision of the estimates. Future studies would benefit from longitudinal or diary-based approaches to more accurately distinguish between momentary perceptions and enduring thermal impressions. Moreover, the cross-sectional nature of the data limits the ability to infer causality between predictors and thermal comfort. Longitudinal research designs could help capture temporal fluctuations and adaptation processes more accurately, especially in environments subject to seasonal variability. Finally, while the model controls for several socio-demographic and institutional factors, other relevant constructs such as individual health status, thermal adaptation behaviours, or cultural attitudes toward energy use were not included and may also shape thermal comfort outcomes.

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