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An Experimental Investigation of the Influence of Indoor Color Temperature on Residents' Thermal Sensitivity

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Abstract: The hue-heat hypothesis proposes that lighting influences perceived temperature, with cool-colored light lowering and warm-colored light raising temperature perception. While studies have supported hue-heat effects, further research is needed in residential settings. This study examined indoor color temperature impacts on thermal sensitivity in a simulated residential environment. Two experiments were conducted in a test room. In Experiment 1, 36 participants experienced Red, White, and Blue lighting orders at fixed temperatures (21 – 23 °C). In Experiment 2, 24 participants were divided into preferred and non-preferred color conditions at the same temperatures. Thermal sensitivity was evaluated after each condition using ANOVA. Results of Experiment 1 supported the hue-heat hypothesis under Blue lighting, aligning with sensory evaluation. However, the hypothesis was not supported under Red and White conditions. Thus, blue illumination enhanced residential coolness perception. In contrast, participants preferred Red and White colors, diverging from hue-heat predictions. Overall, this study provides nuanced evidence for hue-heat effects in residential contexts, suggesting complex interactions between color preferences, lighting, and thermal perception.

Keywords: indoor color temperature; occupants; public health; residential environment; thermal sensitivity; winter

1 INTRODUCTION

In recent years, the increase in single-person households has brought the living room to the forefront as a primary space for leisure and hobbies, prompting a closer examination of individuals' environments and lifestyles. Among the various leisure activities that take place in the living room, watching television (TV) has emerged as the most prevalent form of media-based leisure [1]. Especially during the winter season, indoor activities tend to rise, resulting in a significant amount of time devoted to media-based leisure [2, 3].

This growing trend of indoor activities has sparked a heightened interest in indoor lighting. While indoor lighting serves the functional purpose of illuminating the space for activities, it also has the potential to influence occupants' emotions based on the type of activities being performed. Therefore, the color temperature of indoor lighting becomes a crucial factor to consider. Lower color temperatures create a warm ambiance, while higher color temperatures elicit a cooler sensation [4-7]. Consequently, understanding individuals' emotional responses to color temperature is important since humans' emotional states can vary depending on the color temperature [8, 9]. However, color temperature is an absolute value that compares color to temperature. Therefore, it is more significant to explore the characteristics of thermal sensitivity associated with color temperature. This concept involves a form of synesthesia where visual properties induce tactile and emotional perceptions of warmth or cold, rather than solely focusing on visual sensitivity towards color temperature [10-14].

Thermal sensitivity encompasses the process of perceiving physical aspects related to temperature and evaluating changes in human emotions based on this perceived information. This concept can be examined by considering stimuli and responses. The stimuli for perception include various thermal factors such as temperature, humidity, radiation temperature, and airflow velocity [15-17]. On the other hand, the response refers to the emotional changes induced by the perceived stimuli, which can be expressed through descriptive vocabulary (adjectives) as a behavioral concept [18]. However, it is possible that there may be a discrepancy between the sensory modalities of the stimulus and response when considering compatibility [19-22]. While the sensory modality of thermal-related physical elements corresponds to the tactile sense, the evaluative response through thermal sensitivity vocabulary may align more closely with the auditory sensory modality based on the tactile sense.

In summary, several key points should be considered. Firstly, it is crucial to explore media-based leisure activities in the living room during the winter season as a reflection of modern society. Secondly, the significance of lighting in indoor residential environments cannot be overlooked, and investigating the impact of color temperature on human emotions is essential among the various characteristics of lighting. Thirdly, adopting a synesthetic perspective that associates visual color attributes with tactile sensations of warmth or coldness necessitates studying tactile warmth sensitivity based on color temperature. However, it is important to thoroughly examine thermal sensitivity based on color temperature while taking into account the diverse sensory patterns and stimulus-response relationships involved. Therefore, this study aims to examine the thermal sensitivity of occupants through tactile thermal sensitivity adjectives in the first experiment, where indoor color temperature is adjusted using lighting in an experimental setting that simulates a residential environment during winter. In the second experiment, the focus shifts to exploring thermal sensitivity based on the occupants' preferred color temperature, ensuring that the variation in color temperature conditions is not compromised by individual preferences.

2 METHOD

2.1 Settings of Experiment

The first experiment involved 36 voluntary human participants, with an average age of 21.78 years. This group consisted of 18 males, with a mean age of 22.44 years, and 18 females, with a mean age of 21.11 years. Prior to the start of the experiment, participants were given approximately 10 minutes to familiarize themselves with the assigned experimental environment. During this time, they completed consent forms and received a detailed explanation of the experiment from the experimenter.

To control for the potential influence of clothing and activity levels, participants wore clothing corresponding to a fixed value of 1.0 clo, following the guidelines specified in ISO-7730 (2005) [23] Annex C. Additionally, the level of video watching was maintained at 1.0 met to ensure a consistent level of activity within the experimental environment [24].

In the second experiment, a separate group of 24 participants volunteered to participate, with an average age of 22.21 years. None of these participants had taken part in the first experiment. Among the second group, 12 individuals were assigned to the preferred indoor color temperature condition, with a mean age of 22.33 years. This subgroup consisted of 6 males, with a mean age of 22.83 years, and 6 females, with a mean age of 21.83 years. Conversely, the remaining 12 participants were assigned to the non-preferred indoor color temperature condition, with a mean age of 22.08 years. This subgroup included 6 males, with a mean age of 22.83 years, and 6 females, with a mean age of 21.33 years.

Similar to the first experiment, participants in the second experiment underwent a 10 minute adaptation period in the assigned experimental environment before the study began. They completed consent forms and received a detailed explanation of the experiment from the experimenter.

2.2 The First Experiment
2.2.1 Environment

The experiment took place in a simulated living room environment, which had dimensions of 3.5 × 5.4 × 2.1 m (length × width × height). The primary activity conducted in this space was watching videos. To ensure that the videos presented during the experiment did not influence the measurement of thermal sensitivity, a specific video titled 'EBS Documentary Prime-What Changes Schools Part 3' was selected. This video focused on neutral nature themes and was edited for the experimental duration. The choice of this video aimed to maintain consistent experimental conditions without introducing any potential bias in thermal sensitivity measurement.

2.2.2 Conditions

The experimental design included variations in indoor color temperature conditions (Red, White, and Blue) as within-factor variables, and indoor temperature conditions (21 °C, 22 °C, and 23 °C) as between-factor variables. The color temperature values for the indoor color temperature conditions were measured using the Sekonic C-800 Spectro Master Color Meter. The corresponding temperature values obtained were 3898 K, 5077 K, and 11423 K for the Red, White, and Blue conditions, respectively (as illustrated in Fig. 1). The illuminance level for all conditions was fixed at 400 lux. To ensure that the chosen indoor temperature range aligns with typical winter settings, the study considered three temperature conditions: 21 °C, 22 °C, and 23 °C.

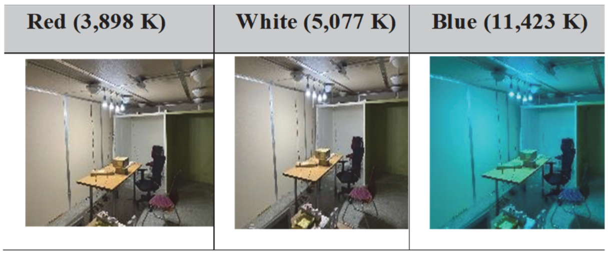

Figure 1 Conditions of the indoor color temperature

2.2.3 Thermal Sensitivity Evaluation

The evaluation of thermal sensitivity in this study utilized a set of tactile temperature sensory adjectives proposed by Kim et al. (2019) [25], as displayed in Tab. 1. These adjectives were paired and presented on a 7 - point scale using semantic differentiation (*SD*) [26]. To ensure the authenticity of responses, the meaning directions of the thermal emotional adjectives in Sets 1 and 4 were configured in the opposite direction to Sets 2 and 3. This design aimed to eliminate insincere or biased responses during the evaluation process.

Table 1 Items configurations of thermal sensitivity

Set	Configuration
1	Cool(siwonhada) - Warm(ttatteushada)
2	Hot(deobda) - Cold(chubda)
3	Hot(tteugeobda) - Cold(chagabda)
4	Cold(shilida) - Warm(ttaseuhada)
5	Comfort(kwaejeoghada) - Uncomfort(bulkwaegada)

2.2.4 Procedure

The experimental procedure followed a specific sequence: "environmental adaptation - color temperature #1 - thermal sensitivity evaluation #1 - color temperature #2 - thermal sensitivity evaluation #2 - color temperature #3 - thermal sensitivity evaluation #3." To minimize the potential bias introduced by the order of color temperature presentation (Red condition (R), White condition (W), and Blue condition (B)), the color temperature sequences were randomized among participants. The sequences used were RWB, RBW, WRB, WBR, BRW, and BWR. As for the indoor temperature conditions, participants were assigned to groups based on the conditions (21 °C, 22 °C, and 23 °C). To ensure that all indoor color temperature conditions were included within each group, the experiment was conducted with the configuration illustrated in Fig. 2.

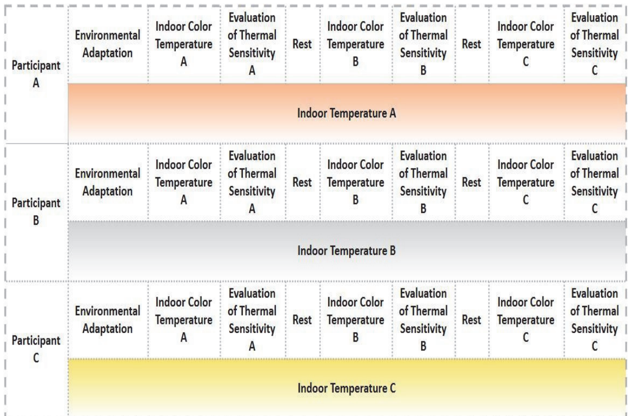

Figure 2 Example of the procedure for first experiment

2.2.5 Analysis Method

To evaluate thermal sensitivity, the participants were classified into thermal sensitivity evaluation Sets 1 - 5. A 3 × 3 mixed analysis of variance (ANOVA) was conducted, considering the factors of indoor temperature conditions (3) and indoor color temperature conditions (3).

2.3 The Second Experiment

2.3.1 Environment

The second experiment was carried out in the same test space as the first experiment, and the images presented to the participants during this experiment were identical to those used in the first experiment.

2.3.2 Conditions

The preferred/non-preferred indoor color temperature condition was designated as a between-factor variable, while the indoor temperature conditions (21 °C, 22 °C, and 23 °C) were considered as within-factor variables.

2.2.3 Thermal Sensitivity Evaluation

The thermal sensitivity evaluation in the Second experiment employed the same assessment tools as those used in the First experiment.

2.3.4 Procedure

Prior to the experiment, the participants' preferred and non-preferred indoor color temperatures were determined. Subsequently, the participants were evenly assigned to the preferred and non-preferred indoor color temperature conditions. The experiment followed a specific sequence, starting with an environmental adaptation period, followed by three rounds of indoor temperature adjustments and corresponding thermal sensitivity evaluations. The order of indoor temperature presentations was randomized to offset any potential presentation order effects. Specifically, the indoor temperatures were presented in the following sequences: 21-22-23, 21-23-22, 22-21-23, 22-23-21, 23-21-22, and 23-22-21. This randomized presentation order is illustrated in Fig. 3.

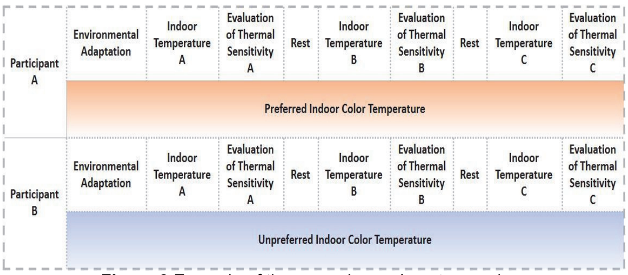

Figure 3 Example of the second experiment procedure

2.3.5 Analysis Method

A mixed 2 × 3 analysis of variance (ANOVA) was conducted, considering the preferred/non-preferred indoor color temperature condition (2) and the indoor temperature condition (3) as the factors. The thermal sensitivity evaluations were divided into Sets 1 to 5 for the analysis.

3 EXPERIMENTAL RESULTS

3.1 Results of the First Experiment

3.1.1 Results of Thermal Sensitivity Evaluation of Set 1

The researchers conducted an analysis to examine the differences in thermal sensitivity evaluation of Set 1 (cool-warm) based on variations in indoor temperature and indoor color temperature conditions. The interaction effect between indoor temperature and indoor color temperature was also explored. The results, as presented in Tab. 2 and Tab. 3, revealed that the main effect of indoor temperature was not found to be statistically significant. However, the main effect of indoor color temperature was found to be significant. Specifically, the Red indoor color temperature condition (M = 5.028) and Blue indoor color temperature condition (M = 3.111) showed distinct thermal sensitivity evaluations of 'warm' and 'cool', respectively, compared to the other conditions.

Table 2 Descriptive statistics of Set 1 thermal sensitivity evaluation

Indoor Temperature	Indoor Color Temperature		
	Red *M* (*SD*)	White *M* (*SD*)	Blue *M* (*SD*)
21 °C	5.08 (1.24)	3.83 (1.40)	3.50 (1.31)
22 °C	5.08 (1.44)	4.25 (1.77)	2.42 (1.08)
23 °C	4.92 (1.38)	3.92 (1.51)	3.42 (1.78)
Total	5.03 (1.32)	4.00 (1.53)	3.11 (1.47)

Table 3 Mixed ANOVA result of Set 1 thermal sensitivity evaluation

Source*	*SS*	*df*	*MS*	*F*	*Sig.*	η^2	PC*
ICT	66.24	2	33.12	15.85	.000	.324	R > W > B
ICT * IT	9.15	4	2.29	1.09	.367	.062	
Error(ICT)	137.94	66	2.09				
Intercept	589.41	1	589.41	828.01	.000	.962	
IT	.32	2	.16	.23	.799	.013	
Error(IT)	23.49	33	.71				

* Note. ICT = Indoor color temperature, IT = Indoor temperature, PC = Pairwise comparison, R = Red ICT condition, W = White ICT condition, B = Blue ICT condition

3.1.2 Results of Thermal Sensitivity Evaluation of Set 2

The researchers conducted an analysis on the thermal sensitivity evaluation of Set 2 (hot-cold (chubda)) based on variations in indoor temperature and indoor color temperature conditions.

Table 4 Descriptive statistics of Set 2 thermal sensitivity evaluation

Indoor Temperature	Indoor Color Temperature		
	Red *M* (*SD*)	White *M* (*SD*)	Blue *M* (*SD*)
21 °C	3.58 (0.79)	4.50 (0.80)	4.83(1.12)
22 °C	3.58 (1.17)	3.92 (1.17)	5.17(1.12)
23 °C	3.75 (1.29)	3.50 (1.00)	4.75(1.60)
Total	3.64 (1.07)	3.97 (1.06)	4.92(1.27)

The results revealed that the interaction effect between indoor temperature and indoor color temperature, as well as the main effect of indoor temperature, were not statistically significant. However, the main effect of indoor color temperature yielded significant findings, as depicted in Tab. 4 and Tab. 5. Specifically, there was no significant difference in the thermal sensitivity evaluation of 'hot' between the Red indoor color temperature condition (M = 3.639) and the White indoor color temperature condition (M = 3.972). However, the Blue indoor color temperature condition (M = 4.917) exhibited a distinct thermal sensitivity of 'cold (chubda)' compared to the other conditions.

Table 5 Mixed ANOVA result of Set 2 thermal sensitivity evaluation

Source*	*SS*	d*f*	*MS*	*F*	*Sig.*	η^2	PC*
ICT	31.63	2	15.82	13.37	.000	.288	
ICT*IT	5.65	4	1.41	1.19	.322	.067	
Error(ICT)	78.06	66	1.18				
Intercept	627.78	1	627.78	1230.02	.000	.974	
IT	.60	2	.30	.59	.562	.034	
Error(IT)	16.84	33	.51				

* Note. ICT = Indoor color temperature, IT = Indoor temperature, PC = Pairwise comparison, R = Red ICT condition, W = White ICT condition, B = Blue ICT condition

3.1.3 Results of Thermal Sensitivity Evaluation of Set 3

In this section, we investigated the variation in thermal sensitivity evaluation of Set 3 hot-cold (tteugeobda-chagabda) in relation to different indoor temperature and indoor color temperature conditions. The results indicate that the interaction effect between indoor temperature and indoor color temperature, as well as the main effect of indoor temperature, did not yield statistically significant outcomes. However, the main effect of indoor color temperature was found to be significant, as illustrated in Tab. 6 and Tab. 7. Notably, the Blue indoor color temperature condition (M = 5.056) exhibited a distinctive thermal sensitivity evaluation of 'cold (chagabda)' compared to the other conditions.

Table 6 Descriptive statistics of Set 3 thermal sensitivity evaluation

Indoor Temperature	Indoor Color Temperature		
	Red *M* (*SD*)	White *M* (*SD*)	Blue *M* (*SD*)
21 °C	3.92 (0.67)	4.50 (1.00)	4.83 (0.84)
22 °C	3.83 (1.12)	4.00 (1.48)	5.50 (0.80)
23 °C	4.08 (1.17)	4.42 (1.17)	4.83 (1.19)
Total	3.94 (0.98)	4.31 (1.22)	5.06 (0.98)

Table 7 Mixed ANOVA result of Set 3 thermal sensitivity evaluation

Source*	*SS*	d*f*	*MS*	*F*	*Sig.*	η^2	PC*
ICT	23.13	2	11.57	13.82	.000	.295	R, W < B
ICT*IT	5.65	4	1.41	1.69	.163	.093	
Error(ICT)	55.22	66	.84				
Intercept	708.15	1	708.15	1197.84	.000	.973	
IT	.006	2	.003	.005	.995	.000	
Error(IT)	19.51	33	.591				

* Note. ICT = Indoor color temperature, IT = Indoor temperature, PC = Pairwise comparison, R = Red ICT condition, W = White ICT condition, B = Blue ICT condition

3.1.4 Results of Thermal Sensitivity Evaluation of Set 4

The researchers conducted an analysis to assess the variation in thermal sensitivity evaluation of Set 4 (cold (shilida)-warm) with regard to indoor temperature and indoor color temperature conditions. The outcomes, as demonstrated in Tab. 8 and Tab. 9, indicate that the interaction effect between indoor temperature and indoor color temperature, as well as the main effect of indoor temperature, did not yield statistically significant results. However, the main effect of indoor color temperature was found to be significant. Specifically, the Red indoor color temperature condition (M = 5.333) and the Blue indoor color temperature condition (M = 3.028) exhibited a more pronounced thermal sensitivity evaluation of 'warm' and 'cold (shilida)' respectively, in comparison to the other conditions.

Table 8 Descriptive statistics of Set 4 thermal sensitivity evaluation

Indoor Temperature	Indoor Color Temperature		
	Red *M* (*SD*)	White *M* (*SD*)	Blue *M* (*SD*)
21 °C	5.42 (1.17)	4.42 (1.00)	3.00 (1.54)
22 °C	5.50 (1.09)	4.58 (1.56)	2.92 (1.08)
23 °C	5.08 (1.38)	4.75 (1.29)	3.17 (1.47)
Total	5.33 (1.20)	4.58 (1.27)	3.03 (1.34)

Table 9 Mixed ANOVA result of Set 1 thermal sensitivity evaluation

Source*	*SS*	d*f*	*MS*	*F*	*Sig.*	η^2	PC*
ICT	99.57	2	49.79	31.31	.000	.487	R > W > B
ICT*IT	2.15	4	.54	.34	.852	.020	
Error(ICT)	104.94	66	1.59				
Intercept	670.24	1	670.24	1060.71	.000	.970	
IT	.03	2	.01	.02	.981	.001	
Error(IT)	20.85	33	.63				

* Note. ICT = Indoor color temperature, IT = Indoor temperature, PC = Pairwise comparison, R = Red ICT condition, W = White ICT condition, B = Blue ICT condition

3.1.5 Results of Thermal Sensitivity Evaluation of Set 5

The researchers investigated the disparity in thermal sensibility evaluation of Set 5 (pleasant-unpleasant) in relation to indoor temperature and indoor color temperature conditions. The findings revealed that the interaction effect between indoor temperature and indoor color temperature, as well as the main effects of both variables, were statistically insignificant (see Tab. 10 and Tab. 11). However, upon examining the mean values, it was observed that the evaluation scores for all conditions were below 4 points, indicating a generally 'pleasant' assessment.

Table 10 Descriptive statistics of Set 4 thermal sensitivity evaluation

Indoor Temperature	Indoor Color Temperature		
	Red *M* (*SD*)	White *M* (*SD*)	Blue *M* (*SD*)
21 °C	2.92 (1.00)	2.92 (1.00)	3.58 (1.51)
22 °C	3.00 (1.35)	3.33 (1.30)	2.67 (1.16)
23 °C	2.67 (1.07)	2.67 (1.30)	3.08 (1.56)
Total	2.86 (1.13)	2.97 (1.21)	3.11 (1.43)

Table 11 Mixed ANOVA result of Set 1 thermal sensitivity evaluation

Source*	*SS*	d*f*	*MS*	*F*	*Sig.*	η^2
ICT	1.13	2	.57	.34	.715	.010
ICT*IT	6.48	4	1.62	.97	.431	.055
Error(ICT)	110.39	66	1.67			
Intercept	320.01	1	320.01	660.79	.000	.952
IT	.67	2	.34	.70	.506	.040
Error(IT)	15.98	33	.48			

* Note. ICT = Indoor color temperature, IT = Indoor temperature,

3.2 Results of the second experiment

3.2.1 Result of Preferred/Non-preferred Indoor Color Temperature Condition Frequency

The distribution of indoor color temperature conditions among participants assigned to the preferred and non-preferred categories was examined. The results indicated that participants in the preferred indoor color temperature condition showed a higher preference for the

Red color temperature. Conversely, participants in the non-preferred indoor color temperature condition did not exhibit a strong preference for the Blue color temperature, as depicted in Tab. 12.

Table 12 Frequencies of preferred and non-preferred indoor color temperature

Condition	Indoor Color Temperature			
	Red	White	Blue	Total
Preferred Indoor Color Temperature	6 (50.0%)	5 (41.7%)	1 (8.3%)	12 (100%)
Unpreferred Indoor Color Temperature	1 (8.3%)	2 (16.7%)	9 (75.0%)	12 (100%)

3.2.2 Results of the Thermal Sensitivity Evaluation of Set 1

The study investigated the variation in thermal sensitivity evaluation of Set 1 (cool-warm) based on indoor temperature and preferred/non-preferred indoor color temperature conditions. The findings, as depicted in Tab. 13 and Tab. 14, revealed that there was no significant interaction effect between indoor temperature and preferred/non-preferred indoor color temperature conditions, nor was there a significant main effect of preferred/non-preferred indoor temperature. However, a significant main effect of indoor temperature was observed. Specifically, there was a consistent trend of perceiving a 'warm' sensation as the indoor temperature increased within the appropriate range for indoor conditions during the winter season.

Table 13 Descriptive statistics of Set 1 thermal sensitivity evaluation

Condition	Indoor Color Temperature		
	21 °C *M* (*SD*)	22 °C *M* (*SD*)	23 °C *M* (*SD*)
Preferred Indoor Color Temperature	3.83 (1.34)	4.25 (1.06)	4.67 (1.30)
Unpreferred Indoor Color Temperature	3.33 (1.50)	3.67 (0.98)	4.08 (1.38)
Total	3.58 (1.41)	3.96 (1.04)	4.38 (1.35)

Table 14 Mixed ANOVA result of Set 1 thermal sensitivity evaluation

Source*	*SS*	*df*	*MS*	*F*	*Sig.*	η^2	PC*
ICT	31.63	2	15.82	13.37	.000	.288	R, W < B
ICT*IT	5.65	4	1.41	1.19	.322	.067	
Error(ICT)	78.06	66	1.18				
Intercept	627.78	1	627.78	1230.02	.000	.974	
IT	.60	2	.30	.59	.562	.034	
Error(IT)	16.84	33	.51				

* Note. ICT = Indoor color temperature, IT = Indoor temperature, PC = Pairwise comparison, R = Red ICT condition, W = White ICT condition, B = Blue ICT condition

3.2.3 Results of Thermal Sensitivity Evaluation of Set 2

The study aimed to investigate the differences in thermal sensitivity evaluation of Set 2 (hot-cold (chubda)) based on indoor temperature and preferred/non-preferred indoor color temperature conditions. The results, presented in Tab. 15 and Tab. 16, indicated that there was no significant interaction effect between indoor temperature and preferred/non-preferred indoor color temperature conditions. However, both the main effect of indoor temperature and the main effect of preferred/non-preferred indoor color temperature were significant. Specifically, it was observed that the thermal sensitivity evaluation of 'hot' became more pronounced as the indoor temperature increased within the appropriate range for indoor conditions during the winter season. Additionally, the thermal sensitivity evaluation of 'hot' was particularly prominent in the preferred indoor color temperature condition.

Table 15 Descriptive statistics of Set 2 thermal sensitivity evaluation

Condition	Indoor Color Temperature		
	21 °C *M* (*SD*)	22 °C *M* (*SD*)	23 °C *M* (*SD*)
Preferred Indoor Color Temperature	4.42 (0.90)	3.92 (0.79)	3.00 (1.21)
Unpreferred Indoor Color Temperature	4.75 (1.29)	4.67 (1.15)	4.25 (0.97)
Total	4.58 (1.10)	4.29 (1.04)	3.63 (1.24)

Table 16 Mixed ANOVA result of Set 2 thermal sensitivity evaluation

Source*	*SS*	*df*	*MS*	*F*	*Sig.*	η^2	PC*
IT	11.58	2	5.79	7.67	.001	.259	A, B > C
IT*P/U	2.53	2	1.26	1.67	.199	.071	
Error(IT)	33.22	44	.76				
Intercept	416.67	1	416.67	658.25	.000	.968	
P/U	3.63	1	3.63	5.73	.026	.207	U > P
Error (P/U)	13.93	22	.63				

* Note. IT = Indoor temperature, P/U = Preferred/unpreferred indoor color temperature, PC = Pairwise comparison, A = 21 °C, B = 22 °C, C = 23 °C, P = Preferred indoor color temperature, U = Unpreferred indoor color temperature

3.2.4 Results of Thermal Sensitivity Evaluation of Set 3

The study aimed to examine the difference in the thermal sensitivity evaluation of Set 3 (hot (tteugeobda) cold (chagabda)) based on indoor temperature and preferred/non-preferred indoor color temperature conditions. The results, presented in Tab. 17 and Tab. 18, indicated that there was no significant interaction effect between indoor temperature and preferred/non-preferred indoor color temperature conditions. However, both the main effect of indoor temperature and the main effect of preferred/non-preferred indoor color temperature showed a tendency. Specifically, there was a tendency for the thermal sensitivity evaluation of 'hot (tteugeobda)' to increase within the appropriate indoor temperature range during the winter season. Additionally, it was observed that there was a tendency for the thermal sensitivity evaluation of 'hot (tteugeobda)' to be more pronounced in the preferred indoor color temperature condition.

Table 17 Descriptive statistics of Set 3 thermal sensitivity evaluation

Condition	Indoor Color Temperature		
	21 °C *M* (*SD*)	22 °C M (*SD*)	23 °C *M* (*SD*)
Preferred Indoor Color Temperature	4.25 (0.62)	4.25 (0.75)	3.67 (0.89)
Unpreferred Indoor Color Temperature	4.92 (1.08)	4.67 (1.30)	4.42 (1.16)
Total	4.58 (0.93)	4.46 (1.06)	4.04 (1.08)

Table 18 Mixed ANOVA result of Set 3 thermal sensitivity evaluation

Source*	*SS*	*df*	*MS*	*F*	*Sig.*	η^2
IT	3.86	2	1.93	3.13	.053	.125
IT*P/U	.36	2	.18	.29	.747	.013
Error(IT)	27.11	44	.62			
Intercept	456.46	1	456.46	781.38	.000	.973
P/U	2.24	1	2.24	3.84	.063	.148
Error(P/U)	12.85	22	.58			

* Note. IT = Indoor temperature, P/U = Preferred/unpreferred indoor color temperature

3.2.5 Results of Thermal Sensitivity Evaluation of Set 4

The study aimed to examine the difference in the thermal sensitivity evaluation of Set 4 (Shilida-Warm) based on indoor temperature and preferred/non-preferred indoor color temperature conditions. The results, presented in Tab. 19 and Tab. 20, revealed that there was no significant interaction effect between indoor temperature and preferred/non-preferred indoor color temperature. However, the main effect of preferred/non-preferred indoor color temperature was found to be significant. Specifically, the thermal sensitivity evaluation of 'warm' was more pronounced under the preferred indoor color temperature condition.

Table 19 Descriptive statistics of Set 4 thermal sensitivity evaluation

Condition	Indoor Color Temperature		
	21 °C *M* (*SD*)	22 °C *M* (*SD*)	23 °C *M* (*SD*)
Preferred Indoor Color Temperature	4.42 (1.31)	4.67 (1.44)	5.17 (1.47)
Unpreferred Indoor Color Temperature	3.67 (1.50)	3.83 (1.27)	4.33 (1.37)
Total	4.04 (1.43)	4.25 (1.39)	4.75 (1.45)

Table 20 Mixed ANOVA result of Set 4 thermal sensitivity evaluation

Source*	*SS*	d*f*	*MS*	*F*	*Sig.*	η^2	PC*
IT	6.36	2	3.18	1.92	.159	.080	
IT*P/U	.03	2	.01	.01	.992	.000	
Error(IT)	72.94	44	1.66				
Intercept	453.56	1	453.56	541.27	.000	.961	
P/U	3.89	1	3.89	4.65	.042	.174	P > U
Error(P/U)	18.44	22	.84				

* Note. IT = Indoor temperature, P/U = Preferred/unpreferred indoor color temperature, PC = Pairwise comparison, P = Preferred indoor color temperature, U = Unpreferred indoor color temperature

3.2.6 Results of the Thermal Sensitivity Evaluation of Set 5

The study aimed to examine the difference in the thermal sensitivity evaluation of Set 5 (pleasant-unpleasant) based on indoor temperature and preferred/non-preferred indoor color temperature conditions. The results, presented in Tab. 21 and Tab. 22, showed that the main effect of preferred/non-preferred indoor color temperature was not significant. However, both the interaction effect between indoor temperature and preferred/non-preferred indoor color temperature and the main effect of indoor temperature were found to be significant. As a result of the significant interaction effect, the preferred/non-preferred indoor color temperature conditions were separated for further analysis.

Table 21 Descriptive statistics of Set 5 thermal sensitivity evaluation

Condition	Indoor Color Temperature		
	21 °C *M* (*SD*)	22 °C *M* (*SD*)	23 °C *M* (*SD*)
Preferred Indoor Color Temperature	2.33 (0.65)	3.50 (1.09)	3.92 (1.00)
Unpreferred Indoor Color Temperature	3.17 (1.19)	3.50 (1.31)	3.17 (0.94)
Total	2.75 (1.03)	3.50 (1.18)	3.54 (1.02)

In the preferred indoor color temperature condition, the simple main effect analysis revealed that the thermal sensitivity evaluation of 'pleasant' was more noticeable as the indoor temperature decreased within the appropriate indoor temperature range in winter. On the other hand, in the non-preferred indoor color temperature condition, there was no significant difference in the thermal sensitivity evaluation based on the changes in indoor temperature.

Table 22 Mixed ANOVA result of Set 5 thermal sensitivity evaluation

Source*	*SS*	d*f*	*MS*	*F*	*Sig.*	η^2	PC*
IT	9.53	2	4.76	6.63	.003	.232	A < B, C
IT*P/U	7.53	2	3.76	5.24	.009	.192	P: A < B < C
Error(IT)	31.61	44	.72				
Intercept	256.67	1	256.67	408.52	.000	.949	
P/U	.01	1	.01	.01	.932	.000	
Error(P/U)	13.77	22	.63				

* Note. IT = Indoor temperature, P/U = Preferred/unpreferred indoor color temperature, PC = Pairwise comparison, A = 21 °C, B = 22 °C, C = 23 °C, P = Preferred indoor color temperature

4 DISCUSSION

This study aimed to investigate the impact of indoor color temperature on the thermal sensitivity of occupants in residential environments during winter. The first experiment involved dividing the indoor color temperature into Red, White, and Blue conditions within the appropriate temperature range for winter. The study examined the differences in thermal sensitivity evaluations among the occupants under these conditions. In the second experiment, the participants were assigned to preferred/non-preferred indoor color temperature conditions to assess the influence of visual color temperature preference on the thermal sensitivity evaluations in response to changes in indoor color temperature conditions. The conclusions of this study are summarized below.

Firstly, the results from the first experiment confirmed that the thermal sensitivity evaluations of occupants in winter varied with different indoor color temperature conditions. Notably, the Blue indoor color temperature condition elicited negative evaluations such as 'cool', 'cold(chubda)', 'cold(chagabda)', and 'cold(shilida)', which align with the findings of previous studies conducted by Jee, Choi, Kim, and Lee (2006) and Joo and Kim (2010). However, the thermal sensitivity evaluations of occupants in winter did not significantly differ when the indoor temperature varied within the appropriate range for winter. This suggests that changes in psychological perception related to indoor color temperature, primarily centered on the visual aspect, had a greater impact on inducing changes in thermal sensitivity evaluations than actual temperature changes through variations in indoor temperature.

Secondly, the second experiment revealed that the preference for indoor color temperature could influence the differences in thermal sensitivity evaluations based on actual indoor color temperature variations. Among the thermal sensitivity evaluation vocabularies from the first experiment, where significant differences occurred based on changes in indoor color temperature conditions, the evaluations of 'cold (chubda)' and 'cold (shilida)' differed depending on whether the occupants preferred the indoor color temperature. This indicates that the preference for indoor color temperature, rather than the changes in indoor color temperature itself, influenced the thermal sensitivity evaluations. On the other hand, the thermal sensitivity evaluations of 'cool' and 'cold (chagabda)' showed noticeable differences based on actual variations in indoor color temperature, suggesting that these terms are more appropriate for evaluating thermal sensitivity in winter, irrespective of individual color temperature preferences.

The study also highlighted the prominence of thermal sensitivity evaluations of 'cool', 'cold (chagabda)', and 'warm' in specific indoor color temperature conditions. The Blue indoor color temperature condition, characterized by a large contrast value of approximately 6000 - 7000 K compared to other conditions, resulted in distinct thermal sensitivity evaluations of 'cool' and 'cold (chagabda)' in winter. Additionally, the Red indoor color temperature condition, with a small contrast value of approximately 1000 K compared to the White indoor color temperature condition, elicited noticeable thermal sensitivity evaluations of 'warm'.

Despite these findings, it is important to consider the influence of individual difference variables on the results, particularly since the number of participants in the study was limited. Additionally, the second experiment was designed to exclude the participants' preference for indoor color temperature. However, it is possible that complete exclusion of each individual's preference was not achieved due to the mixture of indoor color temperature conditions. Therefore, further studies are needed to address these limitations and provide a more comprehensive understanding of the topic.

5 CONCLUSION

The findings from the first experiment revealed that the thermal sensitivity evaluation of occupants varied according to changes in indoor color temperature conditions. Specifically, the thermal sensitivity evaluations of Sets 1-4, which are more sensory-focused, were prominently rated as 'cool', 'cold (chubda)', 'cold (chagabda)', and 'cold (shilida)' in the Blue indoor color temperature condition. This suggests that the difference in indoor color temperature had an impact on the thermal sensitivity evaluations, despite the visual-centered nature of the change, which can be interpreted through Virzi and Egeth's translational mechanism model (1985). According to this model, information is processed and transformed into an appropriate form when the sensory aspect of the input information differs from the sensory aspect required for the final response. In the case of indoor color temperature, although the sensory aspect corresponds to vision, it is converted and processed into a tactile sensory aspect that contributes to the final thermal sensitivity evaluation.

Interestingly, no significant differences were found among participants assigned to different indoor temperatures within the appropriate range for winter. This indicates that the differences in thermal sensitivity evaluations observed based on changes in indoor color temperature were not influenced by variations in indoor temperature. Instead, it suggests that the changes in thermal sensitivity evaluations of occupants were primarily induced by changes in indoor color temperature.

However, since indoor color temperature is linked to the concept of visual color, it is plausible that the concept of preferred indoor color temperature may vary among individuals, similar to their preferred colors. It cannot be entirely ruled out that this preference for indoor color temperature may affect the thermal sensitivity evaluation. Recognizing that sensitivity is a fusion of senses and emotions, it is crucial to consider the emotional aspects of preference in conducting sensitivity evaluations. To address this, the second experiment was conducted to supplement the interpretation. Participants who did not participate in the first experiment were investigated for their preferred/non-preferred indoor color temperatures and were assigned to preferred and non-preferred indoor color temperature conditions. This allowed for the thermal sensitivity evaluation to be conducted based on changes in appropriate indoor temperature conditions during winter.

The results of the second experiment revealed that Red and White indoor color temperatures were preferred, while Blue indoor color temperature was non-preferred. Furthermore, differences in thermal sensitivity evaluations were observed based on the preferred/non-preferred indoor color temperature in Sets 2, 4, and 5. However, in Sets 1 and 3, no significant differences were found in the thermal sensitivity evaluations based on preferred/non-preferred indoor color temperature. This suggests that the effect of whether the presented indoor color temperature is the preferred indoor color temperature for occupants is more influential in the thermal sensitivity evaluations than when indoor color temperature is simply presented in the residential environment. On the other hand, in the thermal sensitivity evaluations of Set 1 'cool-warm' and Set 3 'hot (tteugeobda)-cold(chagabda)', the distinct differences in the presented indoor color temperature were observed to influence the thermal sensitivity evaluations.

Overall, these findings contribute to our understanding of the impact of indoor color temperature on thermal sensitivity evaluations in residential environments during winter. However, it is important to acknowledge the limitations of this study, including the potential influence of individual difference variables and the relatively small sample size. Future studies should address these limitations and further explore the complex relationship between indoor color temperature, individual preferences, and thermal sensitivity evaluations.

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