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A Case Study on Occupants' Thermal and Acoustic Environmental Experiences in an Open-Plan Office - Considering Physical and Non-Physical Factors -

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ABSTRACT

Purpose: This study aimed to explore how occupants in an open-plan office perceived the indoor environment. The research sought to uncover the underlying mechanisms and processes that influence subjective comfort through the application of the stress theory model, categorizing experiences into constructs such as stressors, appraisals, coping strategies, and effects. **Methods:** A mixed-method approach was employed, combining both objective and subjective data collection. Indoor environmental parameters, including sound pressure levels, air temperature, and relative humidity, were measured over 16 days in an open-plan office. Additionally, in-depth interviews were conducted with the office employees to gather qualitative insights into their perceptions of the indoor environment. The data were analyzed using the theoretical model of psychological stress to identify key factors and mechanisms impacting occupants' comfort. **Results:** The study identified that employees' perceptions of the indoor environment in the open-plan office were influenced by a complex interplay of physical and non-physical factors. Physical elements such as noise, temperature, and humidity, along with non-physical factors, including personal stressors, individual appraisals, and coping strategies, were found to affect subjective comfort levels. Intervening and contextual conditions, such as organizational culture and social dynamics, also played a significant role in shaping occupants' experiences. The findings suggested that both physical and non-physical factors must be considered to effectively enhance occupant comfort in open-plan office settings.

KEYWORD

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1. Introduction

Open-plan offices, introduced in the 1950s to promote workplace equality [1], have become increasingly common, with approximately 70% of U.S. companies partially adopting this design [2] and 15-20% implementing fully open layouts [3]. From an operational perspective, they offer economic benefits through efficient space utilization, reduced building expenses, and lower maintenance costs [4, 5]. While these spaces are praised for enhancing communication, collaboration, and teamwork [6, 7], they also present significant challenges to employee well-being and productivity [8].

The impact of open-plan offices on occupants is largely determined by the quality of the indoor environment. Indoor Environmental Quality (IEQ) parameters, particularly acoustic environment, thermal environment, indoor air quality, luminous environment, play crucial roles in shaping occupant experience and performance. For the acoustic environment, noise has been identified as a major environmental factor negatively affecting individual performance in open-plan offices [9-11]. Studies have shown that specific noise sources, such as ringing telephones and background conversations, can significantly disrupt employees' work [12]. In addition, the irrelevant speech effect has been recognized as a primary contributor to employee annoyance [13, 14], with multi-talker irrelevant speech particularly interfering with tasks [15]. Thermal environment is another critical aspect of IEQ in open-plan offices. Research has demonstrated that air temperature variations can impact cognitive performance, productivity, and overall satisfaction [16, 17]. Improvements in thermal environment have been reported to increase productivity by 5-15% [18], attributed to fewer errors, faster work rates, and reduced absenteeism.

Research on IEQ parameters has explored their interrelationships and relative importance. A previous study found that thermal and visual comfort were influenced by acoustic, thermal, and illumination conditions, while acoustic comfort was mainly affected by acoustic and thermal factors [19]. In another research which performed a classroom survey, thermal comfort was found to be the most important, followed by acoustic and visual comfort [20]. Another international study identified indoor air

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quality as the most critical factor in classrooms, while suggesting that the relative importance of IEQ parameters varied by building type [21]. For office spaces, thermal comfort and air quality were ranked highest, though parameter weighting differs across studies. Recent research showed that professional backgrounds of respondents influenced priorities, with building engineers focusing on thermal comfort and architects prioritizing visual comfort, though both agree on the energy demands of thermal regulation [22].

Although previous research has provided valuable insights, many studies have relied on self-reported data measured using questionnaire surveys [23] or focused on short-term measurements potentially missing important temporal variations in the indoor environment. There is limited research combining continuous monitoring of multiple IEQ factors with assessments of occupants' perceptions.

This study aims to fill these gaps by integrating objective measurements of multiple IEQ factors with in-depth analysis of occupants' subjective perceptions. By focusing on continuous monitoring of thermal and acoustic conditions, this research seeks to develop a more nuanced understanding of the complex relationship between indoor environments and employees' perceptions of comfort. The findings may offer valuable insights for improving office design and management strategies.

2. Methods

2.1. Site

The study site was an open-plan office in a 25-year-old building. It was remodeled 8 years ago for improving the building envelope performance. Since the building did not have any mechanical ventilation system for introducing outdoor air, windows needed to be manually opened to ventilate the space. The building was rectangular in shape, with a length of 77m and a width of 18.5m. It was located parallel to a road, with a distance of approximately 50m from the road. The road had a width of approximately 45m with eight lanes, four lanes in each direction. There was an intersection in front of the building.

The building had five floors and the study was conducted on the 5th floor. This space was an open-plan office, with 50 employees working on this floor. The office was equipped with ceiling-mounted heating and cooling units that could be individually controlled by occupants, allowing for personalized thermal comfort adjustments. All employees used their personal computers at their desks. Each desk was partitioned and the partitions were made of metal, with a height of 155cm. This office employed flexible working hours from 7:00 to 22:00, with a mandatory working hour between 10:00 to 16:00.

2.2. Measurements of the Indoor Environments

Noise and temperature-humidity measurements were conducted over a 16-day period from February 28 (Tuesday) to March 15 (Wednesday), 2023. The continuous noise measurement was carried out using a specialized measurement system (Harmonie, 01dB) and software (dBTRIG32, 01dB), and later analyzed using dBTRAIT32 (01dB). A microphone (UC-59, RION) was installed on a tripod at a height of 120cm above the ground. Temperature and humidity were monitored using a temperature-humidity data logger (HOBO, UX100-011A) placed at the same location as the noise monitoring equipment. The logger was attached to the partition next to the occupant's workspace at a height of 140cm from the ground. To compare the indoor temperature and humidity data measured at the site, outdoor temperature and humidity data for the area were obtained from the online public data offered by Korea Meteorological Administration.

2.3. In-Depth Interviews

In-depth interviews were conducted with employees working in the office. As shown in Table 1., a total of 17 interviewees (9 males and 8 females) took part in the study and their mean age was 42.9 years old (SD = 5.6). The interviews were conducted individually and each interview lasted between 0.5 and 1 hour. The whole process of this qualitative data collection and analysis was conducted based on the grounded theory method [24]. The use of this method allowed the whole set of data collection and analysis to gain comprehensive insights into the issue of interest. When it was believed no additional insights emerged from the data, the data collection process was completed [25].

To structure and interpret the emerging themes from the grounded theory analysis, the study adopted the transactional model of stress and coping [26] illustrated in Fig. 1. It provides a framework to explore how individuals perceive and cope with stress in the open-plan office environment. In the present study, the model includes constructs such as stressors, primary and secondary appraisals, coping, and effects, with intervening and contextual conditions (referred to as person-environment

Table 1. Characteristics of the participants

Variables		n
Sex	Male	9
	Female	8
Age group	30s	5
	40s	11
	50s	1
Length of occupancy in the office	< 1 year	2
	1~5 years	3
	5 years <	12

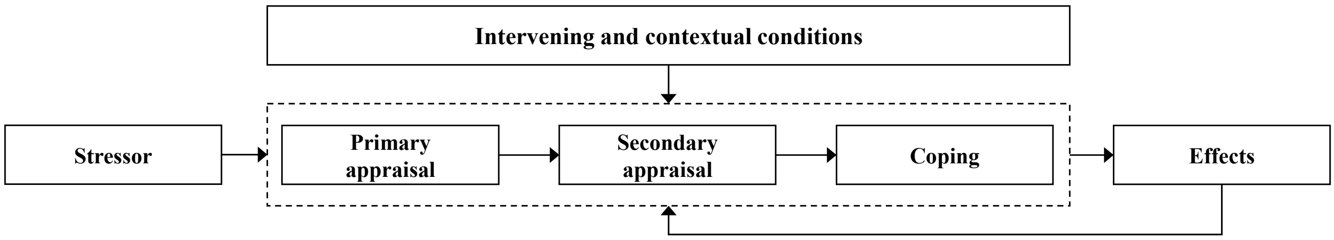

Fig. 1. The theoretical stress model used for analyzing interview data

interaction in the original model) playing a central role in shaping how these constructs influence employee perceptions and responses.

In line with the grounded theory approach, the data were analyzed through three stages of coding: open coding, axial coding, and selective coding [24, 25]. In open coding, the data were broken down into initial categories based on recurring themes. Axial coding then connected these categories, identifying relationships between them, such as coping strategies and effects. Finally, selective coding integrated the categories into a central theme, focusing on how employees perceive and respond to the acoustic and thermal environments in the open-plan office. This process provided a structured understanding of the data.

The interviews were conducted in an open-ended format, allowing participants to freely express their perceptions. The interviewer explained the study's purpose to each participant and asked open-ended questions regarding their general perception of the indoor environment. The statement first given to the participants was "This study aims to explore your perception of the indoor environment in your office. When thinking about the past 12 months, could you describe your experience with the overall acoustic and thermal conditions at your workstation?" The reference to "the past 12 months" was used to avoid focusing on any particular season or period, based on the guidance recommended by ISO/TS 15666:2021 [27]. Interviews were conducted between January and October 2023.

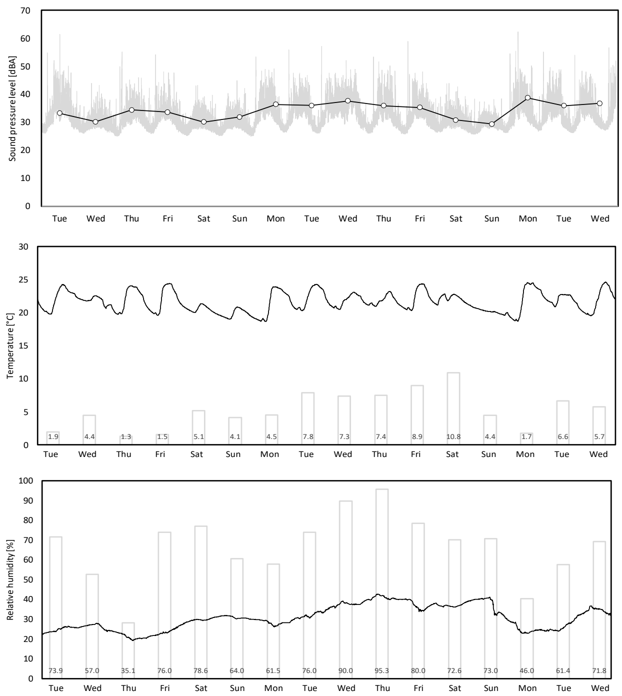

Fig. 2. Indoor noise, temperature, and humidity measured for 16 days. The graph of the indoor noise (top) shows $L_{Aeq,1\text{-}minute}$ and $L_{Aeq,24\text{-}hour}$; that of the indoor temperature (middle) shows 5-minute measurements of indoor temperature (line) and daily mean outdoor temperature (bars); that of the indoor relative humidity (bottom) presents 5-minute relative humidity (line) with daily mean outdoor humidity (bars).

3. Results

3.1. Indoor Noise, Temperature, and Humidity of the Site

Fig. 2. illustrates the measurements of indoor noise, temperature, and humidity. First, the indoor noise is presented in the equivalent continuous sound levels for 1 minute ($L_{Aeq,1\text{-}minute}$) and the equivalent continuous sound levels for 24 hours ($L_{Aeq,24\text{-}hour}$). The graph shows periodic patterns with consistency representing the working hours of each day and weekends. The $L_{Aeq,24\text{-}hour}$ ranged between 30 and 40 dBA. A background noise level of 45 dBA is when a casual conversation can be easily maintained, and a level of 55 dBA is a higher threshold where a conversation is still possible relatively effectively [28]. The measured levels were even lower than the WHO's night-time noise guideline of 40 dBA which corresponds to the sound level of a quiet street in a residential area.

Second, the figure presents the indoor temperature measurements at 5-minute intervals as a line graph, with most readings falling between 20–25℃. The graph clearly shows patterns corresponding to working hours and weekends. Overlaid on the same graph, bar charts represent the daily average outdoor temperatures for the area, ranging from a low of 1.3℃ to a high of 10.8℃. The fluctuations in outdoor temperatures do not appear to significantly influence indoor temperatures. The observed indoor temperature range aligned with the recommended temperature range of office environments during winter [29]. This compliance suggests that the office maintains thermal conditions within acceptable comfort standards for occupants.

The relative humidity is presented with the line graph representing indoor relative humidity and the bar graph showing outdoor relative humidity. Indoor humidity levels primarily fell within the 20–40% range, while outdoor humidity varied more widely from 35.1% to 95.3%. The graph indicates that on rainy days, when outdoor humidity was high, there was a noticeable increase in indoor humidity levels. However, the indoor humidity range generally fell below the recommended levels set, which suggests maintaining relative humidity for optimal comfort [30].

3.2. How Employees Perceived the Environment

1) Stressor

Participants reported exposure to various noise sources in the office, categorized into mechanical and human-generated noises. First, mechanical noises included "excessive" keyboard typing, phone ringing, and printer/shredder operations. Interestingly, these mechanical noises were often associated with negative perceptions towards colleagues rather than the devices themselves. For instance, annoying keyboard sounds were linked to the typist rather than the keyboard.

"It feels like ... the keyboard might break ... Sometimes I wonder if it's a deliberate noise, trying to disturb people around." (Interviewee #8)

Second, human-generated noises were the most prevalent, including conversations, one-sided phone calls, footsteps (shoe heels clicking), nail clipping, sighing, eating (chewing and smacking), and coughing. While initially tolerated, these noises became annoying when prolonged or perceived as exceeding "reasonable" levels.

"I wouldn't complain if (he/she) sighs, 'normally'. But it's almost all day long, every day, even loud." (Interviewee #3)

Participants often interpreted these noises as a result of a lack of consideration for their colleagues. The wording "lack of consideration" was mentioned by nine participants. Further, intermittent but startling noises initially were tolerated, but when they were repeated multiple times by the same person, it led to negative attitudes towards that individual and developed negative emotions. Notably, the perception of noise as annoying varied among individuals, with particular sensitivity to frequently recurring noises from specific colleagues. Despite measured noise levels falling within acceptable ranges, participants still expressed dissatisfaction with the acoustic environment. This discrepancy highlights that noise perception is not solely determined by objective measurements.

Participants expressed diverse opinions regarding indoor temperature and humidity. Unlike the acoustic environment, stressors of the thermal environment tended to be a more physical. Some complained about the office being too hot or cold, or reported discomfort due to dry air from heating systems. A significant finding was the considerable variation in temperature preferences among individuals. Even participants working in the same zone or at adjacent workstations, presumably exposed to similar temperature conditions, reported conflicting perceptions – some feeling too warm while others felt too cold. This was found to be influenced by individual situational, physical conditions, and personal preferences. This observation underscores that temperature perception is highly influenced by personal factors.

2) Appraisals

Primary appraisal for thermal and acoustic environments was found to be similar. First, there was an immediate response. For the thermal environment, this was a physiological response, with the sensation of being hot or cold being the primary reaction. In contrast, the acoustic environment tended to elicit an immediate emotional response. As it was a reaction to noise, annoyance and frustration were the main immediate emotional responses.

Secondary appraisal further evaluated the stressful situation. For both acoustic and thermal environments, individuals considered their ability to control or adjust the situation. They assessed available resources. In the acoustic environment, resources included noise-canceling headphones and the ability to relocate. For the thermal environment, resources were controller access, personal fans, and humidifiers (15 out of 17 mentioned available resources). Lastly, consideration of potential consequences was crucial. Both environments significantly impacted concentration and work quality, while the thermal environment also tended to be evaluated for its health effects.

"I try to move to a quieter place, like a meeting room. If there isn't any place, then that's frustrating." (Interviewee #12)

"... if it's too hot, it's really hard to focus. I get stressed a lot if I need to get the job done quickly." (Interviewee #9)

3) Coping

Coping was classified into problem-focused, emotion-focused, and avoidance strategies. For problem-focused coping in noisy environments, occupants used headphones, requested quieter work areas, or addressed the issue to the noisy colleague(s). In thermal environments, they adjusted clothing, used personal fans, or requested/self-adjusted temperature of the heating/cooling units.

"When it's noisy, I put on headphones and play soft piano music ... If it's cold, I wear a cardigan ... if it's hot, I turn on a personal fan." (Interviewee #15)

Emotion-focused coping for both environments included reframing the situation, acceptance, or negative perception. This type of coping was reported by 11 participants. Occupants annoyed by human-generated noise tended to develop negative perceptions rather than acceptance. This led to behaviors like addressing the issue to the noisy colleague(s) or giving non-verbal signals such as sighing. Avoidance coping involved temporarily leaving the uncomfortable area.

"... feel like (he/she) doesn't consider anybody at all. Why does (he/she) have to talk so loudly on the phone when everyone around is working? I just don't understand." (Interviewee #2)

Table 2. Results from the interviews interpreted based on the stress model components

Stress model components	Aspects	Acoustic environment	Thermal environment
Stressor	Physical level	• Too loud (ie. noise levels)	• Too dry or humid (ie. humidity)
			• Too hot or cold (ie. temperature)
	Other characteristics	• Various noise sources	• n/a
		• Sudden or unexpected loud noises	• n/a
Primary appraisal	Immediate response	• Emotional	• Physiological
Secondary appraisal	Assessment of available resources	• Noise-canceling headphones • Ability to relocate	• Controller access • Personal fans, humidifiers etc.
	Consideration of potential consequences	• Impact on concentration • Work quality	• Impact on concentration • Work quality • Health
Coping	Problem-focused	• Using headphones • Requesting quieter work areas • Addressing the issue to the noisy colleague(s)	• Adjusting clothing • Using personal fans, humidifiers etc. • Requesting or self-adjusting temperature settings
	Emotion-focused	• Reframing the situation • Acceptance or negative perception	• n/a
	Avoidance	• Temporarily leaving the uncomfortable area	• Temporarily leaving the uncomfortable area
Effect	Physiological	• n/a	• Sweating or shivering • Feeling unwell
	Psychological	• Irritability • Decreased concentration • Stress • Negative attitudes toward the noisy person	• Irritability • Decreased concentration • Stress
	Behavioral	• Reduced productivity • Increased breaks • Conflicts with colleagues	• Reduced productivity • Increased breaks
Intervening and Contextual Conditions	Personal	• Individual noise sensitivity • Personality traits	• Individual thermal sensitivity • Clothing choices, • Health conditions
	Environmental	• Office layout • Acoustic performance	• Building design • HVAC system efficiency • Outdoor climate
	Situational	• Workload • Interpersonal relationships	• Workload • Time of the day

4) Effects

The effects of noise exposure or perceived uncomfortable thermal conditions were categorized as physiological, psychological, and behavioral. Physiological effects, mainly applicable to thermal conditions mismatched with individual physical conditions, included sweating or shivering and feeling unwell. Psychological effects for both environments included irritability, decreased concentration, and stress. Behavioral effects common to both were reduced productivity and increased breaks, with conflicts with colleagues being an additional effect in noisy environments.

"We ended up fighting. I told (him/her) that (he/she) was too noisy, but I was a bit emotional too." (Interviewee #16)

5) Intervening and Contextual Conditions

Various intervening and contextual conditions influenced the entire stress perception and response process. These were categorized as personal, environmental, and situational, following the transactional model [26]. Personal conditions for acoustic environments included individual noise sensitivity and personality traits (10 participants mentioned), while for thermal conditions, they included individual thermal sensitivity, clothing choices, and health conditions (8 participants reported).

"I'm really sensitive to noise. I can tolerate being cold or hot, but I can't understand people being loud in the office." (Interviewee #7)

"I get really cold easily. I even have a blanket at my place ... It must have been tough if the people around me were those who get hot easily." (Interviewee #17)

Environmental conditions for acoustic settings involved office layout, acoustic performance of internal walls or partitions, and noise insulation. All of these findings were indoor-focused variables. For thermal settings, they included building design, HVAC system efficiency, and outdoor climate. Situational conditions for acoustic environments primarily involved workload such as task complexity and deadlines, and interpersonal relationships, as noise exposure interfered with work and caused relationship issues with noise sources (usually people). For thermal environments, time of day and workload were the main situational variables.

The key findings of the qualitative analysis are summarized in Table 2., detailing how participants in the open-plan office perceived the indoor acoustic and thermal environments. These perceptions are integrated into the framework of psychological stress theory.

4. Discussion

This study aimed to understand open-plan office employees' experiences regarding indoor acoustic and thermal environments. Existing studies have widely used questionnaire survey methods to collect data from a relatively larger sample size and focus on assessing factors of interest. However, it is a structured method that uses predefined scales and thus, it may restrict respondents to express how they felt and thought freely. The strength of the qualitative method lies in allowing participants to freely express their thoughts using their own language and expressions. Additionally, conducting face-to-face interviews individually allowed for unrestricted conversations, free from time constraints, enabling a thorough exploration of the research topic. Furthermore, the researcher could inquire about any unclear statements made by participants, enabling a deeper understanding of their perspectives.

Through this study, it became evident that when individuals are exposed to noise, their perception is predominantly directed towards the "person" responsible for the noise. During the interview process, when discussing experiences of noise exposure, participants often talked about the person who caused the noise, their perceptions and attitudes towards the person making noise. This suggests that rather than the noise event itself, the relationship with the person generating the noise, the attitude towards the person, and the resulting negative perceptions can act as stressors affecting individual work efficiency, behavior, emotions, and overall quality of life-at-workplace.

In addition to the influence of attitudes toward the noisy person on noise perception, the social context of South Korea cannot be overlooked. In this relationship-oriented society, there is a reluctance to voice dissatisfaction, a fear of drawing attention through such actions, and a fundamental desire to avoid damaging interpersonal relationships [31, 32], all of which likely played a role in shaping responses. As shown in the findings of the present study, the tendency to rely on avoidance coping strategies or limit responses to non-verbal signals could be attributed to the relationship-oriented nature of the society. Furthermore, there may have been instances where the noise source originated from a superior, making it even more uncomfortable to raise complaints in this cultural context.

The findings imply that focusing solely on noise reduction measures may not fully address the issue. Instead, interventions should consider the interpersonal dynamics. Simply reducing noise levels may not alleviate the stress caused by negative perceptions of the individuals responsible for the noise.

Therefore, strategies aimed at improving workplace dynamics, improving positive relationships, and addressing negative attitudes may be necessary to effectively mitigate the impact of noise on individuals' well-being at work and productivity.

In contrast, perceptions of the thermal environment showed somewhat different pattern compared to noise perception. When discussing unsatisfactory thermal conditions (too hot, too cold, too dry, or too humid), participants did not focus on specific individuals. While there were mentions of colleagues in adjacent seats having different thermal sensitivities or preferences, which limited freedom in temperature settings, the tendency to view thermal environment from a more physical perspective was notably stronger compared to the acoustic environment. This suggests that thermal environment control could be more effectively improved through physical environmental control alone, provided that zoning is done meticulously according to individual preferences, sensitivities, or work characteristics. This implies that, unlike noise issues which are often tied to interpersonal dynamics, thermal comfort could potentially be enhanced more straightforwardly through technological and design interventions that allow for personalized control and finer zoning of temperature and humidity levels in the workplace.

The present study offers novelty in its research methods and results, but there are still some limitations. This study focused on the indoor environment of a single open-plan office, and the findings cannot be generalized until data is collected from multiple open-plan offices. Additionally, the office that participated in the study was physically a comfortable space. The noise levels were not high, and the windows effectively blocked external traffic noise, resulting in no complaints from participants about external noise. It was relatively a quiet space where each person worked on their own computers, without loud equipment noise or frequent and loud noises from conversations, meetings, or phone calls. Similarly, the thermal environment was maintained within a comfortable range. Compared to the outdoor temperature and humidity during the measurement period, the indoor temperature and humidity were kept at levels within the recommended values. Therefore, the study lacks insight into the perceptions of occupants in offices with less favorable thermal environments. Future research should investigate a wider range of offices to better understand the relationship between physical environments and subjective perceptions.

4. Conclusion

This study aimed to investigate open-plan office employees' subjective perceptions of indoor environments. It investigated the acoustic and thermal environments in the open-plan office through physical measurements and carried out in-depth interviews, aiming to understand how individuals perceived the indoor environmental conditions as stressors. Key findings revealed that perceptions of indoor environments do not always link directly with measured physical parameters, challenging the notion of a universally optimal indoor environment. For acoustic environments, attitudes towards noise sources (e.g. noisy colleagues) were found to be crucial determinants of stress perception. In thermal environments, it was less person-focused compared to the acoustic environments. Rather, the findings highlighted the impact of individual differences in preferences, physical constitutions, and work-related factors. The findings of this study contribute to expanding the insights of existing quantitative research by conducting an in-depth qualitative investigation into the perceptions of occupants and integrating the findings with the psychological stress theory.

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