



THERMAL COMFORT ADAPTATION IN OFFICE BUILDING PLANNING: A STRATEGY FOR SUSTAINABLE URBAN DEVELOPMENT IN BIREUEN

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Abstract

In tropical urban areas, thermal comfort is a critical consideration in the planning and design of office buildings, particularly in efforts to enhance energy efficiency and promote sustainable development. This study investigates how behavioural, physiological and psychological adaptations to thermal conditions among office users in Bireuen Regency can inform more responsive and sustainable building design strategies. A quantitative descriptive method was applied, supported by digital thermal simulations. Data were collected from 500 respondents across three government office buildings: the Central Government Office, the PUPR Office, and the Universitas Almuslim Rectorate. The parameters examined included ventilation, clothing adjustments, and the utilisation of air conditioning. The findings indicate that 80% of respondents actively modified their room conditions, while 85% relied on air conditioning when experiencing overheating. Approximately 65% of respondents considered the ideal temperature range to be 16°C–20°C – significantly lower than the theoretical optimum of 25°C. Furthermore, 60% of respondents were unaware of the energy implications of their thermal preferences. Notably, the entire sample expressed a willingness to adopt energy-conserving behaviours. The study concludes that user adaptation to thermal conditions plays a crucial role in shaping effective indoor climate strategies and provides valuable insights for planners to support sustainable urban policies.

Keywords: thermal comfort, adaptation, office building, energy efficiency, sustainable Planning

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INTRODUCTION

Thermal comfort is a crucial aspect of creating a healthy and productive building environment, especially in office buildings that operate for extended periods. Most buildings rely on air conditioning (AC) systems to achieve optimal thermal conditions, which significantly contribute to overall energy consumption. Electricity use for air conditioning systems is estimated to account for 50% to 60% of a building's total electricity consumption (Setiawan et al., 2024). Conventional HVAC systems are typically designed without adequate consideration of local climate conditions and contextual thermal comfort, which can result in excessive energy use (Nematchoua et al., 2014). This approach emphasizes individuals' capacity to adapt to thermal environmental conditions through physiological, behavioural, and psychological mechanisms (de Dear & Brager, 2002; Nicol & Humphreys, 2002). to adapt to thermal environmental conditions through physiological, behavioural, and psychological mechanisms. a vital role in minimizing heat gain (Singh et al., 2017). These architectural factors contribute significantly to adaptive thermal comfort by promoting natural ventilation and reducing dependence on mechanical cooling systems. By aligning building features with local climatic conditions, occupants are better able to acclimate to indoor environments, thereby enhancing overall thermal adaptability.

The adaptive approach is especially relevant in hot and humid climates, as it helps reduce reliance on artificial cooling systems such as air conditioning. Consequently, adaptive thermal comfort has become a major focus in research seeking to improve energy efficiency and promote climate-responsive building design. These architectural factors contribute significantly to adaptive thermal comfort by promoting natural ventilation and reducing dependence on mechanical cooling systems. By aligning building features with local climatic conditions, occupants are better able to acclimate to indoor environments, thereby enhancing overall thermal adaptability.

Adaptive models relate indoor temperature to outdoor temperature, based on the assumption that individuals will respond to environmental changes in order to achieve thermal comfort. This approach is derived from field studies and is particularly applicable to free-running buildings, where occupants have greater opportunities to adapt. However, in office environments, the potential for adaptation is often constrained by organizational culture and the use of shared spaces (Lamsal et al., 2023a). Thermal adaptation is generally categorized into three levels: (1) behavioural adaptation, such as adjusting clothing or using thermal aids (Arsad et al., 2023); (2) physiological adaptation, which includes factors such as expectations, past experiences, duration of exposure, and the level of control over the environment (Alta Integra, 2022); and (3) psychological adaptation, which refers to an individual's perception of comfort shaped by previous experiences and expectations (Alta Integra, 2022).

In Indonesia, thermal comfort standards are regulated under SNI 03-6572-2001, which defines the optimal comfort temperatures range as 22.8–25.8°C, with a relative humidity of 40–50%, and air velocity between 0.15–0.25 m/s. Meanwhile, the Predicted Mean Vote (PMV) index, as outlined in ISO 7730, is commonly used to assess thermal sensation on a scale ranging from -3 (cold) to +3 (hot), taking into account six environmental and individual parameters.

Empirical findings indicate that thermal adaptation through clothing adjustment typically occurs at temperature extremes, with peak adaptation observed at cooler temperatures. With the recorded comfort temperature was 27.3°C, the preferred temperature among occupants was lower, at 24.5°C. Furthermore, fan usage increased significantly at 31°C – reaching approximately 50% - but was nearly absent when temperatures dropped below 22.5°C. These findings underscore the importance of incorporating user-adaptive responses into the thermal design of energy-efficient, climate-responsive buildings (Singh et al., 2017). These architectural factors contribute significantly to adaptive thermal comfort by promoting natural ventilation and reducing dependence on mechanical cooling systems. By aligning building features with local climatic conditions, occupants are better able to acclimate to indoor environments, thereby enhancing overall thermal adaptability.

This study emphasizes the urgency of implementing two key strategies in managing thermal energy in buildings: reducing the energy consumption of air conditioning (HVAC) systems and analyzing the influence of behavioural, physiological, and psychological adaptations on shifts in thermal comfort zones, along with their implications for potential energy savings in office environments. This study focuses specifically on three forms of thermal adaptation – behavioural, physiological, and psychological – in the context of enhancing energy efficiency. The study was conducted at three office buildings in Bireuen Regency: the Bireuen Regency Government Headquarters, the Public Works and Spatial Planning (PUPR) Office, and the Rectorate Office of Universitas Almuslim (Umuslim) Bireuen. The findings are expected to contribute significantly to the design of energy-efficient office buildings by promoting an tailored to local climate conditions.

LITERATURE REVIEW

Adaptive Thermal Comfort

The adaptive approach to thermal comfort emphasizes the interaction between the individuals and their thermal environment, assuming that humans actively respond to changes in thermal conditions to improve their comfort levels (Lamsal et al., 2023b). This approach emphasizes the importance of the user adaptation to their surroundings and suggests that field studies more accurately reflect comfort conditions than laboratory tests. Research indicates that comfortable temperatures typically fall within $\pm 2^{\circ}\text{C}$ of thermal comfort standards, and

providing occupants with control over their environment can further expand this comfort range (Nicol & Humphreys, 2002).

The indoor thermal comfort temperature range and occupants' adaptive behaviour are significantly influenced by factors such as climate conditions, ventilation type, building type, and age. Elderly individuals tend to have a wider thermal comfort tolerance compared to other age groups, while children show a narrower tolerance (Neira-Zambrano et al., 2023). Studies in Indonesia have revealed differences in thermal adaptive behaviour among office workers, factory workers, and home occupants, highlighting the role of gender, social norms, and culture in shaping AC usage preferences and clothing insulation. The results indicate that women often wear thicker clothing due to the cultural norms and demonstrate a weaker correlation between AC preferences and adaptive behaviour compared to men (Apriliyanthi et al., 2023).

Thermal conditions, indoor air quality, and energy consumption in office buildings are significantly influenced by climate variations, building design, and occupant adaptive behaviour. Discrepancies between actual temperatures and comfort standards often lead to thermal discomfort, while ventilation and air conditioning strategies play a major role in energy consumption. Thus, an affective design approach – one that considers local climate conditions and promote occupant participation in adaptive behaviour – is essential for achieving both comfort and energy efficiency (Arsad et al., 2023). Thermal comfort is defined as “a state of mind that expresses satisfaction with the thermal environment”. Adaptive behaviour can be categorized into three levels:

1. *Behavioral adaptation* – Conscious adjustments made by occupants to achieve optimal thermal comfort, such as modifying clothing, using fans, or adjusting thermostats (Arsad et al., 2023).
2. *Physiological adaptation* – The body's natural responses to thermal conditions, influenced by factors such as acclimatization, exposure duration, perceived control, and environmental stimuli (Alta Integra, 2022).
3. *Psychological adaptation*: Shifts in perceived comfort due to expectations, past experiences, and contextual factors (Alta Integra, 2022).

These three forms of adaptation occur simultaneously, making it difficult to isolate the individuals effects of each (Nicol et al., 2012). Several adaptive comfort equations have been developed, both as part of international standards such as ASHRAE 55 and EN 15251, and for specific climate regions (Nicol & Humphreys, 2010). However, the comparative trends in the slopes of adaptive models across countries are not yet fully understood. Therefore, further literature review is needed to clarify the effects of outdoor temperature and clothing levels on comfort temperatures (Nicol et al., 2012; Singh et al., 2017).

The adaptive principle

Principles of thermal comfort adaptation, as described in the updated *CIBSE Guide A: Environmental Design* (2021), emphasize the importance of the dynamic relationship between occupants and their environments. The adaptive comfort approach acknowledges that individuals respond to thermal stimuli through physiological, behavioral, and psychological mechanisms. Physiologically, the human body continuously makes internal adjustments to maintain thermal equilibrium, such as regulating blood flow or producing sweat. Behaviourally, occupants may respond – either consciously or subconsciously – by adjusting clothing, using blinds or curtains, opening or closing windows, or activating heating or cooling devices. Psychologically, thermal perception is influenced by personal expectations, perceived control, energy cost concerns, and cultural factors. The adaptive model is based on the principle that when individuals experience thermal discomfort due to environmental changes, they instinctively take actions to restore comfort. *CIBSE Guide A* (2021) highlights that access to personal environmental controls, such as operable windows, can significantly enhance perceived thermal comfort. This model also facilitates the evaluation of thermal comfort in naturally ventilated buildings, where occupant behavior plays a critical role. The greater the control individuals have over their environment, the broader their acceptable thermal range becomes, and the less likely they are to report discomfort. This supports the use of adaptive comfort models in climate-responsive design and in interpreting cross-cultural and cross-climate comfort data (Nicol & Humphreys, 2002).

Indoor and outdoor thermal conditions

The quality of the thermal environment in office buildings is crucial, as thermal comfort is closely linked to worker productivity. Thermal comfort is influenced by factors such as climate, geography, and the surrounding environment. Indoor thermal conditions are significantly affected by outdoor climate, particularly in naturally ventilated buildings. Naturally ventilated buildings typically maintain a comfortable indoor temperature range between 17.6°C and 31.2°C. In contrast, air-conditioned buildings tend to maintain more stable indoor temperatures, generally ranging from 22°C to 27.9°C, regardless of external weather conditions. However, even in air-conditioned buildings, the outdoor temperature can still influence thermal sensation and perceived comfort, especially when transitioning from outside to inside. The corresponding outdoor temperature range associated with these indoor conditions is between 6.7°C and 38°C (Lamsal et al., 2023b; Lisa et al., 2021; Munandar, Aris, Muliani, Zuraihan, 2023).

Personal Characteristics

Respondent information was directly obtained through questionnaires distributed to employees at the Public Works Office, the Bireuen Regency Government

Headquarters, and the Universitas Almuslim Administration Headquarters. The personal data collected included age, gender, and length of service. A total of 500 valid samples were successfully collected from these three offices in Bireuen Regency, consisting of 250 male and 250 female respondents of productive age. An overview of respondents' age and place of work is presented in Table 1.

Table 1: Respondents' characteristics

Number of subjects	Total	Public works Office	Regency Government HQ	Universitas Almuslim Administration HQ
Age, yr	18 – 55			
Male	250	70	160	20
Female	250	50	160	40
Total	500			

Building characteristics

This section discusses the characteristics of both the workplace and residential buildings occupied by the respondents. The information collected includes the type of building – whether air conditioned (AC) or naturally ventilated (NV) – as well as the respondents' adaptive behaviours in each context. These behaviours include the intensity of AC usage (measured in hours per day), use of electric or portable fans, window-opening habits, and other ventilation practices. In addition, their thermal comfort levels in two distinct environments: their workplace and their residence. Understanding the unique characteristics of both office and residential environments is essential, as thermal habits developed in the home can significantly influence an individual's expectations and behavioural responses in the workplace. These building characteristics directly affect office energy consumption and indoor comfort conditions; for example, offices with sealed façades and limited ventilation require greater mechanical cooling energy, whereas buildings designed with natural ventilation can maintain comfort with lower energy demand. By evaluating adaptive comfort strategies across both environments, this study highlights the interplay between environmental control, energy demand, and thermal satisfaction within the workplace context.

RESEARCH METHODOLOGY

The research employed a quantitative descriptive method, involving a field survey on (Nicol & Humphreys, 2002). Data were collected using structured questionnaires and measurement instruments. The instruments utilised in this study covered a range of parameters designed to assess climate-related metrics, ventilation models, building typologies, architectural designs, and the age demographics of the respondents. The questionnaires also addressed clothing adjustments and the use of air conditioning devices, including fans and fixed AC

units. In addition to empirical data, a quantitative simulation approach was applied to assess the influence of climate on . Building simulation were conducted using digital modelling tools to analyze the effects of climate on thermal comfort, allowing data input based on location, building orientation, architectural design, construction materials, weather conditions, temperature, texture, and surface area. This study used AndrewMarsh.com software for sun analysis through 3D Sun Path modelling, while climate and weather data were sourced from climate.onebuilding.org. Wind analysis was carried out using WRPLot software.

A series of simulation measurements were conducted using the CBE Thermal Comfort Tool to evaluate comfort levels in accordance with the standards set by ASHRAE-55. The Predicted Mean Vote (PMV) model was then applied to quantify thermal sensation and overall comfort levels. Thermal comfort is defined as a subjective state of satisfaction with the thermal environment, which can be assessed through the principles of heat balance and individual thermal sensation (Tartarini et al., 2020). The Predicted Mean Vote (PMV) model was then applied to quantify thermal sensation and overall comfort levels. The Predicted Mean Vote (PMV) model was then applied to quantify thermal sensation and overall comfort levels. Thermal comfort is defined as a subjective state of satisfaction with the thermal environment, which can be assessed through the principles of heat balance and individual thermal sensation.

ANALYSIS AND DISCUSSION

CBE Thermal Comfort

The Predicted Mean Vote (PMV) model is a thermal comfort model based on the principle of heat balance and experimental data collected in a controlled climate chamber. The CBE Thermal Comfort Tool uses thermal comfort calculations in accordance with ANSI/ASHRAE Standard 55, ISO 7730, and EN 16798-1. (Tartarini et al., 2020; see Figure 2). The Predicted Mean Vote (PMV) model was then applied to quantify thermal sensation and overall comfort levels. Thermal comfort is defined as a subjective state of satisfaction with the thermal environment, which can be assessed through the principles of heat balance and individual thermal sensation.

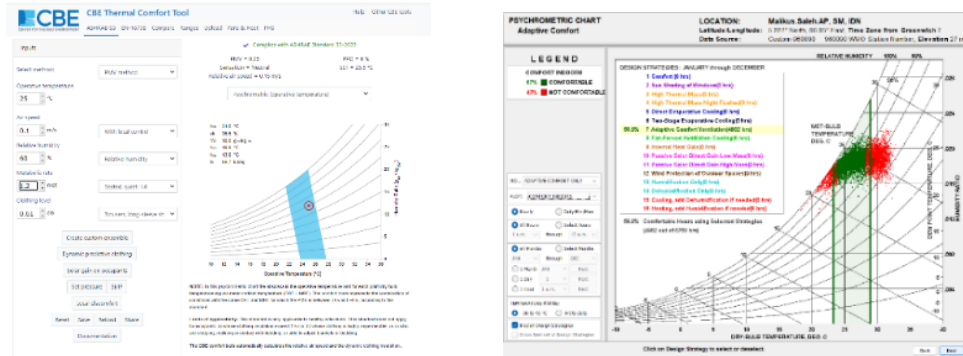


Figure 2: Thermal Comfort Scale based on the CBE Thermal Comfort Tool

Factors that determine heat gain and loss include metabolic rate, clothing insulation, air temperature, mean radiant temperature, air velocity, and relative humidity (see Figure 3).

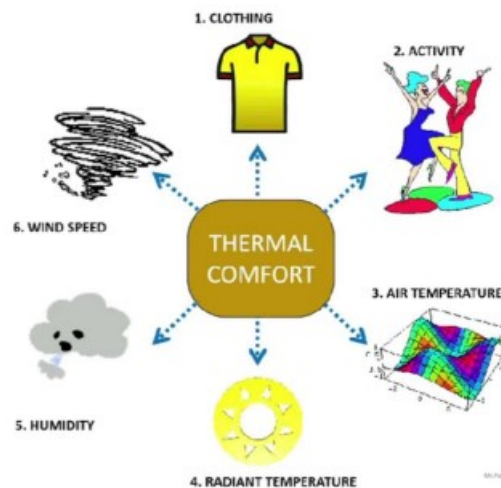


Figure 3: Thermal comfort factors, Figure 4: Psychrometric Chart

The CBE thermal comfort analysis of office buildings in Bireuen Regency determined that the optimal indoor temperature for office spaces is 25°C. This corresponds with an operative temperature of 25°C, air velocity of 0.1 m/s, relative humidity of 60%, a metabolic rate of 1.2 met, and a clothing insulation level of 0.61 clo. These findings are supported by research conducted on three sites: the PUPR Building, the Rectorate Office of Universitas Almuslim, and the Regency Government Headquarters Building. For air-conditioned office buildings, thermal comfort requires the use of an air conditioning (AC) unit in the

room. Furthermore, 65% of for temperatures ranging from 16°C to 20°C. Survey results indicate that 20% of respondents felt comfortable at temperatures between 20°C and 22°C, while 15% reported comfort at 22°C to 25°C. These findings are based on the psychrometric chart (Figure 4). The temperature range considered to meet the adaptive comfort criteria falls between 24 °C and 28 °C.

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Sun and wind factors are closely related to building orientation and the orientation of openings (Figure 5). Building orientation impacts protection against solar radiation – for example, a facade facing south or north can reduce exposure to direct sunlight (Kalangi Judy O., 2016).

Case Study I: Bireuen Regency Government Headquarters

The Bireuen Regency Government Headquarters is located at coordinates 5°12'26.72"N and 96°43'35.18"E. The building is oriented to the south and designed with an open layout featuring a corridor that surrounds the structure, serving as a circulation path between rooms. Artificial ventilation is applied only in enclosed office spaces, while the open corridors rely on natural ventilation. The building's spatial arrangement follows a linear pattern aligned with the sun's path, and its largest facades are oriented according to prevailing wind directions to enhance cross-ventilation. The direction and placement of openings on all facades play a crucial role in maintaining thermal comfort. According to the survey, 85% of respondents stated that the orientation and location of the building affected the amount of sunlight entering the rooms. Excessive sunlight led to increased indoor temperatures and glare, making occupants uncomfortable, especially during working hours. In response, 85% of respondents preferred rooms with lower light intensity to avoid visual strain and overheating. These findings demonstrate that building orientation, solar exposure, and ventilation design significantly influence thermal comfort (Ariffin, 2015). Proper alignment with wind direction promotes passive cooling through natural ventilation, while controlling solar penetration helps maintain acceptable indoor temperatures and

visual comfort (Majid et al., 2018). Therefore, architectural design decisions—such as building orientation and façade openness—are essential for achieving thermal comfort in tropical climates. This finding relates to the study’s objective by showing that visual discomfort due to excessive sunlight contributes to overall thermal dissatisfaction, influencing adaptive behaviour and energy use preferences.



Figure 4: Building characteristics

Case Study II: Office of Public Works and Spatial Planning, Bireuen Regency

The Office of Public Works and Spatial Planning of Bireuen Regency is located at coordinates 5°11'59.02"N and 96°42'7.86"E. The architectural design of the building is enclosed, relying exclusively on artificial ventilation systems for indoor air circulation. The building is orientated toward the east, with a longitudinal spatial layout running from east to west (Figure 6). The fenestration on all sides of the edifice follows the shape and flow of the structure. Survey results indicated that a significant proportion of respondents 85% believed that the building’s orientation and placement had a substantial impact on the amount for sunlight entering the rooms. for rooms with lower light intensity to avoid glare during working hours. This discomfort was attributed to excessive solar exposure. The building’s configuration, combined with its sealed construction and reliance on artificial ventilation, limits opportunities for passive cooling and increase dependence on mechanical systems to regulate indoor temperature (Jamaludin et al., 2016).

Furthermore, high levels of solar radiation have been shown to cause overheating and visual discomfort, both of which negatively affect thermal comfort. Therefore, it is imperative to understand the interplay between spatial design, solar exposure, and ventilation strategies to ensure optimal thermal comfort in tropical environments. This finding relates to the study’s objective by showing that visual discomfort due to excessive sunlight contributes to overall thermal dissatisfaction, influencing adaptive behaviour and energy use preferences.



Figure 5: Building characteristics

Case Study III: Rectorate Office of Universitas Almuslim

The Rectorate Office of Universitas Almuslim is located at coordinate $5^{\circ}11'39.19''\text{N}$ and $96^{\circ}47'15.21''\text{E}$. The architectural design of the building is based on a semi-open concept. The air circulation system integrates a closed ventilation system within the workspaces, complemented by an open-air system in the corridor. The building is oriented to the north, with a symmetrical and linear layout directed along the west-south axis (Figure 7). The apertures surrounding the building have been carefully positioned to align with its geometric configuration. Survey results indicated that a significant proportion of respondents (95%) believed the architectural design – including the orientation and layout – had a noticeable impact on the amount of sunlight entering the interior spaces. Furthermore, 85% of for rooms with low light intensity, motivated by a desire to reduce glare during work activities. These findings suggest that visual discomfort caused by excessive sunlight directly influences workspace preferences. Excessive solar gain in workspaces has been shown to increase indoor temperatures and glare, leading to overheating and discomfort among occupants. In buildings with semi-open designs, effective management of sunlight exposure is essential to maintain thermal balance. It is therefore evident that appropriate building orientation, strategic placement of openings, and well-planned ventilation are crucial for achieving thermal comfort, particularly in tropical climates.



Figure 6: Building characteristics

Behavioral Adaptation

Behavioural adaptation is the most significant contributor to the adaptive thermal comfort model. The patterns of behavioural adaptation and the application of environmental controls in residential buildings vary depending on the season and climate condition (Yadeta et al., 2023). Examples of behavioural adaptations to regulate the indoor thermal environment include openings window, adjusting clothing insulation, and using fans or air conditioners (Arsad et al., 2023). Building orientation – such as facing towards or away from the sun – as well as the location and number of ventilation openings, also influence thermal comfort (Sarinda et al., 2017).

Typical examples of behavioral adaptation for energy conservation include opening or closing windows, adjusting curtains, turning fans or air conditioners on or off, and regulating AC temperature settings. Another common practice is switching off lights and electronic devices when they are not in use. These behaviors are supported by research findings that highlight the significant influence of behavioural adaptation on thermal comfort.

A significant proportion of respondents, approximately 80%, reported regularly adjusting indoor conditions throughout the day in response to changes in the external environment. Such adaptive actions allow occupants to maintain a thermally comfortable indoor climate by responding to variables such as solar radiation, humidity, and outdoor air temperature. By modifying environmental factors including airflow and temperature, residents can effectively mitigate discomfort caused by excessive heat or cold. It can thus be concluded that behavioural adaptations play a critical role in achieving and maintaining optimal thermal comfort in buildings.

Psychological Adaptation

Psychological adaptation refers to a state of mind in which individuals feel satisfied or comfortable with the thermal environment. It involves changes in a person's mindset, attitude, and behaviour in response to new situations or conditions. In the context of energy conservation, psychological adaptation includes the mental processes that enable individuals to alter their habits and lifestyle to become more sustainable. Survey results revealed that 100% of respondents actively engage in energy conservation practices both at home and in the office. They understand the reasons behind these efforts, are motivated to conserve energy, and also seek to influence others to adopt energy-saving behaviours.

Ethical Statement: All respondents participated voluntarily and provided informed consent. The study complied with ethical research standards for survey-based studies established by Universitas Almuslim.

CONCLUSION

Thermal comfort adaptation results from human interaction with the thermal environment, which is influenced by climate, geographic location, and building characteristics. This study identifies three main forms of adaptation: physiological, behavioural, and psychological. Physiological adaptation is reflected in occupants' ability to respond to thermal conditions based on past experiences. Approximately 50% of respondents reported feeling too hot or too cold in the office, and 85% of them indicated they would turn on the air conditioner to adjust the indoor temperature. However, 60% of respondents were unaware that inappropriate indoor temperatures could impact energy consumption, although 65% believed the ideal indoor temperature to be between 16°C and 20°C. In terms of behavioural adaptation, the majority of respondents (80%) actively adjusted room conditions to align with outdoor environments and practiced energy-saving habits, such as turning off air conditioners and lights when not in use. Psychological adaptation was evident in respondents' awareness and commitment to energy conservation: all respondents (100%) demonstrated motivation, understanding, and a willingness to influence others in adopting energy-efficient behaviours. These findings highlight the importance of integrating strategies into office building design – especially in tropical climates – as a key component of sustainable development and energy efficiency initiatives.

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