Available online at www.CivileJournal.org

Civil Engineering Journal

(E-ISSN: 2476-3055; ISSN: 2676-6957)

Vol. 12, No. 03, March, 2026

Assessment of Semi-Indoor Thermal Efficiency on Adaptive Comfort for Senior Buildings Using 3D MRT Simulation

Chorpech Panraluk [1*], Thanasarn Changnawa [1], Atch Shreshthaputra [2]

[1] *Faculty of Architecture, Art and Design, Naresuan University, Phitsanulok 65000, Thailand.*

[2] *Faculty of Architecture, Chulalongkorn University, Bangkok 10330, Thailand.*

Received 24 September 2025; Revised 14 February 2026; Accepted 17 February 2026; Published 01 March 2026

Abstract

Adaptive comfort is a significant element in sustainable building development in hot, humid climates. The study aimed to analyze adaptive comfort in the free-running spaces of senior health and community buildings in Thailand, and propose guidelines for improving these buildings using an adaptive comfort approach. The environmental data from the automatic weather system were employed and calibrated to measure data from field surveys. Utilizing the CBE 3D Mean Radiant Temperature (MRT) Tool software for analysis and preparing data to calculate operative temperature, which was compared in ASHRAE and Southeast Asia adaptive comfort models, the study determined design and material spec modifications in three buildings for development guidelines. The findings revealed that the existing conditions of all buildings were unacceptable by nearly 20% in the rainy season and 50% in the hot season. Thermal acceptability was higher than the ASHRAE adaptive comfort model when estimated via the Southeast Asia adaptive comfort model. In these buildings, two naturally ventilated spaces did not have roof insulation, and one space did not have an overhang. All spaces received solar radiation from the south and west during the daytime. Quality materials and shading devices for MRT reduction should be prepared. This study recommends novel insights into the role of design and select materials in enhancing thermal environments for free-running spaces in senior buildings in hot, humid climates.

Keywords: Adaptive Comfort; Naturally Ventilated Space; Hot Humid Climate; Mean Radiant Temperature.

1. Introduction

The need for occupant comfort directly drives the energy consumption of HVAC systems in buildings [1]. Thermal comfort is an important assessment tool for achieving energy-saving goals [2, 3]. Numerous studies have found that appropriate adjustments to thermal comfort are important, as they help promote health and support people's achievement [4, 5]. As a global issue for climate change, thermal comfort has become an important assessment tool for adaptation analysis. Thermal comfort is a condition of mind that expresses satisfaction with the thermal environment [6]. There are six primary variables. Two variables result from humans, including metabolic rate or activity (Met) and clothing insulation (I_{clo}), while four variables result from the thermal environment, including air temperature (Ta), mean radiant temperature (MRT), relative humidity (RH), and air speed (V). In a hot and humid climate, energy is used to initiate thermal comfort, air conditioning is normally utilized for improving indoor environments. However, there are still areas in public buildings that are used for activities without air conditioning. As Thailand has become a completely aged society [7], the government has established senior buildings to support the activities of the elderly in all regions. In these

* Corresponding author: chorpechp@nu.ac.th

https://doi.org/10.28991/CEJ-2026-012-03-014

buildings, there are multipurpose areas and waiting areas, which are naturally ventilated spaces, used for support activities. If naturally ventilated environments are in the scope of thermal comfort, it will also be beneficial for energy savings. Nevertheless, the microclimate plays a role in the use of passive techniques [8, 9]. Assessing the impact of the existing environment on thermal comfort on a site-by-site basis is necessary. Generally, naturally ventilated spaces in a hot and humid climate zone will use adaptive comfort to assess the thermal comfort.

The study of adaptive thermal comfort was initiated by Humphrey et al. [10], who proposed the use of environmental acceptance. Humphreys & Nicol [11] stated that thermal comfort is a result of an individual's environment and their habit of using air conditioning. Adaptive comfort has been studied extensively using meta-analysis and systematic descriptions [11, 12]. In addition, there are also studies in different climate zones, such as in Indonesia, Brazil [13,14], and Europe [15]. The results showed that thermal comfort conditions were related to monthly temperatures. de Dear & Brager [12] found that people in air-conditioned spaces and naturally ventilated spaces had different expectations. Brager & de Dear [16] considered expectations to be an important factor in the state of thermal comfort. Humphreys & Nicol [11] discussed the adaptive thermal comfort principle, which stated that, "If a change occurs such as to produce discomfort, people react in ways that tend to restore their comfort". Brager & de Dear [16] and Nicol et al. [17] described three types of thermal comfort adaptations for thermal environments, including behavioral adjustment, physiological acclimatization, and psychological habituation or expectation, in which behavioral adaptations and expectations are influential. de Dear & Brager [12] studied adaptive comfort and proposed a new adaptive comfort standard. In a hot, humid climate, de Dear and Brager suggested that, if the prediction mean vote can be used in HVAC, then the adaptive comfort standard can be used in naturally ventilated spaces. In 2004, the adaptive comfort model was used in the standard for the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE 55-2004) [18], which has been popular and used until now.

The ASHRAE adaptive comfort is a widely accepted indicator that uses the equation:

$$T_{comf} = 0.31T_{pmo} + 17.8 \tag{1}$$

where, T_{comf} = comfortable temperature (°C), T_{pmo} = prevailing means outdoor temperature (°C). The 90% thermal acceptability band is the optimum ±2.5°C, while the 80% acceptability band is ±3.5°C [6].

Later, many studies were conducted to understand the population groups in different climate zones, as well as the various equations that have been studied and developed, such as the study of a new comfort band for the adaptive model in Japan [19] and the Southeast Asia adaptive comfort model [20], which covered the Thailand climate zone

The equation of Southeast Asia adaptive comfort model is;

$$T_{comf} = 0.341T_{a\ out} + 18.83 \tag{2}$$

where, T_{comf} = comfortable temperature (°C), $T_{a\ out}$ = means outdoor temperature (°C).

Yao et al. [21] mentioned that culture, society, climate zone, psychology, behavior, and adaptation affect thermal comfort. Toe & Kubota [22] developed an adaptive thermal comfort equation for naturally ventilated spaces in a tropical climate using the regression of the ASHRAE RP-884 database. It revealed results close to the ASHRAE adaptive comfort model. However, this research used both the ASHRAE and the Southeast Asia adaptive comfort models to assess the comfort conditions for developing senior buildings. Although many studies have confirmed that physical changes in older adults affect their thermal comfort [23-25], adaptive thermal comfort with a wide range of acceptance is considered acceptable to older adults.

This paper aims to present an environmental analysis of naturally ventilated spaces in senior buildings to determine their effectiveness in enhancing occupant thermal comfort. It also proposes building renovation approaches to enhance adaptive comfort. The study focuses on thermal radiation, a key factor in tropical climates. The MRT simulation is significant to calculate operative temperature for the analysis of adaptive comfort and to develop guidelines for improving the naturally ventilated spaces in buildings. The CBE 3D Mean Radiant Temperature Tool software was used in the process. Thermal environmental data obtain from the automatic weather system of the Thai Meteorological Department [26] were calibrated with data from field surveys before being entered into the program.

2. Literature Review and Research Gap

This review aims to identify a research gap. The definition of the adaptive model in the ASHRAE 55 standard-2017 [6] is a model that relates indoor design temperatures or acceptable temperature ranges to outdoor meteorological or climatological parameters. Nowadays, climate change has resulted in adaptive thermal comfort studies being considered to improve the building environment for occupants [27]. The adoption of a more adaptive comfort model is important for climate change and resilient spaces, i.e., naturally ventilated spaces. Adaptive thermal comfort is related to outdoor temperature. In previous research, studies have been carried out to control the effect of the outdoors. In hot, dry climates, designing climate-adaptive buildings involves using software for analysis, which previously found that courtyard design strategies can reduce outdoor temperatures in the climate [28]. In hot, humid climates, Computational Fluid Dynamics (CFD) software has been used to develop adaptive comfort in multipurpose rooms with a mixed-mode while not using air conditioning. The findings revealed that the appropriate velocity can adapt to thermal comfort [29] and save energy. For the cold climate conditions of India, CFD was employed to simulate cross-ventilation in a naturally ventilated room. The findings showed that an optimized ventilation strategy can simultaneously decrease energy consumption and enhance indoor thermal comfort for occupants [30-32].

As for the scope of improving the buildings to adaptive comfort, the current issue seems to concern climate change. A previous study presented strategies for architectural adaptation to climate change that prioritize climate resilience and occupant well-being [33]. The improvement of buildings toward a sustainable future should involve enhancing appropriate materials for climate change resilience, such as using cellulose insulation in the wall system for comfort [34], and using appropriate window systems and construction techniques to reduce heat stress build-up within building units [35]. As for improving existing buildings, research has been done on developing buildings to address adaptive comfort. It was found that the post-occupancy evaluation (POE) is significant for monitoring building performance, i.e., thermal comfort, air quality, energy efficiency [36], and improving the surroundings as well as microclimate, which is linked to urban planning [37].

From previous research, various parameters have been studied and simulated through software. However, few studies exist focusing on MRT. A few studies recommend that the thermal radiant field in the form of radiant asymmetry and MRT in many situations is significant and must be treated as an important thermal comfort parameter [38]. Marigo et al. [39] discovered that the increase in asymmetry was not perceived by the occupants. The analysis of radiant asymmetry discomfort requires taking into account the differences in surface temperatures and plane radiant temperature. The temperature has reached above 35 °C. According to the survey campaign, lower radiant asymmetry levels are associated with uncomfortable cold sensations, while the highest ceiling temperature enhances comfort perception. When the supply is activated, the vertical asymmetry of the heated plan, namely the ceiling and heat-dissipating floor, exceeds the standard limit of 4 °C, making it the most adverse scenario.

In the summary of the literature review, this research fills substantial gaps recognized in previous studies through the study of MRT. One research gap found a challenge in controlling the MRT, which is significant for adaptive comfort. Complicating the task is the dynamic nature of environmental conditions, occupant behavior, and the interaction of various building materials. Understanding MRT allows designers to optimize buildings for occupant comfort and energy efficiency by managing surface temperatures (e.g., high-performance glazing, better insulation, strategic shading). According to MRT, it plays a pivotal role in shaping the thermal comfort of occupants in various climates. This study aims to assess and improve thermal environment efficiency, so the ASHRAE adaptive comfort model and the Southeast adaptive model were considered to determine the thermal comfort conditions for this research and present building design strategies that can actively manipulate MRT to enhance occupant well-being.

3. Methods

In this study, all buildings are located in the lower northern region of Thailand. Physical buildings and thermal environments were used to estimate the adaptive thermal comfort in the naturally ventilated spaces of three senior buildings, including the Si Satchanalai senior health and community building and the Pa Feak community building in Sukhothai Province, and the Samorkhae senior health promotion building in Phitsanulok Province.

Data from the automatic weather system of Sukhothai and Phitsanulok weather stations were used to calculate the prevailing mean outdoor temperature for assessing adaptive thermal comfort in the free-running spaces of the Pa Faek community and the Somorkhae health promotion building, respectively. Nevertheless, the Si Satchanalai site is located at higher elevation than the other buildings and is closer to the Uttaradit weather station. Thus, data from the automatic weather system of the Uttaradit weather station were used to determine the prevailing mean outdoor temperature. The study location of all senior buildings is shown in Figure 1.

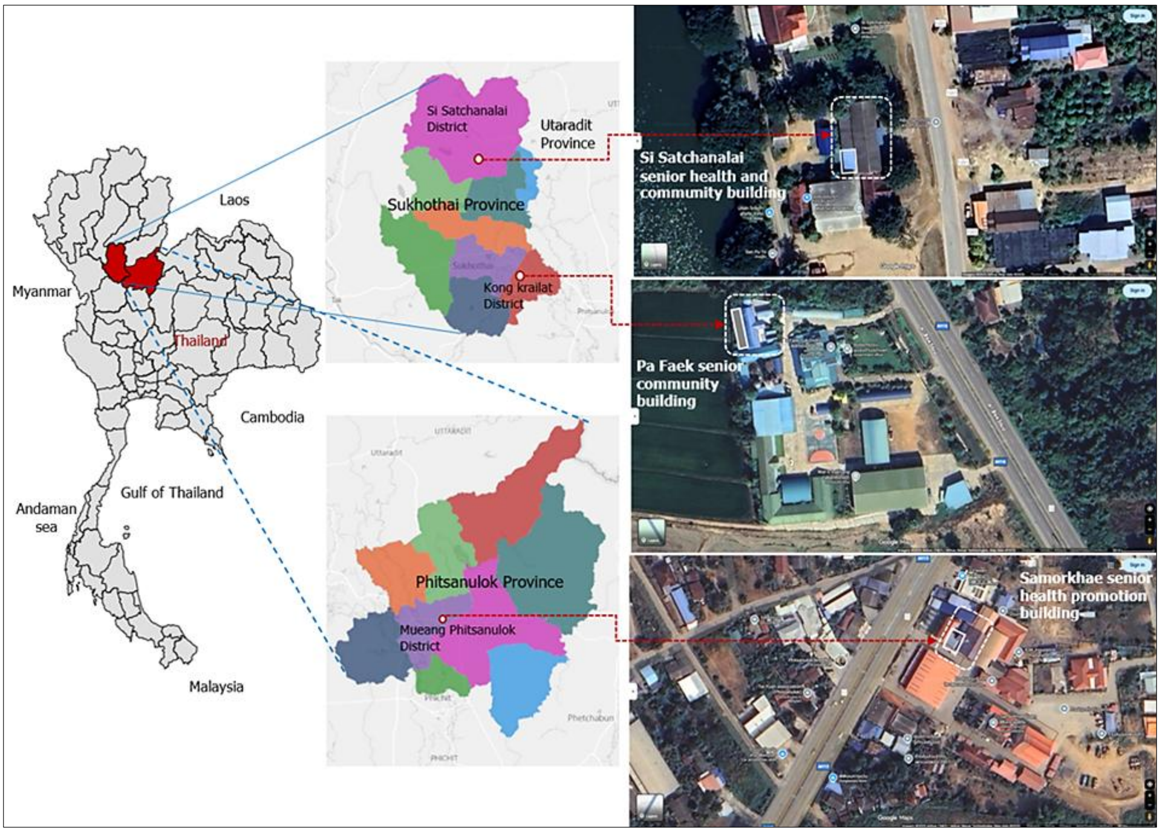


Figure 1. Study location

To achieve the objective proposed, a method flowchart was designed and presented, consisting of five steps, as shown in Figure 2.

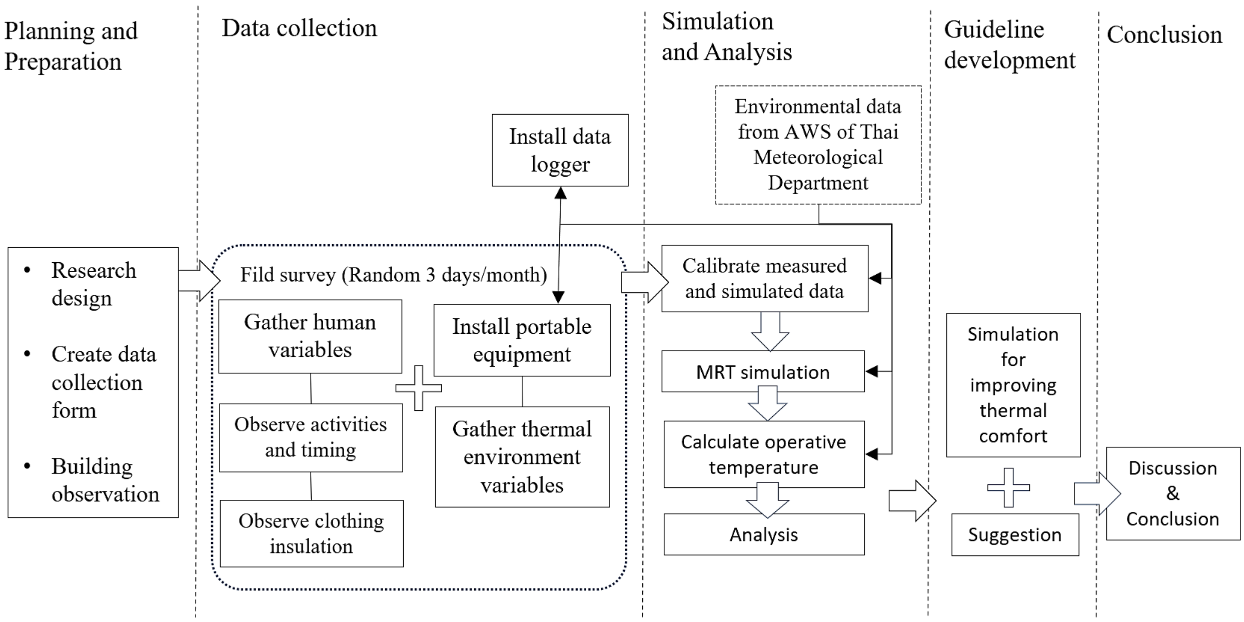


Figure 2. Flowchart of the research methodology

3.1. Step 1: Planning and Preparation

Planning and preparation are the first steps. The study process was designed using data collection forms for utilization in the field surveys, which were created with 4 parts including Part 1: Physical building i.e., form and dimensions; materials; location; orientation; function; details, surrounding; and drawing, Part 2: Activities and clothing insulation, Part 3: thermal environment i.e., air temperature; MRT; air velocity; relative humidity; surface temperatures (ceiling, wall, floor), and Part 4: other and notes from observation. In this step, spaces and buildings were observed.

3.2. Step 2: Data Collection

Data collection forms were used in the field survey. The environmental data in all buildings were operated randomly 3 days per month to collect MRT by using a black globe temperature sensor (SK Sato SK-170GT), gather air temperature, air velocity, and relative humidity by using Tenmars TM-4002, and collect surface temperature (wall, floor, and ceiling) using Bosch GIS500, The research also used a Testo 174H data logger to collect air temperature and humidity in free-running spaces on random days between 9.30 am – 02.30 pm, which is the actual time for activities after registration and opening and closing remark according to the official system, from June 16, 2024, to June 15, 2025.

3.3. Step 3: Simulation and Analysis

For the simulation and analysis part, the surface temperature data from field surveys were entered into the CBE 3D Mean Radiant Temperature Tool of the Center for the Built Environment [40] to simulate the MRT. The simulated MRT was calibrated to the measured MRT, which were gathered from the black globe sensor. The air temperature data from field surveys were calibrated with the outdoor temperature data, which were gathered via the automatic weather system (AWS) of the Thai Meteorological Department [26]. When the characteristics of MRT were clear, this study used the simulated method to find the MRT. Subsequently, the simulated MRT was used to calculate the operative temperature in all senior health and community buildings.

The equation for calculating the operative temperature (To) is

$$T_o = \left(\mathrm{MRT} + \left(T_a \times \sqrt{10V}\right)\right)/(1 + \sqrt{10V}) \quad (3)$$

where the air speed is less than 0.2 m/s, as is typical in general buildings, and the equation can be simplified to:

$$T_o = (T_a + \mathrm{MRT})/2 \quad (4)$$

where, T_o = operative temperature (°C), T_a = air temperature (°C), MRT = mean radiant temperature (°C), and V = air velocity (m/s).

This study used both the ASHRAE and Southeast Asia adaptive comfort models to evaluate and compare the comfort conditions.

3.4. Step 4: Guideline Development

For the simulation in guideline development, to propose the improvement of senior health and community buildings to an adaptive thermal comfort approach, the study used the CBE 3D Mean Radiant Temperature Tool program to simulate the scenarios of MRT in naturally ventilated spaces. The building location, altitude, and azimuth were monitored by SunCalc online software [41]. The physical buildings and materials from field surveys were used to analyze the MRT in this section. Improved adaptive comfort strategies were analyzed, and suggestions were made for guideline development.

3.5. Step 5: Conclusion

In the last step, the results of the study were evaluated and interpreted for the discussion and conclusion. The details of the findings are provided for in-depth interpretation.

4. Results

The purpose of this study is to assess the effect of a thermal environment on adaptive comfort in the free-running spaces of senior health and community buildings, as well as to develop guidelines for improving the three senior buildings researched in this study to achieve comfort environment conditions. Three naturally ventilated spaces from three senior buildings in the provinces of Sukhothai and Phitsaunlok in Thailand, which have different microclimates and environments, were selected and analyzed. The results of the study are shown in this section.

4.1. Observational Data for Physical Buildings

A general feature was that all three spaces were large-scale areas functioning to support the elderly in Thailand, designed as a part of the senior buildings of the Thai government, where the elderly with clothing insulation 0.45-0.5 clo in the hot season, 0.6-1.1 clo in the winter, and 0.45 – 0.55 in the rainy season operated activities at 1.0 – 1.3 met. These values were calculated from the data in the ASHRAE 55-2017 standard [6]. The clothing insulation values were calculated from garment data, and the activity values or metabolic rate were estimated from the data of metabolic rate for the type of task. This study involves details of the survey areas, which were prepared by building observations based on the physical surveys and location determinations by SunCalc [41], as shown in Table 1.

Table 1. Description of observation areas

Survey area	Location	Description	Dimension
Multipurpose area, Si Satchanalai Senior Health and Community Building	Height 69 m. N 17°24'38.16" E 99°47'56.4" UTM 47Q 584863 1925156	Senior health promotion + Senior community building	5 m. × 11 m. (Situated to the southwest of the building)
Waiting area, Samorkhae Senior Health Promotion Building	Height 49 m. N 16°50'26.68" E 100°20'29.01" UTM 47Q 642913 1862422	Senior health promotion building	4 m. × 11 m. (Situated to the southwest of the building)
Multipurpose area, Pa Faek Senior Community Building	Height 49 m. N 16°58'11.72" E 99°57'7.79" UTM 47Q 601372 1876474	Senior community building	7 m. × 24 m. (Situated to the west of the building)

In the case of these buildings, the results of the physical area data are presented in Figures 3-6, which are related to Table 1. Figure 3 shows the free-running multipurpose area situated to the southwest of the Si Satchanalai senior health and community building in Sukhothai Province. It has ceiling fans with a floor-to-roof height of 3.2 m, and no roof insulation.

Figure 3. Multipurpose area (right), Si Satchanalai senior health and community building (left)

Figure 4 shows the semi-indoor spaces situated to the southwest of the Samorkhae senior health promotion building in Phitsanulok Province. It has a floor-to-ceiling height of 2.7 m, and an orbit fan was set up to enhance thermal comfort by utilizing air velocity. However, MRT should be of concern.

Figure 4. Waiting area (right), Samorkhae senior health promotion building (left)

Figure 5 presents the naturally ventilated multipurpose area of the Pa Faek senior community building, which is located to the west of the building. It has a floor-to-roof height of 2.7 m, with no elements to enhance thermal comfort, such as fans, ceiling, or roof insulation. However, a wide outdoor view is useful for human adaptation by translating attention from thermal discomfort conditions.

Notably, from observations in field surveys, evaluation of the environmental conditions in semi-indoor spaces connected to outdoor areas was done by applying the principles of the adaptive comfort model. It sought to determine whether the existing conditions could provide adequate comfort an identify appropriate strategies for improving comfort levels. Therefore, data on environmental satisfaction were not collected. Instead, observations indicated that each naturally ventilated space was typically used by approximately 25-45 occupants. Building occupants are affected by the inconsistent airflow generated by the fans in the area. During the winter and rainy seasons, the fans are used only intermittently, whereas they are operated continuously in the summer. The average measured air velocity ranges from 0.0-0.2 m/s, while areas near the fans exhibit higher velocities of approximately 0.6-0.8 m/s. It is also worth noting that older building users will avoid areas exposed to direct sunlight during the summer and rainy seasons, but some building users will tolerate sunlight during the winter.

Figure 5. Multipurpose area (right), Pa Faek senior community building (left)

4.2. Building Materials

According to the research, it is proposed to develop guideline strategies for improving naturally ventilated spaces in senior buildings. Data concerning buildings, i.e., materials, shape, form, and void, were recorded and estimated. Moreover, the history of the buildings and free-running spaces was studied, as shown in Table 2.

Table 2. Description of the existing building materials

Materials	Location and percentage of materials in each plane			U-value (W/m²·K)
	Multipurpose area, Si Satchanalai senior health and community building	Waiting area, Samorkhae senior health promotion building	Multipurpose area, Pa Faek senior community building	
Brick wall 100 mm	North wall (70%) (Indoor), East wall (80%) (Indoor), South wall (30%), West wall (30%)	North wall (10%) (Indoor), East wall (100%) (Indoor)	East wall (60%) (Indoor)	3.56
Single-glazed window 6 mm	East wall (30%) (Indoor)	North wall (90%) (Indoor)	East wall (40%) (Indoor)	3.69
Concrete slabs 150 mm	Floor (100%)	Floor (100%)	Floor (100%)	0.28
Gypsum board 9 mm	-	Ceiling (100%)	-	21.30
Metal sheet 0.4 mm with structure	Roof (100%)	Roof (100%)	Roof (100%)	117.24

From the building history review, the results found that the free-running spaces were extended to support the activities of the elderly in each community because the government policy aims to support the aging society in Thailand. However, the extended building lacks material guidelines. Thus, the study assumes that materials were selected primarily based on price and local availability, as shown in Table 2. The results showed that the building materials used for free-running spaces were similar in all buildings. Walls were built from 100 mm brick (U-value 3.56 W/m²·K), while indoor windows were made of 6 mm single-glazed glass (U-value 3.69 W/m²·K). Each building space has concrete slabs floors 150 mm thick, and metal sheet roof structures of 0.4 mm thickness. A different ceiling with gypsum board 9 mm thick (U-value 21.30 W/m²·K) was found, which was used only in the waiting area of the Samorkhae senior health promotion building.

From the physical buildings and materials, basic materials have rather high U-values, particularly, a metal sheet roof of 0.4 mm thickness with a structure (117.24 W/m²·K), except for concrete slabs, which are located on the ground (0.28 W/m²·K). This difference in U-value may affect asymmetric radiation, which causes discomfort. It should be a priority to solve this problem. From the percentage of brick walls, it was shown that all buildings have more solid walls in the north and east, which are unable to block the high solar radiation during the afternoon. It should be verified and considered for shading.

4.3. Analysis of Adaptive Thermal Comfort

From the prevailing mean outdoor temperature, which used the average of the 30-day mean daily outdoor temperatures and the operative temperature of all naturally ventilated spaces, the data were plotted into the ASHRAE adaptive comfort model and compared to the Southeast Asia adaptive comfort model.

Although Thailand has a slightly different climate, the environmental conditions are divided into each building to present a comparison of the three case studies from various areas. The rainy season (June 16, 2024 – October 15, 2024) was shown in Figure 6, while the cold season (October 16, 2024 – February 15, 2025) is presented in Figure 7, and the hot season (February 16, 2025 – June 15, 2025) is presented in Figure 8.

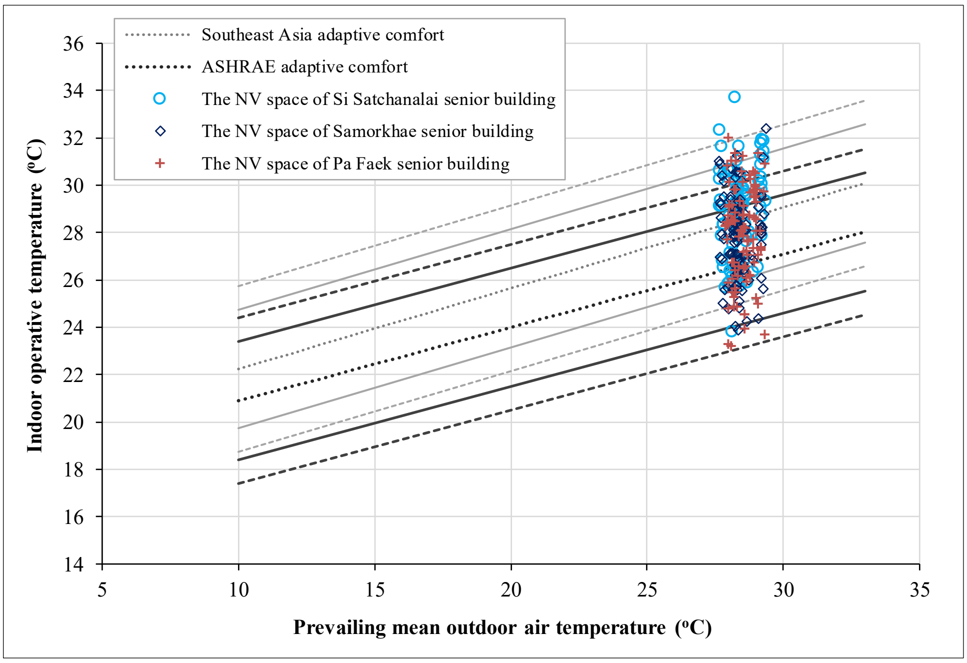


Figure 6. Evaluation of adaptive comfort in the rainy season

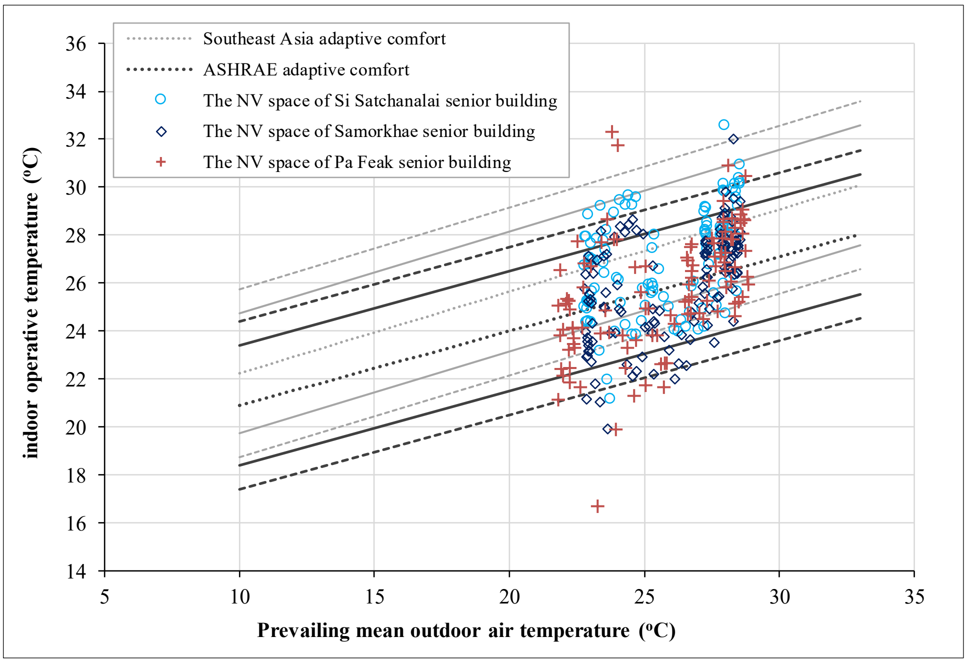


Figure 7. Evaluation of adaptive comfort in the cold season

From Figure 6, the study estimated the thermal environment of all three naturally ventilated spaces in the rainy season. Data were evaluated against the ASHRAE adaptive comfort model (the black line in the graph), and analyzed for the scope of 80% acceptability. It was found that the indoor operative temperature of approximately 20% presented unacceptability. In contrast, almost all semi-indoor operative temperatures were acceptable when the data were estimated by the Southeast Asia adaptive comfort model (the grey line in the graph), According to the findings in the rainy season, the prevailing mean outdoor air temperatures are in a narrow range (27.5°C – 29.0°C). If the stakeholders improve the building for comfort by adapting indoor operative temperature to a range between 24.5°C – 31.0°C, the naturally ventilated spaces show comfort for occupants. The adjustment of operative temperature variables (i.e., MRT, air temperature, and air velocity) is significant. The development of building guidelines should be concerned with a strategy for improving the building environment.

Figure 7 shows the cold season, which analyzed the scope of 80% acceptability of the ASHRAE adaptive comfort model, most indoor operative temperatures in the Samorkhae senior health and community building and the Pa Faek senior community building were acceptable. However, the thermal environment of the Si Satchanalai senior health and community building, which was near 10%, presented unacceptability. When using the Southeast Asia adaptive comfort model to evaluate the thermal environments, it was found that the lower operative temperature approximated 20% of the effect on unacceptability. However, this case can be managed by using clothing insulation to improve thermal comfort. The findings of this section show that, although the range of prevailing mean outdoor air temperatures in the cold season is broad, naturally ventilated spaces still provide comfortable conditions. This study assumes that outdoor temperatures in tropical climates are not lower. Occupants can remain comfortable during the cold season, which is considered the high season in Thailand for saving energy in the buildings.

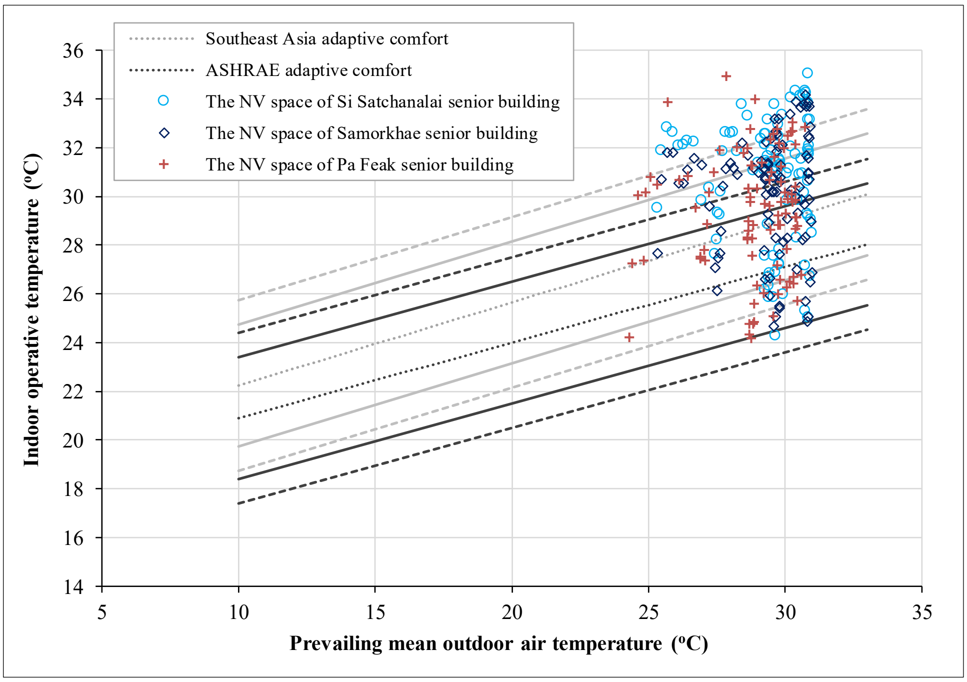


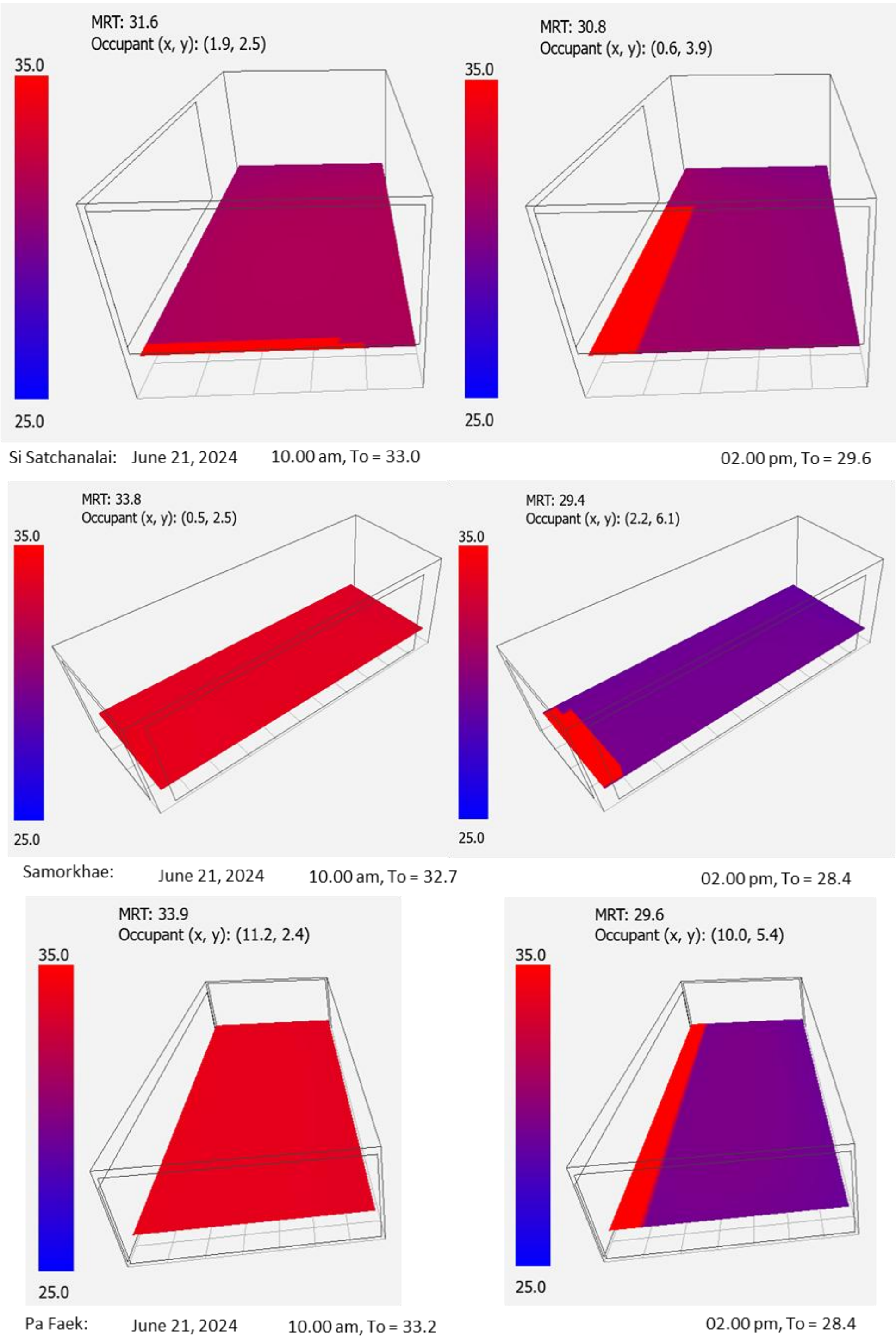
Figure 8. Evaluation of adaptive comfort in the hot season

Figure 8 shows the hot season, in which both the ASHRAE and Southeast Asia adaptive comfort models presented unacceptable environments. When analyzed for the scope of 80% acceptability, the ASHRAE adaptive comfort model showed unacceptable values at 50%, while the Southeast Asia adaptive comfort model presented unacceptable values at 15%. This analysis indicated that the high operative temperature during the hot season causes discomfort. To improve comfort conditions, stakeholders should reduce the upper range of operative temperatures by at least 1.2°C -1.5°C in accordance with the Southeast Asia adaptive comfort model.

4.4. Simulation of the Mean Radiant Temperature in Existing Buildings

In all seasons, the operative temperatures from the field surveys at 10.00 am and 2.00 pm were used to simulate the evaluation of MRT. When the solar angle is the most impacted on the free-running areas of all three buildings in the rainy season (June 21, 2024), the cold season (December 22, 2024), and the hot season (Mar 20, 2025) was analyzed. Based on the simulation by CBE Mean Radiant Temperature Tool program, the details of the rainy, cold, and hot seasons are presented in Figures 9 to 11.

From Figure 9, previous results showed that the operative temperature in the rainy season is close to that in the hot season. In this section, the study analyses the effect of solar radiation by orientation and considers the MRT in the study areas. The MRT simulation was evaluated to assess conditions during the rainy season. The study found that all naturally ventilated areas that are located to the west and southwest of buildings received little effect from the solar radiation angle during the daytime. The solar angle is, in effect, relatively lower than in the cold season. Thus, addressing the effects of asymmetric radiant fields is more significant than using shading devices during the rainy season.



Source: Simulated by the authors based on the CBE 3D Mean Radiant Temperature Tool program.

Figure 9. MRT in naturally ventilated spaces during the rainy season at the Si Satchanalai (top), Samorkhae (middle), and Pa Faek senior health and community buildings (bottom)

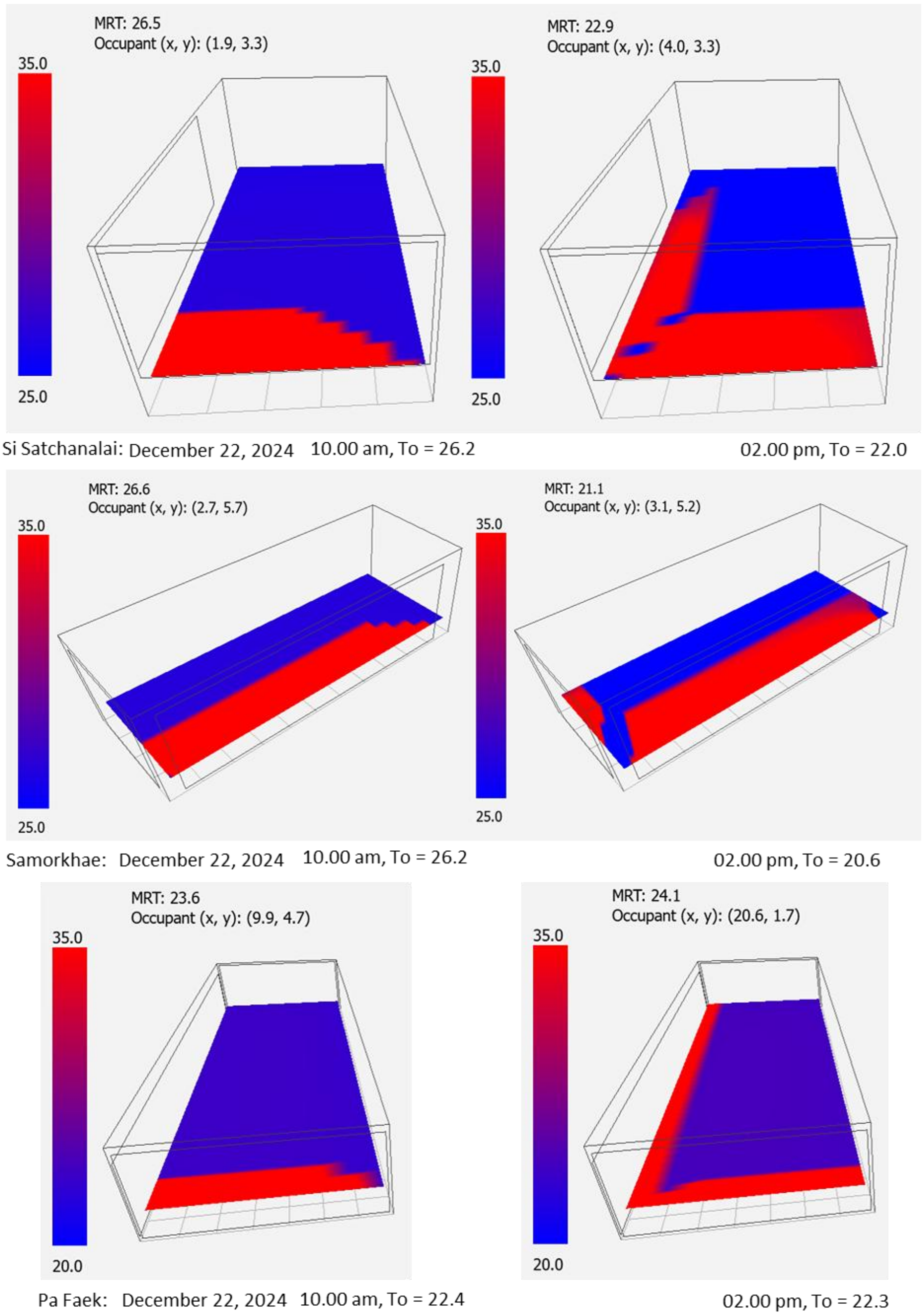
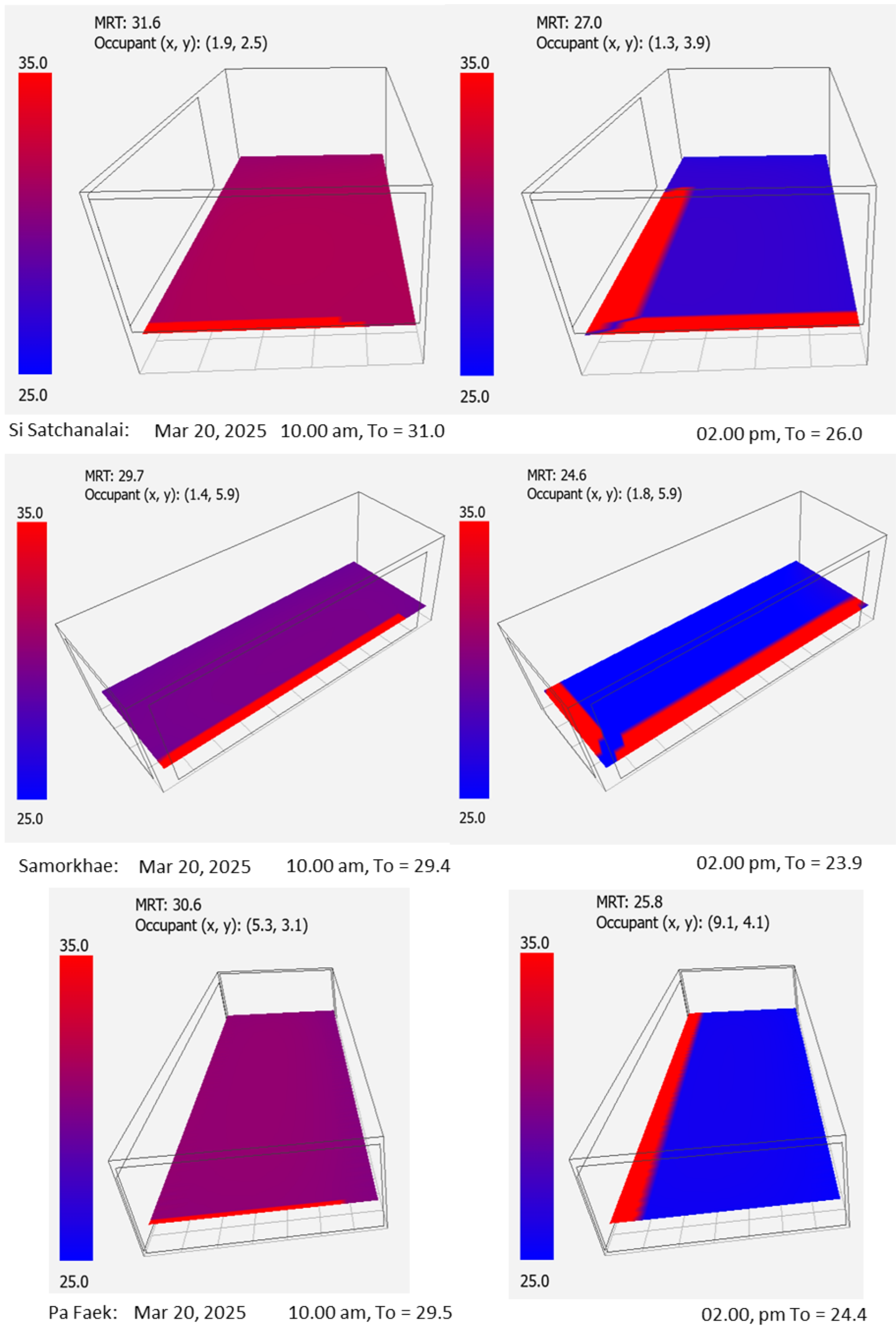


Figure 10. MRT in naturally ventilated spaces during the cold season at the Si Satchanalai (top), Samorkhae (middle), and Pa Faek senior health and community buildings (bottom)

From Figure 10, the naturally ventilated spaces received more solar radiation (due to the effect of solar angle) in the cold season than in other seasons. However, the operative temperature presented that it can take into account the most acceptable adaptive comfort. This season should consider shading devices to resolve the issue and operation.

As seen in Figure 11, the operative temperature in the hot season is close to the rainy season. In effect, the solar angle is lower than in other seasons. However, the MRT is affected by an additionally higher operative temperature, which impacts adaptive comfort. Thus, using materials and design should be done with awareness.

Although the effect of solar angle is less than others, the hot seasons should be of concern. According to the previous results, the environmental conditions reveal the percentage of acceptable conditions. Based on physical building data, two naturally ventilated areas lack insulated roofs, which may contribute to unacceptable conditions. The operative temperatures calculated from the MRT simulation data and field survey data are higher than the scope of adaptive comfort. In addition, the MRT contributes to asymmetric radiation. Nevertheless, the free-running areas can be renovated to add comfort conditions for occupants. Among climate change, building improvement after assessment, which is a part of the POE will help to make targeted corrections. The buildings in the hot season were analyzed and presented in the next section.



Source: Simulated by the authors based on the CBE 3D Mean Radiant Temperature Tool program.

Figure 11. MRT in naturally ventilated spaces during the hot season at the Si Satchanalai (top), Samorkhae (middle), and Pa Faek senior health and community buildings (bottom)

5. Building Simulation for Improving Adaptive Thermal Comfort

During the daytime, the thermal environmental conditions are in a high temperature range and are not suitable for thermal comfort. Adaptive comfort at 2.00 pm must be considered because, during this time, there are more activities in the naturally ventilated spaces and more of an effect by solar radiation in these areas. The hottest day in each senior building was considered. The simulation by CBE Mean Radiant Temperature Tool software was used to analyze the reduction of the MRT scenarios by using roof insulation with a thickness of 3 inches (U-values of 4.51 W/m²·K), as presented in Figure 12.

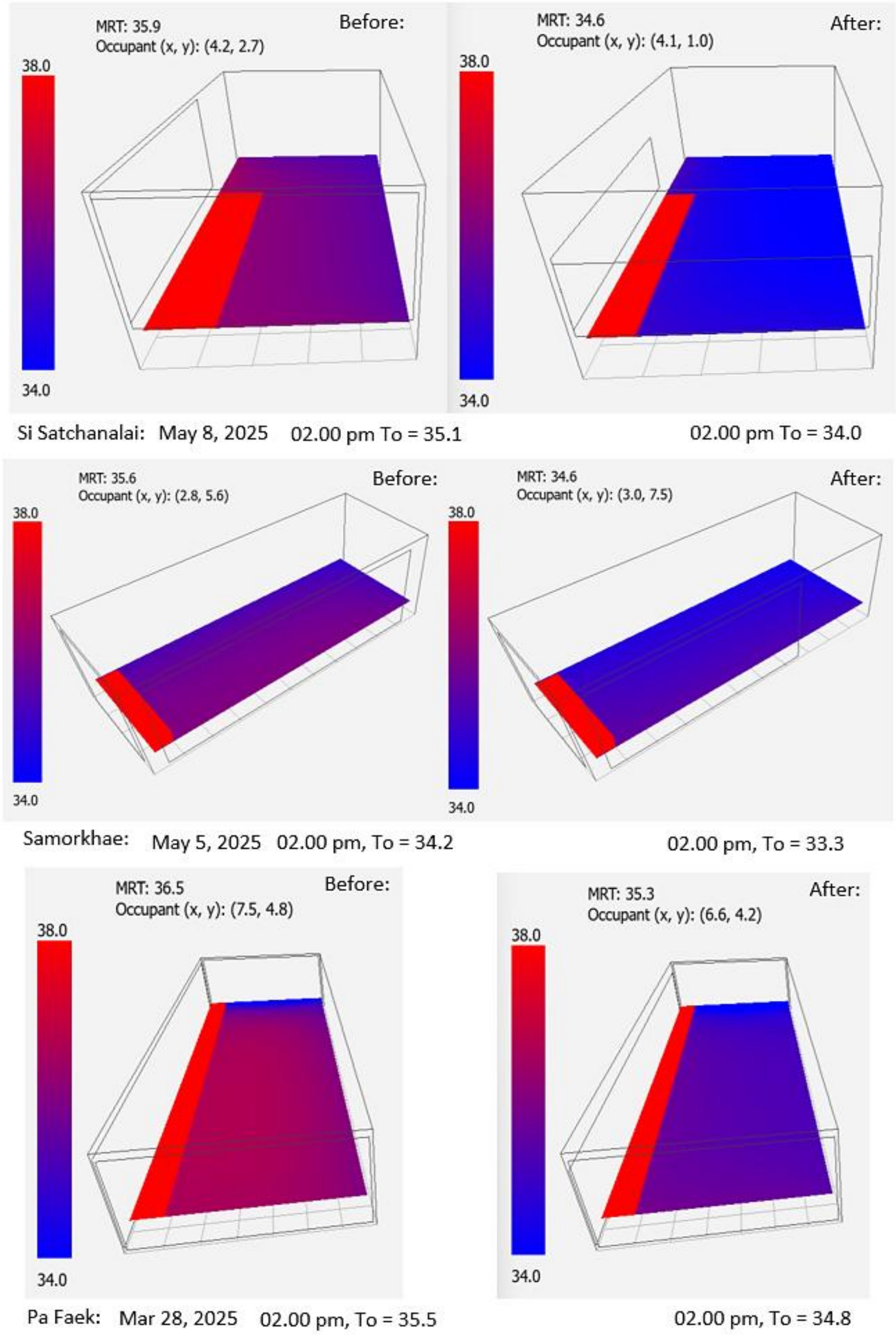


Figure 12. Simulation to reduce MRT in areas with natural ventilation located at the Si Satchanalai (top), Samorkhae (middle), and Pa Faek (bottom) senior health and community buildings

In Figure 12, a high operative temperature was found in the hot season. To improve the free-running areas of all buildings for adaptive comfort, the simulation for MRT reduction was used. According to the field surveys, the study found that the roofs of senior buildings were not insulated. Therefore, using an insulated roof with U-values of 4.51 $W/m^2{\cdot}K$ was simulated. The estimated data showed that all buildings can reduce MRT by approximately 1.0-1.3 °C, which has the effect of reducing the operative temperature by approximately 0.7-1.1°C. In addition, the overhang, transitional space, and fin are significant for reducing MRT, which is a result of solar angle. The observation from the software simulations also showed that, if the floor-to-roof or floor-to-ceiling is high, MRT will be low accordingly. This factor should be considered for adaptive comfort.

Base on simulations from the hottest day of the hot season, it was found that the naturally ventilated spaces in each building were affected by the solar angle. The study areas exhibit high operative temperatures that fall outside the adaptive comfort range. However, the study simulation results reveal that improving only the roof insulation can reduce the operative temperature range. The research assumes that, if the buildings are improved with other materials to reduce the MRT by selecting quality materials with low U-values, this strategy can enhance semi-indoor comfort conditions and reduce energy consumption in buildings, thereby contributing to the mitigation of climate change.

6. Discussion

In the rainy and hot seasons, the evaluation of the ASHRAE adaptive comfort model presents more discomfort than the assessment of the Southeast Asia adaptive model. The existing thermal environments in all buildings, which were evaluated by the ASHRAE adaptive comfort model, are unacceptable by approximately 20% in the rainy season and 50% in the hot season. The results in the hot season are similar to the evaluation of the Southeast Asia adaptive comfort model. It was presented that the higher operative temperature affected unacceptability. In the rainy season, stakeholders can improve the building for comfort by adapting indoor operative temperature variables to the range of 24.5°C – 31.0°C. In the hot season, stakeholders should reduce the upper range of operative temperatures by at least 1.2℃ -1.5°C in accordance with the Southeast Asia adaptive comfort model. However, in the hot and rainy seasons, the solar angle is, in effect, rather lower than in the cold season. Therefore, addressing the effects of asymmetric radiant fields is more significant than using shading devices during the rainy season. The awareness of asymmetric radiant fields is related to the previous research of Halawa [38], which revealed that asymmetric radiant field situations are significant and must be treated as an important thermal comfort parameter.

In the winter, the assessment of the Southeast Asia adaptive comfort model revealed that the lower operative temperature of approximately 20% presented unacceptability. In contrast, when the data were estimated by the ASHRAE adaptive comfort model, almost all semi-indoor operative temperatures were accepted. According to the ASHRAE 55-2017 standard [6], observations and assessments of the clothing insulation values, found that 0.45-0.5 clo in summer, 0.6-1.1 clo in wi nter, and 0.45 – 0.55 clo in the rainy season. The obtained values differed relatively little when compared to different climate zones. The outdoor temperatures in tropical climates are not significantly lower. Occupants can remain comfortable during the cold seasons. In this case, clothing adaptation can improve thermal comfort in the winter. Clothing insulation adaptation was related to the study by Humphreys & Nicol [11].

In the developing guidelines section for improving existing buildings, the environmental assessment for monitoring is significant. It is related to previous research, which found that the POE is significant for monitoring building performance [36]. In the study for improving existing building to adaptive comfort using simulation, the results indicated that thermal environments are in a discomfort range, although senior buildings have fans for operating thermal comfort, which is caused by the height of the MRT. From the field surveys, two naturally ventilated spaces in the three senior buildings did not have roof insulation, and one space did not have an overhang. The simulated results revealed that using an insulated roof would reduce the operative temperature by approximately 0.7-1.1°C, with values occurring from the reduction of MRT approximately 1.0-1.3 °C. Nevertheless, it should be noted that visual comfort may be helpful in the expectation of thermal comfort. The translated attention via outdoor view can support the psychology of the expectation, which is a part of adaptive comfort. Moreover, according to observations from the software simulations, it can be noted that MRT will decrease accordingly if the floor-to-roof or floor-to-ceiling height is elevated, which these results related to the previous study of Marigo et al. [39]. This part should be considered for adaptive comfort. The study assumes that having a high roof and ceiling fans would help to achieve adaptive comfort. Although the air velocity dose not directly affect MRT, it can result in a more acceptable operative temperature.

7. Conclusion

Adaptive comfort was investigated in a semi-outdoor environment of senior buildings in the lower northern region of Thailand. Three naturally ventilated spaces that had different characteristics, such as materials, height, and microclimate, were selected. Seasonal field survey covered a period of the rainy season, the cold season, and the hot season over 36 days in each building or a total of 108 days. Data gathered from June 16, 2024, to June 15, 2025, were utilized and validated during the MRT simulation with the CBE 3D Mean Radiant Temperature Tool. The clear MRT simulation process was used to find the MRT values in all buildings during all seasons. Further, the MRT data were used to calculate the operative temperature in each building. The operative temperature and the mean outdoor temperature from the automatic weather system of the Thai Meteorological Department were evaluated using the ASHRAE and the Southeast Asia adaptive comfort models.

Although the results of the assessment of ASHRAE and Southeast Asia adaptive comfort models tend to be in accordance during the rainy and hot seasons, the evaluation of the ASHRAE adaptive comfort model revealed that thermal environments are more uncomfortable than the assessment in the Southeast Asia adaptive comfort model. In two seasons, the high operative temperatures are significant for discomfort. The assessments for both adaptive comfort models are not identical during winter. The ASHRAE adaptive comfort model revealed that the high operative temperatures are a discomfort cause. In contrast, the Southeast Asia adaptive comfort model presented that the low operative temperatures are a cause. Nevertheless, this result is found only in some senior buildings and for a short time. Thus, the clothing adaptation can improve thermal comfort.

The study on developing buildings to confront adaptive comfort. It was found that the POE is significant for monitoring building performance i.e., thermal comfort, materials, and energy efficiency. From the study, the results indicated that the senior buildings should be improved for thermal comfort. Although senior buildings have fans for operating thermal comfort in the hot season, the higher operative temperature presented discomfort. The MRT in free-running areas is caused. In addition, asymmetry radiation is significant for concerns. The heights of ceiling or roof should be considered. At higher levels, MRT can be reduced. If stakeholders install ceiling fans or ceiling orbit fans on a higher roof or ceiling level, the results are expected to improve adaptive comfort by modifying the operative temperatures.

To develop guidelines using simulation, it is apparent that using an insulated roof would reduce the MRT by approximately 1.0-1.3 °C, which has the effect of reducing the operative temperature by approximately 0.7-1.1 °C. The study assumed that buildings can be improved by using alternative materials to reduce MRT through the selection of high-quality materials with low U-values. This strategy can enhance semi-indoor comfort conditions and reduce energy consumption in buildings, thereby contributing to climate change mitigation. Moreover, the overhang, transitional space, and fin are necessary for the Thai environment in hot humid climates, especially the environment for the elderly.

8. Declarations

8.1. Author Contributions

Conceptualization, C.P. and T.C.; methodology, C.P.; software, C.P.; validation, C.P., T.C., and A.S.; formal analysis, C.P.; investigation, C.P.; resources, C.P.; data curation, C.P.; writing—original draft preparation, C.P.; writing—review and editing, C.P. and T.C.; visualization, C.P.; supervision, A.S.; project administration, C.P.; funding acquisition, C.P. All authors have read and agreed to the published version of the manuscript.

8.2. Data Availability Statement

The data presented in this study are available on request from the corresponding author.

8.3. Funding

This work was supported by Fundamental Research Fund, 2024 of Thai Government, which under the support of Naresuan University.

8.4. Acknowledgments

The authors would like to thank the Naresuan University, Thailand, the Thai Meteorological Department for research support, as well as the Center for the Built Environment, and SunCalc.org for online software support.

8.5. Conflicts of Interest

The authors declare no conflict of interest.

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