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Development of guidelines for enhancement of thermal comfort and energy efficiency during winter for Thailand’s senior centers using surveys and computer simulation

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ABSTRACT

The objective of this study is to develop guidelines for thermal comfort and energy efficiency for senior centers during winter. The study was conducted in Phitsanulok, Thailand and it three methods were applied in development of the guidelines: field survey, laboratory study, and simulation in scSTREAM – a CFD program -- and Visual DOE 4.0 program. With a temperature set-point of 25.0 °C in the existing air-conditioned senior centers, the study shows that occupants feel “Slightly cool”. These feelings change to “Neutral” when natural ventilation and fans are used to generate air speed of 0.57–0.60 m/s during the hours of 8:00 AM–1:00 PM, and by setting the temperature set-point at 26.0 °C with air speed of 0.10–0.26 m/s during the afternoon, from 1:00 PM–4:00 PM. These guidelines can help reduce energy consumption by 23.0 % and can have general application for senior centers.

Keywords: *Thermal comfort, senior centers, energy use, winter, computer simulation*

INTRODUCTION

Member countries in the Association of Southeast Asian Nations (ASEAN) demonstrate a statistically significant association between economic growth, energy consumption, and carbon emission (Lean & Smyth, 2010). Countries in Southeast Asia will encounter a doubling in demand for electricity by 2025 (The International Renewable Energy Agency, 2017). Thailand has hot and humid climate (Kottek et al., 2006); the largest proportion of energy consumed in Thailand is used for cooling the interiors of buildings (Chirarattananon et al., 2006; Yimprayoon, 2016). In general, air-conditioning (AC) is used to provide thermal comfort for occupants. If those occupants remain in thermal comfort, in the result is better health, performance, and satisfaction of the occupants (McCartney & Humphreys, 2002; Özdamar & Umarogullari, 2018; Jitkajornwanich, 2001; Djongyang et al., 2010; Stoops, 2004). On the other hand, if the AC does not meet the needs of the occupants, uncomfortable conditions will result; thus, causing a waste of energy due to the ineffective outcome. In defining sustainable development, the World Commission on Environment and Development (1987) realized the importance of energy use for future generations. Recently, a concrete plan known as “Sustainable Development Goals” (SDGs) was developed by the Commission, and Thailand has devised a strategy in response to the SDGs (Office of the National Economic and Social Development Board Office of Prime Minister, 2017) which includes both energy use and aging population related issues. These issues are challenging, and require good planning for sustainable management.

Thailand has the second-highest proportion of aging population in Southeast Asia after Singapore (The ASEAN post, 2020; Prasartkul et al., 2019). It will enter the aged society, defined as populations with 20 % older adults, by 2021, and this will proportion is expected to rise to 30 % by 2036 (Prasartkul et al., 2019). Thus, the need for energy to operate facilities for an increasing population of seniors is considered important.

The Thai government utilizes rooms in existing buildings and has built new buildings as senior daycare centers to accommodate older adults. Currently, at least 879 senior daycare centers operate in communities nationwide (Strategy and Planning Division, 2019). However, these facilities were not built with consideration of the thermal comfort of this specific group of users. The cooling thermostat set-point is set in accordance with that suggested for the general public, specifically, at 25 °C, which may not be appropriate for seniors. Thus, it is important to study the situation and develop guidelines in order to identify seniors' thermal comfort preferences. A combination of thermal comfort factors considering six parameters of personal factors i.e., metabolic rate (Met), clothing insulation (I_{cl}); and environmental factors i.e., air temperature (T_a), mean radiant temperature (T_{mr}), relative humidity (RH), and air speed (V_a) (American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE], 2017; International Standard Organization [ISO], 2005; Fanger, 1972) for this specific group of occupants should be studied in detail.

In previous studies, it has been found that physical changes in the human body that accompany aging normally include a decrease in metabolic rate (St-Onge and Gallagher, 2010) and a decrease in brown adipose tissue (Drubach et al., 2011; Saito et al., 2009), which produces body heat (Lee et al., 2013; Mahaketa, 2013) and maintains balance of the human body temperature (Geneva, 2019). The changes in metabolic rate affect thermal perceptions of seniors, which Cena et al. (1986) found to differ quite significantly from those of most younger people. Many studies have confirmed that seniors prefer temperatures that are warmer by 2 °C (Hoof & Hensen, 2006; Tsuzuki & Ohfuku, 2002). Moreover, studies in different climates found different temperature preferences for seniors. Typical examples of these preferences include a preference for 22–23 °C in the UK (Lewis, 2015), 20–25 °C in Portugal (Guedes et al., 2009), and 20–26 °C in New South Wales, Australia (Tartarini et al., 2017). As for Thailand, it seems seniors also prefer higher temperatures (Ransiraksa, 2006; Chindapol et al., 2016) and more natural ventilation (NV) than do younger Thai people (Jitkhajornwanich, 2004).

Of particular interest, the research of Busch (1992) and Khedari et al. (2000) found that the Thai people in NV spaces were satisfied with a temperature increase of 2–3 °C, which may offer an opportunity to reduce the use of AC by relying on NV instead, especially in the winter season. However, there are still a limited number of research studies on thermal comfort of Thai elders and a lack of research on the relationship of variables that can be used as guides to appropriate adjustment of thermal environmental conditions.This study aims 1) to study thermal comfort preferences and develop a mathematical model to predict thermal sensation of Thai older adults during the winter season, 2) to propose thermal comfort and energy saving guidelines which can be applied to senior centers, and 3) to evaluate energy saving performance of senior centers after implementing the guidelines.

Previous studies on thermal comfort have been conducted by Fanger (1972) who used a laboratory for research, and Humphrey & Nicol (2002), who used field studies for their research. These approaches were based on the limitations and scope of each study. In addition, the present study on thermal comfort found that the use of computer simulation (Computational Fluid Dynamics [CFD]) can help eliminate limitations, reduce costs, and save time (Aryal & Leephakpreeda, 2015; Samiuddin & Budaiwi, 2018). As mentioned above, this study used 3 methods: field survey, laboratory study, and simulation. The field survey was conducted in 3 senior centers to observe seniors' sensations as well as the environmental conditions. However, it is almost impossible to adjust the indoor environment in the centers, since the area is large and in use. Thus, the laboratory method was also applied. To develop guidelines, the data obtained from senior centers and laboratory tests were used to establish the equation for predicting the thermal sensation vote (TSV) of occupants, which was then analyzed by simulation programs. The CFD can help present the results of both AC and NV by simulating their use. For energy consumption, the Visual DOE 4.0 was used. It is not only possible to apply the results of this study directly to the 3 case studies of senior centers, but they can also to be used as guidance for other centers in order to enhance the well-being of the occupants and achieve energy savings.

MATERIALS AND METHODS

Research procedures

The study was carried out in accordance with the Declaration of Helsinki, and approved by the Ethics Committee of Naresuan University (COA No. 344/2015). The research involved the study of environmental factors that affect sensations of seniors who wear the same type of clothes as they usually wear in winter and who performed light activity (65–70 W/m^2) at least 15 minutes before participation. Questionnaires and environmental measuring instruments were used to gather data in both field and laboratory studies. The collected data were used to develop an equation for predicting TSV, which was later input into the simulation programs based on CFD, scSTREAM, to calculate the air flow velocities and resultant thermal comfort. Subsequently, an energy simulation program — Visual DOE 4.0 -- was used to estimate the energy consumption used to cool the spaces both before and after implementation of the guidelines.

Participants

The participants were Thais, aged 55 and above, from government senior centers in Phitsanulok City, who met the retirement criteria of the private sector in Thailand, and who were eligible to receive social security benefits (Chamchan, 2013).

Regarding the selection criteria, the participants had to use the area of the senior centers for the field study. In terms of the laboratory study, the caregivers determined that senior centers should accommodate 30 elderly people. The formula of Krejcie and Morgan (1970) was used to calculate the appropriate sample size of at least 28 participants per condition. The researchers decided to use 30 participants per condition who were rotated to experience the thermal conditions in the climate chamber.

Participants' data are shown in Table 1. There are 102 older adults in total; 33 seniors (9 males, and 24 females) in center 1, 36 seniors (12 males, and 24 females) in center 2, and 33 seniors (10 males, and 23 females) in center 3. Forty-two seniors from 3 centers were asked to be volunteers. They rotated, forming groups of 30 participants (15 males, and 15 females) who experienced 144 different thermal conditions in an environment-test chamber. The participants in the survey of real buildings had an average age range of 68.70–71.28 years old, Body Mass Index (BMI) between 23.83–24.92 kg/m^2, Body Surface Area (BSA) of 1.57–1.62 m^2, and the I_{cl} between 0.58–0.59 clo. Similarly, the selected 42 volunteer seniors for the laboratory test had an average age of 67.93 years, with BMI of 24.82 kg/m^2 and BSA of 1.63 m^2, but the I_{cl} (0.66 clo) is slightly different. According to the BMI classification for Asian-Pacific population of the World Health Organization—Western Pacific Region Office (WHO–WPRO) (Anuurad, 2003), the participants' BMI, which were in the range of 23.0–24.9 kg/m^2, are classified as overweight, which is similar to general Thai seniors (Health Info in Thailand, 2020).

Table 1: Characteristic of participants

Lists	Details	Senior Center 1	Senior Center 2	Senior Center 3	Laboratory
Participants (Number)	Male	9	12	10	16
	Female	24	24	23	26
Personal	Age (year)	69.83±8.09	71.28±7.43	68.70±8.74	67.93±7.68
Data	Body mass index (kg/m^2)	24.74±3.63	23.83±3.40	24.92±3.64	24.82±3.32
(M±SD)	Body surface area (m^2)	1.61±0.15	1.57±0.14	1.62±0.12	1.63±0.14
	Clothing insulation (clo)	0.58±0.10	0.58±0.10	0.59±0.10	0.66±0.19

Instruments

This study used Tenmars-4002 with external sensors to measure T_a, V_a, and RH. Testo-445 equipped with a black globe thermometer was used to measure T_{mr}. The sensors were placed at 0.75 m above the floor.

Questionnaire

The questionnaire consisted of 4 sections: Section A: indoor and outdoor environments, Section B: basic information about participants, Section C: clothing insulation of participants, and Section D: Thermal Sensation Vote (TSV) using ASHRAE's 7-point scale (ASHRAE, 2017). The Humidity Sensation Vote (HSV) and Air Speed Sensation Vote (ASV) using 7-point scales were adopted from Wang et al. (Wang et al., 2016), as shown in Table 2. In order to analyze, TSV, HSV, and ASV are averaged. The ranges and definitions of Mean Thermal Sensation Vote (MTSV), Mean Humidity Sensation Vote (MHSV), and Mean Air Speed Sensation Vote (MASV) are also shown in Table 2.

Analysis of environmental data

The operative temperature (T_o) is calculated based on ASHRAE (ASHRAE, 2009) in order to examine the thermal preferences. The relationship between the predicted TSV and indoor environmental parameters are established through a multiple linear regression model. T_o is a function of V_a; T_{mr}; and T_a (Simone et al., 2007; Ford, 2000), which is simplified to determine human thermal comfort (Ford, 2000).

Location and time periods for study

The survey was conducted in Phitsanulok. This city receives support from the Thai government and Japan International Cooperation (JICA) (Office of the National Economic and Social Development Board, 2017) for conducting a pilot project designed to create and maintain a zone for a sustainable ageing society. The survey time was 8:00 AM–4:30 PM in winter (November 2017, January–February 2018). A field survey was conducted in 3 senior

Table 2: The 7-point scales for measuring the sensations and mean value ranges for analysis

Scales	-3	-2	-1	0	+1	+2	+3
Mean scales (for analysis)	-3.00 to -2.50	-2.49 to -1.50	-1.49 to -0.50	-0.49 to +0.49	+0.50 to +1.49	+1.50 to +2.49	+2.50 to +3.00
TSV / MTSV:	Cold	Cool	Slightly cool	Neutral	Slightly warm	Warm	Hot
HSV / MHSV:	Very dry	Dry	Slightly dry	Neutral	Slightly humid	Humid	Very Humid
ASV / MASV:	Very low	Low	Slightly low	Neutral	Slightly high	High	Very high

Figure 1:
(A) Senior Center 1, (B) Senior Center 2, (C) Senior Center 3, (D) Environment-test chamber
(Source: Authors)

centers, which are adapted from multi-purpose rooms in public health buildings. Senior Center 1, Praongkhao, is located on the second floor, with its long sides facing the east-west orientation. Senior Center 2, Mahanuphab, has a double space with a U-shaped design. Senior Center 3, Pracha-Uthit, is a standalone building. The long sides of both Centers 2 and 3 face the northwest-southeast axis. The laboratory study was conducted in an environmental test chamber located in the Faculty of Engineering of Naresuan University. The details of buildings and data collections are shown in Figure 1.

Field survey

In Table 3, the operation schedules of all centers are 8:00 AM–4:00 PM. The conditioned areas of Senior Centers 1–3 are 98 m^2, 72 m^2, and 89 m^2 respectively. The window area and the overall window-to-wall ratio (WWR) of Senior Center 3 (33 m^2, and 27.1 %) are the largest, while those in Senior Center 2 (9 m^2, and 4.8 %) are the smallest. The North side WWR is considered an important element of lower energy use, but only north WWR of Senior Center 3 (31.9 %) is higher than non-north WWR (24.5 %). The walls' U-values of all senior centers are the same at 2.88 $W/m^2 \cdot °C$, whereas the solar heat gains coefficient (SHGC) and U-values of glass are slightly different. The measurements of indoor environments show similar values for all senior centers. The range of T_a (24.4–25.8 °C); T_{mr} (25.4–26.7 °C); and RH (48.2–50.2 %) of Senior Center 3 are the narrowest, but the narrowest V_a range is in Senior Center 1 (0–0.33 m/s). The sensation of seniors on temperature (MTSV: from -0.52 to -0.53) and humidity (MHSV: from -0.48 to -0.22) were found to be the same in all centers as "Slightly cool" and "Neutral" respectively, whereas the occupants' sensations of air speed in Senior Center 1 (MASV: -0.70) was reported as "Slightly low", which is quite different from that in Senior Centers 2 (MASV: -0.42) and 3 (MASV: -0.45), reported as "Neutral".

Table 3: Information of case-study senior centers in the field survey

List	Details	Senior Center 1	Senior Center 2	Senior Center 3
The range of	Air temperature (°C)	24.2–26.1	24.2–26.9	24.4–25.8
indoor environment	Mean radiant temperature (°C)	24.9–26.5	24.8–27.1	25.4–26.7
(Min-Max)	Relative humidity (%)	50.1–61.5	49.9–59.6	48.2–50.2
	Air velocity (m/s)	0–0.33	0–0.72	0–0.45
Sensation of users	MTSV	-0.52	-0.53	-0.52
(Mean)	MHSV	-0.48	-0.22	-0.48
	MASV	-0.70	-0.42	-0.45
Shape parameter	Gross room area (m^2)	98	72	89
(Value)	Window area (m^2)	12	9	33
	Conditioned room area (m^2)	98	72	89
	Overall WWR (%)	9.7	4.8	27.1
	North WWR (%)	7.3	4.4	31.9
	Non-North WWR (%)	10.2	4.9	24.5
Thermal parameter	U-value of wall ($W/m^2 \cdot °C$)	2.88	2.88	2.88
(Value)	U-value of window ($W/m^2 \cdot °C$)	5.80	5.62	5.62
	SHGC of window	0.55	0.50	0.46
Operation schedule	Air-conditioned usage time	8:00AM–4:00PM	8:00AM–4:00PM	8:00AM–4:00PM

Note: WWR is window-to-wall ratio, SHGC is solar heat gain coefficient.

Laboratory study

The study was conducted in an environment-test chamber of with dimensions of 3.00 m (width) x 4.65 m (length) x 2.35 m (height), and with a capacity of 4 subjects at a time. The chamber can be adjusted for 144 thermal conditions that can occur from a combination of various environmental variable values (Table 4).

The indoor air temperature was adjustable to 4 values during the experiment, the average values of T_a were 21.54 °C, 24.00 °C, 26.49 °C, and 28.96 °C.

Mean radiant temperature was adjustable to 4 values, using 4 wall panel types (see Figure 1D):

1) the ice box panels were used to lower the T_{mr} by 2.46 °C below T_a,
2) cooled panels (i.e., panels equipped with aluminum coils filled with chilled water) to lower the T_{mr} by 1.47 °C below T_a,
3) warm panels (i.e., gray aluminum panels heated by 400 W infrared heaters to raise the T_{mr} by 1.39 °C above T_a, and 4) black aluminum panels heated by 600 W infrared heaters to raise the T_{mr} by 2.49 °C above T_a.

The indoor relative humidity was adjustable to 3 values, using 250 W ultrasonic mist maker. The average RH values were 44.72 %, 60.53 %, and 74.18 %.

The air speed was adjustable to 3 values, using 50 W electric fans and aluminium shields to lower air speed. The average V_a values were 0.05 m/s, 0.51 m/s, and 1.51 m/s.

Table 4: The conditions in which was adjusted in environment-test chamber for laboratory study

Values of variables	Air temperature (°C) (M±SD)	Mean radiant temperature (°C) (M±SD)	Relative humidity (%) (M±SD)	Air velocity (m/s) (M±SD)
1	21.54 ± 0.21	(T_a-2.46) ± 0.13	44.72 ± 1.05	0.05 ± 0.02
2	24.00 ± 0.23	(T_a-1.47) ± 0.16	60.53 ± 0.96	0.51 ± 0.03
3	26.49 ± 0.20	(T_a+1.39) ± 0.16	74.18 ± 0.86	1.51 ± 0.03
4	28.96 ± 0.19	(T_a+2.49) ± 0.18		

From Table 4, the laboratory expanded thermal environmental conditions to be higher and lower than the air-conditioned space in the senior centers. The hotter environment is therefore similar to a naturally ventilated space. The data obtained from the laboratory with expanded environmental conditions are also used for analysis.

Computer simulation

This study applied 2 simulation software programs to help with investigating the performance of the proposed guidelines. scSTREAM — a CFD program (Software Cradle, 2020) -- was used to evaluate the air movement so as to determine the Thermal comfort of occupants. Visual DOE 4.0, which was developed from the DOE-2 (University of California & Hirsch, 2008) energy simulation program was used to calculate the energy use of the buildings by using data such as building materials, operation schedules, conditioning system, and controls.

RESULTS

Analysis of equation and scope of thermal comfort perception

In order to analyze the relationship between variables and TSV as stipulated in the equation, a total of 102 data items from field surveys and 4,320 data items from the laboratory tests were used. The TSV data from 30 participants of each thermal condition from the test chamber were averaged into 144 MTSV data results. Then, multiple linear regression was conducted to analyze 102 TSV data and 144 MTSV data (Table 5).

Table 5: Multiple linear regression analysis with stepwise of thermal predictors of the thermal sensation

Variable	Field study		Laboratory study		
	Model 1	Model 2	Model 1	Model 2	Model 3
(Constant)	-0.371***	-11.869***	-9.199***	-8.825***	-9.229***
Operative temperature		0.455***	0.340***	0.338***	0.338***
Air velocity	-1.250***	-1.664***		-0.490***	-0.488***
Relative humidity					0.007***
R^2	0.154	0.384	0.872	0.952	0.958
Adjusted R^2	0.145	0.372	0.871	0.951	0.957
SE	0.499	0.428	0.380	0.233	0.219

*Note: *p < 0.05; ** p < 0.01; p*** < 0.05, SE is the standard error for the unstandardized beta, and R^2 is coefficient of multiple determination, and Adjust R^2 is a modified version of R-squared.*

The study found the best-fit equation for predicting TSV_{field} from the field survey (R^2 of 0.38) is:

$$TSV_{field} = 0.455T_o - 1.664V_a - 11.869 \quad (1)$$

The equation for predicting $MTSV_{lab}$ from the laboratory study with the R^2 of 0.96 is:

$$MTSV_{lab} = 0.338T_o - 0.488V_a + 0.007RH - 9.229 \quad (2)$$

$MTSV_{lab}$ is the predicted thermal sensation vote from the laboratory study, and TSV_{field} is that derived from the field survey. (T_o is operative temperature, RH is relative humidity, and V_a is air speed). While Equation (1) covered only narrow ranges of real indoor environments, Equation (2) covered wider ranges like those which occur from environmental controls, However, Equation (2) represented only the test chamber conditions. Thus, Equation (2) was adapted to predict sensations in senior centers through the following methods.

The indoor environment variables used in Equation (1) and (2) were replaced with data from measurements made inside all centers in order to calculate TSV_{field} and $MTSV_{lab}$. At certain indoor conditions, the relationship between the MTSV and TSV obtained from laboratory and field studies is presented as follows.

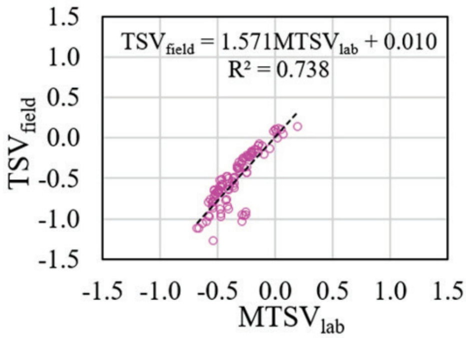

Figure 2:
Comparison of the values of TSV_{field} and $MTSV_{lab}$
(Source: Authors)

In Figure 2, the relationship between TSV_{field} and $MTSV_{lab}$ is shown in Equation (3) (R^2 of 0.74):

$$TSV_{field} = 1.571(MTSV_{lab}) + 0.010 \quad (3)$$

Then, the variable $MTSV_{lab}$ from Equation (3) was replaced with the data used in Equation (2) in order to calculate a final equation for predicting TSV of Thai's older adults in senior centers in winter season with R^2 of 0.71:

$$TSV_{field} = 0.531T_o - 0.767V_a + 0.011RH - 14.489 \quad (4)$$

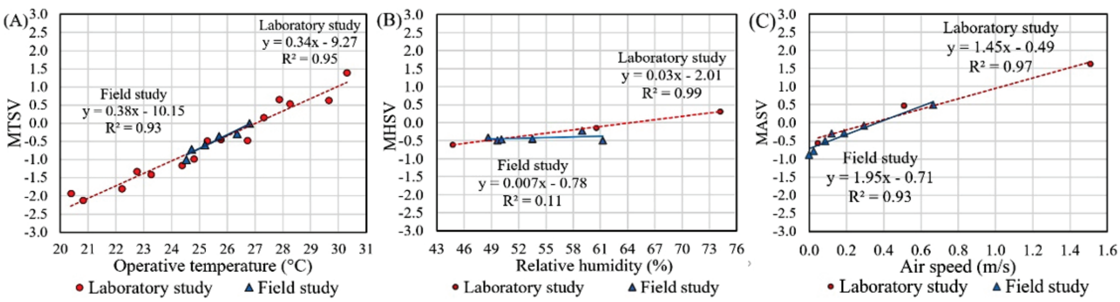

Figure 3:
Sensation towards: (A) Operative temperature, (B) Relative humidity, and (C) Air speed
(Source: Authors)

Further, the scope of seniors' thermal comfort perception was also analyzed. The details are shown in Figure 3.

As shown in Figure 3, it was found that the seniors from both field and laboratory studies are comfortable in the appropriate combinations of 25.60–28.40 °C T_o, 49–75 % RH, and 0.10–0.65 m/s V_a. The field survey found that the relationship between relative humidity and MHSV was stable, whereas, in the laboratory, the MHSV followed relative humidity. Overall the result showed slight differences, which were probably due to the humidity being more difficult to detect. However, this study is reliable because the questionnaire followed the previous research of Wang et al. (2016).

According the analysis in this section, Equation (4) can be used to assess the comfort of occupants once all necessary variables (i.e., T_o, RH, and V_a) are known. This study used a CFD program – scSTREAM -- to generate all those variables, and then input them into Equation (4) in order to calculate the values of TSV on different locations inside the buildings under the scope of comfort preference in winter. It should be noted that these results are different from the study in summer of previous research (Panraluk & Sreshthaputra, 2019).

Examining air flow around and inside Senior Centers

In the scSTREAM program, three-dimensional models of senior centers were created. The details of building material values and their orientations were input into the program. The thermal environments for both AC and NV spaces were simulated using different methods. The method used for NV spaces is as follows.

Based on the outdoor weather data retrieved from the Thai Meteorological Department (The Thai Meteorological Department, 2018), during the hours of 8:00 AM–1:00 PM, the average outdoor temperature (T_{out}) was 27.27 °C, outdoor relative humidity (RH_{out}) was 67.66 %, and outdoor air velocity (Va_{out}) was 1.65 m/s. In Equation (4), when substituting T_o and RH with the average of T_{out} and RH_{out}, and considering thermal comfort perception, it shows that the seniors would be comfortable at the V_a of 0.32–0.65 m/s. If senior centers use NV, the seniors will feel comfortable in this V_a range. Thus, the scSTREAM was used to examine air flow around and inside senior centers, with Va_{out} also input into this program.

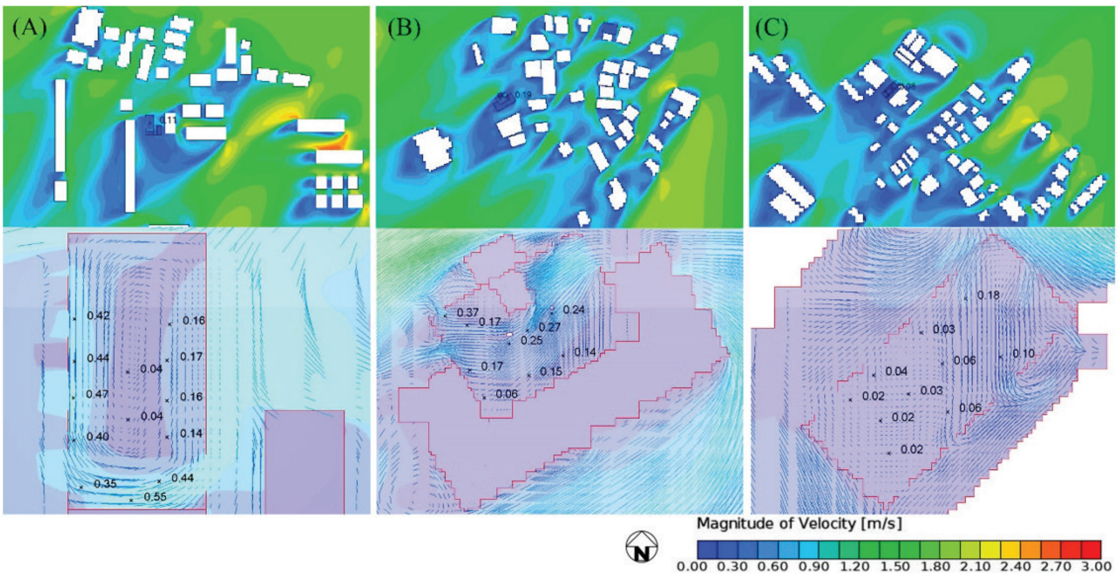

Figure 4: Air flow around and inside: (A) Senior Center 1, (B) Senior Center 1, and (C) Senior Center 3 (Source: Authors)

Ventilation performance around senior centers was simulated by scSTREAM, with the result that the V_a range in Senior Center 1 (0.04–0.55 m/s) is the highest, while those of other senior centers are lower. Specifically, Senior Center 2 was found to be 0.06–0.37 m/s, and Senior Center 3 was found to be 0.02–0.18 m/s. The result shows that the use of NV is effective for reducing the cooling load from AC. However, from time to time, all senior centers encounter the still air state; the idea for solving this problem is to use ceiling and wall orbit fans because they can be operated easily. This strategy of increasing indoor air speed to enhance comfort will be presented in the next section.

Developing guidelines for thermal comfort using the developed equation for winter

This section presents the analysis of both AC and NV spaces by defining the use of equipment. If natural ventilation is used, the simulated method was similar to the Figure 4, and the airflow from the fans created circulation. When it comes to the AC method, the thermal environment was simulated by air velocity value and temperature at the thermostat to determine the most appropriate and comfortable environment for the elderly occupants. The method used for the AC spaces is as follows.

The operation times in winter season were divided into two periods: 8:00 AM–1:00 PM, and 1:00 PM–4:00 PM. Simulation results of the existing conditions (i.e., using AC; temperature set-point 25.0 °C) show that older adults feel “Slightly cool”, which is coherent with the results from the field survey. After implementing the guidelines by using orbit fans instead of AC from 8:00 AM–1:00 PM, and using AC with temperature set-point at 26.0 °C from 1:00 PM–4:00 PM, resulting in a higher indoor T_o, the simulation predicts the sensations of seniors to be “Neutral”, which indicates greater comfort. The results of the CFD - scSTREAM simulation of indoor conditions, both before and after implementing the proposed guidelines for all senior centers, are shown in Figure 5–10. If the TSV shows green, it means “Slightly cool”, and if it shows yellow or orange, it means “Neutral”.

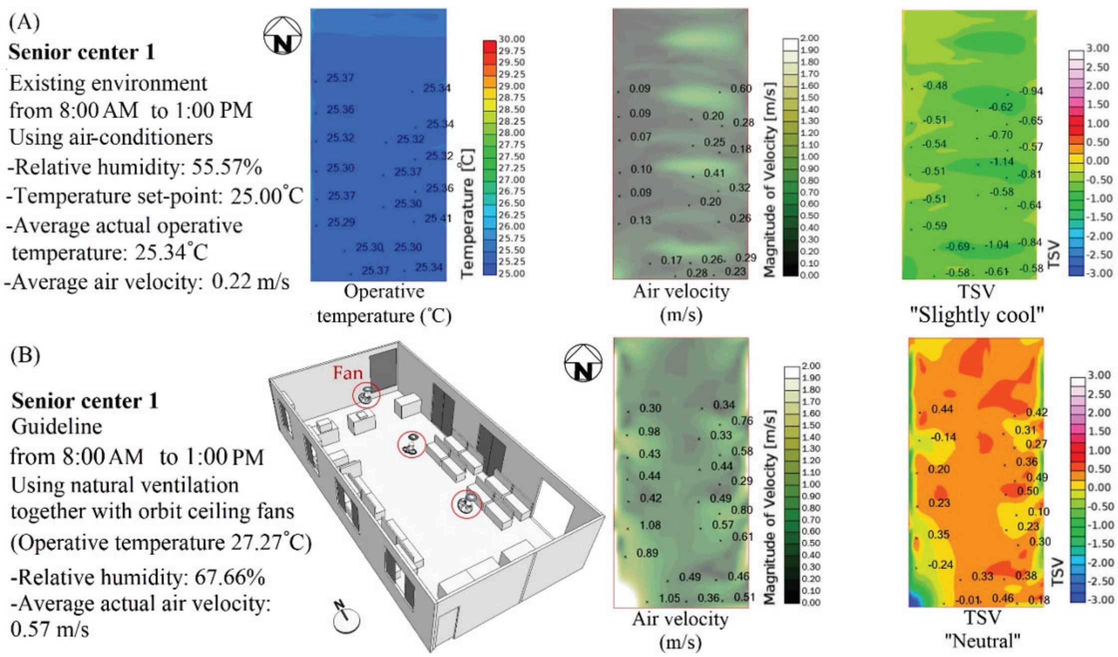

Figure 5:
Senior Center 1; 8:00 AM–1:00 PM, (A) before, and (B) after using the proposed guideline
(Source: Authors)

For Senior Center 1, during the hours of 8:00 AM–1:00 PM, before implementing the guideline (Figure 5A), the existing conditions had a T_o of 25.34 °C and 0.22 m/s V_a, which were the result of AC setting with temperature set-point at 25.0 °C; this resulted in "Slightly cool" feelings. By implementing the proposed guidelines (Figure 5B), using NV and 3 orbit ceiling fans to produce interior V_a at 0.57 m/s, the simulated thermal sensation was "Neutral", which is more comfortable than "Slightly cool". Moreover, it offers the potential to save more energy as the AC can be turned off in the winter, and orbit ceiling fans can come into use.

During the afternoon hours (1:00 PM–4:00 PM) in Senior Center 1, the existing condition in AC mode was measured at 25.70 °C and 0.33 m/s V_a (Figure 6A). This results in "Slightly cool" sensations. By contrast, following the proposed guideline (Figure 6B) by using AC with temperature set-point of 26.0 °C, T_o of 27.03 °C and V_a of 0.23 m/s results in a simulated thermal sensation of "Neutral", which is more comfortable than before implementation of the guideline. This means the senior center can be operated, to not only reduce HVAC fan speeds, but also increase the temperature set-point to improve both thermal comfort and energy saving.

In Senior Center 2 during the hours of 8:00 AM–1:00 PM, the existing condition (Figure 7A), AC mode, has T_o of 25.26 °C and 0.08 m/s V_a, resulting in "Slightly cool" sensations. After implementation of the guideline (Figure 7B), NV and 5 orbit ceiling fans were used to produce V_a at 0.60 m/s inside area, resulting in "Neutral" feelings. This proposed guideline has the potential to save energy by reducing the cooling load from AC.

During 1:00 PM–4:00 PM afternoon hours, the existing condition of Senior Center 2 (Figure 8A), using AC, with interior T_o of 25.39 °C and 0.15 m/s V_a caused "Slightly cool" sensations. After implementation of the guideline (Figure 8B), using AC with temperature set-point of 26.0 °C and 0.10 m/s V_a resulted in "Neutral" feelings, which indicate that the senior participants felt more comfortable than under existing conditions. This guideline can deliver thermal comfort and energy saving by reducing both HVAC fan speeds and increasing the temperature set-point.

In Senior Center 3 from 8:00 AM to 1:00 PM, when using AC with a temperature set-point of 25.0 °C in existing condition (Figure 9A), the actual indoor T_o of 25.62 °C and 0.26 m/s V_a caused "Slightly cool"

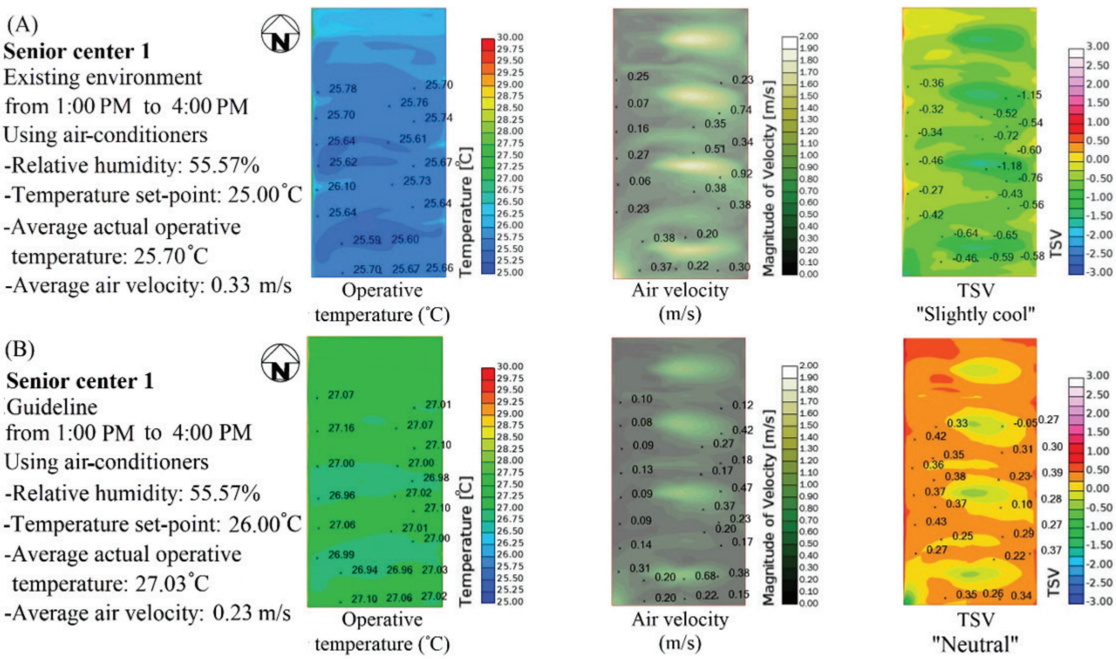

Figure 6:
Senior Center 1; 1:00 AM–4:00 PM, (A) before, and (B) after using the proposed guideline
(Source: Authors)

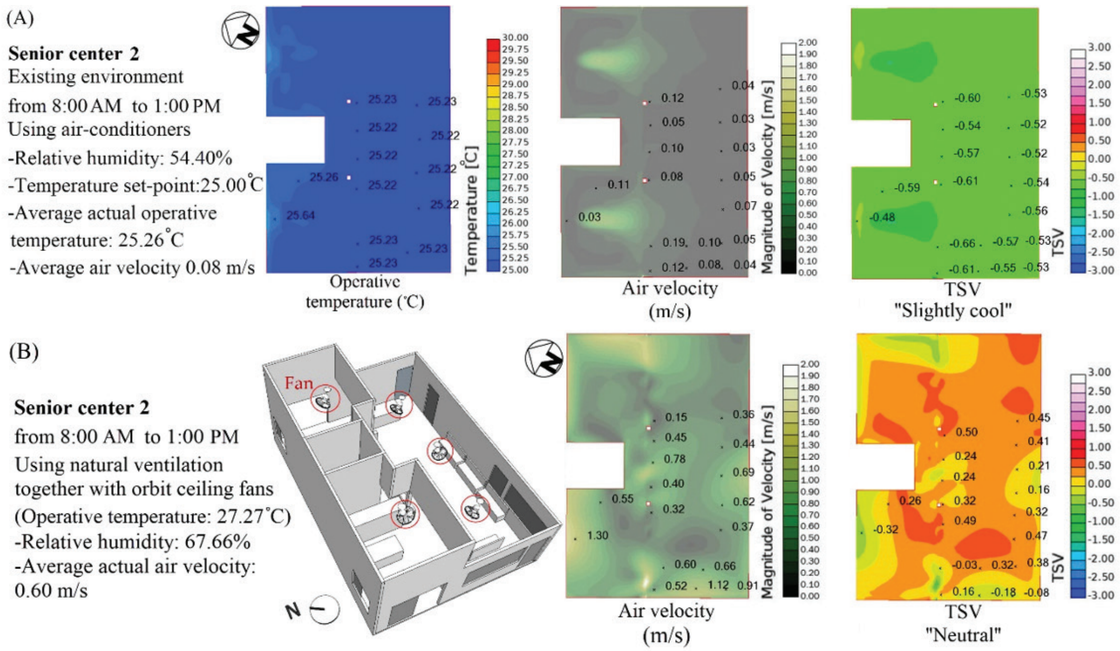

Figure 7:
Senior Center 2; 8:00 AM–1:00 PM, (A) before, and (B) after implementing the guideline
(Source: Authors)

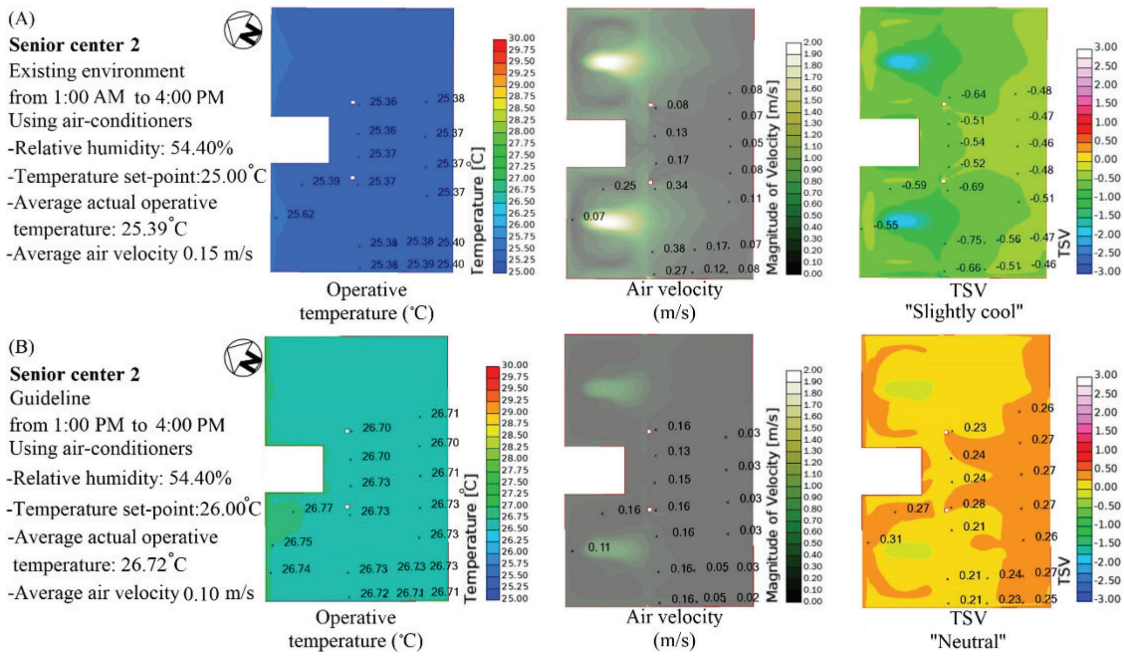

Figure 8:
Senior Center 2; 1:00 PM–4:00 PM, (A) before, and (B) after using the proposed guideline
(Source: Authors)

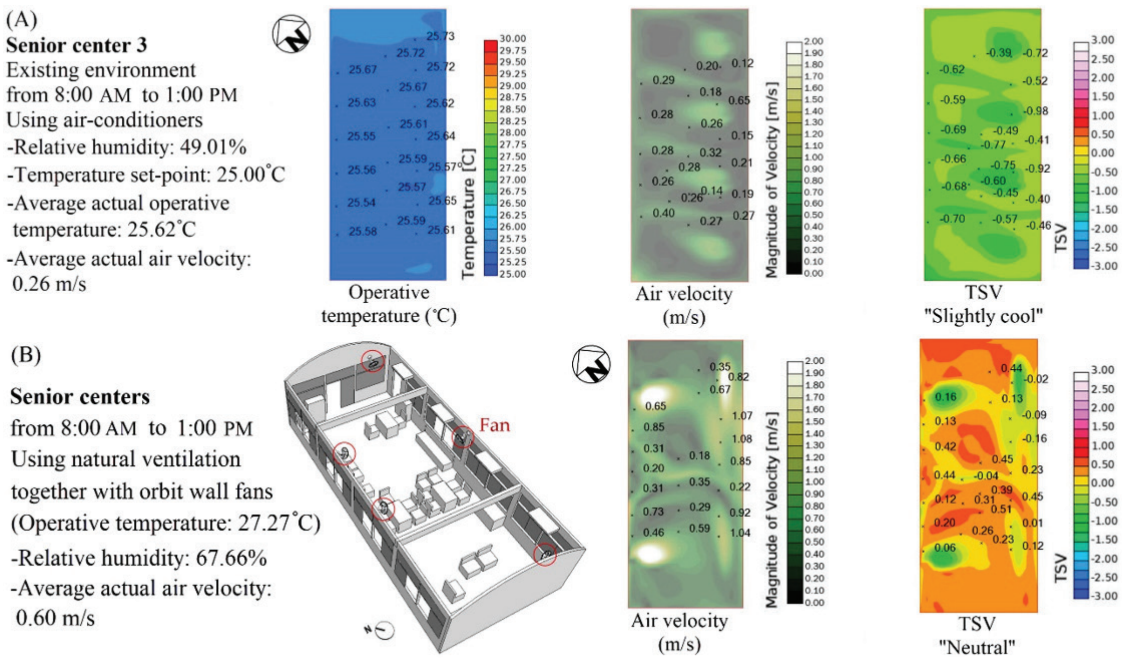

Figure 9:
Senior Center 3; 8:00 AM–1:00 PM, (A) before, and (B) after implementing the guideline
(Source: Authors)

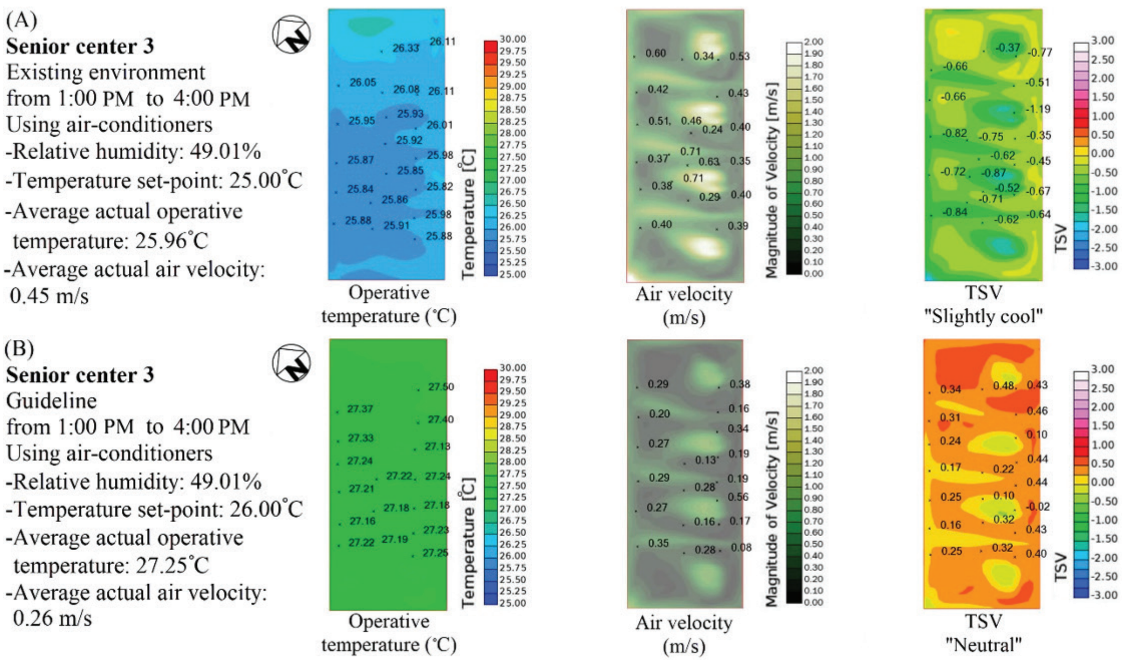

Figure 10:
Senior Center 3; 8:00 AM–1:00 PM, (A) before, and (B) after using the proposed guideline
(Source: Authors)

Table 6: The scSTREAM simulations' summary results both before and after implementing the guidelines

Times	Parameters	Before: Existing conditions (M±SD)			After: Guidelines conditions (M±SD)		
		Center 1	Center 2	Center 3	Center 1	Center 2	Center 3
8:00AM to 1:00PM	Conditions:	Using AC; set-point 25°C, TSV: "Slightly cool"			Using NV (27.27°C T_{out}, 67.66 % RH_{out}); and ceiling or wall orbit fans to produce 0.57-0.60 m/s V_a within spaces, TSV: "Slightly cool"		
	T_o (°C)	25.34±0.03	25.26±0.11	25.62±0.06			
	V_a (m/s)	0.22±0.13	0.08±0.04	0.26±0.12			
1:00PM to 4:00PM	Conditions:	Using AC; set-point 25°C, TSV: "Slightly cool"			Using AC; set-point 26°C, TSV: "Neutral"		
	T_o (°C)	25.70±0.11	25.39±0.06	25.96±0.13	27.03±0.06	26.72±0.02	27.25±0.10
	V_a (m/s)	0.33±0.21	0.15±0.10	0.45±0.13	0.23±0.15	0.10±0.06	0.26±0.11

sensations. When the guideline conditions were implemented (Figure 9B), using NV and 5 orbit wall fans to produce 0.60 m/s V_a, the resulting sensations were described as "Neutral". Once again, this has a potential to save energy as it reduces AC in use.

In Center 3 during the hours of 1:00 PM–4:00 PM, the existing condition (Figure 10A), using AC with a temperature set-point of 25.0 °C, resulted in the T_o of 25.96 °C and 0.45 m/s V_a. This resulted in "Slightly cool" sensations. After implementation of the guideline (Figure 10B), AC with temperature set-point 26.0 °C and 0.26 m/s V_a caused "Neutral" feelings. The use of this guideline has the potential to enhance thermal comfort and decrease energy consumption by reducing HVAC fan speeds and increasing the temperature set-point of AC.

Summary of the guidelines from the simulation program

Based on the description of humidity feelings as "Neutral" under the existing conditions, in the AC mode simulation, the average RH in Centers 1–3 (i.e., 55.57 %, 54.40 %, and 49.01 %) were used to simulate both before and after guideline implementation in order to identify proper indoor T_o and V_a by setting temperature at an appropriate set-point. Moreover, in NV mode, the average outdoor temperature (T_{out}) of 27.27 °C and outdoor relative humidity (RH_{out}) of 67.66 % was used to find suitable V_a. The summary of the results in all senior centers by using scSTREAM is shown in Table 6.

In order to help seniors feel comfortable during the cold season, from 8:00 AM to 1:00 PM, Senior Centers 1–3 should use NV together with orbit fans to produce the air speed in areas at 0.57–0.60 m/s. From 1:00 PM to 4:00 PM, all senior centers should utilize AC and apply the temperature set-point at 26.0 °C to generate the operative temperature of 26.72–27.25 °C, and set the air speed from air-conditioning to produce air velocity in the area of 0.10–0.26 m/s. The application of these findings will help to reduce energy consumption, as examined by Visual DOE 4.0.

Evaluation of energy consumption

The energy consumption was simulated by the Visual DOE 4.0 program. The results are shown in both Figure 11 and Table 7.

Before implementing the guidelines, monthly electricity use in winter of Senior Center 1,2, and 3 are estimated to be 4,870 kWh; 3,398 kWh; and 3,937 kWh respectively. After implementing the developed guidelines, the estimated monthly electricity consumption is reduced to 4,091 kWh; 2,390 kWh; and 2,942 kWh respectively. Due to the double interior volume of Senior Center 2, when reducing the cooling load by adjusting the operation schedules, the energy saving is the largest (30.87 %). For Senior Center 1, as its long sides face the east-west direction, the energy consumption is the largest for both before and after implementing the measures (before: 155.18 %, after: 129.27 %). By comparison, in Senior Center 3, the energy end uses for both modes of operations, which are calculated as the energy use per square meter, are the smallest (before: 136.69 %, after: 107.51 %) as the facility has only one space, which has better orientation and window proportion as compared to the others.

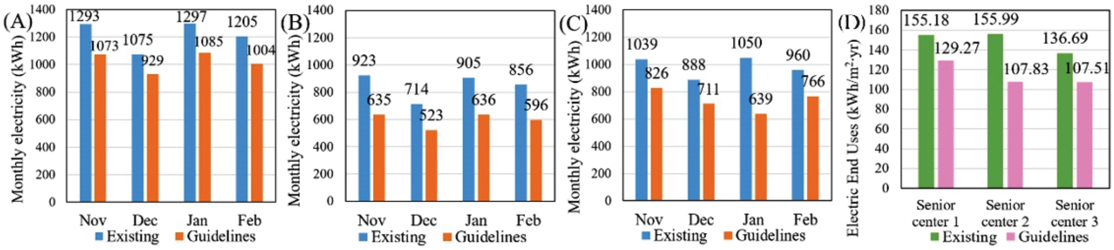

Figure 11:
The estimation of monthly electricity use before and after implementation of the guidelines in (A) Senior Center 1, (B) Senior Center 2, (C) Senior Center 3, and (D) Comparison of electric end uses of all senior centers.
(Source: Authors)

Table 7: The reduction of energy consumption for implementing the proposed guidelines

Case-study	Reduction of Monthly Electricity				Reduction of Electric End Uses
	November	December	January	February	
Senior Center 1	17.01 %	13.58 %	16.35 %	16.68 %	16.70 %
Senior Center 2	31.20 %	26.75 %	29.72 %	30.37 %	30.87 %
Senior Center 3	20.50 %	19.93 %	39.14 %	20.21 %	21.35%

DISCUSSION

Physical changes among the elderly affect thermal sensation. The study shows that seniors prefer a special thermal environment. This research focused on developing simple equations for identifying the most appropriate environmental conditions for senior centers. The approach was to simulate the set point of air temperature and appropriate air speeds for existing senior centers and new buildings in the future. To provide utility in operating and designing senior centers, this study developed equations (i.e., Equation (4)) for predicting the thermal sensation of the Thai elderly in winter while they wearing normal clothing at an average of 0.58–0.66 clo and engaged in light activities at 65–70 W/m^2. This is useful as it will potentially enable energy savings at the same time that it promotes thermal comfort for the Thai elderly. This study also predicts energy consumption and enhanced thermal comfort performance in senior centers by using scSTREM — a CFD program for developing guidelines as the research of Aryal & Leephakpreeda (2015) and Samiuddin & Budaiwi (2018) -- as well as visual DOE 4.0 for evaluating energy simulation. The thermal comfort of occupants and energy use were evaluated in three case studies by using the adaptive thermal comfort approach of Humphrey & Nicol (2002). The study found that weather and natural ventilation are useful for energy saving, which is in line with the research of Cândido et al. (2008) and Spentzou et al. (2018). It shows the significant benefit of taking advantage of outdoor weather conditions in the morning in order to support thermal comfort. In the simulated use of air-conditioning, it was found to be critical to change the period of time in which natural ventilation was used instead of AC. Moreover, this study uses the scSTREAM simulation to find airflow in the buildings. It was found that natural ventilation alone is not adequate for thermal comfort. Thus, orbit fans were used to generate air speed in senior centers at the average of 0.57–0.60 m/s. This is in line with the study of Khedari et al. (2000), who found that Thai people can are comfortable in naturally ventilated spaces with adequate air velocity.

CONCLUSIONS

As the number of older adults has been increasing, the Thai government has been building facilities (such as senior centers) in response. These facilities obviously need energy to operate, and, of course, that energy should be used efficiently. Taking into account the related issues of aging population and energy consumption, this study puts forth effort to evaluate the thermal comfort of seniors in senior centers in order to optimize thermal comfort and energy consumption. The study is intended to develop guidelines for improving thermal comfort and energy efficiency in senior centers while the seniors in those centers are wearing normal clothing in winter -- that is, an average at 0.58–0.66 clo -- and are engaged in light activities (65–70 W/m^2) inside of spaces of the senior centers. Three methods were used in this research: field survey, laboratory study, and computer simulation. The thermal sensation equation in the cold season was developed by field and laboratory studies. Then, scSTREAM – simulation software was used to develop guidelines, and energy consumption was evaluated by the Visual DOE 4.0 program. Referring to the characteristics of participants, the study found that the participants' BMI values are "Overweight" and that this classification is consistent with general Thai seniors, which may be one factor in thermal perception changing as people age. The results of seniors' sensations from both field survey and simulation, in which environmental parameters were set to the same ranges, are similar. Before implementing the proposed guidelines, the buildings were operated during the daytime (8:00 AM–4:00 PM), using AC with a temperature set-point of 25.0 °C and average V_a between 0.08–0.26 m/s in the morning, and increasing to 0.15–0.45 m/s in the afternoon (1:00 PM–4:00 PM). The resulting thermal sensation was reported as "Slightly cool". When following the proposed guidelines, the simulation predicts the sensations as "Neutral". The guidelines proposed in this research suggest that during the morning in cold season, the existing senior centers can use NV with help of orbit fans to generate V_a of 0.57–0.60 m/s to provide comfortable conditions, while, during the afternoon, the senior centers should set the cooling temperature at 26.0 °C and V_a of 0.10–0.26 m/s, instead of 25.0 °C and higher air speed. These proposed guidelines, if implemented properly, could help reduce energy end use by 23.0 %. However, effective design and renovation of senior centers must take into consideration other factors such as solar and wind orientations, and optimum WWR and thermal properties of envelope materials. Finally, the researchers believe that the findings presented in the form of guidelines will benefit seniors. Due to the current COVID-19 pandemic, seniors are regarded as high-risk population, and spend in time in well-ventilated areas should help avoid infection.

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REFERENCES

American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE]. (2017). *ANSI/ASHRAE Standard 55-2017: Thermal Environmental Conditions for Human Occupancy*. Atlanta: ASHRAE.

American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE]. (2009). Thermal comfort. In ASHRAE (Ed.), *ASHRAE Handbook 2009 Fundamentals* (pp.1-30). Atlanta: ASHRAE.

Anuurad, E., Shiwaku, K., Nogi, A., Kitajima, K., Enkhmaa, B., Shimomo, K., & Yamane, Y. (2003). The new BMI criteria for Asians by the Regional Office for the Western Pacific Region of WHO are suitable for screening of overweight to prevent metabolic syndrome in elder Japanese workers. *The Journal of Occupation Health, 45*(6), 335-343.

Aryal, P., & Leephakpreeda, T. (2015). *CFD Analysis on Thermal Comfort and Energy Consumption Effected by Partitions in Air-Conditioned Building.* Paper presented at the 2015 International Conference on Alternative Energy in Developing Countries and Emerging Economies.

Busch, J. F. (1992). A tale of two populations: thermal comfort in air-conditioned and naturally ventilated offices in Thailand. *Energy and Buildings, 18*(3-4), 235-249.

Cândido, C., de Dear, R., Lamberto, R., & Bittencort, L. (2008). *Natural ventilation and thermal comfort: air movement acceptability inside naturally ventilated buildings in Brazilian hot humid zone.* Paper presented at the Air Conditioning and the Low Carbon Cooling Challenge, Cumberland Lodge, Winsor, UK, 27-29 July 2008, London.

Cena, K. Spotila, J. R., & Avery, H. W. (1986). Thermal comfort of the elderly is affected by clothing, activity, and psychological adjustment. In American Society of Heating, Refrigerating and Air Conditioning Engineers [ASHRAE] (Ed.), *ASHRAE Transactions*. (pp. 329-342). Atlanta: ASHRAE.

Chamchan, C. (2013). Issues in Considering the New Concept of "the Elderly's Definition" and "the Age of Retirement" in Thailand, *Thai population journal, 4*(1), 131-150.

Chindapol, S., Blair, J., Osmond, P., & Prasad, D. (2016). Elderly Thermal comfort in tropical climates: Identifying the knowledge gap. *The International Journal of Aging and Sociedty, 6*, 33-44.

Chirarattananon, S., Chaiwiwatworakul, P., Hien, V. D., Rugkwamsuk, P., & Kubaha, K. (2006). Revised Building Energy Code of Thailand: Potential Energy and Power Demand Savings. *Proceedings of the 13th Conference on Energy Network of Thailand*, *Nakhon Ratchasima, Thailand*. 1-10.

Djongyang, N., Tchinda, R., & Njomo, D. (2010). Thermal comfort: A review paper. *Renewable Sustainable Energy Reviews, 14*(9), 2626-2640.

Drubach, L.A., Palmer, E. L., Connolly, L. P., Baker, A., Zurakowski, D., & Cypess, A. M. (2011). Pediatric brown adipose tissue: detection, epidemiology, and differences from adults. *The Journal of Pediatrics, 159*(6), 939-944.

Fanger, P. O. (1972). *Thermal comfort analysis and applications in environmental engineering*. New York: McGraw-Hill.

Ford, B., Schiano-Phan, R., & Vallejo, J. A. (2000). *The architecture of natural cooling*, 2nd ed. New York: Routledge.

Geneva,I. I., Cuzzo, B., Fazili, T., & Javaid, W. (2019). Normal body temperature: A Systematic Review. *Open Forum Infectious Diseases, 6*(4), 1-7.

Guedes, M. C., Matias, L., & Santos, C. P. (2009). Thermal comfort criteria and building design: Field work in Portugal. *Renewable Energy, 34*(11), 2357-2361.

Health info in Thailand. (2019). Retrieved from: https://www.hiso.or.th.

International Standard Organization. (2005). *ISO 7730: 2005 Ergonomics of the Thermal Environment –Analytical determination and interpretation of thermal comfort using calculation of PMV and PPD indices and local thermal comfort criteria.* Geneva: ISO.

Jitkajornwanich, K. (2001). New concept on thermal comfort research. *Journal of the Faculty of Architecture Silpakorn University. 18*, 175-181.

Jitkhajornwanich, K. (2004). *Thermal comfort and adaptability to living for local people*. Nakhon Pathom: Silpakorn University Research and Development Institute.

Khedari, J., Yantraipat, N., Pratintong, N., & Hirunlabh, J. (2000). Thailand ventilation comfort chart. *Energy and Buildings, 32*(3), 245-249.

Kottek, M., Grieser, J., Beck, C., Rudolf, B., & Rubel, F. (2006). World Map of the Köppen-Geiger Climate. *Meteorologische Zeitschrift*, *15*(3), 259-263.

Krejcie, R.V., & Morgan, D.W. (1970). Determining Sample Size for Research Activities, *Educational and Psychological Measurement, 30*(3), 607-610.

Lean, H. H., & Smyth, R. (2010). CO_2 emissions, electricity consumption and output in ASEAN. *Applied Energy, 87*(6), 1858-1864.

Lee, P., Swarbrick, M. M., & Ho K. K. Y. (2013). Brown adipose tissue in adult humans: A metabolic renaissance. *Endocrine Review, 34*(3), 413-438.

Lewis, A. (2015). Designing for an imagined user: Provision for thermal comfort in energy-efficient extra-care housing. *Energy Policy, 84*, 204-212.

Mahaketa, C. (2013). The update of brown adipose tissue in adult human: Possible target to battle obesity? *Royal Thai Army Medical Journal,* 66(2), 83-91.

McCartney K. J., & Humphreys M. A., (2002). Thermal comfort and productivity. *Proceedings of the 9th International Conference on Indoor Air Quality, and Climate, Monterey, California, USA.* 822-827.

Nicol, J. F., & Humphreys, M. A. (2002). Adaptive thermal comfort and sustainable thermal standards for buildings. *Energy and Buildings, 34*(6), 45-59.

Office of the National Economic and Social Development Board Office of Prime Minister, Thailand. (2017). *The Twelfth National Economic and Social Development Plan (2017–2021)*. Bangkok: Office of the Prime Minister.

Office of the National Economic and Social Development Board. (2017). *Phitsanulok City Municipality: Project for promoting sustainability in future city of Thailand*. Phitsanulok: Phitsanulok City Municipality.

Özdamar, M., & Umarogullari, F. (2018). Thermal comfort and indoor air quality. *International Journal of Scientific Research Innovative Technology, 5*(3), 90-109.

Panraluk, C., & Sreshthaputra, A. (2019). Developing guidelines for thermal comfort and energy saving during hot season of multipurpose senior centers in Thailand. *Sustainability, 12*, 1-29.

Prasartkul, P., Vapattanawong, P., Rittirong, J., Chuanwan, S., Kanchanachitra, M., Jaratsit, S., Thianlai, K., Aruntippaitun, S., Mathuam, J., & Sena, K. (2017). *Situation of the Thai elderly 2017*. Bangkok: Deuan Tula Printing House.

Ransiraksa, R. (2006). Thermal comfort in Bangkok residential buildings, Thailand. *Proceedings of the 23rd Conerence on Passive and Low Energy Architecture*, *Geneva, Switzerland.*

Saito, M., Okamatsu-Ogura, Y., Matsushita, M., Watanabe, K., Yoneshiro, T., Nio-Kobayashi, J., Iwanaga, T., Miyagawa, M., Kameya, T., Nakada, K., Kawai, Y., & Tsjisaki, M. (2009). High incidence of metabolically active brown adipose tissue in healthy adult humans: effects of cold exposure and adiposity. *Diabetes, 58*(7), 1526-1531.

Samiuddin, S., & Budaiwi, I. M. (2018). Assessment of thermal comfort in high-occupancy spaces with relevance to air distribution schemes: A case study of mosques. *Building Services Engineering Research and Technology, 39*, 572-589.

Simone, A., Babiak, J., Bullo, M., Landkilde, G., & Olesen, B.W. (2007). Operative temperature control of radiant surface heating and cooling system. *Proceedings of Clima 2007 Wellbeing Indoors, Helsinki, Finland*.

Software Cradle. (2020). *scSTREAM*. Retrieved from: https://www.cradle-cfd.com.

Spentzou, E., Cool, M. J., & Emmitt, S. (2018). Natural ventilation strategies for indoor thermal comfort in Mediterranean apartments. *Building Simulation, 11*, 175-191.

St-Onge, M. P., & Gallagher, D. (2010). Body composition changes with aging: The cause or the result of alterations in metabolic rate and macronutrient oxidation?. *Nutrition, 26*(2), 152-155.

Stoops J. L. (2004). A possible connection between thermal comfort and health. *Proceedings of ACEEE 2004 Summer Study on Energy Efficiency in Buildings, California, USA.* 331-341.

Strategy and Planning Division. (2019). Retrieved from: http://bps.moph.go.th.

Tartarini, F., Cooper, P., & Flaming, R. (2017). Thermal environment and thermal sensation of occupants of nursing homes: a field study. *Procedia Engineering, 180*, 373-382.

The ASEAN post. (2020). Retrieved from: http://theaseanpost.com/article/southeast-asias-rapidly-ageing-population.

The International Renewable Energy Agency [IRENA]. (2017). *Renewable energy rises across Asia: IRENA Quarterly*. Abu Dhabi: IRENA.

The Thai Meteorological Department. (2018). Retrieved from: https://www.tmd.go.th.

Tsuzuki, K., & Ohfuku, T. (2002). Thermal sensation and thermoregulation in elderly compared to young people in Japanese winter season. *Proceedings of the 9th International Conference on Indoor Air Quality, and Climate, Monterey, California, USA,* 659-664.

University of California, & Hirsch J. J. (2008). *Overview of DOE-2.2*. Berkeley: University of California.

van Hoof, J., & Hensen, J. L. M. (2006). Thermal comfort and older adults. *Gerontechnology, 4*(4), 223-228.

Wang, Y., Groot, Rd., Bakker, F., Wörtche, H., & Leemans, R. (2016). Thermal comfort in urban green spaces: a survey on a Dutch university campus. *International Journal of Biometeorology, 61*, 87-101.

World Commission on Environment and Development. *Our Common Future.* (1987). Oxford: Oxford University Press.

Yimprayoon, C. (2016). Zero Energy Building. *Journal of Architectural /Planning Research Studies*, *13*(2), 1-30.