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THE STUDY OF THERMAL COMFORT ZONES FOR DEVELOPING THE GOVERNMENT'S SENIOR COMMUNITY CENTERS USING FIELD AND LABORATORY STUDIES: A CASE STUDY IN PHITSANULOK, THAILAND

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ABSTRACT

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This paper presents a study aiming to develop thermal comfort zones for Thai senior citizens in the government's senior community centers. ASHRAE scale was used to evaluate the thermal sensation vote (TSV) of older adults. This study was conducted in cold and hot seasons in Phitsanulok City, Thailand by using both field and climate chamber studies. The field survey was conducted in 3 senior community centers. One hundred and two copies of the thermal comfort questionnaire were issued in winter and 90 copies in summer. The occupants in all 3 senior community centers were selected for the climate chamber study. Then 30 respondents were arranged to experience 144 various thermal conditions. Linear regression model of TSV and thermal variables were developed. The results showed that the mean of TSV and thermal comfort zones of Thai senior citizens differed from Franger's PMV and ASHRAE's comfort zones. Moreover, due to different clothing insulation between cold season (0.64 clo) and hot season (0.50 clo), the comfort zones of both seasons (at activities 1.1-1.2 met) were found different. To conclude this, in still air (0-0.05 m/s), the preferred indoor thermal environment for senior community buildings in the cold season is a combination of 25.0-27.2°C operative temperature and 49-75% relative humidity. In the hot season, the preferred condition is slightly warmer and less humid at 26.4-29.7°C operative temperature and 47-70% relative humidity. The findings can be used to set standards of operation and design of the country's senior community centers in order to provide more comfortable indoor conditions and save energy.

Keywords: Thermal comfort zone; senior community center; PMV; field study; laboratory study

1. INTRODUCTION

Due to a change in the population structure of Thailand that will become a complete aged society in 2021 (Foundation of Thai Gerontology Research and Development Institute, 2014), senior center buildings that provide senior social participation activities, care, and medical service become a new type of buildings that are in high demand. These buildings were established to support senior citizens, who are a large and important group in the Thai society. Currently, the Thai government has adapted the existing rooms in some buildings (such as public health buildings and office buildings) and constructed new senior community centers for senior citizens to socialize, learn new skills (such as computer, art, and craft), and participate in recreational activities (such as playing board games, and singing). Adjusting the thermal environments to suit these specific users become a necessity (Ormandy and Ezratty, 2012), as it helps promote their comfort, good health, well-being, and performance (Jitkajornwanich, 2001; Mendes et al., 2013; Alfano et al., 2014).

Thermal comfort is evaluated by the relationship between Thermal Sensation Vote (TSV) and 6 variables in personal factors i.e., metabolic rate (Met), and clothing insulation (I_{cl}), as well as in environmental factors i.e., air temperature (T_a), relative humidity (RH), mean radiant temperature (MRT), and air velocity (V_a) (American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), 2017). Furthermore, thermal comfort also influences energy consumption in buildings (Yang et al., 2014). Mishra et al. (2016) reported that humans' response to indoor thermal environments is related to energy-saving potential in buildings. In Thailand, air-conditioners are installed in buildings to control environments, which leads to more energy use in the buildings (Yimprayoon, 2016). If air-conditioners are not suitably installed and controlled, it will result in users' discomfort and loss of cooling output. Therefore, the thermal comfort model, which was created by Fanger (1972), has been adopted in ASHRAE standard. Fanger's Predicted Mean Vote (PMV) has been used to "predict the mean thermal sensation vote on a standard scale for a large group of persons for any given combination of the four thermal environment variables, the activity level, and the clo-value of clothing worn by the occupants" (Fanger, 1972). However, many studies found that PMV values are not appropriate for evaluating the sensations of senior citizens (Tsuzuki and Iwata, 2002; Humphreys and Nicol, 2002).

As for senior citizens' thermal sensations, there are medical studies, which are in line with the concept of age-related physiological change (Touhy and Jett, 2016), confirming that the change in thermal sensation of senior citizens is partly due to a decrease in Brown Adipose Tissue (Graja and Schulz, 2015; Schosserer et al., 2018), which normally acts as a generator of body heat (Cannon and Nedergaard, 2004) together with Myelinated Fiber (Mishra and Ramgopal, 2013). It means that a decrease in skin response and metabolic rate can affect senior citizens' thermal perceptions.

In previous studies, senior citizens' thermal sensations were examined and compared with those of other groups of people. Hwang and Chen (2010) and Schellen et al. (2010) found that senior citizens prefer higher temperatures than younger adults. Hoof and Hensen (2006) also suggested that senior citizens prefer a 2°C higher temperature. Moreover, the report on older adults of Blatteis (2012) stated that "both warm and cold sensitivities decline, but the decrement in the perception of warmth is more pronounced than that of cold." However, research studies on senior citizens' thermal sensations conducted in different countries provided different recommendations. For example, Portuguese senior citizens' comfort temperature in winter and summer was recommended at 20°C and 25°C (Guedes et al., 2009), while that of the senior citizens in the United Kingdom was recommended at 22-23°C (Lewis, 2015). In Thailand, it was found that the thermal comfort of older adults is different from that of people in other age groups (Rangsiraksa, 2006). They feel comfortable at 25.6-29.3°C Ta and 52.7-66.8% RH (Assavavichai et al., 2015). Nonetheless, there are no details about senior citizens' thermal comfort in both cold and hot seasons, in which ASHRAE standard 55 (ASHRAE, 2017) confirmed that humans prefer different thermal conditions in different seasons. As a result, it is possible that Thai senior citizens prefer different thermal conditions in cold and hot seasons. Thus, this study aimed to 1) develop the thermal comfort zones for Thai senior citizens in the government's senior community centers in cold and hot seasons, using both field and laboratory studies, 2) evaluate the Mean Thermal Sensation Vote (MTSV) of Thai senior citizens in order to compare it with PMV, and 3) examine the clothing insulation values of Thai senior citizens in both seasons.

Previous studies on thermal comfort have been conducted using field and laboratory approaches. For example, Fanger (1972) used a laboratory approach, while Humphreys and Nicol (2002) applied a field survey approach. Researchers select to use these approaches based on the scope and limitations of their research. The present research studied on human beings in terms of building use, whereby the results can be used to improve senior citizens' well-being. This study was conducted both in the existing buildings and in the laboratory. The obtained results will help to indicate the thermal comfort preference of a specific type of occupants in a specific type of buildings, which Lewis (2015) suggested that it is significant to building users. The results of this research can be used as a guideline for improving and designing facilities that meet the needs of senior citizens in Thailand. Moreover, thermal comfort in buildings will help to promote social participation and reduce social isolation among senior citizens, especially during daytime when their family members are at work. Therefore, the results of this research can be beneficial for social development as well.

2. MATERIALS AND METHODS

This study surveyed and analyzed TSV of Thai senior citizens in air-conditioned spaces. The study was carried out according to the Declaration of Helsinki, which was approved by the Ethics Committee of Naresuan University (COA No. 344/2015).

Locations and times of observations

The present research was conducted in an urban area of Phitsanulok City, which is proposed as a pilot zone for a sustainable ageing society in Thailand by Japan International Cooperation Agency (JICA) (The National Economic and Social Development Board (NESDB), 2017). In order to eliminate the limitation of data collection, both field and laboratory tests were used in this study. For the field study, the case study buildings had only multipurpose rooms for senior citizens. There was no classroom for specific learning. As it was not practical to adjust thermal conditions in the existing rooms, a climate chamber was then built to resemble a typical classroom of senior citizens for the laboratory study. The survey time was during 8:00 a.m.-4:30 p.m. in cold season (November 2017, January-February 2018) and hot season (March-May 2018).

Field study

The field survey was conducted in multipurpose rooms of 3 senior community centers (Figure 1), namely Praongkhao (Figure 1(a)), Mahanuphab (Figure 1(b)), and Pracha-Uthit (Figure 1 (c)), which were adapted from existing public health buildings and neighboring facilities. The indoor environments of these senior community centers were measured. The responses to the thermal environments of the occupants were also evaluated.

Figure 1: Data Collection in the Government's Senior Community Centers in Phitsanulok City: (a) Praongkhao, (b) Mahanuphab, and (c) Pracha-Uthit

Laboratory study

The climate chamber in the classroom of the Faculty of Engineering, Naresuan University, Phitsanulok City, was used for the laboratory study. The details are as shown in Figure 2.

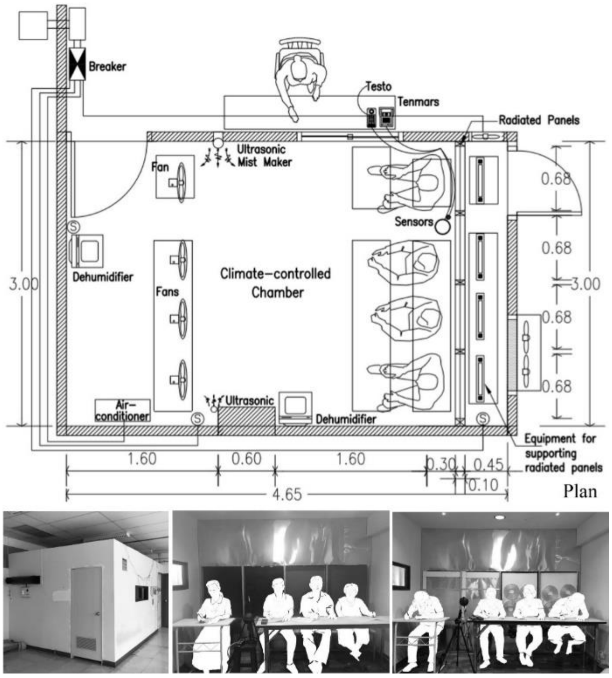


Figure 2: The Climate Chamber That Was Used for the Laboratory Study

The chamber had a dimension of 3.00 m (width) x 4.65 m (length) x 2.35 m (height). It could accommodate 4 respondents at a time. The respondents had to experience various thermal conditions resulting from a combination of 4 environmental variables (i.e., T_a, MRT, RH, and V_a). A total of 144 different thermal conditions (4 T_a x 4 MRT x 3 RH x 4 V_a = 144 thermal conditions) were arranged during the experiments in both seasons.

1. Indoor air temperature: 4 T_a levels (21.5°C, 24.0°C, 26.5°C, and 29.0°C) were controlled by the split-type air-conditioner.
2. Air velocity: 3 V_a levels (0.05 m/s, 0.50 m/s, and 1.50 m/s) were produced by portable fans.
3. Relative humidity: moisture was generated by ultrasonic mist makers and optimized by dehumidifiers. Three levels of RH were 45.0%, 60.0%, and 75.0%.
4. Mean radiant temperature: 4 MRT levels were controlled by 4 types of radiation panels. 1) Aluminum spiral tube panels, where cool water was pumped to flow through the tubes in order to generate the MRT that was 1.5°C lower than T_a. 2) Aluminum box panels, where ice was used to control the MRT that was 2.5°C lower than T_a. 3) Gray aluminum panels, where 400 W infrared heaters were used to produce the MRT that was 1.5°C higher than T_a. 4) Black aluminum panels, where 600 W infrared heaters were used to generate the MRT that was 2.5°C higher than T_a.

The indoor conditions in the field and laboratory studies were systematically measured. The details are shown in Table 1.

Table 1: Thermal Conditions in 3 Senior Community Centers for the Field and Laboratory Studies

Study areas		T_a (°C) (M±SD)	MRT (°C) (M±SD)	RH (%) (M±SD)	V_a (m/s) (M±SD)
Field study					
Senior community center	**Cold season**	24.97±0.46	25.44±0.35	55.57±3.44	0.10±0.10
	Hot season	26.28±0.87	26.53±0.95	56.67±3.95	0.17±0.19
Senior community center 2	**Cold season**	25.24±0.86	25.85±0.85	54.40±4.27	0.17±0.24
	Hot season	25.40±0.46	25.65±0.48	47.27±1.76	0.10±0.14

Table 1: Thermal Conditions in 3 Senior Community Centers for the Field and Laboratory Studies (Continued)

Study areas		T_a (°C) (M±SD)	MRT (°C) (M±SD)	RH (%) (M±SD)	V_a (m/s) (M±SD)
Field study					
Senior community center 3	**Cold season**				
		25.11±0.44	25.82±0.35	49.01±0.62	0.08±0.12
	Hot season				
		26.65±0.47	27.13±0.53	54.17±0.74	0.25±0.22
Laboratory study					
Climate Chamber	**Cold season**				
		21.54±0.21	(T_a-2.46)±0.13	44.72±1.05	0.05±0.02
		24.00±0.23	(T_a-1.47)±0.16	60.53±0.96	0.51±0.03
		26.49±0.20	(T_a+1.39)±0.16		
		28.96±0.19	(T_a+2.49)±0.18	74.18±0.86	1.51±0.03
	Hot season				
		21.55±0.20	(T_a-2.46)±0.13	45.28±1.16	0.04±0.02
		24.02±0.23	(T_a-1.49)±0.16	60.62±1.03	0.51±0.03
		26.52±0.17	(T_a+1.40)±0.16		
		28.95±0.23	(T_a+2.46)±0.15	74.75±1.00	1.51±0.03

Note: M is mean, SD is standard deviation. T_a is air temperature, MRT is mean radiant temperature, RH is relative humidity, and V_a is air velocity.

From Table 1, in the field research, the Ta and MRT in senior community centers in cold season were adjusted to be slightly lower than in hot season. V_a and RH in both seasons had fluctuations. As for the laboratory research, the thermal conditions of both seasons were controlled to be the same.

The respondents

This study aimed to examine the TSV of Thai senior citizens in 3 senior community centers. A total of 42 volunteers in cold season and 33 volunteers in hot season were rotated to be 30 respondents and experience 144 different thermal conditions in the climate chamber. The age ranges of the respondents were divided into two groups: pre-elderly (55-59 years) and elderly (60 years and over), in which these age ranges were mixed in the study.

The questionnaire

The questionnaire comprised 4 parts.

Part 1 was about general information such as date, indoor environments, and outdoor environments. This part was recorded by the researchers.

Part 2 intended to survey demographic data of the respondents.

Part 3 was about the clothing insulation data.

Part 4 aimed to examine the Thermal Sensation Vote (TSV), Humidity Sensation Vote (HSV), and Wind Speed Sensation Vote (WSV). All sensations were measured using a 7-point scale. The ASHRAE's scale (ASHRAE, 2017) was used to measure thermal feelings. The humidity and air speed scales of Wang et al. (2017) were applied to measure RH and V_a. The details are shown in Table 2.

The meanings of mean values, comprising Mean Thermal Sensation Vote (MTSV), Mean Humidity Sensation Vote (MHSV), and Mean Wind Speed Sensation Vote (MWSV) are also shown in Table 2.

Table 2: Details of the 7-Point Scale and the Ranges of Mean Values

7-point Scale	The ranges of mean values (for analysis)	Meaning		
		TSV / MTSV	HSV / MHSV	WSV / MWSV
-3	-3.00 to -2.50	Cold	Very dry	Very low
-2	-2.49 to -1.50	Cool	Dry	Low
-1	-1.49 to -0.50	Slightly cool	Slightly dry	Slightly low
0	-0.49 to +0.49	Neutral	Neutral	Neutral
+1	+0.50 to +1.49	Slightly warm	Slightly humid	Slightly high
+2	+1.50 to +2.49	Warm	Humid	High
+3	+2.50 to +3.00	Hot	Very humid	Very high

Instruments

This study used Testo-445 and black globe thermometer to measure MRT. Tenmars-4002 together with the sensor were also used to measure T_a, V_a, and RH.

Data collection

The respondents in the senior community centers and the climate chamber were required to wear normal clothes. Only the respondents, who had performed light activities with metabolic rate of 65-70 W/m^2

(or 1.1-1.2 met) for at least 15 minutes, were allowed to answer the questionnaire. Meanwhile, the indoor environments were measured. The sensor heights were set according to a standard protocol, which depends on the respondents' posture (sitting, standing, and both sitting and standing) at that time. In this study, the average height of sensors was 0.75 m above the floor. As for the laboratory test, in each condition, the process from adjusting thermal conditions to responding to the questionnaire was done in 17-20 minutes.

Data Analysis

The data analysis could be divided into two parts based on the main factors of thermal comfort.

Personal factors

Metabolic rates were restricted to 1.2 met as it is typical in the buildings. The I_{cl} values were calculated based on the data of International Organization for Standardization [ISO] in ISO 7730 (ISO, 2005), and ASHRAE standard-55 (ASHRAE, 2017). These I_{cl} values were examined using the daily outdoor temperature data obtained from the Thai Meteorological Department (2019). The Body Mass Index (BMI) (Nuttall, 2015) was also analyzed based on the Asian criteria-based BMI of the Western Pacific Region Office (WPRO) as in the study of Anuurad et al. (2003). Moreover, the Body Surface Area (BSA) was evaluated according to the method of Du Bois and Du Bois (1916).

Environmental factors

This study used operative temperature (T_o), which were calculated based on the 2009 ASHRAE handbook - Fundamentals (ASHRAE, 2009), to analyze thermal comfort. T_o is defined by ISO 7730 (2005) as "a uniform temperature of an imaginary black enclosure in which an occupant would exchange the same amount of heat by radiation and convection as in the actual non-uniform environment." In order to examine the thermal comfort, MTSV, MHSV, and MWSV were compared with preferred T_o, RH, and V_a respectively. Then, the preferred thermal environments of Thai senior citizens were developed in form of thermal comfort equations by using the data obtained from both field and laboratory tests. Moreover, the MTSV was compared with the PMV. In this study, the PMV was calculated using the CBE Thermal Comfort Tool based on the ASHRAE standard 55 (Center for the Built Environment (CBE), 2019).

3. THERMAL COMFORT ZONES OF THE THAI ELDERLY: ANALYSIS OF RESULTS

Analysis of Personal Factors

Demographic Data

Table 3 shows the demographic data of the respondents in both filed survey and laboratory study.

Table 3: Descriptive Summary of Demographic Data

Study	List	Cold season	Hot season
Field study (in 3 senior community centers)	**Respondents** (Number)	(N=102)	(N=90)
	Male	31	19
	Female	71	71
	Personal data (M±SD)		
	Age (years)	70.00±7.96	69.43±8.09
	Body mass index (BMI) (kg/m²)	24.48±3.55	24.44±3.34
	Body surface area (BSA) (m²)	1.60±0.14	1.59±0.13
Laboratory study (in a climate chamber)	**Respondents** (Number)	(N=42)	(N=33)
	Male	16	16
	Female	26	17
	Personal data (M±SD)		
	Age (years)	67.93±7.68	65.85±6.85
	Body mass index (BMI) (kg/m²)	24.82±3.32	23.80±3.05
	Body surface area (BSA) (m²)	1.63±0.14	1.65±0.15

Note: M is mean, SD is standard deviation. The number of respondents in 3 senior community centers are consistent with the proportion of males and females in the Thai society, where there are more senior females than senior males.

From Table 3, in the field study, there were more senior females than senior males (cold season: 31 males, and 71 females; hot season: 19 males, and 71 females). This is in line with the proportion of males and females in the Thai society, where there are more senior females than senior males (The Department of Older Persons (DOP), 2019). However, in the laboratory study, the number of senior males and senior females was controlled to be equal. Therefore, the number of senior males and senior females in the laboratory study was slightly different from the field study (cold season: 16 males, and 26 females; and hot season: 16 males, and 17 females).

In both seasons, the average age, BMI, and BSA of the respondents in the field research were similar (cold season: average age 70 years, BMI 24.48 kg/m^2, and BSA 1.60 m^2; and hot season: average age 69.43 years, BMI 24.44 kg/m^2, and BSA 1.59 m^2). As for the laboratory study, the respondents comprised 42 volunteers in cold season and 33 volunteers in hot season. They had a slightly lower average age than the field-based research's respondents (cold season: 67.93 years; and hot season: 65.85 years) but their BSA were slightly higher (cold season: 1.63 m^2; and hot season: 1.65 m^2). The BMI values of these two groups of respondents were similar (cold season: 24.82 kg/m^2; and hot season: 23.80 kg/m^2). When comparing the respondents' BMI with the Asian BMI criteria, the results were "overweight," which is consistent with Thai older adults in general (Aekplakorn et al., 2014). This finding is significant, as it might be one cause that affects a change in thermal perception of senior citizens.

Clothing Insulation

Outdoor temperature (T_{out}) is a major factor influencing people's clothing selection. If T_{out} is high, the I_{cl} values will be low. This study investigated and analyzed the relationship between daily T_{out} and I_{cl} values of the Thai senior citizens (Figure 3).

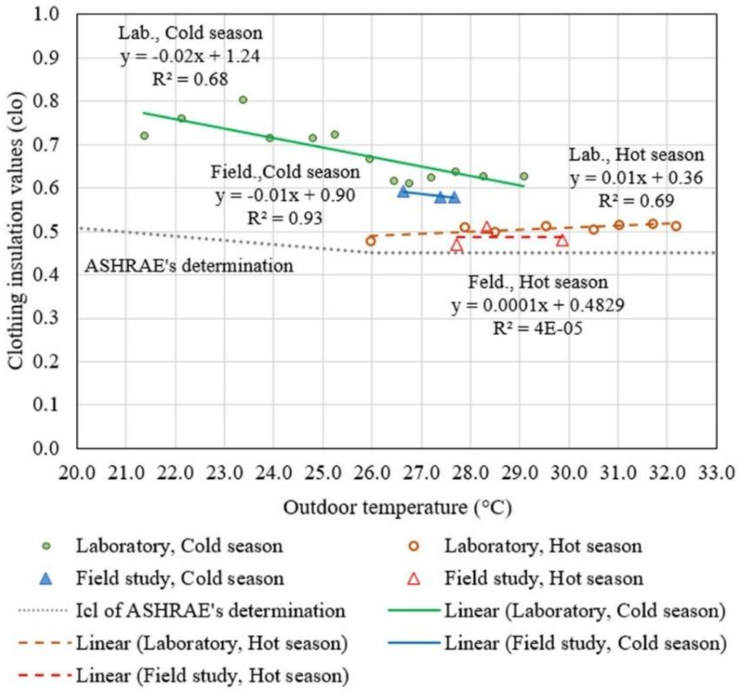


Figure 3: A Comparison of Clothing Insulation Values of Thai Senior Citizens on Average Daily Outdoor Temperature and a Function of ASHRAE Standard

Note: M±SD of clothing insulation (I_{cl}) was 0.64±0.16 in cold season and 0.50±0.08 in hot season.

In Figure 3, the results showed that the average I_{cl} value was 0.64 clo (SD = 0.16) in cold season and 0.50 clo (SD = 0.08) in hot season. When the average daily T_{out} was 21.4-29.1°C in cold season, the average I_{cl} values were 0.58-0.77 clo. When the average daily T_{out} was 26.0-32.1°C in hot season, the average I_{cl} values were 0.49-0.51 clo. Moreover, there were slight differences between the field research and the laboratory study, which were probably due to the fluctuation of T_{out}, especially in cold season. The I_{cl} values of Thai senior citizens were similar to the proposed values in the ASHRAE standard-55 (ASHRAE, 2017). However, Thai senior citizens' I_{cl} values were higher than those suggested by ASHRAE standard-55 by 0.15-0.27 clo in cold season and 0.04-0.06 clo in hot season.

Analysis of Environmental Factors

MTSV of Thai senior citizens and PMV

Due to the use of more thermal conditions in the laboratory test, a comparison of MTSV and PMV in the laboratory test was wider than in the field study. The details are shown in Figure 4.

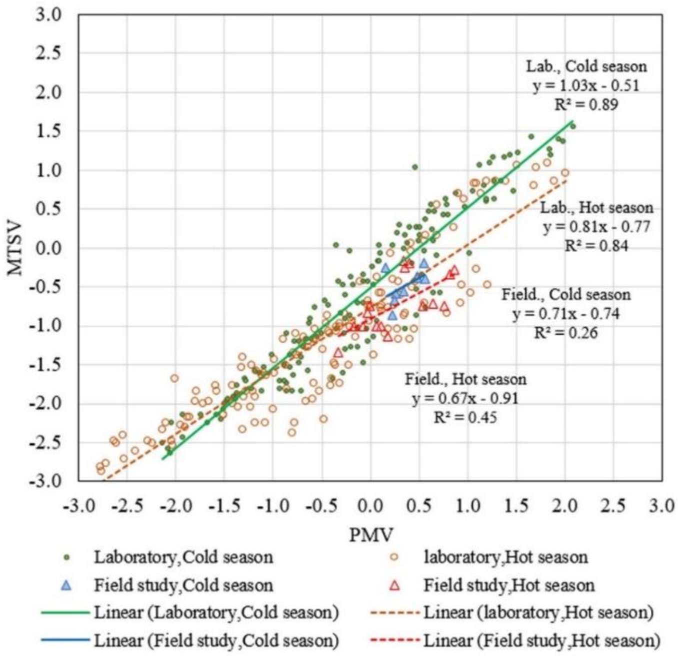
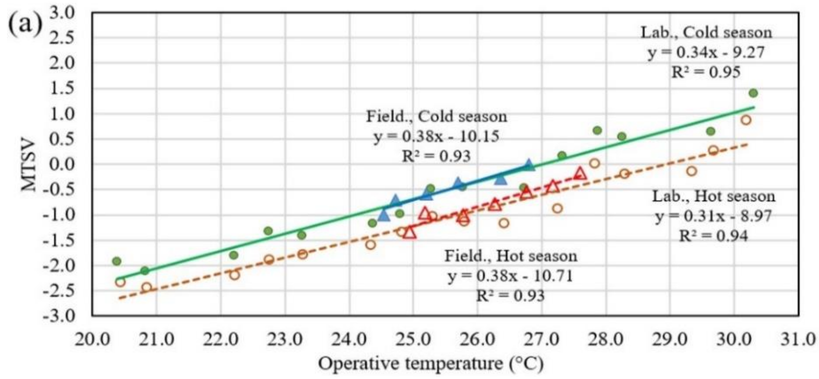


Figure 4: A Comparison of PMV and MTSV in Cold and Hot Seasons Using the Data Obtained from Both Field and Laboratory Studies

From Figure 4, in the same condition, the seniors' MTSV in cold season was higher than seniors' MTSV in hot season due to the difference of I_{cl} values. In both seasons, the MTSV was lower than the PMV. This finding is consistent with the research of Tsuzuki and Iwata (2002) that presented the difference between PMV and seniors' TSV. The MTSV in both studies tended to be similar, but in the same PMV, MTSV from the field study was lower than MTSV from the laboratory study. This might be because the I_{cl} values of the two studies were slightly different.

Overview of Thermal Comfort Sensations

The results showed that the feelings on T_o (Figure 5(a)), and V_a (Figure 5(c)) in the field study and the laboratory test were similar, but the feelings on RH (Figure 5(b)) was slightly different. The thermal comfort preferences in cold season were 25.5-28.5°C T_o, 49-75% RH, and 0.10-0.65 m/s V_a. In hot season, the comfort sensations were 27.0-30.2°C T_o, 47-70% RH, and 0.10-0.90 m/s V_a. However, the V_a was the important variable, which affected the sensations in other environmental conditions. For developing thermal comfort zones on a psychrometric chart, which evaluated T_o and RH in still air, all parameters were examined by using multiple linear regression.



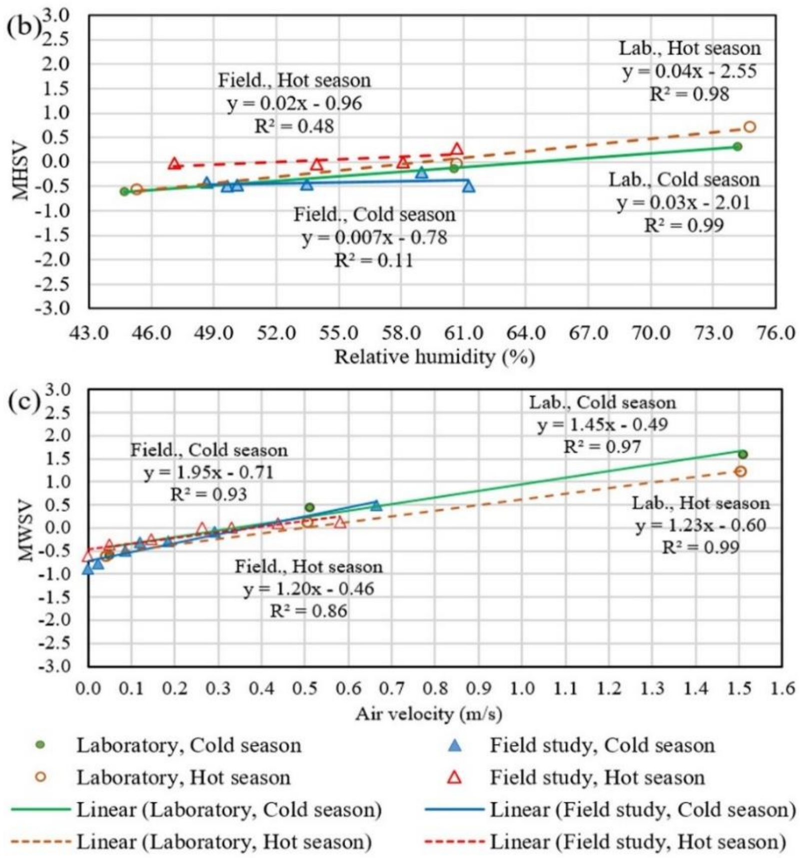


Figure 5: The Relationship of (a) MTSV and T_o, (b) MHSV and RH, (c) MWSV and V_a in Both Seasons

Thermal Comfort Models

The data obtained from the field and laboratory studies were analyzed in order to establish thermal comfort models. The first process is shown in Table 4.

Table 4: Multiple Linear Regression Analysis of Predictors of Senior Citizens' Thermal Sensations

	Variable	B	SE	β	t	*ρ*
Field study						
	Cold season					
	T_o	0.455	0.075	0.498	6.091	0.000*
	V_a	-1.664	0.261	-0.522	-6.385	0.000*
	(Constant)	-11.869	1.888		-6.285	0.000*
	Hot season					
	T_o	0.327	0.052	0.523	6.278	0.000*
	V_a	-1.057	0.238	-0.370	-4.442	0.000*
	(Constant)	-9.122	1.366		-6.680	0.000*
Laboratory study						
	Cold season					
	T_o	0.338	0.006	0.929	53.767	0.000*
	V_a	-0.488	0.030	-0.282	-16.338	0.000*
	RH	0.007	0.002	0.078	4.526	0.000*
	(Constant)	-9.229	0.184		-50.027	0.000*
	Hot season					
	T_o	0.304	0.008	0.902	63.120	0.000*
	V_a	-0.457	0.040	-0.286	-11.467	0.000*
	RH	0.006	0.002	0.073	2.927	0.000*
	(Constant)	-8.877	0.245		-36.176	0.004*

Note: $^{*}p < 0.005$, B is the unstandardized beta, SE is the standard error for the unstandardized beta, β is the standardized beta, t is the test statistic, *p* is the probability value. While T_o is operative temperature, V_a is air velocity, and RH is relative humidity.

In both seasons, T_o; RH; and V_a in the regression equations were used to predict thermal sensations. However, according to the statistical analysis of the data obtained from the field study, only T_o and V_a were significant variables for predicting TSV. Based on Pallant (2001), R^2 = 0.01-0.09 is regarded as weak, 0.09-0.25 as moderate, 0.25-0.49 as strong, and 0.49+ as very strong relationship.

As for the field study, the TSV data were directly used in the regression equation. The equation for cold season (R^2 = 0.38) is:

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

The equation for hot season (R^2 = 0.40) is:

$$TSV_{Field} = 0.327T_o - 1.057V_a - 9.122 \quad (2)$$

Based on the climate chamber data, 30 TSV values collected from each condition were averaged into MTSV. Then, 144 MTSV were analyzed in the regression equation. The equation for cold season (R^2 = 0.96) is:

$$MTSVLab = 0.338To - 0.488Va + 0.007RH - 9.229 \quad (3)$$

The equation for hot season (R^2 = 0.91) is:

$$MTSVLab = 0.304To - 0.457Va + 0.006RH - 8.877 \quad (4)$$

TSV_{Field} is the thermal sensation vote from the field study, $MTSV_{Lab}$ is the mean thermal sensation vote from the climate chamber study, T_o is operative temperature, RH is relative humidity, and V_a is air velocity.

In both seasons, the thermal conditions of the field study were in the narrow ranges. They were different from the wider ranges of thermal conditions in the laboratory study, in which each condition was responded by 30 respondents. The data obtained from the laboratory study are not only useful for evaluating thermal sensations but can also be used to analyze thermal comfort equation for senior community centers, where there are wide ranges of thermal conditions. The equations from the laboratory test were compared to the equations from the field study in order to evaluate the relationship. The details are as follows.

Equation (1) and (3) were substituted by the thermal conditions gathered from the senior community centers in cold season. Equation (2) and (4) were substituted by the thermal conditions in hot season. Then, the results of $MTSV_{Lab}$ and TSV_{Field} were compared by season. A simple linear regression model, which is a function of Equation (6), was developed as shown in Figure 6.

$$TSV_{Field} = a(MTSV_{Lab}) + b \quad (6)$$

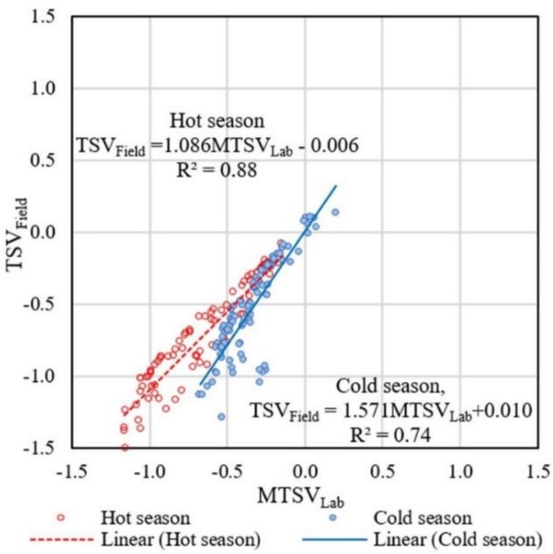


Figure 6: The Relationship Between TSV from the Field Study and MTSV from the Laboratory Study in Both Seasons

When Equations in Figure 6 were substituted by Equation (3) for cold season, and Equation (4) for hot season, R^2 values were calculated. It was found that the final equation for predicting TSV_{Field} of Thai senior citizens in cold season (R^2 = 0.71) is:

$$TSV_{Field} = 0.531T_o - 0.767V_a + 0.011RH - 14.489 \quad (7)$$

In hot season, the final equation for predicting TSV_{Field} of Thai senior citizens ($R^2 = 0.80$) is:

$$TSV_{Field} = 0.330T_o - 0.496V_a + 0.007RH - 9.646 \quad (8)$$

Both Equation (7) and (8) were used to calculate the thermal comfort zones for Thai senior citizens.

Thai Senior Citizens' Thermal Comfort Zones

The equations for predicting TSV of senior citizens in both seasons were used to depict thermal comfort zones in a psychrometric chart (Figure 7).

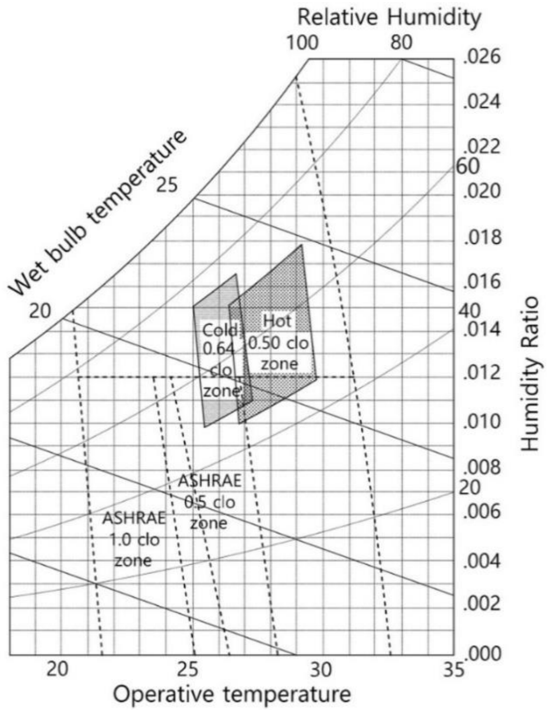


Figure 7: Thermal Comfort Zones of Thai Senior Citizens
Note: Thermal comfort zones of Thai senior citizens with metabolic rate of 65–70 W/m² in a still air state (0–0.05 m/s) for being applied in senior community centers.

From Figure 7, in still air (0-0.05 m/s), the thermal comfort zone in cold season of Thai senior citizens wearing normal clothing (average I_{cl} value of 0.64 clo) overlaps with the ASHRAE's summer comfort zone. During cold season, Thai senior citizens' thermal comfort zone is in the RH range of 49-75%. At 49% RH, the comfort zone is 25.5-27.2°C T_o. However, at 75% RH, senior citizens feel comfortable in lower T_o of 25.0-26.6°C. During hot season, senior citizens wearing normal clothing (average I_{cl} value of 0.50 clo) feel comfortable at lower RH (47-70%), compared to cold season. At 47% RH, the comfort zone is 26.8-29.7°C T_o. At higher RH (70% RH), the optimum T_o ranges between 26.4-29.2°C. The comfort zone of Thai senior citizens in hot season is significantly different from the ASHRAE's summer thermal comfort zone.

4. CONCLUSION

It is widely known that socially active senior citizens tend to be healthier than those who are lonely. Providing indoor environment with thermal comfort will help senior citizens to perform activities together in a more efficient way. This research focuses on providing an insightful understanding of senior citizens' thermal comfort in senior community centers, which is helpful for enhancing their well-being. The research results indicated that Thai senior citizens' thermal comfort zones in senior community centers were different in hot and cold seasons, as a result of the I_{cl} values. The BMI also showed that the respondents were "overweight". This finding is consistent with the general BMI of Thai senior citizens, which may affect a change in thermal perception. Moreover, Thai senior citizens' MTSV were lower than the PMV. When analyzing the relationships between MTSV and T_o, MHSV and RH, as well as MWSV and V_a, the results were meaningful only in the overview, as each function had evaluated other environmental variables before voting. Thus, it is useful to establish thermal comfort models for predicting Thai senior citizens' TSV based on the condition that the metabolic rate is 1.1-1.2 met, the average I_{cl} value is 0.64 clo for cold season and 0.50 clo for hot season. When using Equation (7) and Equation (8) to depict the proposed thermal comfort zones in still air (0-0.05 m/s), it was found that the comfort zone was 25.0-27.2°C T_o with 49-75% RH for cold season, and 26.4-29.7°C T_o with 47-70% RH for hot season. Both equations should also be used to examine appropriate air velocity in indoor environments. However, indoor V_a should be 0.10-0.65 m/s in cold season and 0.10-0.90 m/s in hot season. These findings can be applied to develop the government's senior community centers in Thailand in order to enhance Thai senior citizens' well-being and promote efficient use of energy.

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