Study of Thermal Comfort and the Adaptive Behaviors of the Elderly in Naturally Ventilated Houses

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Abstract

The elderly's adaptive behaviors to achieve thermal comfort is expected to play important roles in the housing designs under hot and humid climate. This research aims to investigate the adaptive behaviors of the elderly and their thermal comfort in naturally ventilated residential houses in Pathum Thani, Thailand. The 90 data sets are collected through questionnaires in 25 houses during the summer. The subjects include people with early old age (60-74 years old) who live with their families. The regression analysis on the survey data finds the subjects' comfort temperature of 29.0 °C. There are 86% of the residents accept thermal environment of their own houses. The elder preferred a circulating fan to the air conditioner besides planting trees to provide shade. One or two circulating fans are always operated because of limitation of air ventilation from windows and doors. The subjects are active through behavioral adjustments to achieve thermal comfort during the warm day. Subjects choose drinking of cold water and taking shower several times instead of turning on air conditioner.

Keywords: Adaptive behavior, Environmental controls, Comfort temperature, Hot and humid climate

1. Introduction

Currently, not only energy saving but also comfort living are mainly considered critical issues in residential building design. It is reported that residential sector in Thailand consumes 15% of total electricity, which is the third rank of final energy shares in 2014 (DEDE, 2014) while thermal comfort standards have been implemented explicitly. For example, setting thermostats within air-conditioned houses in summer is publically recommended at 26°C for energy saving during on peak times (EGAT, 2003). The roles of women in energy savings was vividly found in the previous studies (Jareemit, & Limmeechokchai, 2019), but the role of the elderly in a house is still unexplored. Most of medium-income families in Thailand lived with the elderly. Preliminary survey in this study found that the elderly spent much of daytime in their houses. To implement an adaptive housing design, the behavioral and environmental controls of the elderly to achieve thermal comfort are therefore worth studying.

In fact, a study of thermal comfort in naturally ventilated houses yields physical outcomes of behavioral and environmental adaptations since a house is a private place that allows personal adaptations and environmental controls. The adaptive thermal comfort model as the recent ASHRAE standard (ASHRAE, 2004) is a real-time strategy in energy efficiency under context of climate change and global warming. The adaptive through environmental controls were analysed through occupants in natural ventilated houses utilized fans and opened window so as to increase air movement in their houses (Feriadi & Wong, 2004). The comfort temperature was reported to be 29.2°C, which was slightly higher than those 28.5-28.6°C from the previous adaptive thermal comfort studies in Singapore (Dear et al, 1991, and Feriadi & Wong, 2004). Under inadequate adaptive controls, the comfort temperature range could be in a wide range such as 26.0°C-32.5°C (Indragani, 2010). An experiment in naturally ventilated building suggested the comfort temperature of 27-29°C for air velocity of 0.2-0.3 m/s and 30-35.5°C for air velocity of 1.0-3.0 m/s (Khedari, 2000).

In Thailand, a field study on thermal comfort carried out in residential buildings was reported (Tangsiraksa, 2006). From 300 respondents, the comfort temperature in a naturally ventilated residential building was within a range of 25.5°C to 30.5°C. The main objectives of this study are: 1) to investigate the elders' perception of thermal comfort in their own houses and 2) to examine behavioral adjustment and climatic control to improve thermal comfort in residential houses. The results of responses are useful for implementation of energy saving measures and thermal comfort living in residential sector and development of housing project.

2. Methodology

Questionnaire surveys on thermal comfort are carried out in two villages in Pathum Thani provinces during summer (April-May). During survey, outdoor environmental data is collected with data logger and measuring instrument HOBO (Model: U12), which are set at a reference house. This study performs transverse survey for thermal comfort field study (Dear, et al, 1997). Furthermore, indoor environmental data include air temperature (T_a), globe temperature (T_g), relative humidity (RH) and air velocity (V_a). The dry-bulb air temperature, globe temperature and relative humidity are measured by Lutron WBGT-2010SD. Air velocity are measured by Lutron hot-wire anemometer (Model: AM-4214SD) with a measurement range of 0.2-5 m/s and accuracy of ±5%. In Figure. 1, measurement instruments are fixed with a tripod stand at 1.1 m above ground level and 1.2 m away from the subjects in the interviews.

The survey in this study was carried out during daytime when a house owner and the elderly stay in their houses. At the first meeting, all the subjects were briefly informed about the survey. The elderlies were interviewed and the interviewers fill up their answers to questionnaire sheets in the morning, afternoon, and evening from 10 a.m. to 5 p.m. One subject participate one-day interview. The survey questionnaires were adopted from (McCartney et al, 2002). They have ten sections; 1) identification of house and background of respondents, 2) thermal comfort responses, 3) thermal preferences, 4) thermal acceptability, 5) Overall comfort, 6) skin moisture, 7) clothing, 8) activity level, 9) sensation and preferences of other environment parameters, and 10) behavioral and environmental adaptations. Table 1 shows the scales of thermal responses, preferences, acceptability, and overall comfort. Table 2 and Table 3 present the scales of environmental sensations and environmental preferences, respectively. All subjects sit and rest about 15 minutes before doing the questionnaires. All activities and personal adaptive actions are recorded in surveys.

Figure 1. Subjects and instruments in the surveyed houses.

Table 1. Scales for measuring thermal sensation, preference, acceptability and overall comfort.

Scale	Thermal sensation	Thermal preference	Thermal acceptability	Overall comfort
-3	Cold			
-2	Cool	Much warmer		
-1	Slightly cool	Slightly warmer		
0	Neutral	No change		Very uncomfortable;
1	Slightly warm	Slightly cooler	Yes	Moderately comfortable
2	Warm	Much cooler	No	Slightly uncomfortable
3	Hot			Slightly comfortable
4				Moderately comfortable
5				Very comfortable

Table 2. Scales for measuring environmental perceptions.

Scale	Air velocity	Humidity	Air quality
3	Very high	Very humid	Excellent
2	High	Humid	Good
1	Slightly high	Slightly humid	Slightly good
0	Neither high or low	Neither humid or dry	Neither good or bad
-1	Slightly low	Slightly dry	Slightly bad
-2	Low	Dry	Bad
-3	Very low	Very dry	Very bad

Table 3. Scales for measuring environmental preferences.

Scale	Air velocity	Humidity
2	Much more air movement	Much more humid
1	A bit more air movement	A bit more humid
0	No change	No change
-1	A bit less air movement	A bit drier
-2	Much less air movement	Much drier

3. Sample size and description

The survey is conducted with 25 detached houses in two villages in Pathum Thani Province. The front door of the surveyed houses faces south and south-west. There are 30 residents participating in this survey and a total of 90 data sets were collected during 12 days of April. All houses are two-floor houses with setback between two houses about 2 m. These buildings are post and beam structures with plastered brick walls without insulation. The 1st floor diagram and the picture of houses is shown in Figure 2. 30 female subjects participated have ages of 60-74 years. They are all healthy residents, who have lived in the villages for more than one year. During survey, a mean value of clothing insulation is 0.33 and this implies the typical casual dress in their natural ventilated home.

Figure 2 (a) the surveyed houses (b) the 1st floor plan

4. Environmental conditions in the survey area

4.1. Outdoor and indoor air conditions

Figure 3 shows the results of the average values of outdoor air temperature, indoor air temperature, and relative humidity, which is measured at a reference house. During the survey, the average outdoor air temperature and relative humidity are 35.2°C and 51.0%, respectively. The outdoor air temperature increases from 32°C from 9.30 am to 36°C at 3 pm. There is no rain during the survey in summer. The indoor conditions are changed according to outdoor conditions closely due to natural ventilation in a living room. The peaks of indoor and outdoor temperatures occur around 3.30 p.m. The average indoor temperature of 32.0 °C is slightly higher than a comfort zone of 31.0 °C in hot and humid climate for low air velocity (Olgyay, 1963). The air velocity in a living room is 0- 0.4 m/s without a circulating fan. During 9.30 a.m.–6.30 p.m., the indoor temperature is less than the outdoor temperature by 0.6-2.5°C.

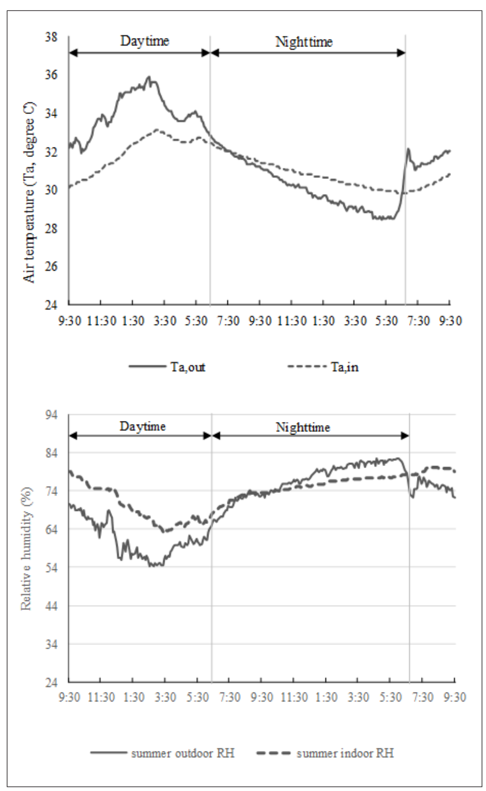

Figure 3. Average of outdoor/ indoor air temperature and relative humidity

5. Results and discussions

5.1 Thermal sensation and analysis of comfort temperature

Thermal sensation is the most important psychological measurement of thermal comfort. The seven-point thermal sensation scale of -3 (cold) to +3 (hot) is adopted in this study. Figure 4 shows percentage distribution of thermal sensation votes of 30 data sets in this survey. The 56% of subjects votes three central categories (-1, 0, +1). The percentage is too low to claim that the indoor conditions in naturally ventilated houses are acceptable all year round. Due to very high air temperature in summer, 65% of occupants votes outside of the comfort band and only 35% votes inside of the comfort band (-1, 0, +1). This result can be interpreted that the indoor conditions are uncomfortable in summer.

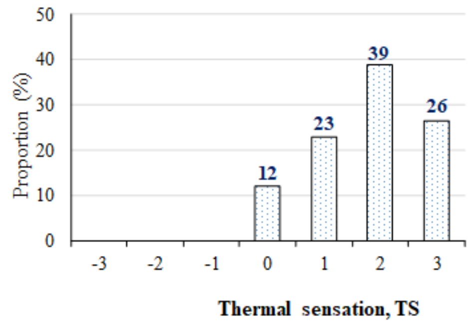

Figure 4. Percentage distribution of thermal sensation.

The relationships between thermal sensations and globe temperature (T_g), indoor air temperature (T_{in}) and outdoor air temperature (T_{out}) are shown in correlation (r-value) in Table 4. The indoor temperature and the globe temperature have strong correlations with thermal sensation. On the other hand, the outdoor temperature is moderately related to thermal sensation.

Table 4. Summary of globe-, air- and outdoor temperatures and correlation (r) with thermal sensation (TS)

Descriptive statistic	(T_g, °C)	(T_{in}, °C)	(T_{out}, °C)
Mean	31.3	31.4	32.9
SD	1.4	0.50	1.3
r	0.50	1.2	0.30
Mean	33.4	33.7	35.2
SD	1.6	0.67	1.7
r	0.65	1.7	0.53
Mean	32.4	32.6	33.9
SD	1.8	0.70	1.9
r	0.69	2.0	0.58

Determination of neutral temperature can be achieved by a regression analysis between the mean radiant temperature, and the thermal sensation votes. In this study, the mean radiant temperature is obtained from the globe temperature. Figure 5 shows the result of regression between the globe temperature and the thermal sensation. The result of the regression analysis is derived as $TS = 0.42T_{in} - 12.17$, $R^2 = 0.52$, and $r = 0.70$ and $p < 0.00001$. The regression coefficient is slightly lower than the study in Indonesia (Feriadi & Wong, 2004). To predict the comfort temperature, TS is set to zero and comfort temperature (T_{in}) of 29.0°C is obtained. To find the comfort band in the

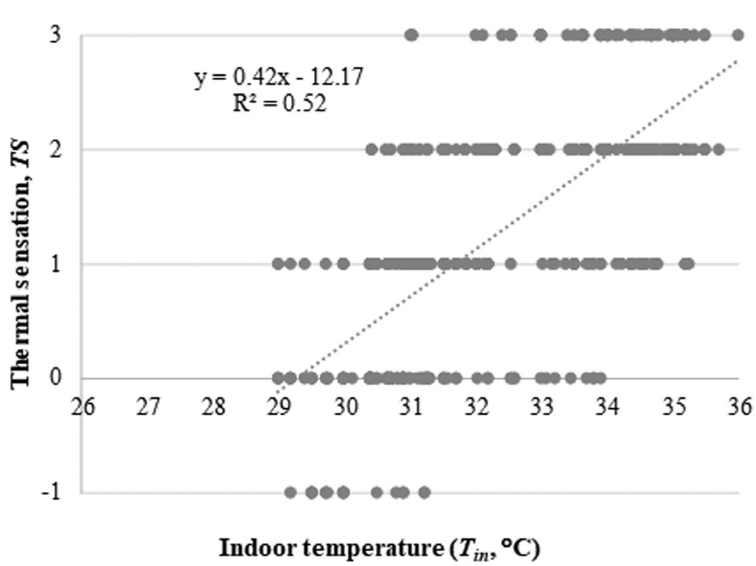

Figure 5. Regression analysis of thermal sensation

range of -0.5 ≤ TS ≤ +0.5, TS is set at -0.5 and +0.5. Therefore, the comfort band can be specified in the range of 27.8-30.2°C. This comfort range has good agreement with the range 27-31°C (Busch, 1992) and 27.17-32.42°C (Khedari, 2000) under similar relative humidity.

5.2 Thermal preference, thermal acceptance and overall thermal comfort

Thermal preference represents the discrepancy from the thermal comfort. To test the preferences, the question is "at this point of time, would you prefer to feel warmer, cooler, or no change?" There are 5 scales to measure this parameter, that is, -2, -1, 0, +1, and +2. They infer much cooler, a bit cooler, no change, a bit warmer, much warmer, respectively. The optimum thermal comfort condition corresponds to the vote 'no change' in the thermal preference. As listed in Table 5, the mean votes for thermal preference is -0.83. This result implies that most subjects prefer the cooler side of the neutrality. The mean votes of thermal sensation TS is 1.2. The thermal preference is closer to the vote of no change (TP=-0.83). This finding also agrees with studies of (Indragani, 2010) and (Karyono, 2000). According to observation, i.e. the elderly is rather stationary in thermal environment. The thermal acceptability is high, 86% of subjects accept the current conditions of their houses. From the full score of six, 75% of subjects in the adult group rate the overall comfort of 3 (slightly comfortable) and 4 (modrately comfortable), which yields the average score of 3.42

5.3. Analysis of environmental controls

The adaptive controls of environment in this survey include 1) the external permanent controls like planting trees and/or installing of shading devices and 2) the indoor environmental control relating to natural ventilation such as operable windows, wire screens, doors and curtains. There are 68% of surveyed houses planting trees to provide shades around the houses and 44% of windows are covered on the top with shading roofs to prevent sun and rain.

Table 5. Summary of percentage of thermal responses and mean votes total number of votes = 90.

Scale	Thermal sensation	Thermal preference	Thermal acceptance	Overall comfort
-3				
-2		13		
-1	4	57		
0	25	30		3
1	30		86	3
2	24		14	11
3	16			26
4				49
5				
6				9
0				
Mean vote	1.2	-0.83	1.1	3.42

The window systems consist of three layers: the glass window panes the iron grills and wire screen in the innermost. The iron grills at the windows are fixed with the window frame and the iron grills at the front door are operated with a sliding frame or an openable frame. There are 86% of houses with wire screens on the windows and doors and 62% of them are shut for most of the time to prevent insects entering the houses. The barriers to operate windows are:

1) too many windows to shut during rains,

2) difficulty to reach the window panes through the wire screens and the iron grills, and

3) the loss privacy.

There are 89% of the living rooms with curtains or blinds and 28% of the living rooms are found with fully opened curtains. The front doors are frequently opened due to the indoor and outdoor activities. Apparently, windows and doors in the surveyed houses are not fully performed openings for natural ventilation because the iron grills, the wire screens and the curtains obstruct wind.

The results of subjective perceptions and preferences of other environmental parameters are shown in Table 6 and Table 7, respectively. In analysis, it is found that all subjects perceive slightly low and low air velocity in their houses and prefer higher air movement. Subjects perceive either too high or too low air humidity and they prefer no change in humidity. The air quality in their houses are mostly slightly good.

Table 6. Proportions of subjective perception of environmental parameters.

Scale	Air velocity	Humidity	Air quality
3			
2		7	1
1		20	67
0		55	21
-1	55	17	10
-2	45		1
-3			

Table 7. Proportions of subjects' preferred environment.

Scale	Air velocity	Humidity
2	78	2
1	22	13
0		74
-1		9
-2		

Table 8. Percentages of installed and usage of air conditioner.

	Percentage
Living room with no AC	28
Living room with AC	72
AC On	25
AC Off	75

5.4 Usage of circulating fans and air conditioning units

The usage of circulating fans is the most preferred adaptive control found in this study. All subjects turn on one or two circulating fans every time they are in living rooms. 88% and 12% of subjects use one circulating fan and two circulating fans, respectively. It is reported that the second circulating fan is switched on if the first circulating fan cannot provide enough air movement. The openings of doors cannot provide sufficient air movement when the outdoor temperature increases during the daytime; therefore, the subjects highly depended upon circulating fans. Table 8 explains the percentage of usage of air conditioning units during the daytime in summer. There are 72% of the houses with air conditioning units installed in the living rooms However, only 28% of these air conditioning units are used in the afternoon. The 44% of installed air conditioning units are not used in hot and humid summer because the subjects need to save electricity. Also, some of the subjects do not use air conditioning units in the daytime because they do not like to stay in air conditioned space all the time. Instead, they use air conditioning units to necessary making comfortable during sleeping at night.

5.5 Behavioral control actions

The survey results of personal adaptations involve 1) drinking water, 2) taking shower, 3) moving to airy place, 4) avoiding direct sun, 5) washing face, 6) removing clothes, 7) doing less vigorously, 8) applying cool body powder, and 9) sleeping. These behavioral adaptations can be found in (Indraganti, 2010) while the action 8) is added for a few subjects in this study. Figure 8 illustrates the percentage of behavioral adaptation. The subjects are asked to choose the action that "most likely happen" at 15 minutes prior to interview. Because the subjects act one or several actions to restore their thermal comfort, they choose 1) - 9) actions from the provided list. The subjects naturally act in subsequence to recover their thermal comfort such as washing face, drinking water and turning on circulating fan. The habitual actions and activities are recorded with their questionnaire answers as well.

The results in Figure 6 shows that drinking water (77%) and taking shower (73%) are two of the most preferred adaptive actions in summer. The percentage of taking shower more 3-4 times a day is 16% of the overall showering. The percentage of avoiding direct sun is 64% as subjects experience direct sun around their houses. Other favored adaptive actions are moving to airy space and avoiding direct sun with the percentage of 51%. There is no subject adapt to the weather by sleeping. The drinking water and taking shower are found corresponding to the most energetic activities of subjects during the survey.

5.6 Obstruction of using adaptive controls

In this study, the subjects are asked to choose the possible obstructions in using adaptive controls where a single subject may choose more than one obstruction. As shown in Figure 7, the intrusion of insects is found as the main obstruction to opening of windows and doors where wire screens are always remained close. The second major obstruction is the dust from burning agricultural waste from rice farms. The security reason causes installation of iron grills in windows and doors, which impedes opening of windows. The economic reason to reduce electricity cost is another obstruction to use air conditioning units. However, the percentage of economic reason is only 15% since the subjects depend alternatively upon circulating fans and other behavioral control actions.

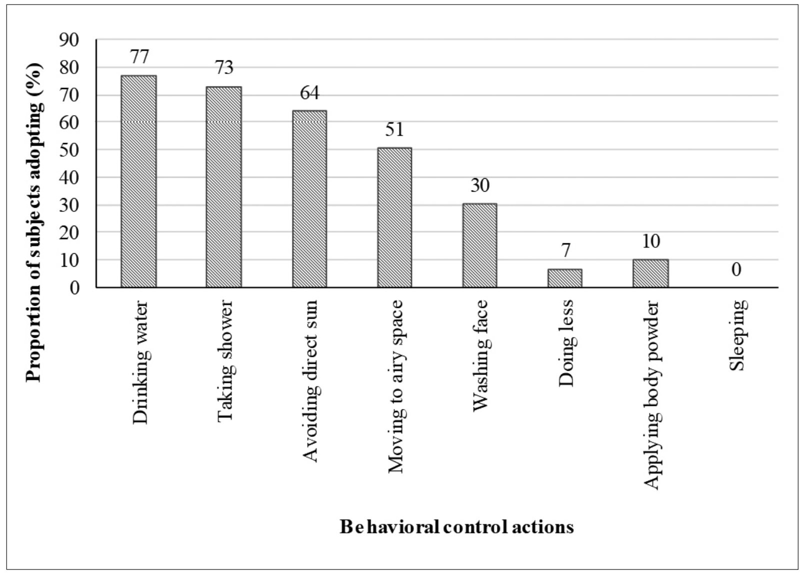

Figure 6. Percentage of behavioral control actions.

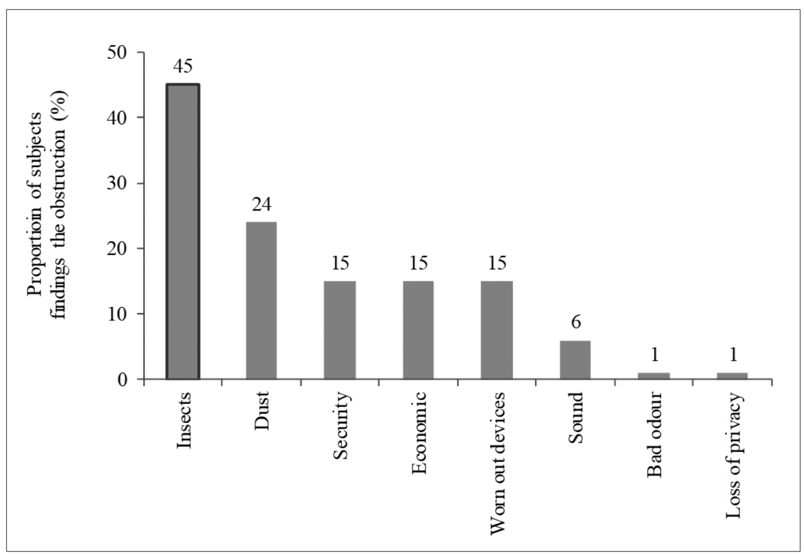

Figure 7. Percentage of obstructions to environment control.

6. Conclusions

This paper investigates thermal responses of residents of 25 detached houses in two villages with identical house designs. In the survey, the adaptation controls such as windows, circulating fans, taking shower and drinking water are applied by 30 subjects. The total of 90 datasets are collected from transverse survey on 15 days in the summer. The ASHRAE class-II protocol for field studies are carried out in obtaining indoor at the surveyed houses. The outdoor and indoor conditions are also recorded during the survey.

The following are the conclusions:

1. The percentage of the thermally satisfied occupants is 35% in summer due to high indoor and outdoor temperatures. The comfort temperature of 29.28°C and a comfort range (voting between -1 to +1) of 26.9-31.68°C is obtained from the regression analysis. This range is similar to the previous study by Busch (1992) and Khedari (2000).

2. The female elderlies with age of 60-80 years are able to endure temperature. There are 92% of subjects prefer the cooler indoor conditions. Even with these high preferences in cooler conditions, the acceptability in the thermal indoor climate is high (86%). The thermal endurance contributed from their active in behavioral adaptation.

3. Two of the most preferred behavioral control actions are drinking water and taking showers. It is observed that possibility of drinking water and taking showers can be related to the metabolism rate of the residents.

4. The environmental controls such as adjusting windows and curtains is low due to difficult to operate through iron grills and the wire screens. Windows and doors do not fully function for natural ventilation.

5. The circulating fans are the most favorite environmental adjustment. One or two circulating fans are always operated because of limitation of wind. There are 72% of living rooms with air conditioning units, but only 28% of them are turned on during the daytime in summer. The obstruction to use air conditioning units is reduction of electricity cost.

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