

Subjective assessment of thermal comfort for residents in naturally ventilated residential building in Malaysia

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Abstract. Thermal comfort is a mean of being satisfied with the thermal environment. A study was conducted in the field to assess thermal comfort perception for the residents in a naturally ventilated residential building in Malaysia. The objective of this study was to find out whether the residents are thermally comfortable in buildings without the use of air-conditionings. The result showed that the residents are generally satisfied (i.e. comfortable) with the thermal environment, even though their thermal sensation was outside the central three categories of ASHRAE standard, which reflects their acclimatization to the local hot and humid climate.

1. Introduction

Thermal Comfort is defined as “the condition of mind that expresses satisfaction with the thermal environment and is assessed by subjective evaluation” [1]. As people spend most of their time in buildings, the indoor environments are needed to be more comfortable and healthy [2]. Psychological, physical, and social factors are involved when studying thermal comfort [3]. They can be categorized into three groups, namely; environmental factors (i.e. air temperature, relative humidity, air movement, and mean radiant temperature), individual factors (i.e. metabolic rate/activity and clothing), and contributing factors (i.e. Acclimatization, Experiences and Expectations, food and drink, body shape and subcutaneous fat, age and gender, and state of health). Due to variations in these factors, it is difficult to satisfy everybody in a space [1]. Therefore, a comfort zone is “the range of conditions where at least 80% of the people would feel comfortable” [4].

Natural ventilation is an attractive passive alternative that can provide and maintain a comfortable and healthy indoor environment. Besides, it helps to alleviate the associated problems with air-conditioned buildings and reducing energy consumption [5]. The objective of the current study is to investigate residents’ perception of thermal comfort in a naturally ventilated residential building in Malaysia.

2. Literature review

Thermal comfort is more than just an air temperature. Psychological, physical, and social factors are involved when studying thermal comfort [3]. Current standards for thermal comfort are essentially based on either heat balance model or adaptive model [6]. The heat balance model is based on comprehensive analyses of the body thermal physiology by means of assuming a controlled steady-state conditions and a high accuracy for the six parameters of thermal comfort. However, the adaptive model depends on the active relationship between the occupant and the surrounding environments



based on the concept that people usually react to restore their comfort levels whenever a discomfort condition existed.

Thermal comfort in hot climates was achieved with high temperatures. For example, in non-air-conditioned residential buildings in Kota Kinabalu city [7], a comfort temperature of nearly 30 °C was obtained with an acceptable range of 27 – 32.5 °C. Additionally, the neutral temperature for university students in their accommodations was 28.9 °C, while the comfort range was 27.6 – 30.1°C [8].

Studies in hot-humid climate for naturally ventilated buildings indicate that with higher indoor air velocity, an increase in the comfort temperatures voted by respondents is observed [1,6]. Additionally, moderate air velocity (>0.25 m/s) in the range 32-40°C reduce both thermal discomfort and skin moisture [9]. As a result, a study proposed lower limit for air velocity for three ranges of operative temperature; 0.4 m/s for 24-27 °C, 0.41-0.8 m/s for 27-29 °C and >0.81 m/s for 29-31 °C [10].

3. Methodology

A quantitative approach was selected for this research using questionnaire survey on thermal comfort. The thermal environment assessment was based on residents' votes using seven-point scales [1,11,12] including thermal sensation (TS) scale (ASHRAE scale), comfort perception (TC) scale (Bedford scale), votes of preference, direct votes of acceptability (Table 1).

Table 1. Rating scales of the survey.

ASHRAE scale	Bedford scale	Preference	Acceptability
+3 Hot	+3 Much too warm		
+2 Warm	+2 Too warm		
+1 Slightly Warm	+1 Comfortable warm	+1 Warmer	Acceptable
0 Neutral	0 Comfortable	0 No change	
-1 Slightly Cool	-1 Comfortable Cool	-1 Cooler	Not Acceptable
-2 Cool	-2 Too Cool		
-3 Cold	-3 Much too cool		

3.1. Case Study

N-Park, a high-rise residential building, was selected for this study due to: (1) Building's layout (i.e. single loaded corridor type) can provide the optimum opportunity for cross natural ventilation. (2) The orientation to north-south represents the recommended in Malaysia. (3) All the flats have the same orientation to the south, which provides the same conditions for all participants. It is located on the east coast of the Penang Island, Malaysia. It consists of four blocks (Figure 1) and has a total number of 988 flats. Each flat has a built-up area of 700 sq. ft., and comprises a master bedroom, two children bedrooms, living room, kitchen and two bathrooms. The design of all flats relies on natural ventilation. Even though, the owners installed air conditioners individually.

3.2. Population and sample size

Cochran's sample size equation for continuous data was used [13]. Based on this equation, for a population of 988, which represent one participant in each flat of all the 988 flats that involved in this study, the required sample size is 105. For 70% return rate [8], the required questionnaires to be distributed are 150 questionnaires.

3.3. Data Collection

Data collection lasted from 14th of February to 11th of March 2016. All the questionnaires were distributed from 9.00 am to 9.00 pm to the residents in their homes. Researcher effort was made in order to ensure getting participants with almost equal percentage of men and women with a range of ages and from different floor levels. Once the collected questionnaires were found not enough to achieve the required sample, another 50 questionnaires were distributed.

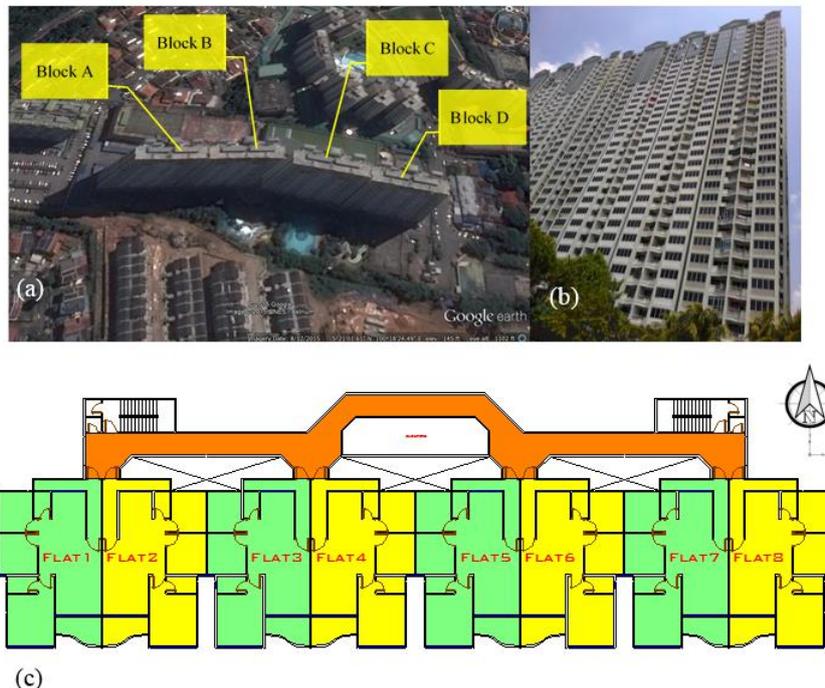


Figure 1. Case study (a) Building's blocks (source: Google earth), (b) Part of the south elevation (c) Block layout.

4. Results and discussion

From the 200 distributed questionnaires, 116 were collected and 106 were valid. The percentage of female to male is 38% to 62%.

Figure 2 shows respondents' votes for their thermal perception using ASHRAE scale (TS). It can be said that their votes clearly increased on the warm side of the scale. According to ASHRAE standard [1], the thermal condition may consider acceptable where at least 80% of the occupants voted within the central three categories (i.e. Slightly cool, Neutral, Slightly warm). The total respondents who voted within the three central categories is 77.3%. This indicates that the thermal condition considers not acceptable for the occupants. However, when respondents voted for their thermal comfort on Bedford scale (TC) (Figure 3), noticeably respondents' votes increased within the three central categories to 89.7% with an increase of 12.4% compared to ASHRAE scale.

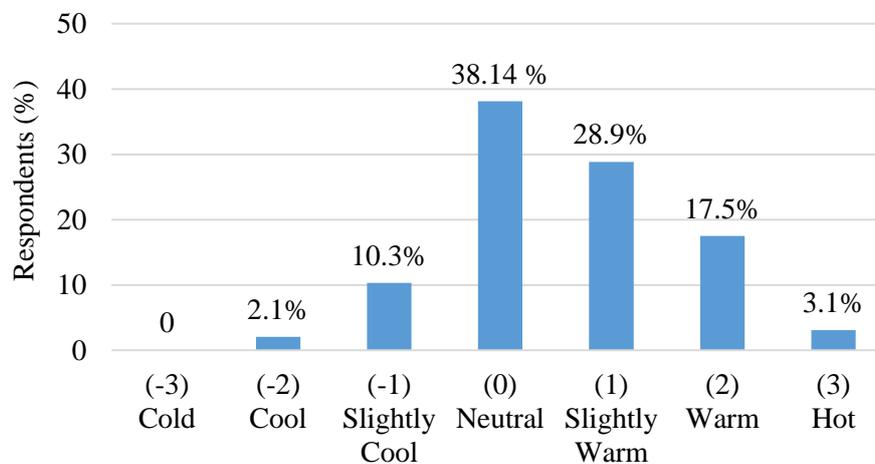


Figure 2. Thermal perception using ASHRAE scale (TS).

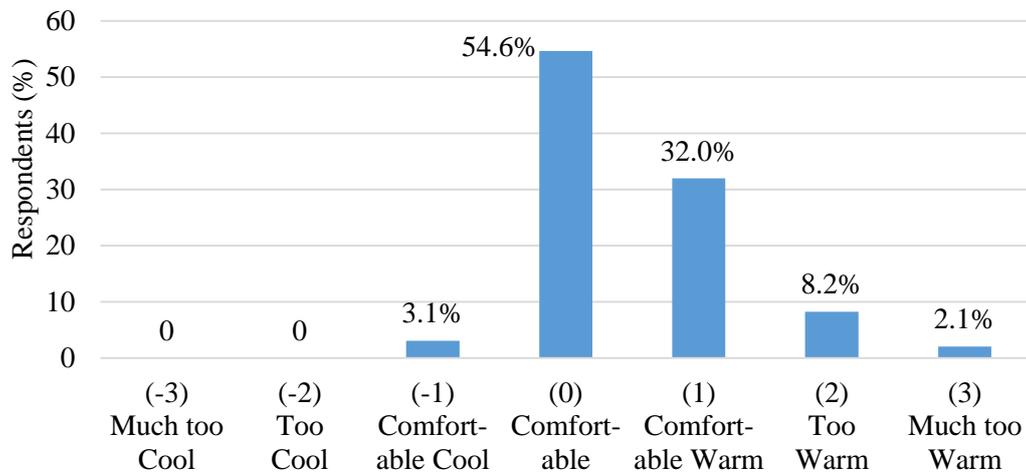


Figure 3. Comfort perception using Bedford scale (TC).

Similar results were found in studies conducted in hot and humid climates [8,14,15]. They mentioned that comfort assessment does not only depend on thermal sensation, but also on other non-physical factors (e.g. psychological factors such as expectation and emotional background). Evidence can be found in Table 2 (a cross frequency matrices of thermal sensation and comfort perception scales). From the 17.5% respondents who voted warm on thermal sensation scale, nearly two third (i.e. 11.3%) voted comfortable and comfortable warm.

Table 2. Cross frequency matrices of thermal sensation and comfort perception.

		Comfort perception (Bedford scale)					Total	
		Comfortable Cool	Comfortable	Comfortable Warm	Too Warm	Much too Warm		
Thermal sensation (ASHRAE)	Cool	Total%	1.0%	0.0%	1.0%	0.0%	0.0%	2.1%
	Slightly Cool	Total%	2.1%	7.2%	1.0%	0.0%	0.0%	10.3%
	Neutral	Total%	0.0%	33.0%	4.1%	1.0%	0.0%	38.1%
	Slightly Warm	Total%	0.0%	10.3%	17.5%	1.0%	0.0%	28.9%
	Warm	Total%	0.0%	4.1%	7.2%	5.2%	1.0%	17.5%
	Hot	Total%	0.0%	0.0%	1.0%	1.0%	1.0%	3.1%
	Total	Total%	3.1%	54.6%	32.0%	8.2%	2.1%	100.0%

Data from the comfort survey was used to derive a regression of thermal sensation vote on reported comfort perception vote (Figure 4). The obtained linear regression equation ($r^2 = 0.3776$) is:

$$TC = 0.4522 TS + 0.2497$$

In this equation, for (TS) vote of -0.55, the (TC) is zero, which indicates that the individual is at the (TC) of neutral state. This demonstrates that respondents normally will feel comfortable in a cooler environment. For TC votes of -1 and +1, the corresponded TS votes are -2.76 and +1.66 respectively. The higher TS votes on the cooler side are being rated as more comfortable than the warm side. This also proves that respondents can be thermally comfortable with TS votes outside the central three categories that suggested by (ASHRAE) for comfort conditions.

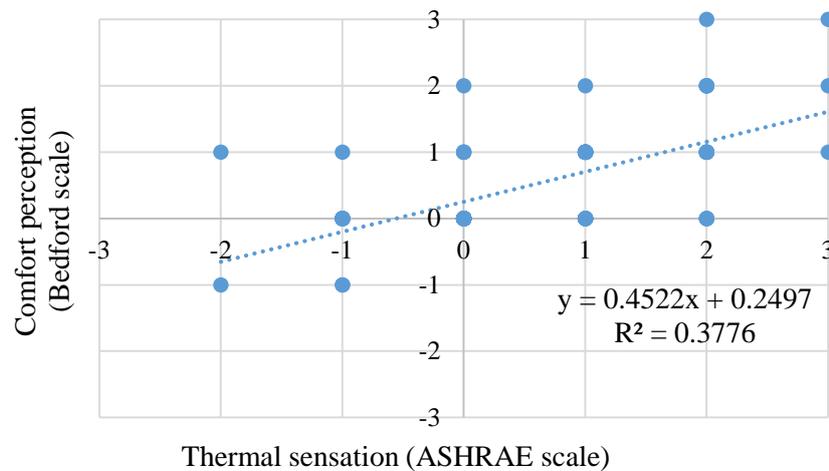


Figure 4. Liner Regression of thermal sensation and comfort perception scales.

Additionally, when residents were asked about their preference to change the thermal environment, 63.2% voted to be cooler, while just 34.9% voted for no change, Figure 5 (a). People may find an environment thermally comfortable even if they still preferred to be cooler, which supports the earlier findings with linear regression. This is also in line with Toe & Kubota finding that people in hot climates can adapt to higher neutral temperatures, yet they still prefer cooler conditions [6]. Furthermore, Figure 5 (b) shows that as much as 84.9% of the respondents accepted the environment. This further confirms the findings from comfort perception Bedford scale. It also proves the concept of acclimatization and how the human body in hot climates may develop a tolerance to high temperature and feel comfortable compared to people in other climates.

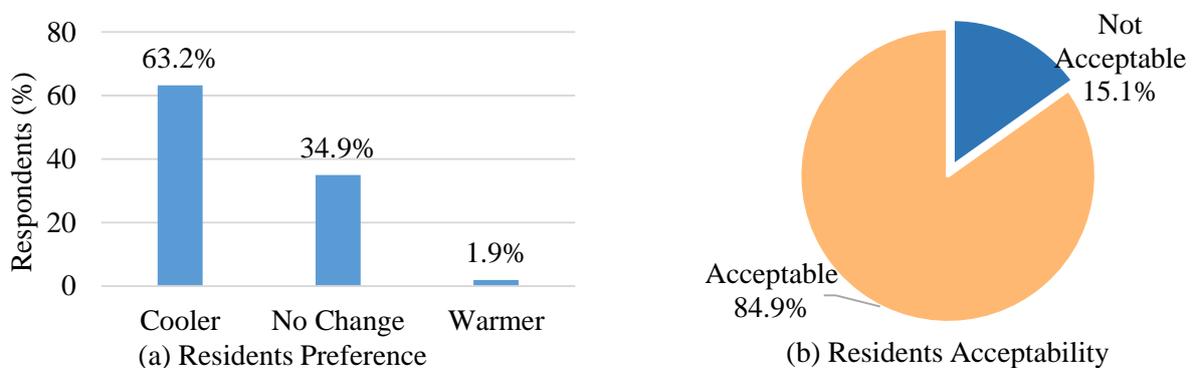


Figure 5. Residents Preference and Acceptability.

5. Conclusion

This study was conducted to assess thermal comfort perception for the residents in naturally ventilated residential building in Malaysia. The main results showed that residents are generally satisfied (i.e. comfortable) with the thermal environment in the naturally ventilated building, even though their thermal sensation was outside the central three categories of ASHRAE standard, which reflect their acclimatization to the local hot and humid climate.

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