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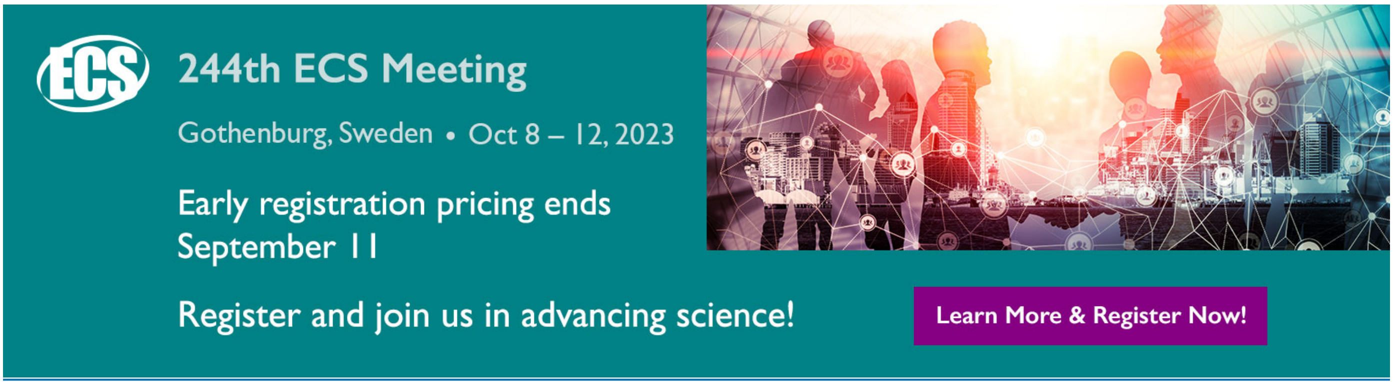

Analysis of Thermal Performance of Naturally Ventilated Residential Building in Tropical Climate: Case Study of Phnom Penh, Cambodia

Kimnenh Taing [1,3,*] ,Philippe Andre[2], Pierre Leclercq[3]

[1] Faculty of Civil Engineering, Institute of Technology of Cambodia, Russian Federation Blvd., P.O. Box 86, Phnom Penh, Cambodia

[2] Faculty of Sciences, University of Liege, Bât. BE-014 Surveillance de l'environnement avenue de Longwy 185, 6700, Arlon, Belgium

[3] Faculty of Applied Science, University of Liege, Quartier Polytech - allée de la Découverte 9 - Bât B52, 4000, Liege, Belgium

* Correspondence: kimnenh.taing@doct.uliege.be

Abstract. Comfort of the building is one of the important factors that is hard to achieve for architects and engineers as it depends on both physic and psychological parameter. This paper discusses these two aspects on the thermal performance of residential building in context of hot-humid climate. Three different types of residential buildings including townhouse, detached house and apartment building in Phnom Penh, Cambodia were chosen as the case studies. The analysis of thermal performance of each house is based on (a) the measurement of physical parameters (air temperature, relative humidity, air velocity), (b) occupants survey to compare with data from the measurement and (c) interview with the occupants to know about their satisfaction and sensation to the physical parameters. Impact of different designs of houses on thermal performance and the importance of influential physical parameters for tropical climate is analysed. Comparison of results to the Fanger's model also indicate the importance of air velocity in thermal comfort for tropical region. The survey shows that in natural ventilation, women in their 20s to 30s feel comfortable with the temperature of 29 to 30ºC and humidity of 73 to 75%.

Keyword: Thermal comfort, Natural ventilation, Residential building, Tropical climate, Fanger's model

1. Introduction

To design a building that provides comfort to occupants is still a challenge especially with the climate change nowadays. One of the factors that is hard to achieve for architect or designer is thermal comfort as it is a state of mind and can be different from one person to another even they are in the same room [1]. American Society of Heating, Refrigerating and Air-Conditioning Engineer (ASHRAE) gives definition to thermal comfort as the condition of mind in which satisfaction is ex-pressed with thermal environment'[2]. Thermal comfort of the building is influenced by 6 factors including air temperature, relative humidity, radiant temperature, air velocity, metabolic rate of occupants and clothing insulation [3]. There are a few standards such ASHRAE and ISO 7730 that have been used world-wide to evaluate thermal performance of building. However, the adaptation of people with the climate conditions that they have lived in for a long time made them accept a certain difference of number of parameters that are mentioned in those international standard [4]. Several studies have been done trying to find a standard for thermal comfort in tropical region. A study conducted by Taweekun and Tantiwhichien [5] for Thailand climate has shown that the acceptable comfort zone is in the range of relative humidity 50% – 70% and temperature of 24ºC – 27ºC for air velocity of 0.2 m/s. Earlier study by Busch [6] also shows that the neutral temperature for a natural ventilated building is 28.5ºC for Thailand and Singapore. Another study also revealed that in a natural ventilated public housing in Singapore, a sensation of +2,+3 scale of comfort is still acceptable [7]. More than that, a study on a natural ventilated apartment in Indonesia has indicated that the acceptable temperature can rise up until 29.2ºC. However, the use of electrical fans or opening the window is still practiced by the occupants in order to make them feel thermally comfortable thanks to air movement [8]. To our knowledge, the standard comfort for Cambodia climate hasn't been defined by any scientist yet.

Vernacular or traditional architecture are designed to respond strongly to the surrounding environment and help to promote comfort and sustainability in the building. However, with economic growth, new technology and changing of lifestyle, the style of housing has been changing dramatically [9]. This new architecture evolution also raises questions on the thermal performance of the building as well.

In the past decade, air-conditioning has become the main solution that were put into place for the concern of thermal comfort in the building in region with hot-humid climate conditions. As an example, residential building that have been built in Phnom Penh between 2000s until now are more focused the aesthetic and the construction budget than on the comfort that the building would provide to occupants. The rate of using air conditioner is 15% in Phnom Penh and with economic growth, it is expected to increase rapidly in the near future [9]. In Cambodia, the major use of electricity in each household in the urban area is cooling energy of air-conditioning [10]. The study of Noeurn [11] has identified that the household cooling energy consumption in Cambodia is 41% of total energy consumption or 81kWh per month. According to Ministry of Mines and Energy of Cambodia the growth rates of electricity has increased to 18% annually between 2010 and 2018. In order to provide a suitable solution to decrease the energy consumption for cooling or the usage of air conditioner, the investigation of the current situation of building performance and also the identification the design mal-functions that lead to these issues, need to be put in place.

Even though there are plenty of research on thermal performance of building that have been done for tropical climate, a case study for newly constructed residential building in Cambodia hasn't been done yet. People's mind and feel playing an important factor for thermal comfort, tradition and occupant's behaviour can provide a different impact of thermal performance for building in Cambodia. This research aims to investigate on building performance of residential building in hot-humid climate region discussing on both influence physical parameter and occupant's behaviour for both rainy and dry seasons. Residential buildings in Phnom Penh, Cambodia were chosen as the case study which concentrate on three different types of residential buildings that mostly can be found now in the suburb and urban area, such as townhouse (flat), detached house (villa) and apartment building. The chosen case study buildings will also allow us to identify different design of housing influencing the thermal performance of building as well.

2. Methodology

Three methods have been put into place to conduct our study. First, the measurement of physical parameters that influence thermal comfort such as air temperature, relative humidity and air velocity were conducted. The result of this measurement will allow us to compare the thermal performance of the case studies buildings to the different comfort standards that were found by previous researcher for tropical climate. Secondly, an occupant survey will be carried out also during the period of the measurement to compare the satisfaction and sensation of occupants to the data that we get from the sensor and to identify a comfort standard for physical parameter. Plus, an in-depth interview of occupants will allow us to investigate in more details about their thermal sensation to the building and different solutions that they have been used to improve their satisfaction.

2.1. Phnom Penh occupant survey

A survey has been put online to identify the occupant's satisfaction and sensation to thermal comfort inside their house in Phnom Penh in general. This survey will give us a first idea of the thermal performance of residential building in Phnom Penh globally and the study on case study building will allow us to investigate more in detail for this matter. The survey form is based on the ASHRAE thermal comfort form which ask them first about general information (sex, age, profession, education…), then about information of their house (type, size, occupation…), about their satisfaction and sensation to the temperature inside their house (from a scale of 1 to 7) and finally, about what they use as solution to improve their satisfaction.

2.2. Physical parameter measurement

The measurement of 3 physical variables that influence thermal comfort which are air temperature, relative humidity and air velocity was conducted. We use a data logger (EL-USB-2+) to measure the air temperature and the relative humidity. All the sensors were put in the living room in each house at about 1m above the ground and away from the direct sunlight. The measurement of air temperature and relative humidity has been done from 1st April 2021 to 1st May 2021 for dry season and from 25th June 2021 to 05th August 2021 for rainy season.

The air velocity in each case study building was measured with a hot-wire anemometer (Alnor Velometer). The measurement was conducted in room that occupant mostly stay in, such as living room or bedroom and it was done once a week between 25th June 2021 to 05th August 2021 in different climate conditions (sunny, rainy, windy…), different times of the day and 4 different ventilation conditions such as:

- open all the windows and doors
- open all the windows, doors and fans
- close all the windows and doors
- close all the windows and doors but open

2.3. Occupant survey

We asked the occupants that live in each house to complete a survey that de-scribes their satisfaction and sensation of the thermal performance of their house likely when they feel the most comfort and discomfort. The questions on the survey are based from ASHRAE thermal comfort survey that include their satisfaction to the temperature from scale of 1 (most satisfy) to 7 (most dissatisfy), their sensation from scale of 1 (very hot) to 7 (very cold). The survey has been completed by occupants during the same period as the measurements.

2.4. Occupant interview

A small interview with all the occupants who live in each house was conducted after each measurement period and during the measurement of air velocity. These interviews let us know in more details about their satisfaction and sensation to the thermal comfort in their house throughout the day and also what kind of solution they use to improve their satisfaction and what time of the day they normally use that solution. More than that, it allows us to know the air temperature and relative humidity that occupants can tolerate when they use the electrical fan. The questions in the interview are mostly based on ASHRAE thermal comfort survey form.

2.5. Case study

Phnom Penh is the capital of Cambodia, a country located in South-East Asia which is submitted to a tropical (hot-humid, Moonson) climate. The country has two seasons which are the dry season (from November to April) and the rainy season (from May to October). The average temperature in Phnom Penh in dry season is 33ºC and 31ºC in rainy season (Meteoblue). The hottest month is between March and May where the temperature can rise up until 40ºC and the coldest month is between December and January where the temperature can go down to 27ºC. As in other parts of Cambodia, the wind direction in Phnom Penh flow from northeast in dry season and from the south in rainy season with average wind speed of 3.33 m/s. Humidity in this region seems to be higher in rainy season (more than 80%) than in the dry season (more or less 70%).

There are 4 different types of housing in Cambodia. (1) The townhouse, also known as flat where each unit shared their walls, mostly built in the urban area, using bricks and concrete as construction material. (2) Detached house, also known as villa mostly built in the urban area and using the same construction material as flat. (3) The Khmer traditional house which is built from wood and mostly on stilt which can be found in the suburb and rural area. And (4) the apartment complex that just appears in the 2010s mostly found in the urban area of big cities.

Five different residential buildings were chosen as our case studies which are all located in Phnom Penh as shown in Table 1 and Figure 1. The case study includes 3 different types of residential buildings such as, town house (T1, T2), detached house (D1) and apartment complex (A1, A2) as they are the most common types of home that can be found in Cambodia and that will continue to grow in the future.

Table 1. Description of each case study building (authors' compilation).

House	Type	Surface (m^2)	Built	Occupant
T1	Townhouse	216	1997	4
T2	Townhouse	96	2015	4
D1	Detached house/villa	336	2013	3
A1	Apartment	35	2010	3
A2	Apartment	42.5	20184	0

Figure 1. Location and perspective of case study buildings (authors' compilation).

3. Result and discussion

3.1. Global Analysis

We received 207 answers with the survey from people between 20 to 55 years old living in different part of Phnom Penh. From these 207 answers 61% live in townhouse, 11% live in detached house and 22% live in apartment. 65% of people who live in townhouse, 57% that live in detached house and 63% that live in apartment say that they are not satisfied with the thermal performance of their house and that the temperature is either hot or too hot. They mostly use electrical fans which can help improve their thermal satisfaction from 50 to 75% or air conditioners which can help to improve their satisfaction from 75 to 100%. These solutions are mostly used at noon, during the afternoon and at night when they go to sleep. The use of air conditioners is shown to be mostly during the night time when they go to sleep as 70% of them have installed air conditioner only in the bedroom. This shows that in order to have a comfortable sleep, temperature is the most important factor.

3.2. Air temperature

The average air temperature of each house is between 30ºC (A2) to 32ºC (A1) in dry season and between 30ºC (T1) to 31ºC (A1) in rainy season. Figure 2 shows the evolution of air temperature of all case study building in both seasons. Following the outdoor temperature, the air temperature inside all case studies is much higher during noon and afternoon than during the night and dawn. Early morning is found to have the lowest air temperature throughout the day at around 28.5ºC to 29ºC. While during the afternoon the air temperature can rise up until 33ºC.

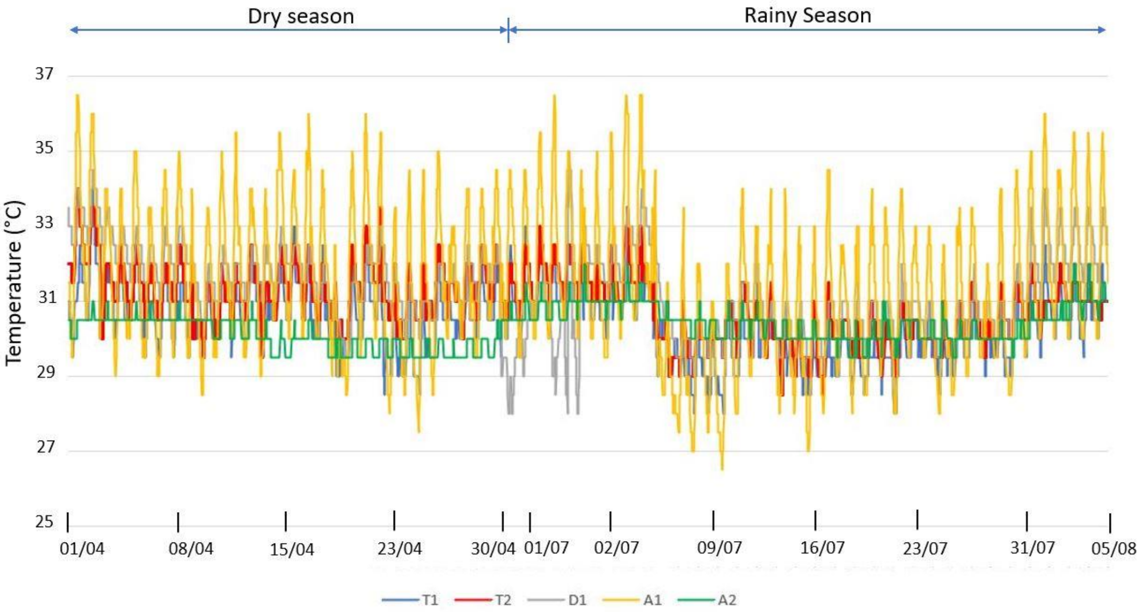

Figure 2. Air temperature of each case study building in both seasons (authors' compilation).

The apartments (A1, A2) show to have the highest and also lowest (31.81ºC, 30.85ºC) average air temperature while townhouses (T1, T2) have an intermediate air temperature (30.75ºC,31.37ºC). The detached house (D1) also has a high air temperature (31.76ºC). However, the air temperatures in each house are still close to each other. If we look at the houses that have the same type which are townhouse (T1, T2) and apartment (A1, A2), the average air temperature difference between T1 and T2 is only 0.4ºC to 0.7ºC. T1 that was built in 1997 has always a lower temperature than T2 that was built in 2015. The floor plan, the construction material and the structure of both houses are the same and both measurement sensors were placed in living room. However, as T1 has 4 floors and T2 only has 1 floor and a mezzanine. T1 is less exposed to the direct sun-light, hence the lower floor tends to have lower temperature than the upper floor. Moreover, floor of T1 has a higher ceiling height than T2 which let the wind to circulate better which also led T1 to have a lower temperature in building than T2 as well.

On the other hand, A1 and A2 have a big difference of temperature between each other. The temperature in A2 is between 0.72ºC to 1.76ºC lower than in A1. The temperature in A2 is also much more constant than A1 as it wasn't occupied during the measurement period. The A2 is also situated in the middle of the building while A1 is situated just under the rooftop, which mean that A1 receive not only the heat from the façade but also from the roof. The detached house (D1), which has the highest air flow among the chosen case study as there are a lot of open spaces surrounding the building, however shows to have the second highest average temperature (31.76 ºC). This show that the type of the house can’t define exactly their thermal comfort level but it depends of course on how the house is situated, how its façade is exposed to the direct sunlight and the architectural design concept.

Between dry and rainy seasons, there isn’t a significant difference in terms of air temperature and each case study has a similar level of indoor air temperature. The in-door air temperature follows the outdoor temperature, with dry season having 1ºC or 2ºC higher than rainy season. However, as the rainy season brings a cooler air, due to Moonson weather, it tends to make people much more comfortable in the building, especially during and after the rain.

Compared to the standard comfort temperature in tropical region that have been studied in previous research, even if it is higher than the international standard, the average air temperature that we observe in each house is still unacceptable. The temperature in all case study building is relatively 1 to 3ºC higher than the standard for tropical region in both seasons.

3.3. *Relative humidity*

For relative humidity, the average in dry season is between 65% (A1) to 72% (D1) and between 67% (A1) to 70% (T1) in rainy season. Figure 3 shows the evolution of relative humidity of all case study buildings in both seasons. In the morning the humidity relative can rise until 77% and it can go down until 60% during the afternoon. The relative humidity during the day stays in range of less than 70% and is normally higher than 70% during the night.

Similar to temperature, comparing between the different types of housing, the relative humidity in apartment (A1, 66%) is the lowest and highest for detached house (D1,72%) while the townhouse always stays in the middle (T1, 69%). Even with a higher amount of rain that falls during the rainy season than the dry season, the difference of relative humidity between the two seasons isn’t significant. However, contrasting to the air temperature, the average relative humidity in all 5 case study buildings is very close to each other in rainy season and more different in the dry season.

In the hot-humid climate region, higher relative humidity can increase the dis-comfort percentage rapidly as the body can’t be able to sweat to cool down as quick as it should be. As we can see, the relative humidity during the day stays within the range of acceptable comfort standard for tropical region. However, as it stays at the highest number in the comfort range and as the occupants are more active during the day (high metabolism rate), people tend to find that the relative humidity is the cause of their discomfort. On the other hand, during the night, even with a relative humidity that is above the standard comfort, the occupant is mostly asleep and as the air is also cooler during that period, the percentage of discomfort wouldn’t increase as much.

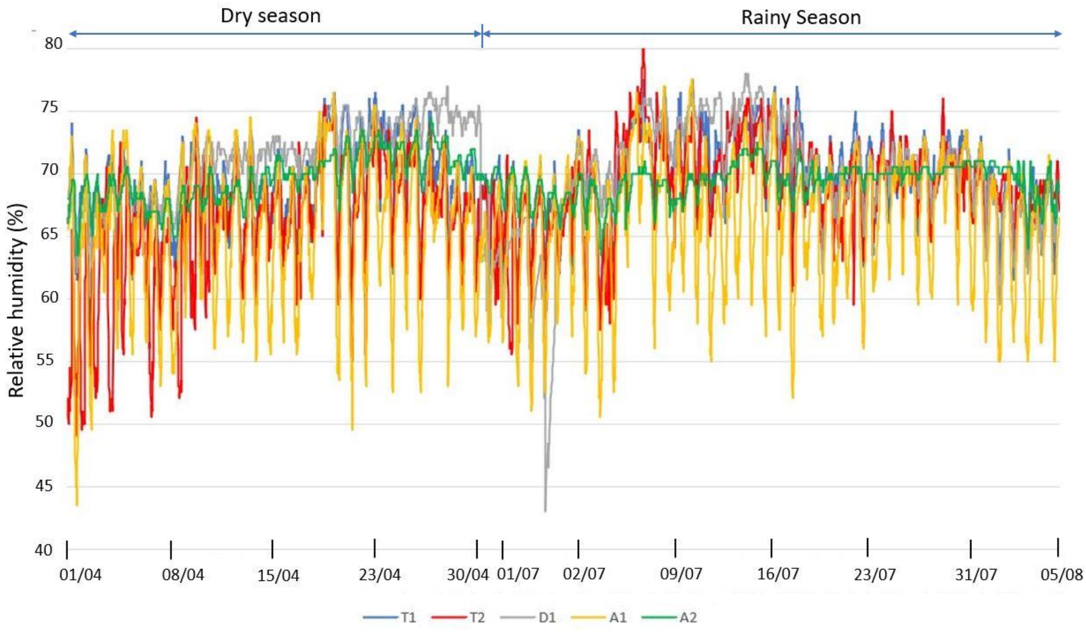

Figure 3. Relative humidity inside all case study buildings in both seasons (authors’ compilation).

3.4. Air velocity

Air velocity is the only parameter that wasn't measured in the dry season. However, as the outdoor wind speed between each season has a slight difference from each observed building, we assume it would be the same case for indoor air velocity. More than that, different ventilation conditions and outdoor weather play a more important role for measurement of air velocity. A significant difference that can be found between these two seasons is that the rainy season bring cool air while in dry season brings in hot air.

The results that we received are from the measurement by putting the sensor near to the window where the air flows into the room. On a normal sunny day, the average air velocity in living room (Figure 4) in each case study building in natural ventilation without help from the electrical fan is between 0.13 m/s (T1) and 0.04 m/s (A1). While on a windy day, the average air velocity is between 0.40 m/s (D1) and 0.11 m/s (A1). For the bedroom (Figure 5), air velocity on a windy day and a calm day are the same for town house with the average 0.02 m/s (T2). However, for the apartment, the air velocity on the windy day (0.24 m/s) is much higher than during the calm day (0.14 m/s). And for the detached house the air velocity can be much different as well, since the floor plan of the house allows more air to flow inside. With doors and windows all close, the air velocity in all case study building, whether in bedroom or living room, whether it's windy or not windy outside, the air velocity is relatively the same between 0 to 0.02 m/s.

When opening all windows and doors and turning on the electrical fan, the air velocity in the living room rises up to 2.28 m/s (D1) and 0.82 m/s (A1). The air velocity with the electrical fan turned on can depend also on the level of speed the occupant put it in. On a sunny and not windy day, the air velocity with the fan is between 2.33 m/s (T2) and 0.73m/s (A1) while on a windy day it stays at 2.22 m/s (T2) and 0.83 m/s (A1). During the measurement period, we can see that the air velocity with the help from electrical fan and all the windows closed is more constant than when the windows are opened. However, people still prefer to open their window when turning on the fan to ensure that the air is always fresh. This can also be the reason why people like to use air conditioner during the night time, since they have to close their window due to their need of privacy and security.

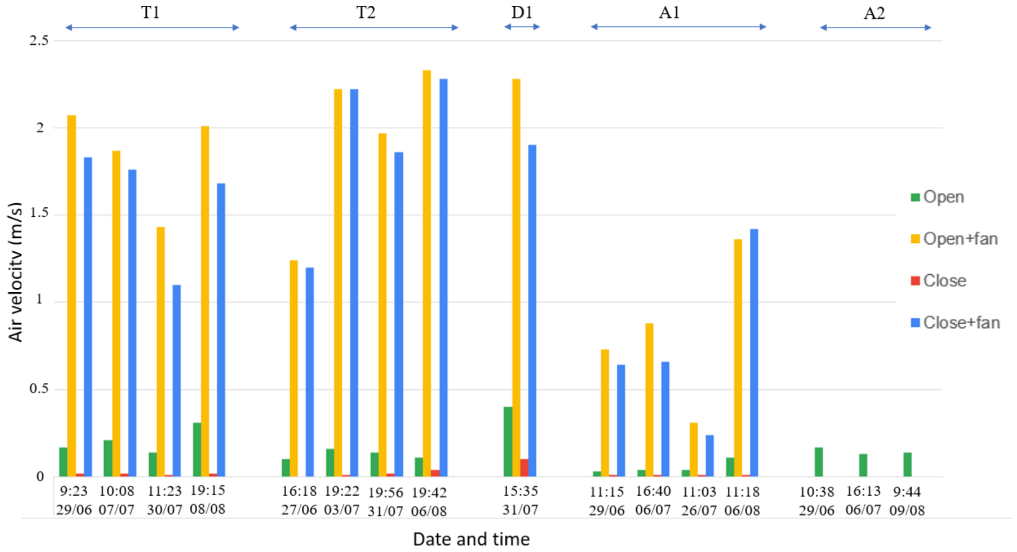

Figure 4. Air velocity in the living room of each case study building in different ventilation conditions (authors' compilation).

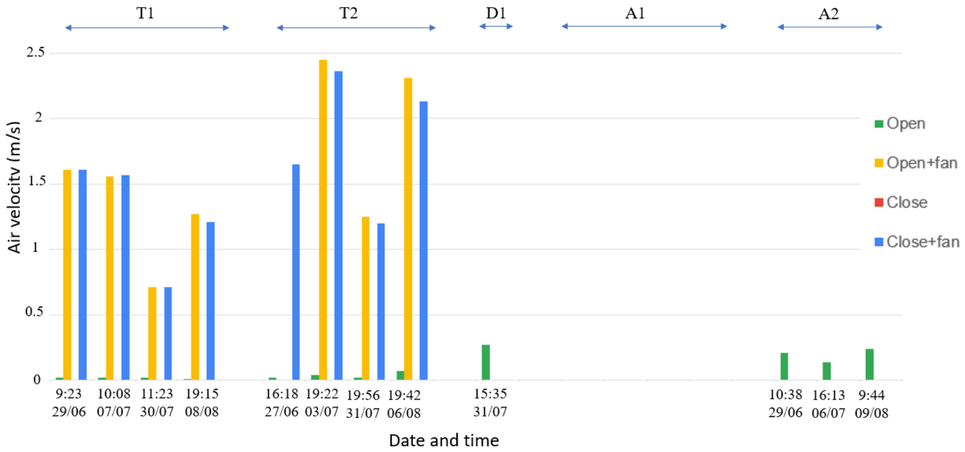

Figure 5. Air velocity in the bedroom of each case study building in different ventilation conditions (authors' compilation).

Overall, as the temperature and relative humidity is similar between each house, the air velocity plays an important role to make a difference of the thermal performance in the building. If we compare to the standard, beside the detached house, the air velocity in other case study buildings in the living room in natural ventilation conditions is below the acceptable range. Therefore, with the help of air velocity, the detached house would have a better thermal performance than the others. Further evaluation on how the difference between air velocity in detached house and other houses will influence on the occupant comfort will be discussed from the answer that we got from the inter-view with occupants in each house.

3.5. *Occupant survey*

We received 66 evaluations from online occupant survey which are only from the occupant in T1 as occupants in others buildings didn't put any answer to their survey. They are all female between 25 to 35 years old. The period of the survey is the same as the period of the measurement. Thus, it allows us to be able to identify at what temperature and relative humidity that the occupants feel comfort and discomfort in natural ventilation as they vote for their satisfaction and sensation to the thermal performance of the building. The comparison is given in the table below.

Table 2. Comfort level votes by occupant compared to data received from the sensor (authors' compilation).

T1	Comfort	Discomfort
Air temperature (°C)	29–30	31.5–34
Relative humidity (%)	73–75	67.5–70

From the comparison that we obtain, people in hot-humid region can really adapt to the higher temperature than the international standard comfort temperature from 3 °C to 4 °C. However, it highly depends on air velocity and outdoor environment. 90% of the data that we received saying that they are "comfortable in that temperature" is observed during the early morning and late night, when there is cold breeze coming into the house. As the answer from the survey is only from female and also from one type of house, we wouldn't advice to use this as an accurate standard yet. Further investigation needs to conduct to prove this statement as a standard comfort for climate in Phnom Penh, Cambodia.

3.6. *Occupant interview*

The interview was done at the end of each measurement in each season with each occupant who lives in the four case study buildings during the measurement period. All the occupants tell us that the temperature in their house is very hot. It is unacceptable during the noon and afternoon and slightly acceptable during the night. On a sunny day, the occupants who live in the townhouse and apartment have to use electrical fan 24/7 to make them feel comfort inside their house, while the occupants who live in the detached only use it during noon, afternoon and when they go to sleep. On the other hand, on a windy or rainy day, all occupants use the electrical fan only during the noon and when they go to sleep. However, they found themselves often ready to turn off the fan at dawn.

As the temperature and relative humidity are similar between each house, the air velocity appears to play an important role to make a difference of the thermal performance in the building. Therefore, the occupants who live in the detached house which has the highest air velocity, feel more comfortable than the others. Nevertheless, the use of electrical fan is still necessary even if the air velocity stays within the comfort range in order to make the occupant feel thermally comfortable and when the air temperature is too high during the afternoon which is a similar finding to the study of Feriadi and Wong [8].

The interview during the measurement of air velocity also led us to define that, with fan ventilation of air speed of 1.4 to 2.33 m/s, the occupants can tolerate to air temperature from 31.5 to 32.5ºC and relative humidity from 67 to 75%.

3.7. Comparison of Fanger's model

The Fanger's model is one of the methods that used to evaluate thermal performance of building based on calculation of influenced parameters result in predicted mean vote (PMV) in a scale from -3 (very cold) to +3 (very hot) [12][12]. Many researchers have been used PMV method to analyse thermal comfort of buildings in different climates including the tropics [13]. As the model were developed for cold weather country, many adaptive models have been created to be suitable with respective case study location especially for hot weather region such as tropics. An adaptive model has been proposed by researcher for the context of Malaysia by increasing limitation of PMV from ±1.0 to ±1.3 for 80% occupant satisfaction [14]. As it turns out, the adaptive model not only modified to adapt with the weather condition but also the social cultural of occupants as well [15].

To further evaluate on the thermal performance of the building, the Fanger's model method is used to calculate the PMV (Predicted Means Vote) to identify thermal comfort level of the building. The collected physical parameters such as air temperature (AT), relative humidity (RH) and air velocity (AV) are used for the calculation of PMV and it was done based on website https://comfort.cbe.berkeley.edu/ . Table 3 and Table 4 show the result that we received from the calculation (PMV_Cal) and compare them to PMV that vote by the occupant (PMV_Vote) during our interview in natural and electric-fan ventilation.

Table 3. PMV calculated and PMV vote in natural ventilation (authors' compilation).

Building	**AT (ºC)**	**RH (%)**	**AV (m/s)**	**PMV_Cal**	**PMV_Vote**	**Difference PMV**
T1	30.50	67.50	0.17	1.44	2.00	0.56
T1	29.00	73.00	0.21	1.02	1.00	-0.02
T1	30.00	70.50	0.14	1.51	3.00	1.49
T1	31.50	73.50	0.31	1.38	0.00	-1.38
T2	33.00	58.00	0.10	2.19	2.00	-0.19
T2	32.50	62.50	0.16	2.03	2.00	-0.03
T2	31.50	68.50	0.14	1.99	2.00	0.01
T2	31.50	67.00	0.11	1.99	2.00	0.01
D1	32.00	67.00	0.40	1.40	0.00	-1.40
A1	33.50	61.50	0.03	2.03	3.00	0.97
A1	29.00	71.50	0.04	1.59	3.00	1.41
A1	30.50	68.50	0.04	1.69	3.00	1.31
A1	32.50	64.00	0.11	2.16	3.00	0.84
A2	30.50	69.00	0.17	1.46	2.00	0.54
A2	30.50	70.00	0.13	1.62	2.00	0.38
A2	30.50	73.00	0.14	1.64	2.00	0.36

Table 4. PMV calculated and PMV vote in electric-fan ventilation (authors' compilation).

Building	AT (ºC)	RH (%)	AV (m/s)	PMV_Cal	PMV_Vote	Difference PMV
T1	30.50	67.50	2.07	0.54	-1.00	-1.54
T1	29.00	73.00	1.87	0.20	-1.00	-1.20
T1	30.00	70.50	1.43	0.57	0.00	-0.57
T1	31.50	73.50	2.01	0.96	-1.00	-1.96
T2	33.00	58.00	1.24	1.32	0.00	-1.32
T2	32.50	62.50	2.22	1.08	0.00	-1.08
T2	31.50	68.50	1.97	0.92	0.00	-0.92
T2	31.50	67.00	2.33	0.52	-1.00	-1.52
D1	32.00	67.00	2.28	0.69	-1.00	-1.69
A1	33.50	61.50	0.73	1.66	-1.00	-2.66
A1	29.00	71.50	0.88	0.13	-1.00	-1.13
A1	30.50	68.50	0.31	1.20	-1.00	-2.20
A1	32.50	64.00	1.36	0.96	0.00	-0.96

The Fanger's model show that all case study buildings consider hot in natural ventilation. There's always a difference between PMV_Cal and PMV_Vote. The PMV_Vote should be lower than PMV_Cal considering that people from tropical region can tolerate higher standard of comfort. However, the PMV_Vote turns out to be higher than the PMV_Cal when the air velocity is low. When the air velocity starts to rise above 0.30 m/s, the PMV_ Vote becomes lower than PMV_Cal which follow the above statement. The difference of the PMVs starts to rise higher when the air velocity starts to rise higher as well as seen in the case of electric-fan ventilation. The difference of PMV also shown to be varies from each other when there is a higher difference in the air velocity as appear in the case of T1. This shows that the Fanger's model which was developed for temperate climate region didn't take into account the importance of air velocity for hot-humid weather. While in electric-fan ventilation PMV calculated show that the buildings are still considered slighter hot, the PMV vote are either neutral or slightly cool. Even though turning on the electric fan make them feel slightly cold, people in tropical region still prefer to use them in order to make them feel satisfied. Hence, the use of PMV to predict thermal performance of building in tropical should be done only with some modification to the equation or create an adaptive PMV (a-PMV) model. The subjective part of Fanger's model should be adapted. The modification or the proposed a-PMV model should take into account not only the climate condition but also the social cultural and ethnicity of occupant as example for the a-PMV model that was done for case study in Malaysia, China and Benin [13] [14][15].

4. Conclusion

Even if people from tropical region can adapt to higher temperature, the naturally ventilated residential building still can't provide enough thermal comfort to occupants. Overall, during both dry and rainy seasons the temperature in houses is 1 to 3ºC higher than the acceptable standard temperature in tropical regions. With a high temperature and a relative humidity higher than the range of acceptable standards provided by previous research, it led to significantly higher discomfort percentage as the body can't cool down rapidly as it requires to do. Consequently, air velocity appears as a factor that highly contributes to the comfort of occupant in naturally ventilated houses in the hot-humid environment. As a result, even with higher temperature the occupants in detached house declared to feel more comfortable than the others as it has better performance of airflow and the highest air velocity. The importance of air velocity for thermal comfort in tropical region also appears in the comparison of Fanger's model. Whether the building is occupied or not is also influenced on the performance of the building as the building that isn't occupied by people has a lower temperature and is more constant. An acceptable value of physical parameters for comfort for female aged between 25 to 35 years old has also been defined from the survey with temperature of 29 to 30ºC and humidity of 73 to 75% in natural ventilation. And with the help of electrical fan generation of air speed from 1.4 to 2.33 m/s is observed and, people can tolerate to air temperature of 31.5 to 32.5°C and relative humidity of 67 to 75%. However, a much larger scale of survey needs to be done to make sure that this standard is applicable.

An energy simulation software such as EnergyPlus or TRNSYS, calibrated on the measurements, would be interesting to use to analyze the thermal performance of the building throughout the whole year. With a lot of integration of BIM in construction sector, a thermal performance investigation using BIM model with Green Building Studio would be a valuable extension of this research.

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