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Development of a Passive House Standard for Tropical Climates (Indonesia) - The Initial Stage

Santy[#1], Hiroshi Matsumoto[*2], Lusi Susanti[*3]

[#1]*Industrial Engineering Department, University of Pembangunan Nasional Veteran Jakarta*
JL RS Famawati, South Jakarta, Indonesia

[#1,*2]*Department of Architecture and Civil Engineering, Toyohashi University of Technology*
Aichi Prefecture, Toyohashi-shi, Tenpaku-cho, Hibarigaoka 1-1, Japan

Industrial Engineering Department, Andalas University
Limau Manis, Padang - West Sumatera Indonesia

[1]santy@upnvj.ac.id
[2]matsu@ace.tut.ac.jp
[3]lusi@ft.unand.ac.id

Abstract

Research on thermal comfort in residential buildings in Indonesia is limited. Previous research in this field indicates that compared to Western thermal comfort standards, such standards (ASHRAE 55, EN 15251, ISO 7730) are believed and have been proven to be higher for Indonesian people due to different historical experience of climate. Therefore, the present study attempted to develop a new predictive thermal comfort standard suitable for Indonesian people. This standard aims to provide minimum requirements for acceptable indoor thermal environments. On the other hand, in order to feel comfortable, Indonesian people often tend to use mechanical fans or air conditioners to cool their environment. Results of data collection from eighteen households showed that the electricity consumption for cooling needs in several cities in Indonesia ranged between 16-25% of total consumption, and ranked as the second highest use among the total consumption. The challenge is how to reduce household energy consumption without compromising the comfort level of occupants. For this aim, it is necessary to develop a passive house standard for a tropical climate region like Indonesia. This paper presents the initial stage of this project by outlining the current climate in Indonesia, characteristics of typical houses, their temperatures and electricity consumption. Thermal comfort vote was also collected to investigate feelings regarding thermal environments in the residential buildings.

Keywords–thermal comfort; tropical climate; passive house; energy consumption

1. Introduction

In this era of modern technology, the tendency to use technologies for heating or cooling to maintain indoor thermal comfort is increasing. This habit results in consuming a large amount of energy and has led to a deficiency of fossil-fuel reserves on the earth. In addition, greenhouse gases such as CFC (chlorofluorocarbon) released by cooling and heating devices have had a significant role increasing pollution. There are also many types of diseases that can be generated from these gases. All of these problems have garnered the attention of many researchers. One of the solutions offered by some researchers to the problems described above is to look back to vernacular design principles with the use of natural ways to grant indoor comfort to occupants.

There are many design principles that can be used to reduce dependence on heating and cooling devices to achieve comfortable conditions, including natural ventilation, shading devices, thermal insulation, radiant cooling, evaporative cooling, etc. A house which utilizes such principles without the use of active space heating or cooling is called a passive house [1].

In the database on passive houses around the world compiled by iHPA, Passive House Institute and Affiliates, there have been 1,883 single detached family houses registered as passive house in several countries, but none in Indonesia. In point of fact, the development of passive houses in Indonesia is an urgent matter. The population of Indonesia increases every year and this leads to ever-increasing energy consumption. Passive houses are expected to suppress energy consumption, especially for cooling energy needs. Previous research in Indonesia found that cooling energy consumption in Yogyakarta, Bandung and Padang were about 25% [2],16% [2] and 17% [3] of each city's total energy consumption, respectively. Although Indonesia is located on the equator and subject to a summery climate throughout the year, it is still necessary to reduce the energy demand of cooling through proper house design and the environmental control thereof.

This paper presents the initial stage in the development of a passive house standard for Indonesia's tropical climate. In this stage, a field investigation on the climate, current characteristics of houses and their energy consumption was carried out. Thermal sensation vote was also done to investigate comfort temperature for occupants. All these data are needed to simulate energy performance in typical houses in Indonesia.

2. Indonesian Climate

First, outdoor and indoor relative humidity and temperature data were collected from eighteen houses in Depok, West Java (Fig. 1), very close to South Jakarta. In previous research, the climate of this city was in line with the majority of cities in Indonesia. Data collection was done using a thermometer (ESPECMIC RS-12) for one week and set to record every hour.

The device was located in the living room where the occupants spent the majority of their time in the house. Furthermore, for purposes of analysis, the data is categorized into four time zones: morning, noon, evening and night, as shown in Table 1. The time zones are based on the peak trend during 24 hour surveillance. Furthermore, the zones will also be used for investigation of occupants' awareness of comfort in the outline of the next section.

Results in Fig. 2 and 3 show the relationship between indoor and outdoor air temperature and relative humidity in the morning, noon, evening and night. In these figures, differences can be seen in the scatter distribution of air temperature and relative humidity at the four time zones. Regression lines were also drawn to demonstrate the relationship of outdoor and indoor air temperature and relative humidity. The result shows a positive value for the regression coefficients, both for air temperature and relative humidity. Thus, the coefficient of determination (R2) was lower than 0.5, which reveals that the outdoor air temperature/humidity was not good enough to predict the indoor air temperature/humidity. One possible reason for this may be the various kinds of materials used in the construction of each house. It is well-known that building envelope materials affect how heat transfers from outdoor to indoor. In addition, Fig.4.a demonstrates that the average indoor and outdoor air temperatures ranged between 25.6-35.5 ^{o}C and 28.8-30.9 ^{o}C, respectively. The indoor and outdoor relative humidities ranged between 54.5-60.1% and 43.2-71.9%, respectively. The air temperature was highest at noon at 35.5 ^{o}C, and on the other hand the relative humidity was decreased to its lowest around 43.2%. The difference between indoor and outdoor temperatures ranged between 1 ^{o}C (night) to 4 ^{o}C (noon), and the differences in relative humidity between indoor and outdoor were 1% (evening) and 12% (morning), respectively.

Fig. 1 Map of Indonesia and data collection area

Table 1. Time grouping within a day

	morning	Noon	evening	night
Time	06.00 - 08.00	12.00 - 14.00	17.00 - 19.00	20.00 - 22.00

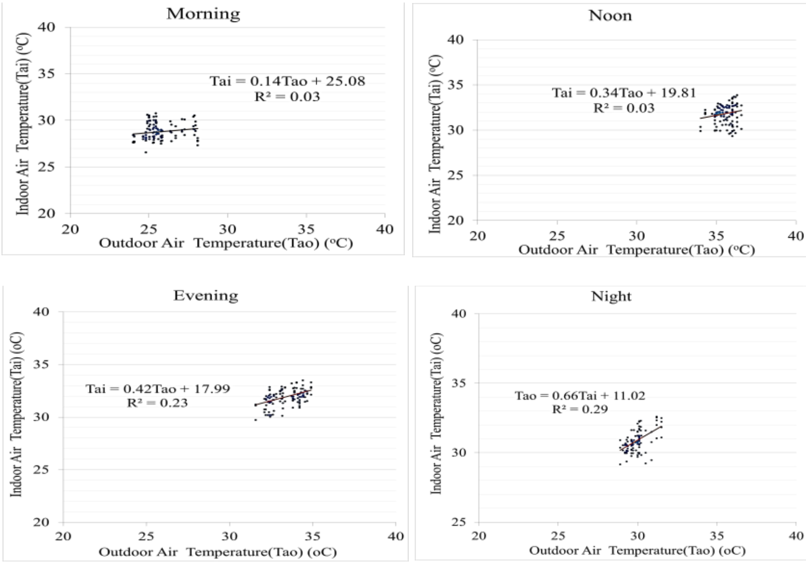


Fig. 2 Outdoor vs indoor air temperature

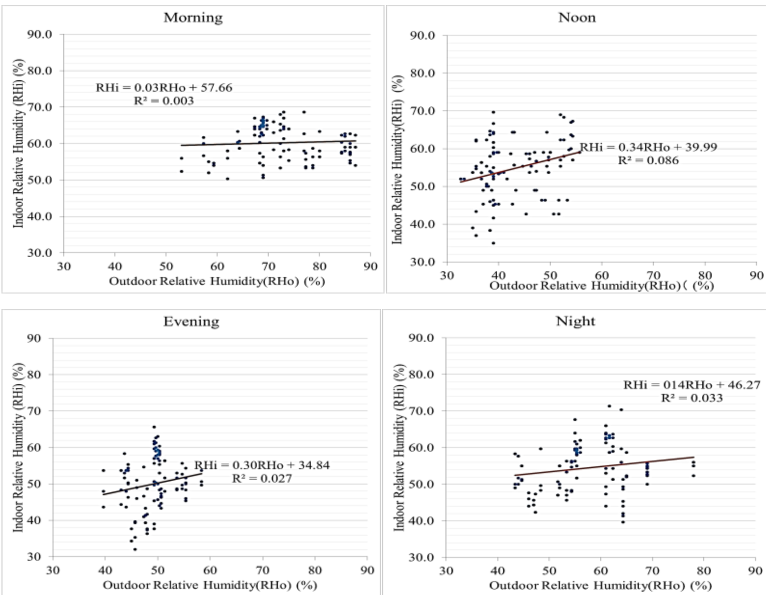
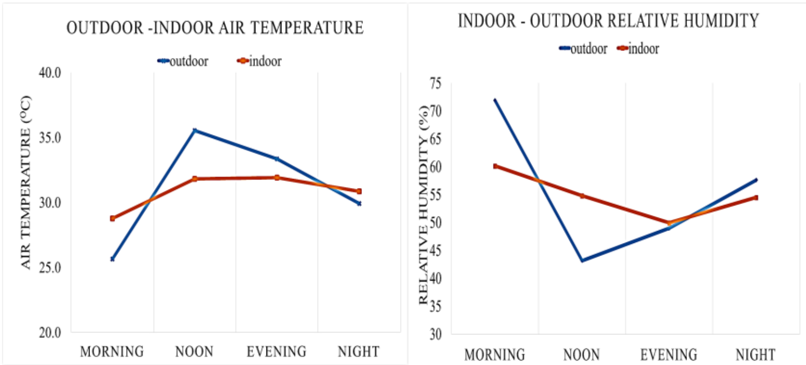


Fig. 3 Outdoor vs indoor relative humidity



(a) (b)

Fig. 4 Average air temperature (a) and relative humidity (b) in a day

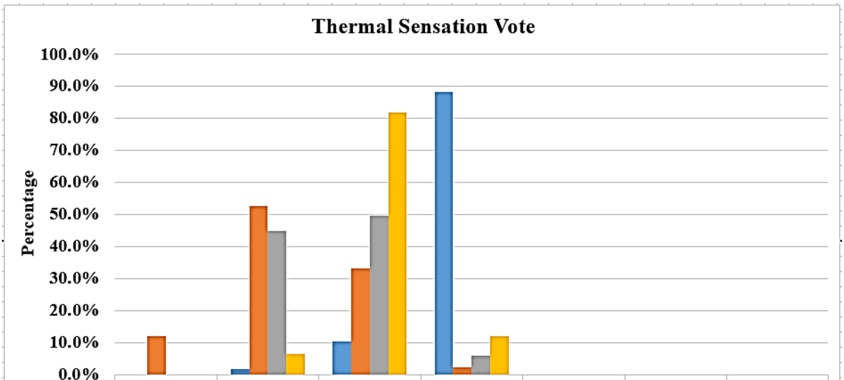
3. Thermal Comfort

Two occupants from each house (36 subjects total) were asked to fill out the thermal sensation vote(7 ASHARE Scale) when they were at home for a week. They had to fill out the thermal sensation vote at four time zones as shown in Table 1. In total, 916 votes were collected. They were asked to stay in the living room for about 15 minutes before they filled out the questionnaire. This is because of the body's precondition to maintain the same metabolic rate, which is estimated to be 1.0 Met.

Results in Fig. 5 exhibit the percentage distribution of votes. In the morning, most of the occupants (88%) feel "neutral" (Scale 0), but at noon 52.6% feel "warm" and 33.1% feel "slightly warm". In the evening about 44.7% feel "warm" and 49.4% feel "slightly warm", and in the evening, most of them feel slightly warm. The interesting point is that they never feel cold within a day when the mean daily temperature is 30.8^{o}C.

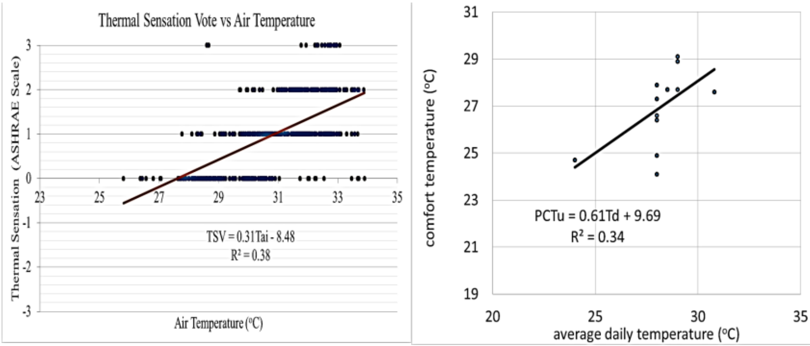
In order to know the neutral temperature, regression analysis was done for the indoor air temperature and thermal sensation votes (Fig. 6.a). Based on this regression, the neutral temperature was found to be 27.6 ^{o}C which was slightly lower than that found by Feriadi and Wong [4] in Yogyakarta, where the comfort temperature was estimated to be 29.1 ^{o}C for a daily mean temperature of 29 ^{o}C. Furthermore, the result of the present study was in line with Karyono [5], which compiled research on thermal comfort in various kinds of buildings in Indonesia. The research disclosed that a neutral temperature for people in Indonesia was about 27 to 28 ^{o}C, which is higher than the current national standard (24.5-27 ^{o}C) (SNI 6390:2011). In addition, Sujatmiko [6] observed the level of neutrality, acceptability and thermal preferences of the occupants in naturally ventilated buildings in Bandung, Semarang and Bekasi, and asserted that the acceptable operative temperature was between 22.8 to 30.1 °C. This range is quite wide due to large differences in the daily mean temperature between Bandung (24°C) and Semarang/Bekasi (28°C). Yet, the regression equation of indoor dry bulb temperature and neutral temperature revealed a tendency similar to that of the present study, which showed the comfort temperature to be 27.5 °C.

Karyono compiled thermal comfort research in various kinds of buildings in Indonesia and suggested a simple regression equation to predict comfort temperature (PCT) [5]. This regression was the result of daily mean temperature and comfort temperature data from several studies in Indonesia. Yet, this equation was validated only for locations with daily mean temperatures between 24 and 29 °C. Therefore, this equation should be improved by the result of the current research. An upgraded PCT (PCT_u) was developed by adding the comfort temperature obtained in Depok. As a result, this equation can be applied for a wider range of daily temperatures than the previous one, from 24–30.8 °C. This equation is proposed to predict comfort temperatures in Indonesia and also serves as an essential element to the development of passive house standards in this country. This equation can be applied to specify the housing design that can achieve this comfort temperature in the specific daily temperatures defined by this study.



	3	2	1	0	-1	-2	-3
morning	0.0%	1.6%	10.3%	88.1%	0.0%	0.0%	0.0%
noon	12.0%	52.6%	33.1%	2.3%	0.0%	0.0%	0.0%
evening	0.0%	44.7%	49.4%	5.9%	0.0%	0.0%	0.0%
night	0.0%	6.3%	81.7%	11.9%	0.0%	0.0%	0.0%

Fig. 5 Percentage distribution of thermal comfort votes



(a) (b)

Fig. 6 (a) Thermal sensation votes and (b) Predictive comfort temperature (upgrade)

4. House Characteristics

House characteristics of 18 houses in Depok were compiled in Table 2. The majority of the houses (78%) are detached houses. Depok is attached to South Jakarta which has a population density of 6.863 people/km^2, and classified as a high density region [7]. Most workers in Jakarta live in the BODETABEK (Bogor, Depok, Tangerang and Bekasi) area encircling the province of DKI Jakarta, and they usually commute every day to their workplaces. This is due to the strong demand for houses, but due to land limitation, detached house is preferred than town house. Most of the house's wall are made of concrete brick and bricks, plus a few made of hebel (aerated concrete brick). The low price of concrete bricks was the reason for this choice. Flooring material is dominated by ceramics, especially to give a sense of cooling within a house. Roof and ceiling materials are mostly tiles and gypsum respectively. Latex paint with various light colors such as white, avocado, and light blue are chosen by the resident. The ceiling height was 3 m on average and average wall thickness was 13 cm. The window material is dominated by tinted glass (black) to retain heat and sunlight, and finally reduce the cooling energy requirement. The window's type is mostly awning, which gives more privacy to the residence.

In the future, all this information will be used to design a typical house in order to know the energy performance. EnergyPlus software will be utilized for this purpose. The results should also be compared with the energy performance in the passive house design in the future to validate and prove the eminence of the passive house over the typical house.

Table 2 House Characteristics

House characteristic		Percentage	House characteristic		Percentage
House type	Town house	22%	Ceiling height	=< 3	89%
	Detchad house	78%		> 3	11%
Storey	1	83%	Thickness of wall	=< 13	50%
	2	17%		> 13	50%
Number of rooms	=< 6	50%	Paint colour	Various	0%
	> 6	50%	Paint material	Latex	100%
Wall material	Bricks	39%	Windows type	Cesement	22%
	Concrete bricks	50%		Awning	78%
	Hebel (Aerated Concrete Brick)	11%	Windows material	Tinted glass	89%
Floor material	Ceramics	83%		Transparant glass	11%
	Tiles	11%	Doors material	Wood	100%
	Granite	6%	Orientation	West	22%
Roof material	Tiles	89%		South	28%
	Asbestos	11%		North	28%
Ceiling material	Gypsum	44%		East	17%
	Tripleks	39%			
	Bamboo	6%			
	Asbestos	6%			
	GRC board	6%			

5. Electricity Consumption

The electricity consumption of the 18 houses investigated is summarized in Table 3. Half of the households consumed electricity at a rate of 300-400 kWh/month, and this result was in line with Sukarno and Matsumoto [8] in Padang, which found the average electricity consumed to be 327.07 kWh/month.

In addition, Fig.5 portrays the average use of electricity consumption by a household. Cooling energy consumption was ranked second and this result was also in line with the previous research [2][3]. This cooling energy refers to the use of fans or air conditioners to provide a comfortable living space. Air conditioners and fans were used an average of 8 hours/day, but most of the households have more than one fan in the house, which means the total fan use was 16 hours or more. The price and ease of maintenance are potential reasons to choose fans for cooling devices rather than air conditioners. This electricity consumption will be employed as the standard and be compared to the consumption by the future passive house.

Table 3. Electricity consumption per month

	Percentage	Number of house
<300 KwH	29%	5
300KwH - 400KwH	59%	10
>400 KwH	12%	2
Total	100%	17

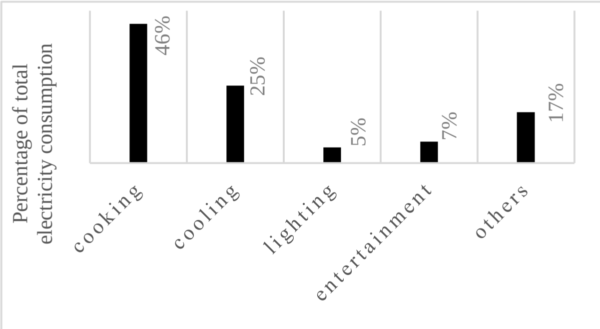


Fig. 5 Percentage distribution of electricity consumption

6. Conclusion.

This research is the initial stage for the development of a passive house for the tropical climate of Indonesia. At this stage, the relationships between indoor and outdoor temperature and humidity were shown. They do not have a significant correlation, except for indoor and outdoor relative humidity at noon. One possible reason for this result might be the various kinds and sizes of rooms, and house envelope materials. In order to develop a passive house, the occupant comfort temperature should be defined. An upgrade of predictive comfort temperature was modified from Karyono [5] due to a wider range of daily mean temperatures gained in this study.

In addition, future research needs to investigate the energy performance of current typical houses in Indonesia, and to compare with future passive house design. Moreover, the electricity consumption of the typical house in Indonesia, which ranges between 300-400 kWh/month, is relatively high and needs to be reduced as much as possible, by designing a passive house which adapts to Indonesian climate.

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