Thermally adapted design strategy of colonial houses in Surabaya

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Abstract. Colonial buildings, including houses, have been considered as a representation of climate-responsive architecture. The design was thought to be a hybrid model of Dutch and tropical architecture. It was created by way of reinventing tropical and Dutch architecture design principles, and expressed in a new form, i.e. neither resembling Dutch nor tropical building. Aside from this new image, colonial house does show good climatic responses. Previous researches on colonial house generally focus on qualitative assessment of climate performance of the building. Yet this kind of study tends to concentrate on building elements, e.g. wall, window, etc. The present study is designed to give more complete picture of architecture design strategy of the house by exploring and analysing thermal performance of colonial buildings and their related architecture design strategies. Field measurements are conducted during the dry season in several colonial building in Surabaya. Air temperature and humidity are both taken, representing internal and external thermal conditions of the building. These data are then evaluated to determine thermal performance of the house. Finally, various design strategies are examined in order to reveal their significant contributions to its thermal performance. Results of the study in Surabaya confirm findings of the previous researches that are conducted in other locations, which stated that thermal performance of the house is generally good. Passive design strategies such as mass effect and ventilation play an important role in determining performance of the building.

1. Introduction
Colonial houses and buildings scatter in many places around Indonesia. These buildings commonly share characteristics such as thick wall construction, large openings, big and steep roof, and considerable open space around the building. Passchier cited in [1] considered this building type as a hybrid architecture, which takes into account both Dutch architecture design principles and mode of construction, and tropical climate. Since this takes relatively new form, it, therefore, neither resembles Dutch nor tropical building.

Many scholars have studied in this subject, and they could focus on a formal or architectural aspect of the design, and on an environmental condition of the building. From the study of formal characteristics of colonial building of educational facilities in Yogyakarta [2], it was found that the building design commonly has a rectangular shape, symmetrical configuration, big volume of space and
rhyming composition. Rina and Meyka [3] also revealed similar characteristics but with different case, i.e. railway station. In the case of formal study of colonial building in Malang, Santoso et al. [4] stated that formal characteristics and construction of the colonial building is not only influenced by European architecture and construction, but also influenced by Chinese architecture as well as the traditional dwelling of Indonesia. This statement is similar to that claimed by Passchier.

Regarding the environmental aspect of the colonial house, some studies revealed the success of its climatic response. Santosa [5] who did research on the thermal adaptability of three type of buildings in Surabaya (i.e., traditional, modern and colonial) found out that thermal performance of the colonial house was higher than the other two buildings. An increase in an opening area, however, did not have a significant thermal contribution in both Colonial and Modern house. Other studies which focus on the adaptability of a colonial office building to the warm-humid climate of Semarang also ends up with similar conclusion [6][7].

The above studies indicated that colonial buildings built in tropical climate have succeeded to put climate as its design reference. This indication underlines that specific characteristics of the building a logical consequence of building occupying a place. As Ball [8] noted, all architecture is influenced by climate. The reason for this is building is required to protect internal conditions from unwanted climatic influences and to provide protection that can shield the building from detrimental impact of climate.

The present study is designed to explore design strategy of a medium-size house of colonial type of building. It is meant to be a complement to previous studies that primarily concentrate on office buildings and small houses. This study will analyze and evaluate the thermal performance of the building to explore its climatic design strategy and adaptability with the warm-humid climate of Surabaya.

2. Method
The present study use field measurement as the research method. Detail of the methods is as follows.

2.1. Field measurement
Indoor and outdoor thermal conditions in two colonial houses in Surabaya are recorded over a three-day period. Two thermo-hygrometers were used to record hourly air temperature and relative humidity in two rooms, namely sleeping, and living room and mini weather station was employed to record outdoor climatic conditions. The internal thermal measuring instruments were located at 120 mm above the floor and in the centre of the spaces. The weather station is allocated at the back, and courtyard of the houses.

The two houses are in urban areas, i.e. Sutomo street (H1-Sutomo) and Musi street (H2-Musi). Area of the first building is 157.7 m² and the second is 236.5 m². The colonial house considered in the study were those that have minor physical modifications and small building extensions. Drawing depicting elevation of the two houses are illustrated in figure 1. below.

![Elevation of the two colonial houses under study: H1-Sutomo (a), H2-Musi (b)](image)

Figure 1. Elevation of the two colonial houses under study: H1-Sutomo (a), H2-Musi (b)

2.2. Analysis and evaluation
The first analysis conducted in this research is climate analysis to explore characteristics of the climate of the city, including its potencies and problems. The second is analysis on building form, configuration, and elements that are intended to explore design strategies used in colonial buildings. Comparison with
traditional house design is made to validate climatic adaptability of the building. Comfort evaluation is a method conducted to assess thermal performance of the dwellings. Basis of the evaluation used bioclimatic chart developed by Olgyay [9].

3. Results and Discussions
This section is ordered to present four parts of analyses and discussions. The first is climatic description and analysis. This part is then followed by analyzing thermal conditions and evaluating comfort level of the building. The final part describes design strategies used in the house.

3.1. Climate Description and Analysis
Figure 2 depicts average climatic conditions of Surabaya which are gathered from the MET Office of Juanda. From this figure, it can be said that city of Surabaya is hot and humid. This condition is indicated by high average air temperature (28-30 °C), high solar radiation (up to 1200 W/m2), and high relative humidity (max. average RH is 80%). This condition represents a typical climatic condition in warm-humid regions. People in this type of climate tend to suffer constant overheating during the day and almost throughout the year. As can be seen from figure 2c, wind speed is low (2.6-3.6 m/s), and can drop up to half of it when it reaches an urban area that is characterized by dense physical development. In this regard, the reliance on wind as a means of restoring comfort can be difficult to attain.

The city is typically wet as it is indicated by high monthly rainfall (280-400 mm), especially during the rainy season (figure 2b). The sky is overcast, and the sun shines within a range of 42-85% out of its possible sunshine hours (figure 2d). This condition prevents heat dissipation towards the atmosphere and thus worsen the thermal condition in the city. Szokolay considered this characteristic as a condition which is not easy to handle [10]. Careful climate and design analysis become a prime concern of architect in this area.
3.2. Thermal Conditions of the House
Indoor air temperatures in H1-Sutomo showed fluctuation within a narrow range of 21-31 °C (figure 3a). If these conditions are compared with those of outdoors, it can be seen that indoor air temperatures are lower during the day than the outdoors, whereas during the evening and night the conditions are warmer. The building modified the wide fluctuated profile of outdoor conditions and turned it into flat temperature profiles. Maximum indoor air temperature is about 1 °C lower than the outdoors, while minimum temperature is 2 °C warmer. There is no significant difference found between thermal conditions in the sleeping room and living room.

![Figure 3a. Thermal condition in the colonial house H1-Sutomo: air temperature](image)

![Figure 3b. Thermal condition in the colonial house H1-Sutomo: relative humidity](image)

**Figure 3.** Thermal condition in the colonial house H1-Sutomo: air temperature (a), relative humidity (b)

Conditions of air humidity show similar pattern with those of air temperature. As shown in figure 3b, during the evening and night relative humidity (RH) tend to be dryer (70-75%) as compared to that of outdoors (max. 85%). During the day RH falls within 65-73%. Minimum indoor RH is around 66%, and minimum outdoor RH is about 61%. Conditions in the sleeping, and living room showed no significant difference in terms of RH.
Observation of the profile of air temperature in H2-Musi revealed a similar tendency to that of house-1. Outdoor air temperatures which range from 27-35 °C (8 °C difference) are modified by the house in such a way that indoor air temperatures fluctuate from 29-31.5 °C (2.5 °C difference). It follows that the building can prevent heat from entering interior space during the day, and dissipate some of the heat gain and retain some of that heat inside during the night. Indoor air temperature of the living room in the house-2 was recorded to be lower in comparison with that of sleeping room. The difference can reach 1 °C in the morning. The disposition of the space and characteristics of its envelope seem to have an influence on this condition.

![Graph showing temperature and humidity trends](image)

**Figure 4.** Thermal condition in the colonial house H2-Musi: air temperature (a), relative humidity (b)

Similar to those conditions experienced in H1-Sutomo, Indoor RH during the evening and night are also found to be lower (max. 70%) than those of outdoors (max. 78%). Conversely, indoor RH are higher (min. 57%) than those recorded outdoors (min. 45%). This condition can be beneficial when air temperature is high during the day, but it can pose a problem during the night when the indoor condition still warm. Examination concerning how this thermal environment contribute to comfort is presented in the following paragraph.
3.3. *Thermal Comfort Evaluation*

Thermal performance of the building was evaluated by plotting thermal condition onto the bioclimatic chart and examining the conditions that fall within a comfort zone. Those that are within the comfort zone are those which regarded as comfortable. As can be seen in figure 5, the indoor thermal conditions of the house are well above the comfort zone. This follows that both H1-Sutomo and H2-Musi suffer from overheating. Combination of air temperature and air humidity is not yet able to promote comfort inside the house. In this figure it can also be seen that outdoor thermal conditions are also found to be outside of the comfort zone, but are close to those of indoors.

![Thermal comfort zone chart](image)

**Figure 5.** Thermal comfort evaluation of the colonial house: H1-Sutomo (a), H2-Musi (b)

Figure 5 also shows the possibility of utilizing air movement to restore comfort in the building. Wind speed of 0.4 m/s can extend the comfort zone to include almost all of the indoor thermal conditions in this comfortable area. Outdoor conditions recorded in H1-Sutomo are all within the extended comfort zone, while small observation of outdoor thermal conditions in H2-Musi fall outside the comfort zone.
Results of this analysis indicate that even though the colonial building can reduce air temperature well below the outdoors, this condition could not manage to provide the comfortable indoor environment for their occupants. However, with the help of air movement with a speed of at least 0.4 m/s, the comfortable condition may be promoted in the building.

3.4. Design Strategy

It is mentioned previously that thermal performance of the colonial building can be tied in with its design characteristics. Colonial houses were shaped by big and step roof, and it is equipped with high ceiling height. The house was constructed with thick-wall and large openings. The big roof and thick-wall construction contribute to the high thermal mass of the building, and this type of construction could prevent the high outdoor air temperature to directly penetrate the building, and hence could lower the indoor air temperature particularly during the day. However, during the night indoor air temperature could be warm as this is the consequence of having high thermal mass constructions. Table 1 below describes this specific thermal characteristics of the colonial building.

Large openings are important design feature of colonial building that can be employed to restore comfort when air temperatures are above comfort level. By allowing air to flow through the building, warm or hot air can be dissipated. This environmental strategy offer occupant to experience better thermal conditions in internal spaces both during the day and night. Existing design on the house indicated that window to wall ratio (WWR) of the building are about 24-25%. Ratio of opening to floor area are higher in comparison with standard minimum value for ventilation. H1-Sutomo and H2-Musi have ratio of 25% and 32% respectively.

| Table 1. Thermal properties of the building elements [10]. |
|----------------------------------------------------------|
| Building elements                                       | U-value (W/m²K) | t-lag (hours) | Dec-factor | Sgf |
|----------------------------------------------------------|
| Roof Pitched roof with terracotta tile, plasterboard ceiling | 2.52            | 0.39          | 1          | -   |
| Wall Single skin, 335 mm brick, plastered both sides     | 1.79            | 9.9           | 0.26       | -   |
| Window Operable 6 mm clear glass window-wood frame-shaded | 5.6             | 0             | 1          | 0.16|
| Door Wood panel                                         | 2.8             | 0.5           | 0.99       | -   |
| Floor Slab on ground covered by terrazzo tile            | 0.51            | 0             | 0          | -   |

Aside from the above characteristics, the position of space relative to others will have an influence on the thermal condition of the space. The characteristic is the case of the living room in the house-2 where this space is surrounded by many openings and doors from other rooms. By having this configuration, this room becomes permeable to air flow. As a result, warm air can be wiped out, and hence air temperature can decrease.

Design strategies adapted in colonial house to some extent have similarity with those of traditional dwelling [11]. This can be seen from the use of big and step roof. It represents a strategy for adapting to strong impact solar radiation and high rainfall. The use of opaque and thick wall is not a common characteristic of traditional buildings which usually adopt lightweight materials such as timber and bamboo. Yet there is a case where such heavyweight building material is used. This, for instance, can be found in Bale Daja of traditional Balinese house [12]. Openings are also common in traditional building, but the size is not as large as those of colonial building. High porosity of the wall compensate the slightly small openings of traditional house. Similarly, large opening of colonial building could be regarded as a form of compensation of the non-porous wall of this building.

The above discussion shows that colonial building design are largely in accordance with traditional house design strategies, and thus tropical climate design principles. Since the colonial building could have moderately low air temperature both during the day and night, the dwelling offers more freedom to the occupants. This, therefore, could be seen as an advantage for modern peoples.
The last strategy is in contrast with that of the traditional house which allows the building to be occupied only during the evening. In the past, traditional people tend to spend their time outdoors during the day, i.e. in farms and paddy fields.

4. Conclusions
Results of the present study validated the findings of the previous researches by [5][6][7] and [11] which deal with small houses and other building types. The above analyses and discussion show that colonial buildings are in general able to modulate the internal thermal condition in such a way that indoor air temperatures are lower than the external condition during the day and night, and slightly higher during the early morning. Indoor relative humidity tends to be low during the night and it is slightly higher than the outdoors. However, this resulted thermal conditions is not yet able to provide comfort for the occupants as far as the combined effect of air temperature and humidity is considered, but if the building can promote ventilation comfort can be experienced.

The study also shows that elements and formal characteristics of the building are thermally adapted with the warm-humid climate of Surabaya and conform with occupancy pattern of the modern house which allows occupant to use the building throughout the day and night. Results of the study also recommend designer of future tropical houses in Surabaya in particular and Indonesia in general to use the hybrid design strategy of the colonial building which is stemmed from tropical principles and the Dutch mode of construction.

Acknowledgements
The authors wish to acknowledge the support of Ministry of Research and Technology and Higher Education of the Republic of Indonesia for providing research grant under the scheme of Penelitian Unggulan Perguruan Tinggi (PUPT) ITS 2017.

References
[1] Peter JMN 2009 Masa Lalu dalam Masa Kini Arsitektur di Indonesia (Jakarta: Penerbit Gramedia Pustaka Utama)
[2] Jarwa PSH 2015 Jurnal Inovasi dan Kewirausahaan 4 (1) pp 21-30
[3] Rina W and Meyka W 2012 Jurnal Ilmiah Desain & Konstruksi 2 (11) pp 3-14
[4] Joko TS, Noviani S and Antariksa 2013 Jurnal Ruas 11 (2) pp 37-50
[5] Mas S 2001 Dimensi Teknik Arsitektur 29 (1) pp 34-42
[6] Leonardus M F P 2004 Dimensi Teknik Arsitektur 32 (2) pp 138-39
[7] Antonius A, Achmad D, Ikaputra and Jatmika A S 2015 International Journal of Scientific and Research Publication 5 (4) pp 1-6
[8] Torben D 2010 Climate and Architecture (Oxon: Routledge)
[9] Victor O 1992 Design with Climate: Bioclimatic Approach to Architectural Regionalism (New York: Van Nostrand Reinhold)
[10] Steve S 2004 Introduction to Architectural Science: The Basis for Sustainable Building (London: Architecture Press)
[11] Antonius A, Achmad D, Ikaputra and Jatmika A S 2014 DIMENSI Journal of Architecture and Built Environment 41 (1) pp 37-42
[12] Ciptadi T and Steven D 2011 FORUM Ejournal 10 pp 66-77