Indoor temperature in perimeter spaces on warm humid tropical courtyard housing model

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Abstract. In general, Indonesia housing provides open space at front and fence. Open space inside that expose to sky is predicated as inner courtyard. Housing provide open or green space on side rarely. In humid tropics, high temperatures most of the year have an effect on thermal comfort. To fulfill thermal comfort, a housing model with inner courtyards on side and fence is proposed. In this case, representation of warm humid tropic is Surabaya. Simulation method is used to predict indoor temperature of spaces in perimeter courtyard. Spaces located on inner courtyard perimeters are living room, bedrooms and kitchen. These rooms have duration of occupancy more than one hour. With the existence of these inner courtyards, inhabitants can connect with green open space. The result show, on the hottest month, side and fence of inner courtyard model could support indoor temperature. For 14 hours, living room and bedrooms in thermal neutral zone. Except kitchen, only for 4 hours in thermal neutral zone

1. Introduction
Global warming is an issue that has been widely discussed. It has an impact on rising temperatures and sea levels. Enhancement cooling energy use in urban areas as trigger global warming. Application of bioclimatic design is an effort to reduce the impact of global warming in urban area, in response to climate change. Bioclimatic design is a strategy for designing buildings in order to provide comfort for their occupants based on climatic conditions [1]. Degree of accuracy of climate analysis holds a key factor in the bioclimatic concept that is useful for designing buildings. Accuracy of climate analysis supports efforts for thermal comfort and energy efficiency. Climate analysis in bioclimatic should use microclimate data. Bioclimatic chart principally uses some climate elements [1]. It is still valid today with some adjustments [2]. On the bioclimatic chart, there is a comfort zone, where the user feels comfortable [3]. The comfort zone can be expanded by providing wind flow [4].

Several studies of bioclimatic have been conducted. Bioclimatic concept has been applied to the proposed design in the fishing settlement. The design aims to anticipate sea level rising [5]. Design considers climatic elements, namely temperature, wind speed and rainfall. The application of bioclimatic principles to building envelope materials can reduce cooling energy consumption, including the implementation of stack effect strategy can provide better thermal conditions [6]. Mapping of distinct climate zone in Madagascar region show thermal comfort range from 20°C to 26°C [7]. Bioclimatic designs are generally aimed to achieve thermal comfort or physiological cooling and energy savings.

Thermal comfort is a condition where residents feel comfortable with the surrounding temperature [4]. Humans are in thermal equilibrium if they are in normal body temperature, which is around 37°C,
while the body's skin surface temperature is around 31-34°C. In terms of comfort, temperature is the main factor in determining thermal comfort. Outside temperatures influence indoor temperature in building spaces. Neutral temperature is the basis that can be used to range of thermal comfort. Thermal comfort range is ±2.5K from neutral temperatures [4]. Previous research show that thermal comfort for Surabaya is at 24.5°C – 28.9°C [8]. Thermal comfort range for Thailand is in range 27°C - 31°C [9]. In general, buildings in dry tropics have courtyard, as a center of mass orientation. Courtyard building as a building that has an indoor or semi-outdoor open space [10] and [11]. The characteristic of courtyard is that one side of courtyard faces the sky. In Iran, courtyard support non-physical comfort for inhabitants [12]. In this study, courtyard is referred as inner courtyard.

Microclimate has a role in modifying outdoor thermal comfort. This is important so that users feel comfortable doing activities in the courtyard [11]. Research on indoor temperature has been carried out on 5 types of boarding house which have courtyards [13]. The results show that the indoors temperature are 4.9-7.3°C lower than the outdoor temperature for 12 hours. But at nighttime, it is higher around 0.8-1.3°C for 5 hours.

Research objective was to observe indoor temperature in perimeter spaces. These spaces are spread across the two-inner courtyard in a humid tropical area. Thermal conditions in these spaces are categorized as comfortable or not, especially when they are used. If the space is passively comfortable, the cooling energy usage can be reduced. Thereby, proposed model could participate in mitigation of climate change

2. Design method

Surabaya is a city located near the equator and has a high residential growth. Therefore, Surabaya is used as a representation of warm humid tropic urban housing. Field study was used as a tool to obtain characteristics of a model proposal, and typology of spaces in courtyard perimeter. It shows that housings have two inner courtyards, rarely. The application of courtyard is one of the responses to passive cooling strategies. Propose model has two inner courtyards, at side and fence, which are assumed to be in a grid patterned residential neighborhood. It has building covered ratio of 50%. Inner courtyard in this model has sky view factor in 0.7-0.8 or 70-80% open to sky. 20-30% of courtyard area shadowed by roof. Model canyon or height to width ratio is 0.4-0.6. This ratio has a higher opportunity of wind flow compared to another ratio [14]. Wind flow accelerates heat loss by convection process.

(a) First floor
Simulation used design builder V4.1, for prediction indoor temperature. Simulations are carried out for 24 hours in the hottest month. The observed spaces are located on perimeter of inner courtyard. These rooms have usage duration more than 1 hour per day. The spaces on perimeter of side inner court are living room and kitchen. Living room and kitchen windows are oriented to side inner courtyard. Both of bedroom windows are oriented to fence courtyard. All spaces utilize natural ventilation. Model applies jalousie as type opening. Application of natural ventilation is expected to reduce energy use. designs that apply natural ventilation are expected to be sustainable design. The simulation assumed that wall on the model using plastered bricks, painted white. Roof material is dark red concrete tile. Model proposal can be seen in figure 1.

3. Result and discussion

3.1. Climate analysis
In this study, hottest month was determined based on climate data for the last 10 years. The climate element used to determine the hottest month is temperature. Based on data, November has highest temperature. It is over upper neutral temperature. Climate data is obtained from Meteorology, Climatology and Geophysics Bureau (BMKG), Juanda-Surabaya. Figure 2 below shows the average temperature over the last 10 years.

In Figure 2, the highest air temperature is November. The highest temperature shows 30.25°C, while the lowest temperature is in July, around 26.9°C. For over 10-year, the difference in highest and lowest temperature is less than 5K. Based on equation, neutral temperature is 27°C [4]. Range of comfort zone is +/- 2.5. During January till September, outdoor air temperature has been in the upper limit of neutral temperature, except October-December.
3.2. Indoor temperature on side inner courtyard spaces

The facade of the model is oriented to North. Short side wall of inner courtyard wall is oriented to North and South, while the long side wall is oriented to East and West. East side is bordered 9 meters wall. Wall on East side block solar radiation at 06.00-09.00 a.m. Window in living room is oriented to the east, has 30% window to wall ratio. The window at kitchen parallel to short side of courtyard wall. It has 20% window to wall ratio. When both of rooms are used at 05.00-07.00 a.m. and 4.00-10.00 p.m. all windows are opened. Apart from these hour windows are closed. Figure 3 show the result of indoor and outdoor temperatures of the model in the hottest month

**Figure 2.** Average air temperature of Surabaya in the last 10 years

**Figure 3.** Indoors temperature in living room and kitchen, and outdoor temperature at side inner courtyard
The neutral temperature in this study is 27°C. Range of comfort zone are 24.5-29.5°C. Side of inner courtyard at 08.00 p.m. - 08.00 a.m. in comfort zone, but it is in the upper limit comfort zone. Except at 02.00-07.00 a.m., it is in the lower limit comfort zone. Outside temperature of side courtyard at 8 a.m. to 7 p.m. always above the comfort zone (see figure 3). Because the side courtyard is 70% open to sky. It means more exposure to solar radiation.

In the morning, living room is in a comfort zone. When inhabitants have activities in morning and at night, temperature in kitchen almost above comfort zone. It is caused by internal heat loads. It produces latent heats and sensible heats, such as stoves, rice cookers, dispensers. At 04.00-07.00 p.m., indoor temperature in living room is still above the comfort zone. This is influenced by outdoor temperature of side inner courtyard. Temperature is still above the comfort zone. From 08.00 p.m. till 09.00 a.m., living room is in the comfort zone. The volume of living room 3 times larger than kitchen volume, encourage slow down the heating process. At living room inhabitant can feel thermal comfort for 14 hours, or 60% of 24 hours, while at the kitchen feel comfort for 4 hours or 20% of 24 hours.

At nighttime outdoor temperatures of the side inner courtyard is in comfort zone. It provides an opportunity for heat loss convection from inside to outside building. Indoor temperature in the living room has always lower than the kitchen and side inner courtyard. The temperature difference between living room and inner courtyard approximately 0.5-1 K.

Around the side courtyard is a high wall, approximately 9 meter. On the west side is a brick wall painted dark gray. Time lag from materials previously exposed to the sun also contributes to the increase in the side courtyard temperature in the afternoon. Materials with high albedo and exposure to the sun can increase the temperature of the surrounding air during the day [15].

3.3. Indoor temperature on fence inner courtyard spaces

In contrast to the side inner courtyard, the long side of fence inner courtyard is facing to North-South, while the short side is East-West. East and South sides are shadowed by 9 meters high wall. During the day it receives heat from the West and South. This courtyard is almost 80% open to the sky.

![Figure 4. Indoor temperature at perimeter spaces of fence courtyard housing model](image)

At 08.00 a.m.- 05.00 p.m., outdoor temperatures in the fence courtyard is above comfort zone. The highest temperature at 12.00 as shown in figure 4. Fence inner courtyard is assumed to be covered by
plants, with a cover percentage of around 40%. Low albedo material and medium green spaces was able to reduce the temperature by around 2.1-5.30K compared to the use of low albedo material and zero greenery [16]. This means that the use of plants is able to reduce environmental temperature.

This model has two bedrooms. Two bedrooms have 30% window to wall ratio. Windows are facing to South. Inhabitants have daily activities in bedroom from 10 p.m. to 7 a.m. Its is assumed that both rooms are used all windows are opened. Apart from these hours the windows are closed. Figure 4 shows the bedrooms are in the neutral temperature zone from 7 p.m. to 8 a.m. or for 14 hours. If calculated as is 60%.

4. Conclusion remark
Open space has an important role in the fulfilment of thermal comfort. This is shown by the proposed model in this study. The model is designed to have two inner courtyards. With two inner courtyards located in different positions, it provides opportunities for spaces on the perimeter to be connected to the outer space. The spaces on the perimeter are bedrooms, family rooms that have a high space occupancy duration. The kitchen is also placed on the perimeter of the inner courtyard to get fresh air. The simulation results show that the three rooms located on the perimeter of the inner courtyard can meet the neutral temperature of 14 hours, except for the kitchen. When bedroom and living room are used, temperature in a neutral temperature zone. Another thing to note is the characteristics of the inner courtyard. It is open approximately 70-80% and gives a greater chance of sun exposure. It will raise the temperature, unless the floor material in the inner courtyard is covered with green plants.

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