Environmental and Climate Technologies

Nov. 2017, vol. 20, pp. 51–66
doi: 10.1515/rtuect-2017-0010
https://www.degruyter.com/view/j/rtuect

Wall Cladding Effects and Occupants' Perception of Indoor Temperature of Typical Student Apartments in Surabaya, Indonesia

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Abstract **– Three types of apartment claddings in Surabaya, Indonesia were studied to analyze their effect into bedroom temperature. They were glass windows in a niche, glass door in a balcony, and glass windows on a plain wall with glass door in a balcony. On-site temperature measurement was recorded and complemented with questionnaire surveys of occupants' perception regarding room temperature. The study showed that an apartment cladding with the largest proportion of opaque material combined with a balcony offered an indoor temperature of up to 9 °C lower than the outdoor compared to the other cladding types. Nevertheless, 72 % of occupants participated in this study, who use air conditioners during night time, including one with the cladding with the largest temperature difference claimed that the indoor temperature before air-conditioners was still too warm, which triggered air-conditioners initial time more than 10 minutes to achieve the desired indoor temperature. It indicated that the opaque material time lag played a significant role in heating the room during night time when the air-conditioner is about to be operated.**

Keywords **– Apartment; cladding; temperature; perception; Surabaya**

1. INTRODUCTION

Heat transfer in buildings or thermal condition of the building changes with time and depends on the physical element of the building, the thermal properties of all elements, and the climatic condition [1]. Here, the thermal property of a building element in the tropics was investigated. Buildings located in the tropics experience excessive solar radiation throughout the years. As for single floor buildings, the heat enters the building through the roof and walls. For multi-storey buildings, it enters mostly through walls. Whenever walls control solar heat gain predominantly, it requires careful design and precise material selection. A good design enables wall to maintain indoor temperature from solar heat gain. In the case of an apartment building, low indoor temperature maintained by its cladding is expected to shorten air conditioners initial time to reach the desired indoor temperature. Thus, promoting energy efficient.

Three types of apartment's wall cladding in Surabaya, Indonesia were studied. Apartments were selected due to a condition of unoccupied during daytime and utilization of air-conditioners during night time. Night occupancy brings a consequence that a night cooling by means of natural ventilation [2]–[5], is not practical here. The study was limited to single bedroom or studio type unit in apartments occupied by students predominantly. The study was focused on bedroom temperature, since in a single bedroom type apartment, occupants, mostly conduct their activities in the bedroom.

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Apartments for students are typically modest and effective in room layout and constructed from low or middle-quality materials that have limited capability to insulate solar radiation. For a view and natural daylighting, the apartments usually use ordinary glass type such as monolithic glass. This type of glass easily passes through solar radiation into the bedroom environment, where particular attention to cladding design and composition of material should be paid. When specific materials, to block solar radiation, such as low E-glass or insulated bricks are in use, the indoor temperature will be maintained at lower levels automatically [6].

Some student apartments use plain cladding, some with small niches or canopies and some have small balconies. In this study, these 3 types of claddings were observed to study its effect into bedroom temperature during the day and the evening time when air-conditioners are in use. The findings may guide students in renting or buying apartments to select more comfortable and less energy consuming apartment units by considering the cladding types and guide building designers and developers to carefully select cladding design and materials.

2. OBJECTIVE

The aim of this study is to investigate the effects of cladding type and cladding materials composition on the indoor temperature of typical student apartments in Surabaya, Indonesia to be confronted with the occupant's perception on the indoor temperature.

3. THEORETICAL APPROACH

Apart from the definition in the dictionary, there are no particular academic definitions of a cladding. Cladding is something that covers or overlays (Merriam Webster Online Dictionary). To be more specific to the context of this study, available definitions of cladding on online resources were used. One said that exterior cladding is the visible external finish of a building [7]. It means a plain wall with or without window and door can also be regarded as cladding. Another said that cladding is a definition of an additional protective layer affixed to the exterior side of a building enclosure system [8]. It means an ordinary plain wall is not a cladding. In this study, cladding is used to define the exterior wall of the selected apartments. It is typically a combination of plain wall, windows, door, a balcony, a niche to protect glass windows from direct sunlight, and additional shading devices.

It is not easy to find references on studies focused on cladding and its impact of the indoor temperature, particularly in apartment buildings. They mostly discuss on the whole building envelopes [9], [10], indoor comfort with regard to relative humidity [9], indoor temperature and indoor comfort in buildings other than apartments [11]–[15]. A study specific to the indoor temperature in apartment buildings is important as vertical living is now a trend where the reference of effective night cooling is hardly applicable. In addition, humans are more sensitive to variations in temperature than those of relative humidity [9]. Surveys of occupant's comfort temperature are also important, especially for an area in the tropics, where current standards are considered weak [16]. Local field surveys are also important to fully reflect the local climate and culture [16].

There are two outdoor factors, which affect indoor temperatures, i.e. outdoor ambient air temperature and the solar radiation striking the walls [10]. In the tropical climate, these two factors are both very significant, which cause buildings to employ large energy to cool the building. Cooling energy needs can be reduced using low-energy technologies [2]–[5]. The low energy technology suitable for each building type may differ. Such as in an office building that is unoccupied during the night, the use of night ventilation is particularly suitable. In apartments that are mostly occupied during the night, night and day ventilation are both not suitable. Day natural ventilation when the outdoor temperature in the tropics is mostly high is not recommended, especially for high-rise buildings, where the intrusion of outdoor wind can be very strong. Nevertheless, design and selection of materials of wall cladding are the most important factors to reduce cooling energy requirements in apartments. When wall cladding is capable to block or reduce solar heat gain and to maintain indoor temperature from the previous night of an air conditioned room, this will shorten AC initial time to achieve the desired temperature of the following night.

Each material has decrement factors and a time lag [17], which is a definition of the time delay for heat waves to pass through due to the thermal mass. The thicker and more resistant the material, the longer it will take to heat waves to pass through [17]. A material with a long time lag is not suitable to be used in climates that are constantly hot or cold. In the hot climate, buildings tend to be open and lightweight, which is opposite to buildings in the cold climate. Selection of material with suitable time lag will maintain indoor temperature from the previous night, which also maintains indoor comfort. Additional layer that is directly attached to the main wall may change the main wall time lag, but additional layer with particular gap to the main wall will not affect the main wall time lag [18]. Additional cladding attached to the main wall was particularly effective in reducing cooling and heating load [19].

There are several factors affecting indoor comfort. Indoor temperature, including relative humidity, is considered as the most significant. For air-conditioned rooms, indoor temperature affects the initial time of AC to reach the desired temperature to achieve comfort. Using a wall or cladding materials with a short time lag will maintain indoor temperature low at the beginning of night time before AC is on. Additional layers that are capable of blocking solar radiation will support the task of the wall with a short time lag to maintain the indoor temperature lower [20].

4. METHODS

There were 3 types of apartment's wall claddings of 3 apartment buildings observed in this study with 3 variations, i.e. glass windows in a niche, plain wall cladding with a glass door with a small balcony, and windows on a plain wall and glass door with a small overhang balcony (Fig. 1). The glass window in a niche cladding is the façade of studio (one bedroom) units in High Point Apartment (named as A apartment later in this paper) located in Jalan Siwalankerto, Surabaya. This apartment mostly serves Petra Christian University students due to the close proximity to the university. The plain wall cladding with a glass door with small balcony is the façade of studio units in Gunawangsa Apartment (named as B apartment later in this paper) located in Jalan Menur Pumpungan, Surabaya. This apartment serves students of several universities located in the east area of Surabaya, such as Institut Teknologi Sepuluh Nopember, STESIA, Perbanas, etc. Whilst, the plain wall cladding with wall and glass door in a small overhang balcony is the façade of studio units in Universitas Ciputra Apartment (named as C apartment later in this paper) located in Sambikerep, Surabaya. As shown by the apartment's name, it serves the students of Ciputra University.

The study was conducted as a field research to record outdoor and indoor temperature on site. The field measurement was complemented with questionnaire survey to gather occupants' perceptions of indoor temperature affected by the presence of particular cladding. The occupants' perception was studied to strengthen the finding of the field measurement. The temperatures were taken outdoors (directly outside the selected apartment unit) and within the bedroom. The data were recorded using Hobo Data Logger U12-012 with surface sensors. Placement of HOBOs is as in Fig. 7 to Fig. 9.

4.1. Cladding Specifications and Microclimatic Conditions

The apartments cladding specification, i.e. material composition, proportion, and room layout were as in Fig. 2 to Fig. 5. At a glance, all these figures indicate that cladding of Gunawangsa apartment (B apartment) was constructed with the largest proportion of opaque material.

Fig. 1. Façade of High Point (A), Gunawangsa (B), and Universitas Ciputra (C) apartments (from left to right).

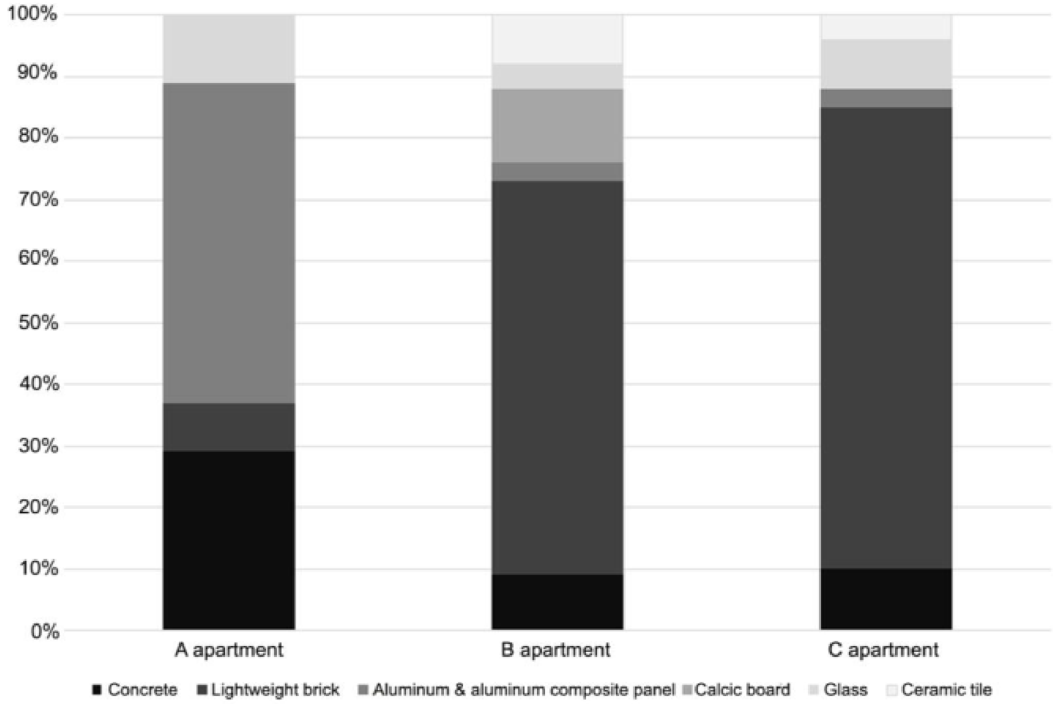

Fig. 2. Cladding material composition of the 3 selected units in 3 apartment buildings.

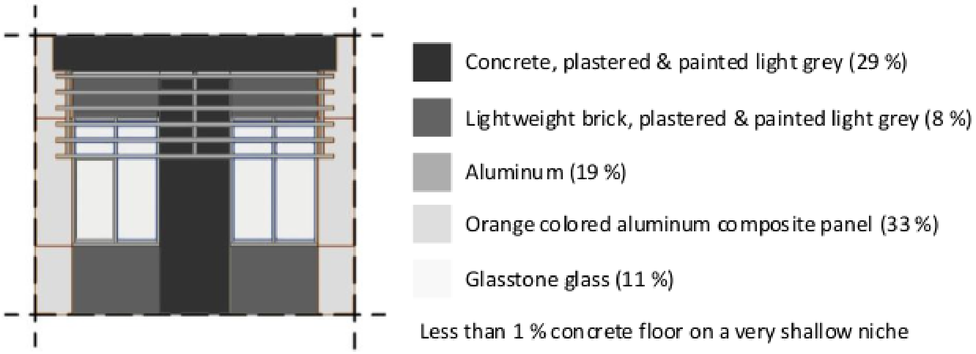

Fig. 3. Façade of apartment units with glass windows in a niche (A apartment).

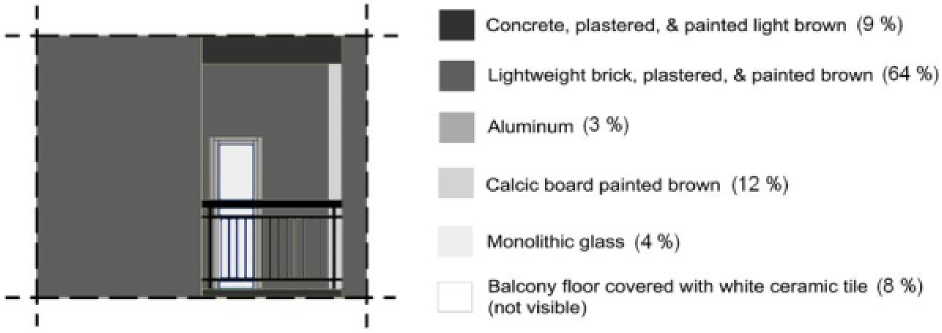

Fig. 4. Façade of apartment units with glass door in a small balcony (B apartment).

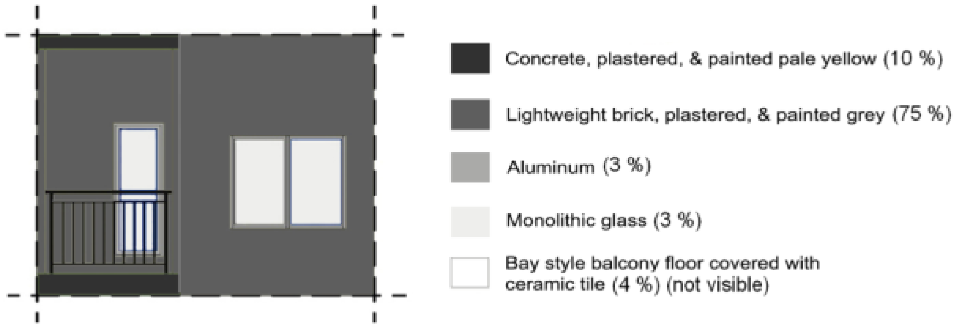

Fig. 5. Façade of apartment units with glass windows on plain wall and glass door in a small balcony (C apartment).

A studio or one bedroom unit type from the 3 apartment buildings was selected for the study considering the simple room layout within. Simplicity of room layout is important for ease and more representative temperature measurement compared to two-bedrooms or family units where room layout are more complicated. Besides, by selecting the studio type, room dimension of the unit could be managed as one of the fixed variables, i.e. approximately at 24 m^2 (Fig. 6). This was not the case with other unit types where the room dimension is quite varied.

The indoor-outdoor temperature measurement was conducted inside and outside the bedroom in each apartment unit. The measurements were recorded 3×24 hours consecutively for each unit during a similar period of time, i.e. the second week of April 2016. Even though the temperatures were recorded within similar period, since the apartments location is all in different parts of Surabaya, it is quite challenging for the author to maintain the outdoor temperature and solar radiation variations during the measurement period to be as similar as possible. A apartment is in South Surabaya, B is in East Surabaya, and C is in West Surabaya. However, since the measurement was conducted in one city, i.e. Surabaya (07º15'S, 112º45'E) and that the farthest distance between objects in latitude is approximately 6 km only (between A and B apartments), this will not change the latitude even 1º, which mean the variation in solar radiation do not significantly exist. According to global horizontal irradiation maps [21], all three objects received and exposed to similar levels of solar radiation, i.e. 2000 kWh/m^2 (Fig. 10). Here, the different object location was considered to have an insignificant effect on the solar radiation that affects the outdoor temperature. Another consideration that solar radiation would insignificantly affect the measurement taken was that the objective of the study is to investigate the temperature difference only offered by the apartment claddings. Herewith the insignificant difference in outdoor temperatures was considered acceptable. Fig. 14 shows the average outdoor temperatures during three days measurement marked similar pattern.

During temperature measurement, the selected apartment units were conditioned as unoccupied and all electric equipment such as AC, refrigerator, artificial lighting, etc. were turned off. Natural ventilation was also blocked with all windows and doors were closed. This setting was employed to limit variables affect temperature difference between indoor and outdoor only by the cladding.

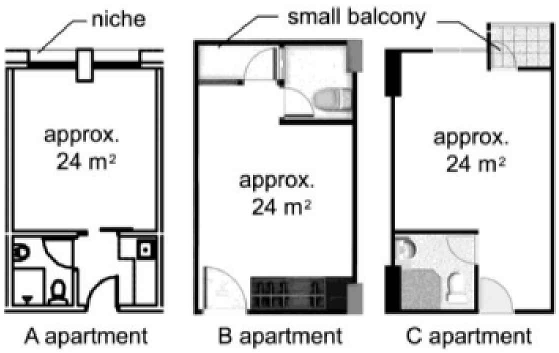

Fig. 6. The room dimensions and layout of A, B and C apartment units.

TABLE 1.OBJECT VARIABLES

Variables	Unit Specification	A apartment	B apartment	C apartment
Controlled (fixed) variables	Orientation	North	North	North
	Floor to floor height	3.5 m	3.5 m	3.5 m
	Floor height above ground	14 m	14 m	15 m
	Room space	24 m^2	24 m^2	24 m^2
Variables	Cladding characteristics	Glass windows in a niche	Glass door in a small balcony	Glass windows on plain wall & glass door in a small overhang balcony
	Window-to-wall ratio	0.11	0.04	0.08

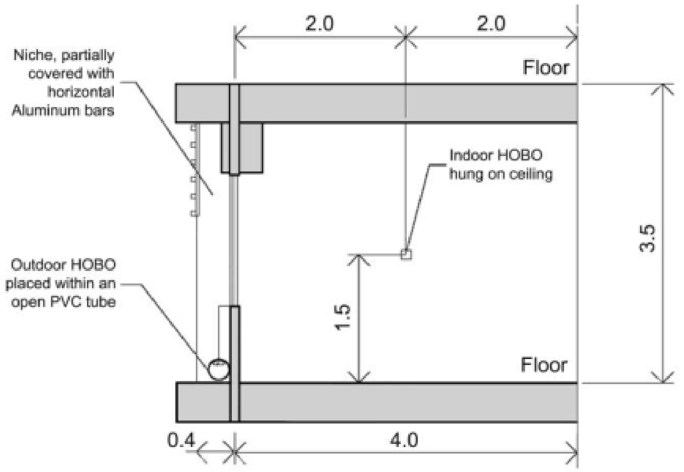

Fig. 7. Section of the A apartment unit.

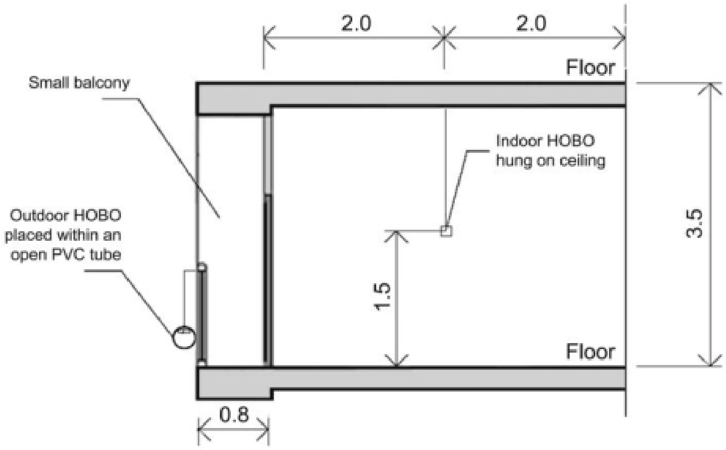

Fig. 8. Section of the B apartment unit.

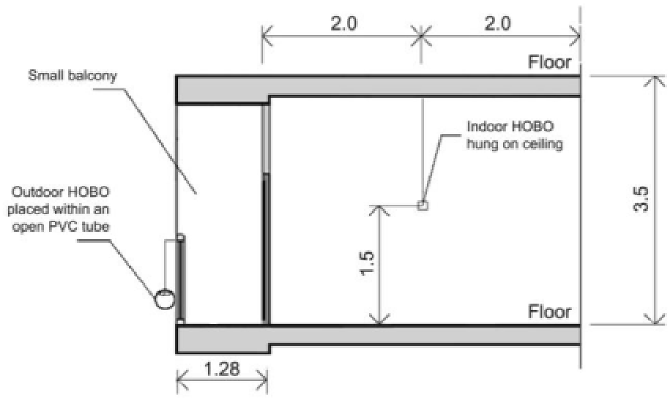

Fig. 9. Section of the C apartment unit.

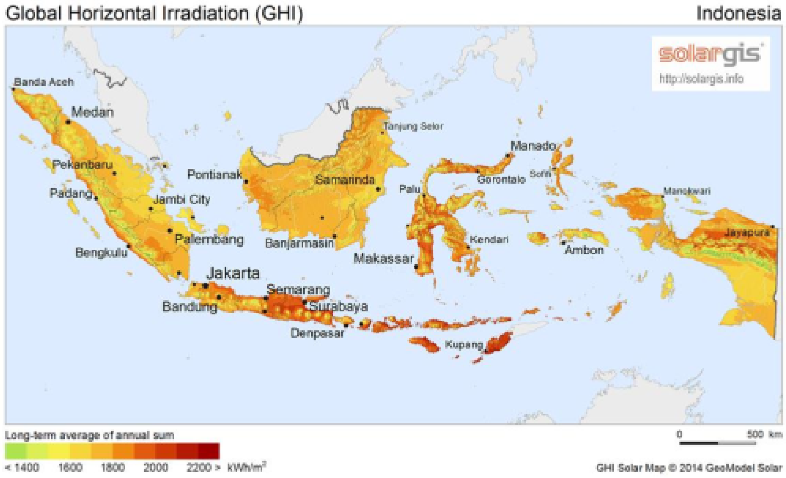

Fig. 10. Global Horizontal Irradiation (GHI) of Surabaya, Indonesia [21].

4.2. Occupants' Perception Surveys

Occupants' perception of the indoor thermal comfort limited only on the indoor temperature was collected using a questionnaire survey within the same period to the period of temperature measurement. An earlier study indicated that occupants with more access to control their environment have a tendency to accept wider ranges of indoor temperatures and showed a lower motivation to modify their current environment [22], will also be investigated.

At first, a Likert's scale model was used to construct the questionnaire. However, at the later, a simple multiple choice questionnaire system downgraded from the Likert's model was finally used. This type of question was considered more powerful to describe the occupants' perception and to create a clear polarization of the answers given by the respondents. In the 3 apartment buildings, there were totally 350 studio units (one bedroom) with 350 occupants. One hundred sets of questionnaires were distributed to the occupants of the 3 apartment buildings and 81 was returned. The completed questionnaires were in a quite equal proportion of the 3 apartments, i.e. 18 questionnaires were returned by the occupants of A apartment, 27 by the occupants of B apartment, and 36 by the occupants of C apartment. Demographic and occupancy characteristics of the 81 respondents are presented in Fig. 11 and Fig. 12.

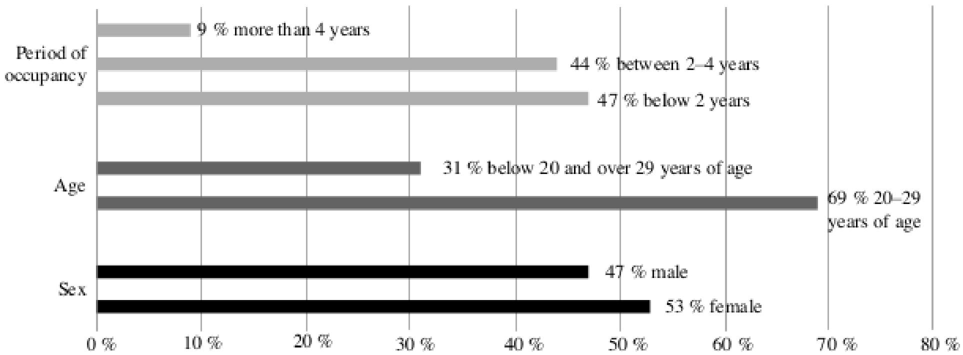

Fig. 11. Demographic characteristic of the respondents.

5. Findings and Discussion

The study was limited to measure temperature difference (δ) between outdoor (T_i) and indoor (T_o) to study the effect of different types of claddings. It was possible for the δ to be affected by other factors other than the claddings. However, since the other variables were controlled as in Table 1, it was quite reliable to use the cladding effect on temperature difference as the only reference. Fig. 12 to Fig. 14 draw the outdoor and indoor temperatures recorded at 3 apartment buildings. Here we learn that during the measurement period of 3×24 hours for each apartment, the outdoor temperature of B apartment was the highest. In overall, the outdoor temperature lied between 27 °C to 41 °C, excluding anomaly occurred at A apartment day #3 and C apartment day #1, when the outdoor temperature dropped as triggered by rain during day time. If the precipitation was excluded from the data collected, we may see that the pattern of outdoor temperature of the 3 apartments was quite identical, where the temperature raised and reach the peak at day time, which may reach around 40 °C. The outdoor temperature of B apartment was generally slightly higher than A and B. Whilst, the indoor temperature of the 3 apartments remained in horizontal lines. The indoor temperature of A apartment was generally the lowest during data recording, where in most points were below 30 °C. The indoor temperature of B apartment was mostly at or above 30 °C, and the C apartment was more dynamic compared to the A and B.

Fig. 15 and Fig. 17 show the temperature difference δ (T_o–T_i) between outdoor and indoor of the 3 apartments. Here, the B apartment showed the condition where the δ was the largest of up to 9 °C during day time. B apartment is apartment with the smallest window-to-wall ratio (WWR). A and C apartment with larger WWR offered relatively similar smaller δ, except in day #3 of A apartment during precipitation. However, by Fig. 13 and Fig. 16, we see that the largest δ and the smallest WWR did not automatically affect the indoor temperature of B apartment to be the lowest. Fig. 16 is the average indoor temperature of the 3 apartments during 3×24 hours of data collection. This figure was created to study more clearly of the indoor temperature condition in general and for the ease of comparison between indoor and outdoor temperature. It was a phenomenon where the apartment with a cladding of the largest δ experienced highest indoor temperature. By these figures we see that the outdoor temperature of C apartment was the highest during daytime. But at night time, where the outdoor temperatures have dropped at relatively similar temperatures, the indoor temperature within B apartment remained constantly high compared to A and C (Fig. 16). It means that the opaque material used in B apartment, which is predominantly lightweight bricks, possesses long time lag. A question may arise due to the opaque cladding of B apartment was the wall of the lavatory. As an additional information, throughout the measurement period, the lavatory door was opened. Thus the heat released from the lavatory wall was transferred to the bedroom area.

By Fig. 15 and Fig. 17 we learn that C apartment which was also constructed by a large proportion of lightweight bricks had a different indication compared to B apartment. Here, the overall opaque and transparent cladding provided a δ of 3 °C only at day time (Fig. 17). Thus the indoor temperature was relatively high, similar to that of the indoor temperature of B apartment. In A apartment where parts of the wall were constructed of lightweight bricks as was in B apartment, during night time, the indoor temperature in A apartment was dropped, means that the lightweight bricks used in A differ to the one used in B apartment. Here, the A lightweight bricks possess short time lag. Time lag or thermal mass was proven to have a significant effect on indoor temperature [10].

The temperature within A apartment was the lowest at day time, which was affected by the outdoor temperature and the use of niche and glasstone glass. Actually, this glass type does not have specific features due to solar radiation insulation except the color tinted. Nevertheless, even the slightly tinted glass combined with a niche and horizontal aluminum bars was capable lowering indoor temperature compared to the two others during day time. At night time, the cladding type of A apartment which was constructed by a quite even proportion of concrete-lightweight brick-aluminum-glass each of 20 %, 26 %, 22 %, 24 %, respectively, had a short time lag.

In overall, cladding design with a material combination as was of A apartment seemed to be the most reliable cladding type to provide a low indoor temperature of day and night time. The presence of a deeper niche and denser horizontal shading bars may play a more significant role in reducing solar heat gain and creating a larger δ to effectively reduce cooling needs [19].

When on-site temperature measurement was confronted with the occupants' perception of indoor temperature due to AC initial time, 75 % respondents encountered warm air when entering the bedroom just before starting the AC (Fig. 19). This correlates to Fig. 16 where the average indoor temperature at 6 pm was still over 30 °C. Six pm was the starting time of bedroom occupancy for most respondents (88 % refer to Fig. 18). An earlier study that indicated inhabitants with more individual access to control over their environment have a tendency to accept wider ranges of indoor temperatures [22] seemed not be the case in tropical climate. Although people living in tropical climate show higher thermal comfort level compared to Fanger's PMV15, the recorded indoor temperature in the range 28 °C–32 °C was regarded as warm [12]. In accordance with the occupant perception of the indoor temperature, they also stated AC initial time that required more than 10 minutes predominantly (72 % of those using AC during night time, Fig. 19) was too long. Initial time below 10 minutes was preferable.

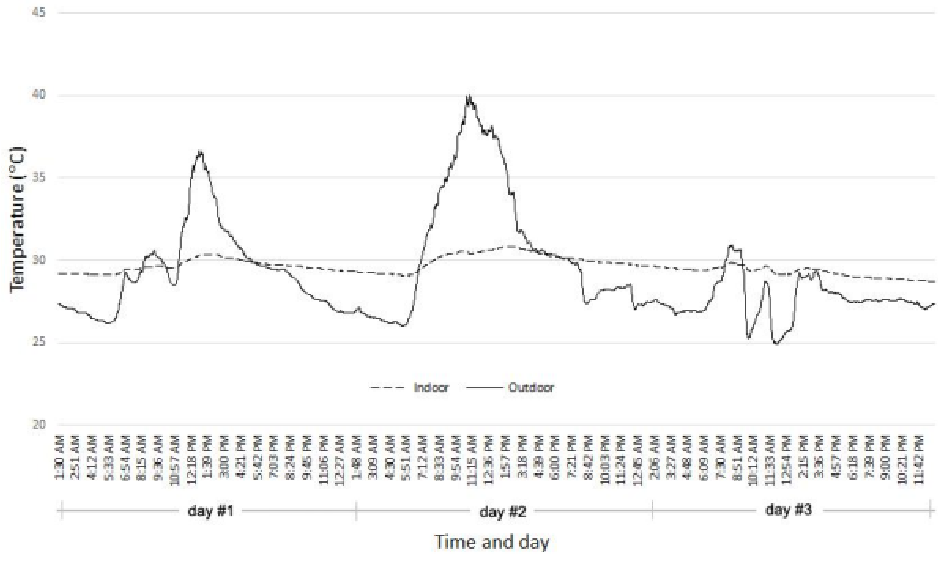

Fig. 12. Outdoors and indoors temperature recorded of A apartment.

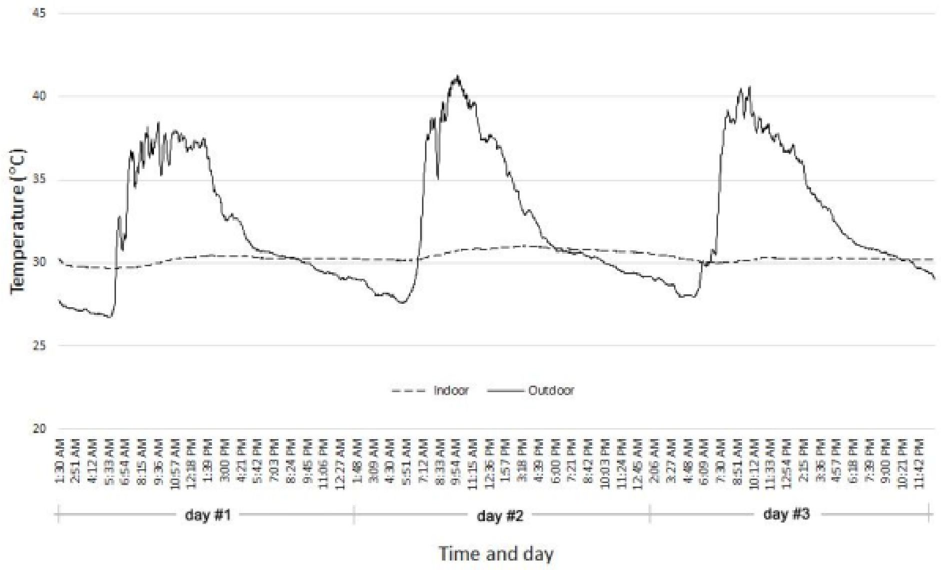

Fig. 13. Outdoors and indoors temperature recorded of B apartment.

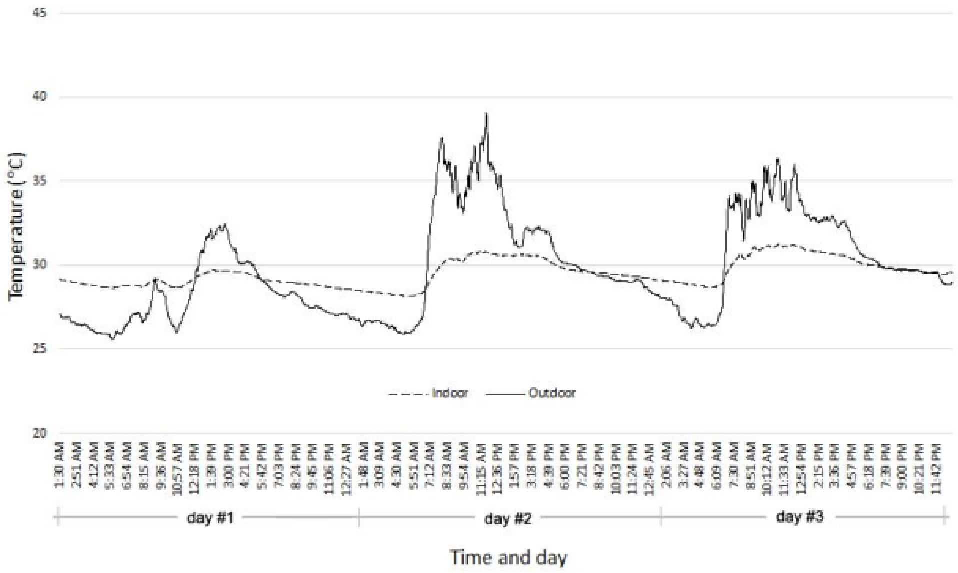

Fig. 14. Outdoors and indoors temperature recorded of C apartment.

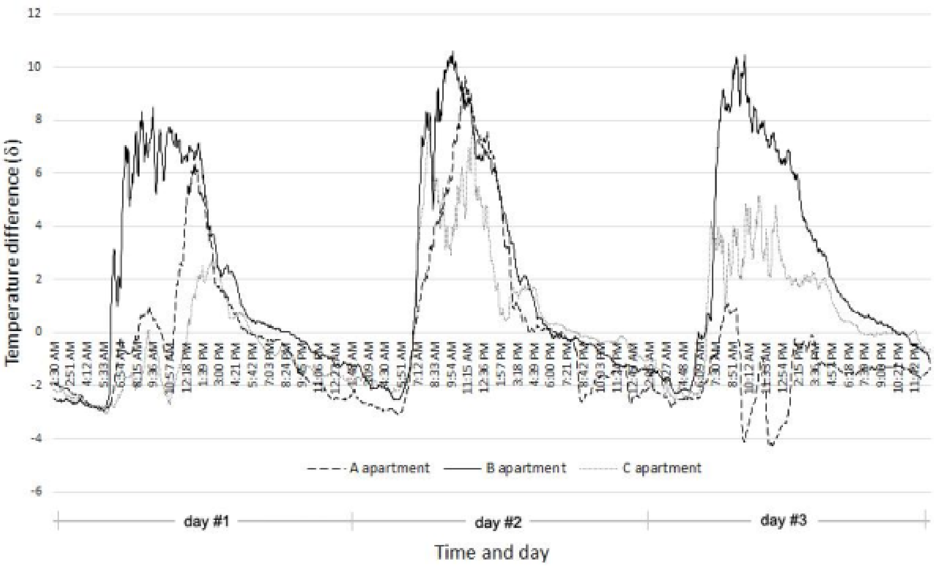

Fig. 15. Outdoors and indoors temperature difference (δ) of A, B, and C apartment buildings.

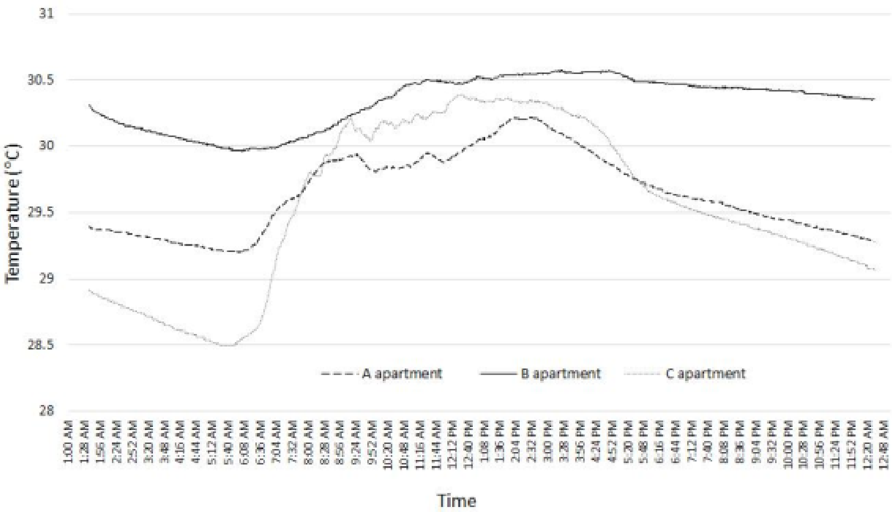

Fig. 16. Average indoor temperatures of 3×24 hours measurement period.

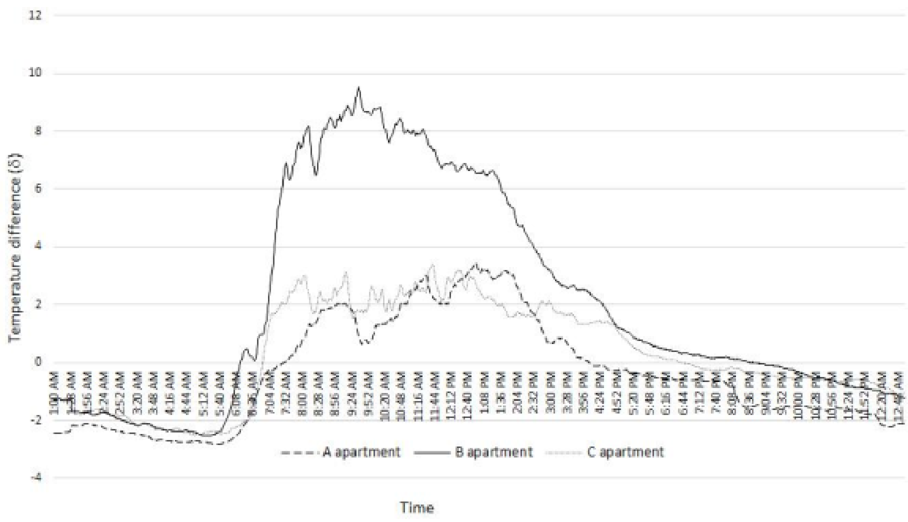

Fig. 17. Average temperature difference δ of 3×24 hours measurement period.

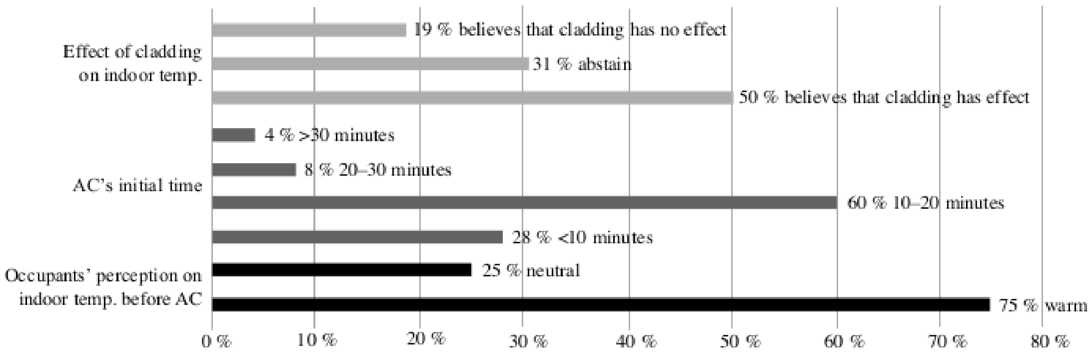

Fig. 18. Occupancy characteristic of the respondents.

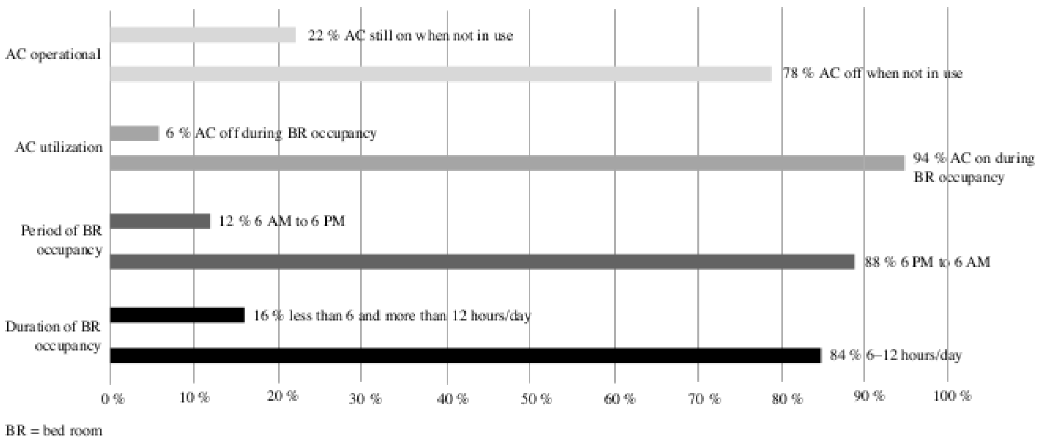

Fig. 19. Occupants' perception on the AC and the claddings.

6. Results

This study concludes that cladding with a large proportion of opaque material compared to transparent material offered a larger δ of outdoor-indoor temperature. However, when the opaque material has long time lag as in this study, the indoor temperature remained warm the whole evening. The opaque material ideally has short time lag so as not to distribute heat gained at day time to the night time. A wall with appropriate thermal mass had the ability to significantly reduce the energy usage in residential buildings by maintaining a comfortable internal temperature with no heating or cooling [23].

In overall, cladding type which covers transparent material within a niche combined with lightweight bricks with a short time lag offered the lowest indoor temperature. The fact that the indoor temperature was still above the ideal room temperature and whilst 50 % respondents believed that cladding has an effect on indoor temperature, the cladding types studied here were all not capable of suiting the occupants' need for comfortable indoor temperature. These 3 types need to be upgraded to support occupants' needs of a lower indoor temperature before AC utilization period.

7. Conclusion

Thermal performance assessment of building envelopes by using temperature only may be considered not comprehensive, but an earlier study indicated that this method is quite reliable [1]. A study on 3 types of cladding that are typical cladding of student apartments in Surabaya has been carried out. With the tendency of the increase of annual average outdoor temperature, which will significantly increase the risk of overheating and where the energy used to cool down the building will also increase [24], the finding of this study may be used for reference to counter these issues. The most practical way is by carefully considering composition between opaque and transparent materials and detailed design of building envelopes for minimizing solar heat gain. This study indicates that the use of simple and small balconies will do the task of reducing solar heat gain while using transparent materials for cladding. The finding of the study may be used by students to select apartment cladding types before buying or renting or be used by building designers and developers to select a proper cladding design and materials.

Further studies on the most effective type of balconies to create a sufficient temperature difference with small time-lag for less initial time of air conditioning systems is recommended. A longer monitoring period and a survey with more massive respondents be conducted to provide stronger justification of the results is also recommended.

Acknowledgment

C. E. Mediastika and J. Hariyono are grateful to building managers of High Point, Gunawangsa Manyar and Ciputra University Apartments, Surabaya, Indonesia for giving access to collect data for this study.

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