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Effect of PCM in Glass Facade of High-rise Apartment on Indoor Temperature

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Abstract: *In high-rise building systems, the envelope, one of which is the facade, has a major role in the reception of heat into the building. This type of glass facade material has properties that can transmit solar heat directly, so that the heat that enters the building is trapped inside and makes the temperature in the room increase. Therefore, there is a need for a solution or solution to reduce the temperature in the room. Currently, technology is increasingly developing, so there are many variations of materials that effectively reduce the cooling load of the space. One of them is PCM (Phase Change Material) which can be used to store the heat energy that enters through the building envelope in very large quantities. To find out the effect of PCM material on the glass facade in the apartment, a study was carried out. The purpose of this study was to evaluate and analyze the effect of the application of PCM material on the facade of the apartment on the temperature in the room. The method used in this study is an experimental method, using field measurements and simulations with Design Builder software. The results of the simulation with PCM material obtained that the most optimal material configuration for thermal reduction is a combination of double glass (tinted and reflective) with PCM gap (Bio-PCM), the temperature reduction is 1.84°C. The effect of thermal performance inside the building on orientation at 60% WWR with double glass and gap Bio-PCM, namely east orientation is better at reducing heat around 2-8°C. compared to the west, north and south orientations.*
Keywords: *apartment façade; thermal properties; tropical climate*

I. Introduction

Along with the development of the times, in line with the increasingly widespread application of modern architecture, glass has become a commonly used material as building facades. This type of glass facade material was chosen because it has advantages, namely faster installation time, has an expressive impression, and is modern. However, this material has a high thermal conductivity value and cannot reflect short wave radiation, so the heat entering the building is trapped inside and makes the temperature inside the room higher than outside the building. More advanced technology makes material technology more advanced, one of which is Phase Change Material (PCM) which can be used as thermal storage in buildings. Development is a systematic and continuous effort made to realize something that is aspired. Development is a change towards improvement. Changes towards improvement require the mobilization of all human resources and reason to realize what is aspired. In addition, development is also very dependent on the availability of natural resource wealth. The availability of natural resources is one of the keys to economic growth in an area. (Shah, M. et al. 2020)

Research on PCM in buildings has been conducted by Nematchoua et al. (2020) who researched the application of PCM materials, thermal insulation, and external shading on building facades to increase thermal performance and reduce cooling energy in office buildings with tropical coastal climates. The tactic of this research is done by simulation within a period of one year with Design Builder software. The results show that Phase

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Change Material (PCM) material has a significant effect on decreasing indoor temperature and energy consumption in the office under different coastal tropical climates.

Another study related to the performance of glass facades has been carried out by Uribe and Vera (2021). In his research, the analysis of the Phase Change Material (PCM) which was integrated into the glass was carried out through a real-scale experiment for one year at two offices in Santiago, Chile, with east-oriented facades and a 56% window-to-wall ratio (WWR). The results were analyzed in two timescales (seasonal and daily) on the energy consumption of the HVAC system. This study resulted in a synthesis that PCM glass was able to reduce energy consumption during summer and mid-season and significantly reduce peak loads in summer. A significant reduction in temperature was achieved due to control of the average radiation temperature throughout the year. This study also considers visual comfort, there is an increase in lighting distribution in winter and mid-season cold conditions.

Based on Pustaka (2002) on climate classification, Indonesia is classified as a tropical country because it is located on the equator, so the dry season falls when the sun is higher, this results in a longer day. According to BMKG Surabaya climate data for the last 5 years,the hottest month occurs in October with an average air temperature of 30.25 C and the coldest month occurs in July with an average air temperature of 27.94 C.Surabaya has the highest air temperature reaching 36 oC. Therefore, it is necessary to have a heat mitigation strategy so that the temperature inside the room is lower than outside. The purpose of this study was to evaluate the effect of the application of PCM material on the glass facade of the apartment on the thermal performance in the building based on the combination of PCM and glass types, as well as different building orientations.

II. Research Method

This research is quantitative research and uses experimental method with the help of computer simulation and field measurement. The simulation method was chosen because it can make it easier for researchers to freely modify existing conditions without having to change existing conditions. In addition, this simulation strategy is possible to save time and minimize costs. The computer software used is Design Builder. Design Builder is a software for analyzing thermal energy and load simulation.

The apartment sample selected for this research is the Aryaduta Surabaya Apartment with a WWR ratio > 60%. Temperature measurements in the field were carried out for 5 days in March 2022. The temperature measurement tool used was the Heat Index WBGT Meter which was placed at a position 1.5 from the floor surface. The tool is placed at an outdoor point of the building, namely the sky garden & pool on the 15th floor. BMKG data and temperature measurement data in the field serve as a reference for verification between simulated conditions and existing conditions. In addition to data related to temperature, data on building envelope materials, functions and input heat gain in buildings are also needed for the input process into simulation software so that the simulation conditions can approach the existing conditions. The facade wall material uses precast concrete and the indoor partition wall uses gypsum with a hollow iron frame. The glass facade uses tinted glass (panasap green 8 mm) with an aluminum frame. The 1st to 14th floor buildings are hotel buildings that are not yet operational, so only staff can access the area. In this research simulation, buildings on floors 1-14 are categorized as offices with a heat gain classification in the building which can be seen in Table 1.

Table 1. Input Heat Gain

Activity	Floors 1-14 (Office)	15th Floor (Lobby)	Floors 16-31 (Apartment)	Source
Occupancy density	0.05 people/m2	0.3229 people/m2	0.05 people/m2	ASHRAE 90.1 and ASHRAE 62.1 - 2007
Metabolic factors	0.90	0.90	0.90	CIBSE
Clothing	0.5	0.5	0.5	Frick and Koesmartadi(2008)
Lighting	80 lux	120 lux	80 lux	SNI 6197-2011
Lighting Schedule	7 Days/week 18.00-6.00	7 Days/week 7.00-24.00	7 Days/week 18.00-6.00	
HVAC	VRV (Air-Cooled)	VRV (Air-Cooled)	VRV (Air-Cooled)	Daikin (2020), DesignBuilder Library Data (2022)
Cooling set point	25 C	25 C	25 C	SNI 6390-2011
HVAC Schedule	7 Days/week 10.00-17.00 20.00-5.00	7 Days/week 7.00-22.00	7 Days/week 10.00-17.00 20.00-5.00	
ACH (L/s-person)	4	5	4	BPC Ventilation (2022

2.1 Description of Research Object

The research object chosen is the Aryaduta Apartment which is located on Jl. Ahmad Yani No.288, Surabaya City and is connected to the City of Tomorrow Mall as well as Pelita Harapan University (UPH). This apartment is oriented north, but when viewed from the horizontal circulation, this building is included in the type of building with a double loaded corridor, because it has circulation and corridors in the middle, so that the openings and windows in each apartment unit are oriented towards east and west. This building has 31 floors with space functions in between, floors 1 to 3 are parking and office areas, floors 4 to 14 will function as a hotel, but have not been inaugurated and opened to the public, floors 15 are used as public facilities, and floors 16 to 31 functioned as unit rooms. On one floor there are 14 apartment units. The shape of the apartment facade can be seen in Figure 1.

Figure 1. *Apartment facade*

III. Results and Discussion

3.1 Simulation Result of Combination PCM and Glass Material

To see the effect of PCM type on thermal performance in buildings, simulations were carried out in several scenarios as described in Table 2. The WWR applied was 60% and the time period for the hottest month was on one of the days in October, and the coldest month on one of the days of the month. July. The simulation was carried out for 24 hours. The observed building zone is on the 31st floor with the orientation following the existing model, namely west and east. The simulation is set using mechanical ventilation without any window opening and closing treatment (windows and openings are closed). The simulation results are shown in Figure 2. When compared with the existing simulation model, the addition of PCM material can reduce the temperature by 2-4 °C. Simulations with the addition of PCM were able to maintain a constant temperature from 16.00 to 23.00. The increase and decrease in temperature is caused by the phase change process in the PCM. PCM material begins to absorb heat marked by a decrease in room temperature, while PCM begins to release heat when the room temperature begins to increase (Umar, 2020). The average temperature generated for 24 hours with this simulation is 27.34 °C, lower than the simulation with paraffin with a difference of 0.37 K. The difference between paraffin simulations and Bio-PCM can be caused by specifications of thermal properties and different melting temperatures. The comparison of outdoor temperature to the five scenarios resulted in an average temperature decrease of 3.25 °C.

Table 2. Simulation Scenario

Treatment (Code)	Material	Properties
Scenario 1 (paraffin)	*Tinted glass*(8mm)	• Density 2500 kg/m3 • Conductivity0.96 W/mK • Specific heat 840 J/kgK • Emissivity 0.33
	Paraffin (7mm)	• Density 880 kg/m3 • Conductivity 0.2 W/mK • Specific heat 2000 J/kgK
Scenario 2 (Bio-PCM)	*Tinted glass*(8mm)	• Density 2500 kg/m3 • Conductivity0.96 W/mK • Specific heat 840 J/kgK • Emissivity 0.33
	Bio-PCM (7mm)	• Density 235 kg/m3 • Conductivity 0.2 W/mK • Specific heat 1970 J/kgK
Scenario 3 (Inf-PCM)	*Tinted glass*(8mm)	• Density 2500 kg/m3 • Conductivity0.96 W/mK • Specific heat 840 J/kgK • Emissivity 0.33

	Infinite PCM (7mm)	• Density 929 kg/m3 • Conductivity 0.815 W/mK • Specific heat 3140 J/kgK
Scenario 4 (DGU_tint)	*Tinted glass*(8mm)	• Density 2500 kg/m3 • Conductivity0.96 W/mK • Specific heat 840 J/kgK • Emissivity 0.33
	Bio-PCM (7mm)	• Density 235 kg/m3 • Conductivity 0.2 W/mK • Specific heat 1970 J/kgK
	Tinted glass(8mm)	• Density 2500 kg/m3 • Conductivity0.96 W/mK • Specific heat 840 J/kgK • Emissivity 0.33
Scenario 5 (DGU_ref)	*Reflective glass*(8mm)	• Density 2500 kg/m3 • Conductivity0.96 W/mK • Specific heat 840 J/kgK • Emissivity 0.33
	Bio-PCM (7mm)	• Density 235 kg/m3 • Conductivity 0.2 W/mK • Specific heat 1970 J/kgK • Latent heat 165 kJ/kg • Solidus temperature 22 C • Liquidus temperature 29 C
	Tinted glass(8mm)	• Density 2500 kg/m3 • Conductivity0.96 W/mK • Specific heat 840 J/kgK • Emissivity 0.33

Sources: Asahimas (2020), Rubitherm (2021)

From this simulation, it can be seen that the performance of the Infinite PCM material to room temperature has almost the same results as the simulation using paraffin. The highest temperature is 32.56 °C and the lowest temperature is 24.8 °C. The temperature drop resulting from the simulation with Infinite PCM (salt hydrate) ranged from 0.3-2 °C. If sorted by material with the most optimal temperature reduction, Bio-PCM is the most superior material in reducing heat entering the building. Next is paraffin material, and the last is infinite PCM (salt hydrate). Based on the research of Vigna et al. (2017), Bio-PCM has the advantage that it has a smaller impact on the environment, because it is non-toxic and non-corrosive. In addition, Bio-PCM has a low crystallization rate, so that when combined with glass or other transparent materials it will not affect the visuals of the material much. However, some of the shortcomings of Bio-PCM are the availability of Bio-PCM materials in the market is still limited.

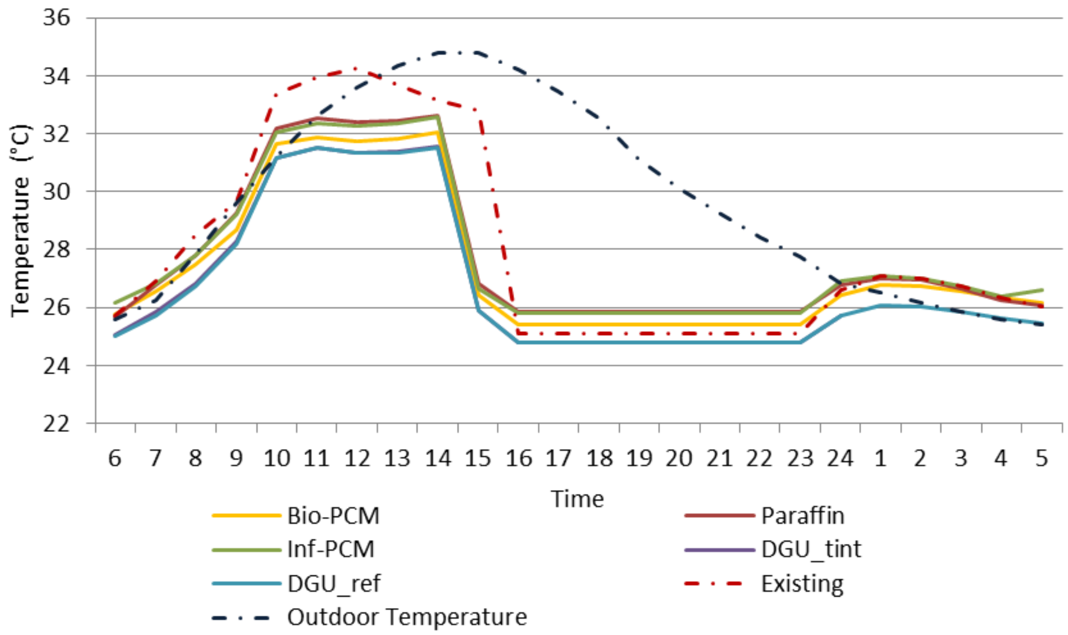

Figure 2. *Graph of Simulation Result of Combination of PCM Type and Glass Type*

Double Glass Unit (DGU) is a layering technique on a glass facade consisting of two pieces of glass joined by a gap in the middle which are generally then sealed into one (Yulianti, 2020). The results of this simulation show that the performance of double glass and Bio PCM is able to reduce the temperature compared to the existing simulation model for 24 hours. with simulation with single glass+Bio-PCM. The comparison table of the existing simulation results and these 5 scenarios can be seen in Table 3. Of the five scenarios carried out, scenario 5 is treatment using double tinted and reflective glass with a gap of 7 mm.

Table 3. Comparison of Existing Simulation with 5 Scenario Simulation

Simulation type	Coldest month average temperature (°C)	Temperature drop range	Hottest month average temperature (°C)	Temperature drop range	Highest temperature (°C)	Lowest temperature (°C)
Existing	26.25		28.02		34.26	24
Paraffin	26.16	0.1-1 °C	27.71	0.4-1.83 °C	32.54	24.7
Bio-PCM	26.13	0.2-1.2 °C	27.34	0.3-2.5 °C	32	24.3
Inf-PCM	26.17	0.2-1 °C	27.72	0.3-2 °C	32.56	24.8
DGU_tint	25.83	0.6-3.3 °C	26.75	0.6-2.9 °C	31.55	24.3
DGU_ref	25.48	0.6-4 °C	26.73	0.5-3 °C	31.51	23.7

3.2 Effect of Orientation on Indoor Temperature

Simulation of the effect of orientation on the indoor temperature of the building was carried out on one representative of the apartment floor. If viewed from the orientation of the building, the configuration of DGU and Bio-PCM materials can reduce the temperature more optimally in apartment units with east and south orientations. The difference between the unit temperatures in the west and east ranges from 2-6 °C in the coldest month, and 3-7.6 °C in the warmest month. The difference between the temperatures in the southern and northern units is not much different, which is 0.5-1.5 °C.

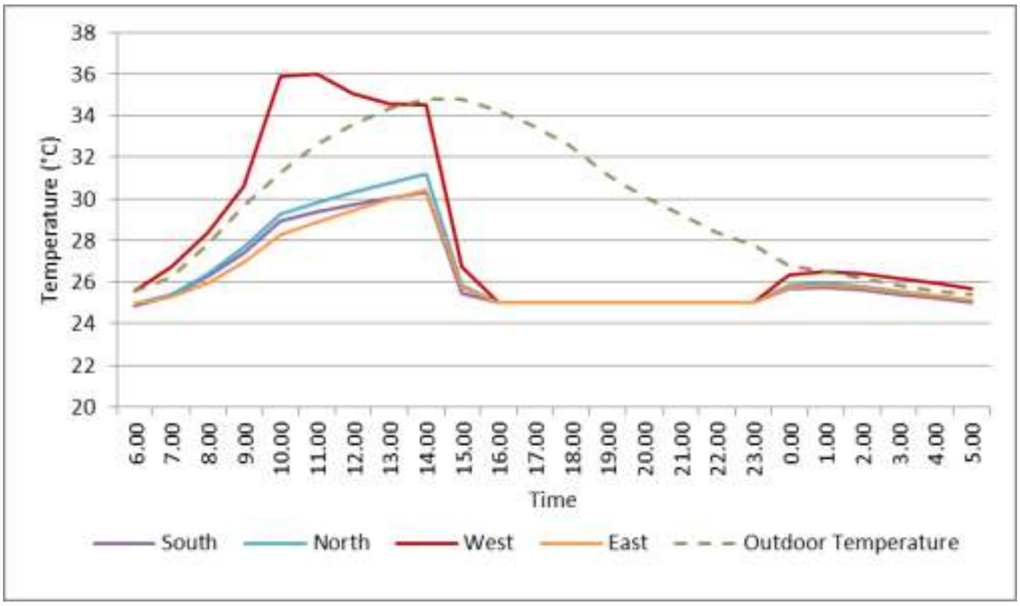

Figure 3. *Graph of Simulation Results of Changes in Orientation to Thermal Conditions*

The highest temperature of the four orientations reached 35.98 °C, so that at peak hour or around 9.00 to 14.00, additional treatment is needed. According to (Handoko & Ikaputra, 2019) the design strategy of high-rise facade designs in tropical climates is by adding sun shading (treating by closing curtains), maximizing natural ventilation (treatment of opening and closing windows) so that the room inside is protected from solar radiation and increases temperature reduction. that happens in space.

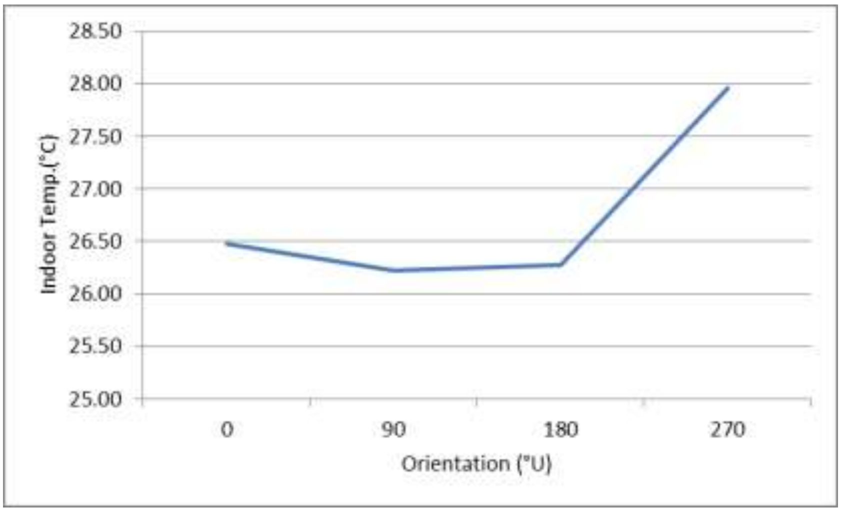

Figure 4. *Effect of orientation on indoor temperature*

From several simulations that have been carried out, it can be concluded that the most optimal orientation for thermal performance is the eastern orientation. According to Heinz (2008) the position of the building that has an orientation parallel to the wind direction is the most favorable position for the comfort of occupants in the space. Based on the BMKG (2021), the wind direction in Surabaya is mostly from the east and south. This causes the temperature in the south and east orientations to be lower than in the west and north orientations. This result is in line with Gumelar's research (2018) which states that the construction of houses in Surabaya generally chooses to be oriented to the north,

Table 4. Orientation simulation results for the hottest and coldest months

Orientation	Coldest month average temperature (°C)	Temperature drop range	Hottest Month average temperature (°C)	Temperature drop range	Highest temperature (°C)	Lowest temperature (°C)
West	25.62		27.96		35.98	21.97
East	24.31	2-6 °C	26.22	3-7.6 °C	30.4	21.5
North	24.33	1-2.5°C	26.48	0.5-1 °C	31.2	20.17
South	23.84	1-2.1 °C	26.27	0.1-0.9 °C	30.3	20.10

IV. Conclusion

The addition of the most effective material in reducing thermal is PCM type Bio-PCM. The addition of Bio-PCM to the glass facade can reduce the temperature by about 2-4 °C compared to the existing model. This is because Bio-PCM has a lower density and thermal conductivity compared to other types of PCM. In addition, this material has a high reflectance value. The application of double glazing has a significant effect on decreasing the temperature in the room. The range of temperature decrease that occurs in the hottest month reaches 0.6-2.9 °C, 0.45°C better than the simulation with single glass+Bio-PCM. Of the five scenarios carried out, scenario 5, namely treatment using double tinted glass and reflective with a gap of 7 mm Bio-PCM is the most optimal treatment to reduce temperature, compared to the other four scenarios. This can be due to the fact that reflective glass has lower density, thermal conductivity and emissivity values compared to tinted glass, so the heat flowing through the surface of the glass is getting smaller.

The effect of thermal performance on orientation is that the east orientation is better in reducing heat in the building than the west, south and north orientations. The configuration of DGU and Bio-PCM materials can reduce the temperature more optimally in apartment units with east and south orientations. The difference between the unit temperatures in the west and east ranges from 2-6 °C in the coldest month, and 3-7.6 °C in the warmest month. The difference between the temperatures in the southern and northern units is not much different, which is 0.5-1.5 °C. Buildings that are parallel to the direction of the wind, it will increase the thermal comfort of the occupants in it. In this case, the wind direction in Surabaya is dominated by the east and south directions

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