OUTDOOR THERMAL PERFORMANCE COMPARISON OF SEVERAL GLAZING TYPES

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ABSTRACT

Recently, urban air temperature has been increasing, which can be attributed to the vast development, land cover changes, urban geometry, and surface material. Several strategies can be applied to mitigate the urban heat island intensity. one of which is the use of a cool and reflective material to avoid solar heat gain. In this study, we simulate a simplified model of the Asia-Afrika region in Bandung and conduct a comparative analvsis to determine the thermal performance of glass in the outdoor thermal environment. The study results demonstrate that the shading coefficient value of glass has a negative correlation with the outdoor air temperature.

Keywords: glass; shading coefficient; outdoor thermal environment

INTRODUCTION

Currently, the building facade in Bandung is dominated by heavyweight materials, such as brick, glass, and concrete (Wonorahardio, 2012). In addition, the city's surface lacks vegetation and natural covering. Both these conditions lead to the urban heat island (UHI) phenomenon. Mas'at (2009) stated that the average air temperature in Jakarta, Indonesia, has increased by 0.17° in the last 25 years, and that the urban area of Jakarta is 0.7°C-1.0°C hotter than the rural area. Heat island intensity, defined as the air temperature difference between two areas (Oke, 1982), can cause several problems in a tropical-climate area, such as increasing cooling load and overall energy

consumption of a building (Rajagopalan, P., Lim, K.C., Jamei, 2014).

design process, the energy In а consumption of a building design is commonly assessed by calculating the thermal transmittance overall value (OTTV), which is calculated from the amount of heat received by the building facade, both from conduction of opaque and transparent bodies and radiation through a transparent body on the facade (90A-1980, 1980; ASHRAE Standard 90-1975, 1975) Some of the variables affecting this value include the U-value, or the thermal transmittance value of a facade component, and the shading coefficient, especially on its openings or windows. The U-value shows that the effectivity of a facade component works as a thermal insulator: the lower the U-value of a facade component, the slower is the transmission of heat through it. This means that, to obtain a good OTTV, architects should use as small a U-value as possible.

Meanwhile, the shading coefficient of an opening expresses the amount of solar heat gained through an opening, and is determined from the reflectivity value and colour of the glass. The shading coefficient ranges between 0 and 1, where the lower the shading coefficient value, the lesser is the solar heat transfer, and thus, the lesser is the energy consumed (Yin, R., Xu, P., Shen, 2012; Bahadori-Jahromi, at.al, 2017).

The previously conducted outdoor thermal environment studies have applied several strategies for reducing the heat island intensity and air and surface temperature. The Cooling Singapore researchers wrote in the Cooling Singapore (2017) that

architects and planners can apply five strategies to reduce the air and surface temperature: usage of vegetation on urban surfaces wall. roof. and (Alghannam. 2012; pavements Santamouris, 2012; Wonorahardjo, S., Sutjahja, I.M., Kurnia, D., Fahmi, Z., Putri, 2018) controlling urban geometry, such as building heights and street width and breezeway optimizing and building porosity: utilizing water bodies and features for allowing cooling by E.A., evapotranspiration (Hathway, 2012; Sharples, Takebayashi, Η., Moriyama, 2009), using a high-albedo, reflective, permeable material on streets, open spaces, roof, wall surface material, as well as an active and dynamic facade, for avoiding solar heat gain (Akbari, H., Matthews, D., Seto, 2012; Elsayed, 2012; Santamouris, 2012; Wonorahardjo, 2012; Yaghoobian, N., Kleissl, 2012), and providing shading on the building facade by arranging building orientation and using shading devices and vegetation (Emmanuel, Rosenlund, R., Η., Johansson, 2007; Wonorahardjo, 2012). Controlling urban geometry and utilizing water bodies will be difficult to apply in the existing environment, and even if applied, will incur a huge cost and time. In contrast, modifying urban surfaces by using a high-albedo, reflective material is more feasible for application in the existing environment.

Meanwhile, the indoor thermal and energy performance due to the use of glass material as a building facade has been extensively studied, but the effect of facade glazing on the outdoor thermal environment has been hardly studied. Bahadori-Jahromi at.al (2017) conducted a case study on the impact of filmed windows on energy performance by using building energy simulation software, and concluded that the usage of a filmed window can reduce 35% of the annual overall cooling energy consumption. The application of a film on a clear and tinted glass showed similar result. However, the study did not discuss the outdoor thermal environment.

Lee, S.K., at.al, (2013) studied the thermal performance of window glazing in an

indoor thermal environment. He compared the thermal performances of clear glass, low-emission glass, and a glass tinted with TiO_2 as a protective film on the exterior side. He concluded that the tinted glass with TiO₂ film and low-emission glass showed a lower indoor temperature. However, this study did not discuss the effect of the thermal performance on outdoor temperature. Several studies have been conducted on using cool surfaces with high-albedo, shiny, and bright-coloured materials for mitigating heat island intensity, but there is a lack of research on the effect of glazing thermal performance on outdoor temperature.

In this study, the author conducts a microscale simulation on the thermal performance of several glass types on outdoor temperature, using a simplified numerical model and weather data of a region in Bandung, West Java, Indonesia. As a result, outdoor temperatures before and after application of several glass types on the building facade are collected and compared.

THEORETICAL REVIEW

The thermal conditions of an area are influenced by heat storage and air trapping that occurs in the area (Wonorahardjo, at.al, 2018). According to the literature, the variables that determine the cooling load and temperature of an area include the distance between buildings, building height, and the surfacecovering material of the region.

According to Wonorahardjo (2009), the air temperature of a city is influenced by the building geometry. In that study, it was known that the area with a narrow distance between buildings will result in air trapping, where the air flow is trapped in a narrow space so that hot air faces difficulty in moving out of the area. In contrast, in an area with a larger distance between buildings, air movement can easily occur and minimize the occurrence of air trapping. The building height in the area would determine the surface that would dominate heat reception. А vertically developed area (three floors or

more) with a narrow distance between buildings (high-intensity) will receive more heat through the building facade surface than the road surface. In contrast, a horizontally developed area (less than three floors) with increased spacing between buildings (low-intensity) will receive more heat through the road surface. Phinyawatana (2006) discussed the impact of urban geometry on the surface temperature of urban areas, considering that an increase in the distance between buildings can increase the heat release.

The use of materials with high albedo values is a design approach that is often used to reduce surface temperatures in urban areas and building's cooling loads. The most widely used approach is to apply a reflective material on the roof and roads, such as cool pavement and cool roof (Phinyawatana, 2006; Rosenfeld, A.H., 1998; Santamouris, 2012; Yuan, J., Emura, K., Sakai, 2013,Pratiwi, 2018). However, the effect of using a reflective material in the building facade on outdoor temperature has not been discussed much.

Phinyawatana (2006) stated that a material with a high emittance value can increase the rate of heat flux and reduce the difference in surface temperature. while that with high reflectance values can reduce the rate of heat flux and the difference in surface temperature. Alchapar and N.L., Correa (2015) indicated that the vertical side of a building envelope significantly affects the decrease in heat gain, which will affect both the temperature in the building and that of the area. Ihara, T., at.al (2015) also argued that the material properties of a building envelope significantly affect the energy performance of buildings. Ihara concluded that the decrease in the heat gain coefficient value and the increase in the reflectance of the opaque part of a window can reduce the energy requirements. Meanwhile, a decrease in the U-value in the opaque parts of the facade can increase the cooling load.

Wonorahardjo (2009) stated that areas that use heavyweight materials have lower

outdoor temperatures than those that use lightweight materials. This is because of the thermal properties of heavyweight materials, which have a high heat capacity, where a material can store more heat for a longer time as compared to the lightweight material (Wonorahardjo, S., at.al. 2018).

United States Environmental Protection Agency (EPA), (2012) stated that building walls that have large heat capacity and low albedo absorb short-wave radiation and do not release heat back into the atmosphere, which results in increased outdoor temperature. Albedo is a value that shows surface reflectivity on a scale of 0-1, where a material with albedo 0 absorbs all radiation, whereas that with an albedo value close to 1 reflects radiation. Albedo is influenced by the colour and roughness of the material, where a value closer to 1 indicates that the material has a brighter and smoother surface. Areas with high surface albedo material have lower surface temperatures and smaller cooling loads, whereas those with lower albedo values have higher surface temperatures and cooling loads.

Similar to the surface of other materials, glass also has solar energy characteristics (R/Reflection), that reflect absorb (A/Absorption), continue (T/Transmission), and re-emit (E/Emission) the solar energy reaching its surface. The E value of glass is equal to its A value. The values of R, A, T, and E differ for each type of glass and their thickness. In addition, the shading coefficient value of each glass differs depending on the colour, thickness, and coating on the surface of the glass. Table 1 shows the energy characteristics and shading coefficients for five types of 6mm-thick glass available in Indonesia.

The outdoor thermal environment can be studied through several methods. includina field measurement Wonorahardjo (2009) and simulation using models (Gao, W., at.al, 2002; Giovannini, at al, 2013; Li, K., Yu, 2008: Phinyawatana, 2006). The selection of this must be adjusted to the method environmental scale to be studied and the purpose of the study. Mirzaei (2015)

divided the modelling approach into three scales: building-scale models, microscale models, and city-scale models. The building-scale model aims to determine the performance of building envelopes and is influenced by the surrounding environment. The variables that are generally used include the space's function, type of building material, opening's design, solar radiation, and outdoor temperature.

Table 1. Energy Characteristic and Shading
Coefficient of Glass

Glass Type	Energy Characteristic				SC
	Т	R	Α	ΤUV	-
Clear Glass	79	7	14	62	0.95
Tinted Absorptive Glass	44	5	51	22	0.68
Clear Reflective Glass	67	20	13	40	0.82
Tinted Reflective Glass	23	25	53	10	0.44
Clear Low Emission Glass	51	9	40	44	0.67

(Source: Asahimas Product Catalogue, http://www.amfg.co.id/en/product/flatglass/brochure/)

The tools used include EnergyPlus and TRSNYS. The microscale model is used to determine the relationship between the outdoor environment and the performance of a building. The parameters that are often used in this model include building geometry, distance between buildings, building height, type of material used, radiation. solar and weather data. Examples of tools used in microscale models include computational fluid dynamics (CFD) (ENVI-met, FloVENT, ANSYS Fluent, Autodesk CFD) and Urban Canopy Model. The city-scale model is used to observe the thermal imagery from an area through remote sensing (Li, K., Yu, 2008). The parameters that influence

this model include building volume, land covering, and orientation.

FloVENT is a CFD program that can model microscale thermal conditions and the effects of material use. Phinyawatana (2006) modelled thermal conditions in urban canyons and buildings by changing the material properties. Their results showed that FloVENT can model changes in thermal environment due to material property modification.

METHODOLOGY

Based on the theoretical review of research methods, it is concluded that the use of microscale models is the most appropriate choice for examining the thermal conditions of a region due to the of materials. This study was use conducted qualitatively by 1) performing experimental simulations using а microscale model. namely FloVENT (using Institut Teknologi Bandung license, 2015), by retrofitting the existing building facade using glass as a second skin and 2) conducting a comparative analysis of the initial outdoor air temperature with the outdoor air temperature after the retrofit. Figure 1 depicts a picture of an old building whose facade has been retrofitted using a glass second skin.



Figure 1. On-going retrofit process of an old building facade using a glass second skin to achieve better building performance (Source: The New York Times, <u>https://www.nytimes.com/2008/09/03/busine</u> <u>ss/03facade.html</u>)

Selection of the type of area to be modelled was based on the orientation of the area, building height, and the distance between buildings. The measurement point in the model was placed 1.5 m above the street surface, at two points in an area with buildings facing East-West, having a building height of three floors or more, with narrow distance between the buildings. The case study was selected based on the results of the theoretical studies of areas having most suitable heat release and heat storage conditions for the application of glass material as facades. building Modelling was conducted using the data from JI. Asia-Africa, Bandung, West Java, Indonesia. The weather data used in this study were of field the results measurements conducted by Wonorahardjo (2009). Figure 2 shows the model of the Asia-Africa region, Bandung, and the location of the measurement points in the model.

In the experimental simulation, five types alasses with different thermal of specifications were tested using a 6-mmthick glass: clear glass, tinted absorptive glass. clear reflective glass, tinted reflective glass, and low-emission glass. Then, the simulation results in the form of outdoor air temperature were analysed through a comparative analysis of the existing conditions with those after the use of glass material on the building envelope. Then, the findings of this study were concluded.

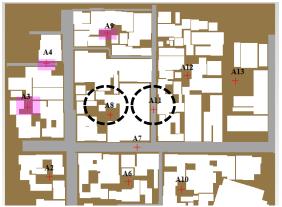


Figure 2. Model of Jl. Asia Afrika, Bandung. Measurement points are marked with circular dashed lines

To study the effect of glass application as building facade on outdoor thermal environment, the existing condition needs to be simulated. In the existing condition, a brick wall is applied as the external wall of the building. Based on the simulation of the existing condition, at Measurement Point A, the initial temperature increases significantly from 25.92°C at 07:00 AM to 34.49°C at 12:00 PM, where it reaches its peak. After 12:00 PM, the outdoor temperature slowly decreases to 29.23°C at 05:00 PM. The same pattern is shown by the simulation result of the existing outdoor temperature of Measurement Point B, where the initial temperature increases significantly from 25.88°C at 07:00 AM to 34.61°C at 12:00 PM, where it reaches its peak, and then decreases to 29.23°C at 05.00 PM. The outdoor temperature changes can be seen in Figure 3.

Then, the application of the five glass types is simulated. From each result of simulation, the outdoor temperature on each measurement point is collected and compared with the initial outdoor temperature on each measurement point. The temperature differences between the initial outdoor temperature and outdoor temperature on each glass type are expressed as ΔT , where a positive value means that the outdoor temperature increases from the initial temperature, while a negative value means that the outdoor temperature decreases from the initial temperature. Figure 4 shows that at Measurement Point A, the application of a clear glass and clear reflective glass shows a negative value of ΔT , while the low-emission glass, tinted absorptive glass, and tinted reflective glass show a positive value of ΔT .

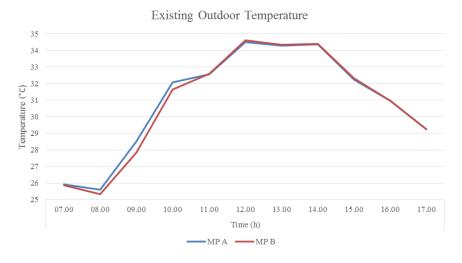


Figure 3. Initial outdoor temperature of Measurement Points A and B

At Measurement Point B, the phenomenon is repeated. Clear glass and clear reflective glass exhibit lower outdoor temperature than the initial condition, whereas the tinted absorptive glass, lowemission glass, and tinted reflective glass exhibit higher outdoor temperatures than the initial condition. The differences between the initial condition and after glass application at Measurement Point B can be seen in Figure 5.

At both measurement points, the application of clear reflective glass demonstrates the largest decrease in outdoor temperature, followed by clear glass, whereas the tinted glasses, irrespective of being reflective or absorptive, increase the outdoor temperature. In Table 2, it can be concluded that the shading coefficient has a linear relationship with the outdoor temperature: the larger the shading coefficient value of the glass used as the building facade, the lower is the outdoor temperature, and vice-versa.

In minimizing the cooling load strategy and UHI mitigation, the use of high-albedo materials will reduce the outdoor air temperature and building's cooling load. It is known that the albedo value of a material is related to the surface reflectivity value, which in this case is solar reflectance of glass, and affects the amount of outdoor temperature. If this premise is true, then the tinted reflective glass should produce the lowest outdoor

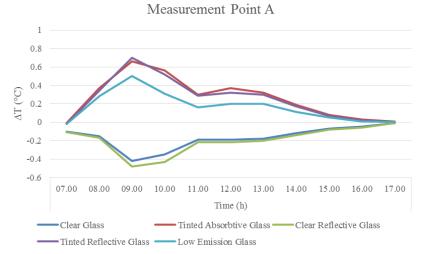
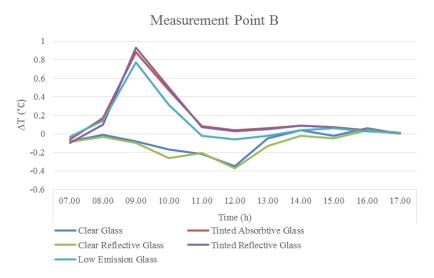


Figure 4. Outdoor temperature before and after retrofit on Measurement Point A

air temperature. However, the simulation results do not show this pattern. The tinted reflective glass produces the highest outdoor air temperature, while clear glass, which has the lowest solar reflectance, decreases the outdoor air temperature. temperature. This finding contradicts the selection of an appropriate glass type for producing a low OTTV, where a high shading coefficient value will lead to a high solar heat gain and cooling load and a low shading coefficient will lead to a low



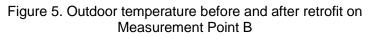


Table 2. Comparison of Solar Reflectance, Shading Coefficient, and Temperature Changes

Glass TypeSRSCEffect on Outdoor TemperatureClear Glass70.95DecreaseTintedAbsorptive50.68IncreaseGlassClearClearClearReflective200.82DecreaseGlassTintedClearClearReflective250.44IncreaseGlassClear Low-Clear Low-CleassEmission90.67Increase			•	
TintedAbsorptive50.68IncreaseGlassClear200.82DecreaseGlassTinted250.44IncreaseReflective250.44IncreaseGlassClear Low-250.67Increase	Glass Type	SR	SC	Outdoor
Absorptive50.68IncreaseGlassClearReflective200.82DecreaseGlassTintedReflective250.44IncreaseGlassClear Low-Emission90.67Increase	Clear Glass	7	0.95	Decrease
Reflective200.82DecreaseGlassTintedReflective250.44IncreaseGlassClear Low-Emission90.67	Absorptive	5	0.68	Increase
Reflective 25 0.44 Increase Glass Clear Low- Emission 9 0.67 Increase	Reflective Glass	20	0.82	Decrease
Emission 9 0.67 Increase	Reflective Glass	25	0.44	Increase
	Emission	9	0.67	Increase

However, if we compare the outdoor temperature change with the shading coefficient value, we obtain an appropriate pattern of outdoor air temperature change, according to which a higher shading coefficient leads to a lower outdoor air solar heat gain. It also can be said that the albedo value of a glass facade is more related to the glass shading coefficient value, rather than the value of the solar reflectance glass; thus, the outdoor temperature changes more in relation to the shading coefficient of a glass than its solar reflectance value.

DISCUSSION

The heat island mitigation strategy on an existing area can be tricky. A suitable strategy should be chosen on a case-bycase basis. In a high-density environment, where the availability of open space is limited and modifying the urban geometry is not feasible, modification of the building facade can be applied. From the simulation result and analysis, clear glass and clear reflective glass can be used if the architect wants to perform retrofit on an old building. Both these glasses yield a similar result on decreasing the outdoor temperature. However, the application of clear glass will cost less than that of clear reflective glass. Retrofitting an old building facade may be more suitable on a middle-

high-rise building than a low-rise building, because roof surfaces gain more heat from direct sun radiation than the wall surface in a low-rise building. Retrofit using second skin glass is also not suitable for an environment with a small gap between buildings, where the second skin glass itself needs an area of at least 60 cm to 1.2 m to yield the best thermal performance (Poirazis, 2004).

CONCLUSION AND RECOMMENDATION

This study found that the shading coefficient value of glass used as a building facade affected the outdoor air temperature of its surrounding. The findings of this study can be used as a guide for architects and policy-makers. For architects, this finding can be used as a consideration before choosing the glass type they will use in their design, as it has a contradictive effect on building energy consumption and outdoor thermal environment. Meanwhile, for policymakers, this finding can be used as a complement to the existing regulatory document related to the building code, so that the regulations not only regulate the effects of building design on building energy alone but also the impact on urban thermal environments.

However, FloVENT, as a microscale simulation model, cannot incorporate the aspects of meteorology and climatology, such as the greenhouse effect, and thus, further research is needed by performing direct measurements using a 1:1 model or other simulation to prove the results of this study.

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Vol. 04, No.1, February 2019: 22-31

Outdoor Thermal Performance Comparison of Several Glazing Types

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