DIMENSI − Journal of Architecture and Built Environment, Vol. 42, No. 2, December 2015, 59-68 DOI: 10.9744/dimensi.42.2.59-68
ISSN 0126-219X (print) / ISSN 2338-7858 (online)

REDUCING SURFACE TEMPERATURES OF NORTH-SOUTH BUSINESS CORRIDORS IN YOGYAKARTA

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ABSTRACT

The heat island has made the warm-humid climate city of Yogyakarta thermally more uncomfortable, which induces its people to depend more on energy consuming air conditioners. Business corridors are constructed from building walls and roofs, pedestrian paths, the streets and the vegetation, which convert solar radiation into heat. Infrared mappings of the four north-south axis business corridors of Yogyakarta found that streets and vehicles have their temperatures higher than the air temperature. Exception is at Gejayan St., where the street's temperature is close to the air temperature. This street has rows of trees on its median, which effectively shades the street. Further study on Gejayan St. using a computer simulation method confirms that columnar and spreading form trees can reduce incident solar radiation on the street surface by, respectively, 13.35% and 22.02%. Putting creeping plants on pergolas reduce incident solar radiation on the west and the east walls by, respectively, 37.05% and 37.45%.

Keywords: Heat island; plant shade; surface temperatures; warm humid climate.

INTRODUCTION

Global warming and heat islands have become a double cause of urban air temperature increase in recent decades. In cities where the air temperatures are already naturally warm, such as those situated in the warm humid climate regions, the air temperature increase results in more thermal discomfort and energy consumption from building air conditioning. While the global warming phenomenon needs global scale efforts to remedy it, heat islands can be mitigated on a local scale.

Just like other cities in Indonesia, Yogyakarta has developed into a busy, crowded and dense city with 12,123 people per square kilometer (based on the 2012 census, Statistic Bureau online). Climatic data shows that from 1984 to 1994 the air temperature of Yogyakarta increased 1^{o}C, from average air temperature of 26^{o}C to 27^{o}C (Figure 2). Presently, outdoor air temperature ranging from 32^{o}C to 36^{o}C is common. Recent random measurements found that on building terraces, air temperatures can reach around 40^{o}C in mid-days. If this condition is not improved, people will soon need to rely fully on air conditioners to stay comfortable, which will generate multiplier effects that make the situation worse. In 2014, for example, sales of air conditioners was up by 33% (Sismanto, 2014), obviously a response to the hotter air.

Heat islands have been studied in-depth by Lisa Gartland (2008). In her book, she delves into the matter in detail, from the causes of heat islands to the suggestions to mitigate them. However, she mostly discusses heat islands in non-tropical contexts. While Gartland's book provides invaluable information on heat islands in the non-tropical context, this paper will focus on the context of Yogyakarta which is situated in the warm humid tropical climate. In particular, this paper reports measurements of the surface temperatures of Yogyakarta's business corridors, links them to the air temperature and offers shading method to reduce the surface temperatures with locally adapted plants. Plant shades are more preferable than those of common materials, such as concrete and metals, as plants have an evapotranspiration process, which helps prevent their temperature from rising too high. As addition, plants absorb pollutants and reduce noise. This study only focuses on the business corridors, however. It is hoped that broader applications of the findings will have greater impacts on the city, i.e. reducing the heat island (lowering urban air temperatures) and creating more comfortable air temperature. Even though a heat island phenomenon covers the whole urban area, the busy business corridors have been assumed to have more intense heat as there are combustion engine vehicles that emit significant heat.

URBAN HEAT ISLAND PHENOMENON AND ITS MITIGATION

A heat island is simply defined as a phenomenon in which during the nights urban and sub-urban areas have higher surfaces and air temperatures than their surrounding countryside. It is caused by reduced evaporation, increased heat storage, increased net radiation, reduced convection and increased anthropogenic heat. It exhibits hotter air temperatures, hotter surface temperatures, larger effects during clear-calm weather, and increases thermal inversions (Gartland, 2008). It relates to the urban surface conversion and intense inhabitants' activities. Under solar radiation, greeneries and wet surfaces can maintain their temperatures relatively low through the process of, respectively, evapotranspiration and evaporation. On the other hands, materials such as asphalts, concrete blocks and clay tiles will have their temperatures soar since they absorb the solar radiation and convert it to heat. More urban inhabitants' activities, such as transportation, cooking, lighting, and building air conditioning, put out more heat to the urban environment.

Heat islands in warm humid climates have been studied by some researchers. In 1966, Niewolt found 3.0°C to 3.5°C differences between the air temperatures of Singapore central and its periphery (Emmanuel, 2005). Elsayed (2006) found that the air temperature of Kuala Lumpur was 3.9°C to 5.5°C higher than its surrounding areas. Other Malaysian researchers, Ahmed et al (2015), reported a heat island intensity of 2°C at Putraja during nighttime but a negligible one during daytime. Nurul et al (2013) studied heat island phenomenon in Yogyakarta. With surface thermal mapping, she revealed that Yogyakarta downtown had higher surface temperature than its surrounding areas. The highest and lowest surface temperatures were, respectively, 36°C and 27°C. She noted that the high surface temperatures found in built up areas had decreased according to the higher proportion of greeneries. A temperature mapping by Juniwati et al (2015) of a smaller area, i.e. Petra Christian University in Surabaya, using field measurements and STEVE-tool, confirmed that zones with less vegetation have higher ambient air temperature.

To reduce heat islands, all urban heat emissions should be controlled and reduced. Heat island mitigation methods are available so that people can actually get involved in the mitigation process in their daily life. Latest technologies provide newer equipment (air conditioners, televisions, monitors, lighting, etc.) with lower heat emissions. Electric motor vehicles, for example, will emit less heat than combustion engine ones though stigmas about their higher price and lower performance have been preventing people from converting to electric motor vehicles. For urban planners, architects, and city authorities, one of the involvements is to find ways to control the heat emission from the warm urban surfaces, which are abundantly available in references. Unfortunately, sometimes most of the suggested methods are not readily applicable in the warm humid climate context. Applying a solar reflecting paint to dark colored roofs, for example, cannot easily be applied since that paint is not always available in local hardware shops. Painting the roofs white is not popular either since in warm humid climates the dominant glary bright overcast sky will make those white roofs very eye irritating. Replacing the darker colored asphalts with the lighter colored concrete blocks to reduce solar heat absorption is also unpopular for city streets with heavy traffics and rains.

The two basic methods of minimizing a surface's temperature increase are (1) to prevent direct sunshine from hitting that surface with a sun shade; and if number 1 cannot be avoided, (2) to use a high solar reflectance and high heat emittance material for that surface. However, even though a sun shade can reduce the temperature of the shaded surface, the sun shade's temperature will still rise. Thus, this method is only good to protect, for example, a room from the strong sun radiation but it will not reduce the environment's temperature unless the sun shade is made of plants or materials with high solar reflectance and high heat emittance. Painting a roof white increases its solar reflectance but it introduces glare. Using plants to shade a surface is better but the plants should be chosen carefully. The Vertical Greenery System (VGS), for example, has many benefits such as reducing thermal heat and improving air quality. It is not yet popular in tropical climate, as it also has some disadvantages such as inviting unwanted animals and high cost of maintenance. Most people see it just as a device for improving visual quality, bringing natural harmony and reducing stress (Abdul-Rahman et al, 2014).

There are some other thoughts regarding the heat island phenomenon. Ventilation and shades play an important role in urban outdoor thermal comfort, in particular to induce physiological cooling. A thermal bioclimatic analysis in tropical climate by Abreu-Harbich et al (2013) in Campinas, Brazil, using air temperature, mean radiant temperature and Physiologically Equivalent Temperature (PET) found that ventilation and shade can improve comfort even for PET above 35°C. A study by Ng (2015) resulted in an interesting finding. While his study confirmed the heat island phenomenon that compact high rise area had 2°C warmer air than the open high rise residential area from midnight to 6. a.m., the mean air temperature for the entire 5 day period was greater at the open high rise site. Introducing more water to reduce air temperature by evaporation is debatable in warm humid climate. While the evaporation process helps the air temperature in not increasing to high, the increased air humidity reduces the thermal comfort. Water Sensitive Urban Design (WSUD) can still be used to provide good conditions for greenery growth. (Coutts et al, 2012).

SURFACES OF BUSINESS CORRIDORS OF YOGYAKARTA

Four business corridors were surveyed, i.e. (1) Malioboro St., (2) Kaliurang St., (3) Gejayan St., and (4) Seturan St. All of them elongate nearly to north-south axis. (See Figure 1). Those four streets are at busy business districts that are active almost for 24 hours. They are inside the 7.80° to 7.76° South Latitude and the 110.40° to 110.41° East Elongations. In terms of history, Malioboro St. is the oldest street, as it was developed since the dawn of the Yogyakarta Palace (1755 A.D.) and has a special meaning for local people as well as attracts domestic and foreign tourists. This street has been renovated many times and such renovations included the changing of its façades form as well as their surfaces' materials. The Seturan St. becomes the newest street as it was developed only around ten years ago and started out a very busy street since it connects Adisucipto St. and the north outer ring road of Yogyakarta.

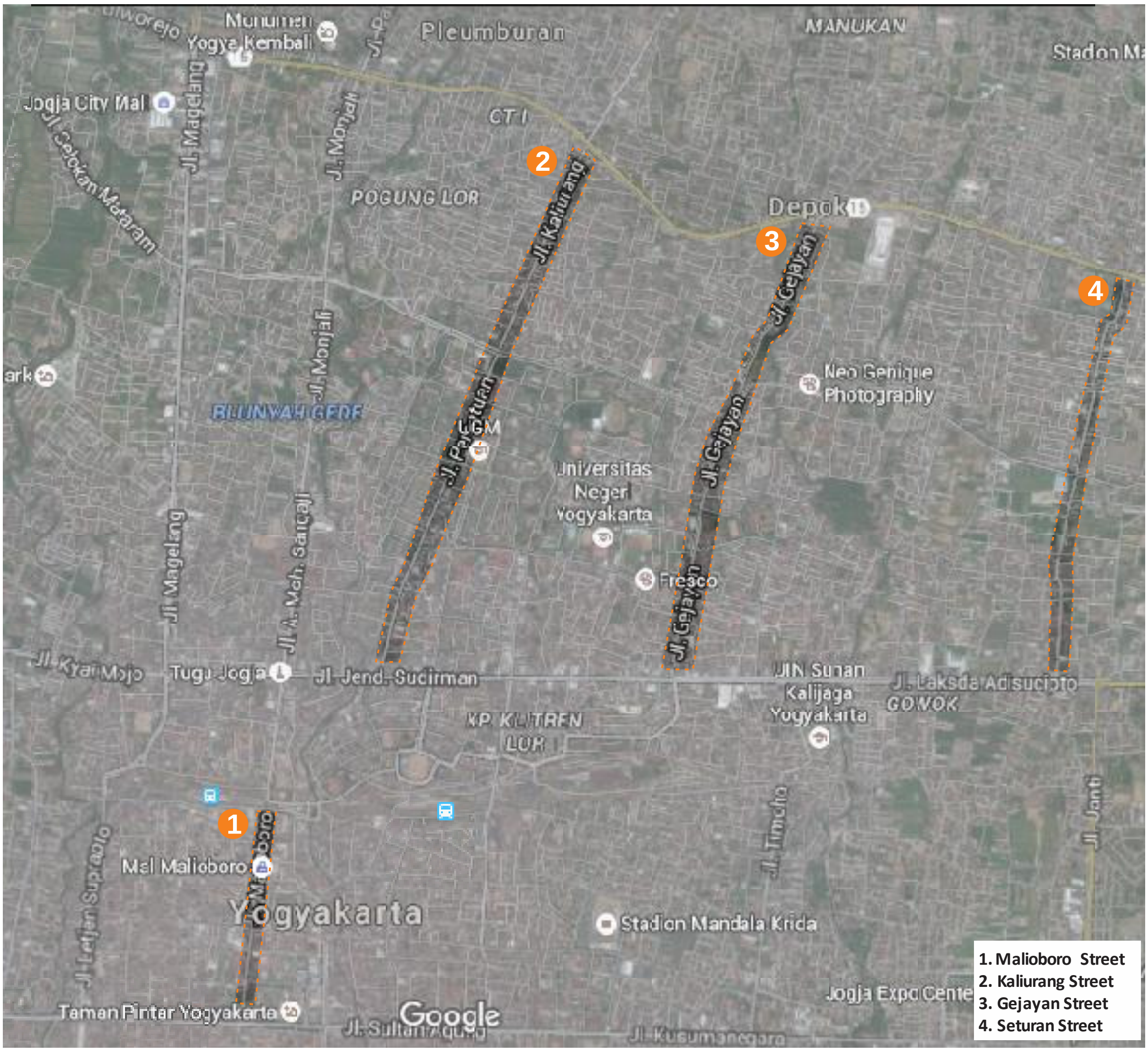


Figure 1. The four business corridors in Yogyakarta being surveyed. These corridors are not perfectly aligned with the north-south axis. The daily sun path from east to west has made the buildings' row at the east and west side of the street shade the street, respectively, in the morning and afternoon

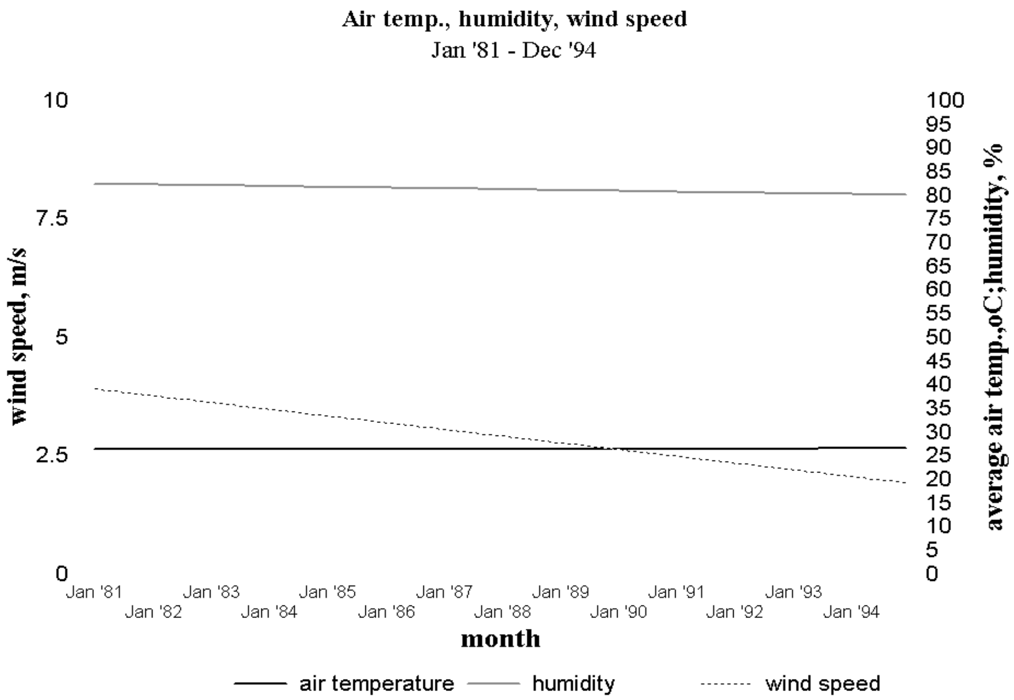


Figure 2. Linear fitted graphs of air temperature, humidity and wind speed. Within 14 years humidity and wind speed tended to fall, whereas air temperature tended to rise. (Source: Satwiko, 2004; based on data from the Adisucipto International Airport)

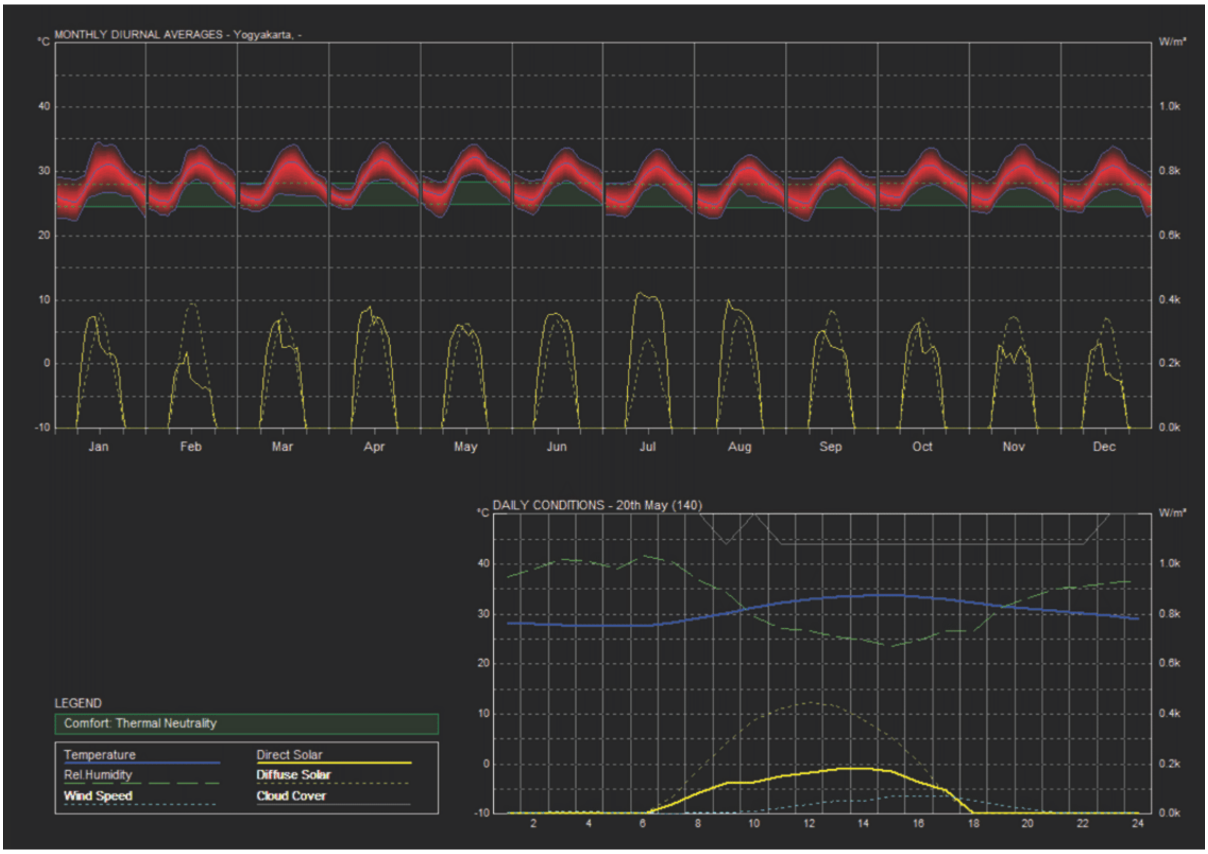
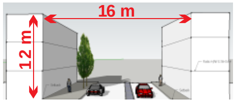
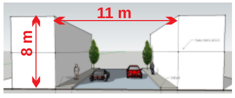
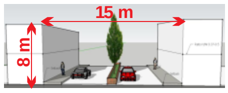
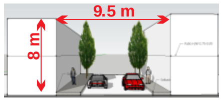


Figure 3. Typical climate of Yogyakarta shows a daily similarity pattern throughout the year. The air temperature range is 22ºC – 35ºC. (Source: compiled from local data and Meteonorm software)

Table 1. Street Condition.

	Malioboro St.	Kaliurang St.	Gejayan St.	Seturan St.
Photos				
Section				
H(eight)/W(idth)	12 /16 or (8/10.6)	8 /11	8 /15	8 /9.5
Length of street (km)	1.26	3.3	2.8	2.4
Dominant activities	Shops and street traders	Shops, restaurants	Shops, restaurants	Shops, restaurants and services
Traffic	One-way, motor cycles, cars, buses, tri-cycles, bi-cycles, horse carts.	Two-way, motor cycles, cars.	Two-way, motor cycles, cars.	Two-way, motor cycles, cars.
Pedestrian path	Covered, crowded, mixed with street traders.	Uncovered.	Uncovered.	Uncovered.
		Surface material		
Roof	Dominantly clay tiles and some asbestos (red or dark brown).	Clay tiles and asbestos (red or dark brown).	Clay tiles and asbestos (red or dark brown), some concrete tiles.	Clay tiles, some asbestos (different colors), some concrete tiles.
Façade	Dominantly brick plastered (mostly light color: cream, grey, yellow), mostly covered by banner made of GRC (Glass fiber Reinforced Concrete) or textiles.	Brick plastered in almost building's facade, some GRC applied in some building (various colors)	Brick plastered in almost building's facade, some GRC applied in some building (various colors).	Brick plastered in almost building's facade and some GRC applied in many buildings (various colors).
Street	asphalts	asphalts	asphalts	asphalts
Vegetation	Creeping plants as shading devices of building entrance or pedestrian path, some medium and big trees on pedestrian path.	Medium and big trees at both side of the street sides nearly Gadjah Mada University Campus, Medium and small trees in the northern part (moderately).	Medium trees at the street median.	Sparsely big and medium trees at both sides of the street.

The orientations of the four business corridors that nearly align with the north-south axis give some consequences. The dominant wind orientation of Yogyakarta is from the south to the north at daytimes. These corridors might provide a channeling effect for the wind that helps flushing the heat from, especially, transportation means. The east to west sun path results in the east-facing façades receiving direct morning sunrays and the west-facing façades receiving the direct afternoon sunrays. The proportion of the façade's height to the street's width (H/W) will determine the shading effects between the east and west façades and also between both façades and the street between them.

METHODOLOGY

This research follows a procedure of (1) literature study on the state of the art of heat island research and its mitigation, (2) field study on the local potentials to mitigate local heat island problem, (3) measurements of the air and surface temperatures of the four Yogyakarta's business corridors, and (4) solar incident radiation simulations. Air temperature measurements used a laser infrared psychrometer AZ 8857 which can also be used to measure the temperature of a point at a surface. To measure the temperatures of the four business corridors' surfaces, a FLIR thermal imaging camera (i5) was used. The incident solar radiation simulation used Autodesk Ecotect Analysis 2011 Software with Yogyakarta climate file.

Each business corridor was divided into ten segments or measurement points. At each point, the thermal imaging camera took photos that reveal the temperatures of the street, the roofs, the walls, the vegetation and the pass by transportations. As many as 545 photos were taken from the four corridors. The surface temperature distribution was represented by a different color coding. Each photo was analyzed using Thermacam Researcher Pro software. The color coding range was set from 20ºC to 60ºC. An MS Excel 2013 spreadsheet was used for simple statistical calculations and making comparative graphs.

Since their measurements were not taken at the same time, the temperatures of the surfaces and the ambient air comparison between the four corridors could not be done. Instead, the surface temperatures were compared to the ambient air of the corresponding corridor. Thus, in this study, the focus was on the correlation between the surface temperatures and the ambient air of the same corridor. Otherwise, the conclusion would be bias.

RESULTS AND DISCUSSION

Measurements using an infrared thermal imaging camera and an infrared thermal hygrometer revealed the thermal map of the corridors' surfaces. Table 2 shows that the sky conditions were clear during the measurements and the temperature ranges of the four corridors' surfaces do not show an extreme difference, spanning from 28ºC to 37ºC. The air temperature ranges from 28ºC to 30.1ºC. Data from the Meteorology and Geophysics Agency confirm that the urban air temperatures on the corresponding dates of the measurements did not show extreme condition as well, spanning from 25ºC to 34ºC. Those data reflect the typical condition of a warm humid climate city in Yogyakarta. Table 3 shows infrared images of the four corridors. It can be seen that the streets and vehicles had the higher temperatures. (The photos were taken in perspective views. The actual data were derived from photos taken at normal or perpendicular views).

The four figures (Figure 4 to Figure 7) show an interesting phenomenon. In all corridors, except Gejayan St., the streets' temperatures are higher than the air temperatures. From a picture at Table 2, it can be seen that Gejayan St. has a row of plants in its median, which separates the two-way traffic, as well as many trees in its both sides. Not all of the plants have a spreading form. Trees at the north section part have the columnar form. Even though the spreading form trees will shade more of the street areas, they might disrupt the busy traffic flow, in particular when the branches are too low. The columnar form trees can well shade the street if they are put close one to the other in the north-south axis corridors.

The roofs' temperatures are lower than the air temperatures as it is shown by the four graphs (Figure 4 to Figure 7). This phenomenon is interesting since the roofs are dominated by clay tiles and asbestos sheets, which are heat storage. The clear sky (during the measurements) and the wind blows may encourage the radiation and convective cooling. (In cloudy skies, the radiation cooling is low). Most roofs are steeply inclined and oriented to the north and south, which make the sunrays striking the roofs in relatively more oblique angles to result in smaller sun radiation absorption.

The walls' temperatures range from 27.8ºC to 30.8ºC, which are almost the same as the air temperatures' range of 28ºC to 30.1ºC (Figure 4 to Figure 7). The west and east walls get direct sunrays in the morning and afternoon, respectively. As the measuring times were between 6.00 and 7.30 p.m., those walls had ample time to cool down. The walls' temperatures are higher than the roofs', as the walls cannot easily take the advantage of radiating their heat to the clear sky.

The temperatures of vegetation range from 26.5ºC to 28.7ºC, lower than air temperatures range of 28ºC to 30.1ºC (Figure 4 to Figure 7). The range of the vegetation temperatures is also lower than that of the street, which is 27.85ºC to 31.92ºC. This implies that a higher proportion of vegetation on the street will ensure the city gets less hot surfaces, which is beneficial in lowering the temperature of the environment.

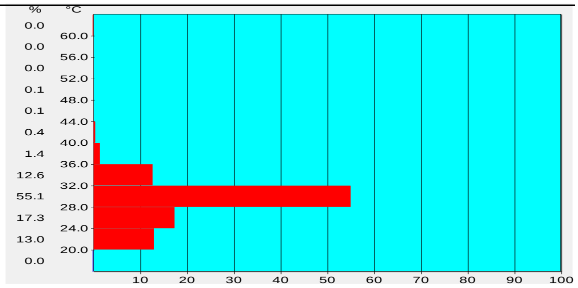
The surface temperatures of the passing vehicles are higher than the air temperature. All of the graphs show it consistently. The air temperatures of Malioboro St. and Seturan St. are 2ºC lower than that of the vehicles' surfaces. Meanwhile, at Gejayan St. and Kaliurang St., the air temperatures are 1ºC lower than the vehicles' surfaces. The latter two streets have more trees. However, the infrared camera cannot measure the engines' temperatures of the passing vehicles. Thus, the contribution of combustion engines to the higher air temperature still cannot be clearly explained yet.

Having observed the streets, roofs, walls, vegetation, vehicles and air temperatures of the four corridors, it can be concluded that the streets' and the walls' temperatures can potentially be reduced. In contrast, it is difficult to reduce the vehicles' temperatures since there is no simple method available at the moment. It can be assumed that the streets' and walls' temperatures strongly relate to their exposure to the sun radiation. Reducing the exposure by shading those surfaces, thus blocking or filtering solar radiation, is an effective and efficient way to go. A sun shade made of a low solar reflectance and low heat emittance material prevents the shaded surface's

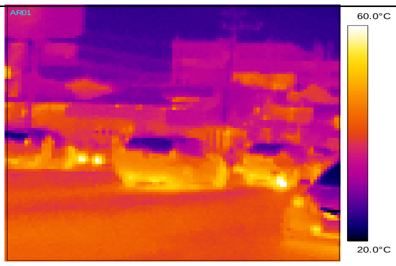
Table 2. Measurements Data

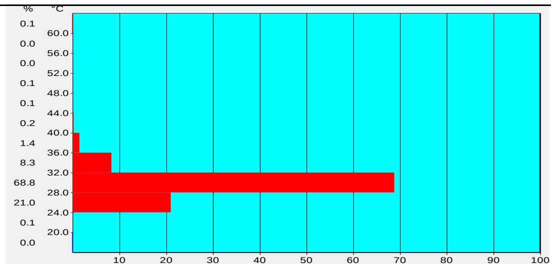
	Malioboro St.	Kaliurang St.	Gejayan St.	Seturan St.
Time of measurements	6.00 – 7.30 p.m.	6.00 – 7.30 p.m.	6.00 – 7.30 p.m.	6.00 – 7.30 p.m.
Date of measurements	8 May 2015	15 May 2015	3 June 2015	10 April 2015
Street segments	10	10	10	10
Infrared photos taken (shots)	112	157	170	106
Sky condition in the morning to afternoon before measurements	clear	clear	clear	clear
Sky condition during measurements	clear	clear	clear	clear
Urban ambient temperature recorded by Meteorology and Geophysics Agency. (°C)	25-33	26-34	25-34	25-33
Range of surfaces' temperatures (°C)	33-37	30-35	30-35	28-35

Table 3. Infrared images showing the surface temperatures

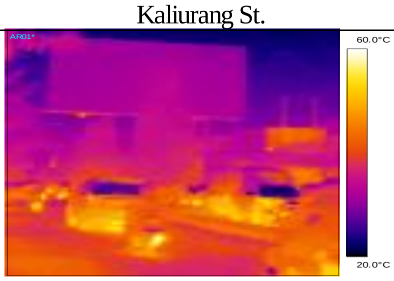


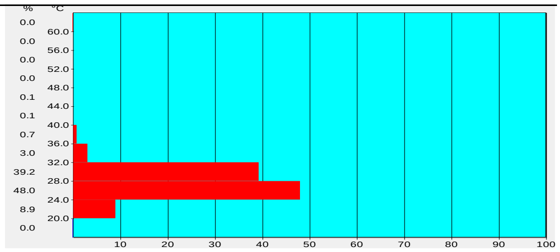
Malioboro St.



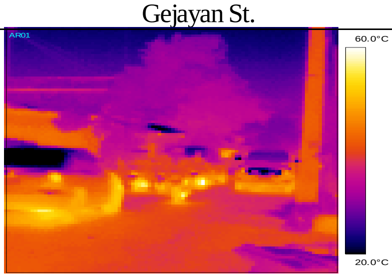


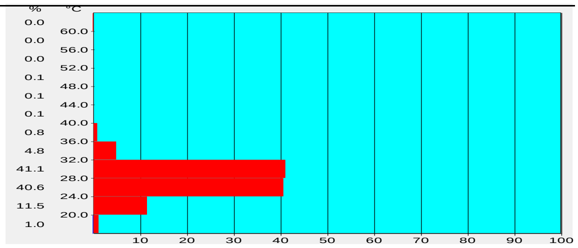
Kaliurang St.





Gejayan St.





Seturan St.

temperature from rising under the sun. However, the sun shade's temperature itself will rise, thereby ensuring no improvement for the environment. On the other hand, a tree can provide shading for a surface without necessarily increasing its temperature, thanks to the evapotranspiration. Gejayan St. is a real example of the contribution of trees to reducing the street's temperature.

Two simple methods can be offered to reduce the streets' and walls' temperatures. Learning from Gejayan St., planting trees on the median of a north-south axis street can reduce the streets' temperature. Columnar form trees, such as Glodogan tiang (lt. Polyathea longifolia), which are arranged in a close array, will shade the streets. Spreading form trees, such as Tanjung (lt. Mimusops elengi), can provide wider shadings from their long branches. Meanwhile, creeping plants, such as Fikus rambat (lt. Ficus pumila), can be put in pergolas to shade walls. (See Table 4 for those three types of trees). To learn the effect of plants on the incident of solar radiation intensity, computer simulations were conducted based on Gejayan St.'s profile (See Figure 8). Table 5 and Table 6 show that trees and creeping plants can reduce streets' and walls' temperatures.

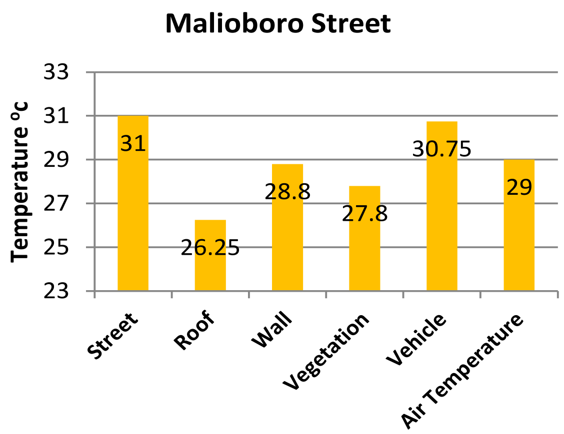


Figure 4. Surface and air temperature of Malioboro St.

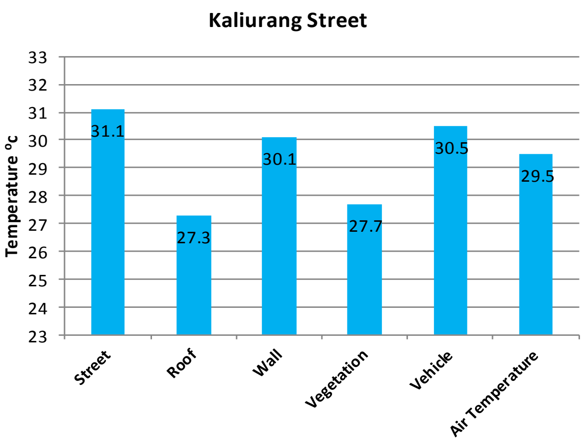


Figure 5. Surface and air temperature of Kaliurang St.

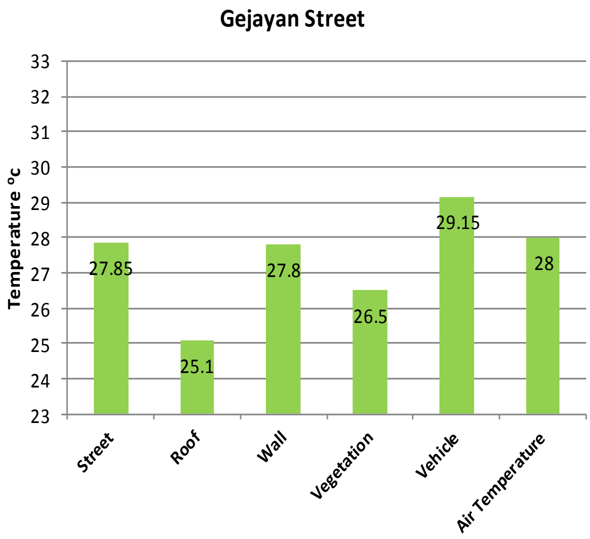


Figure 6. Surface and air temperature of Gejayan St.

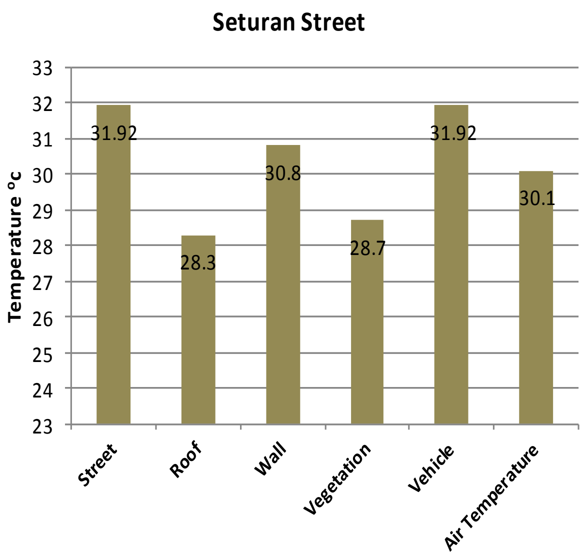


Figure 7. Surface and air temperature of Seturan St.

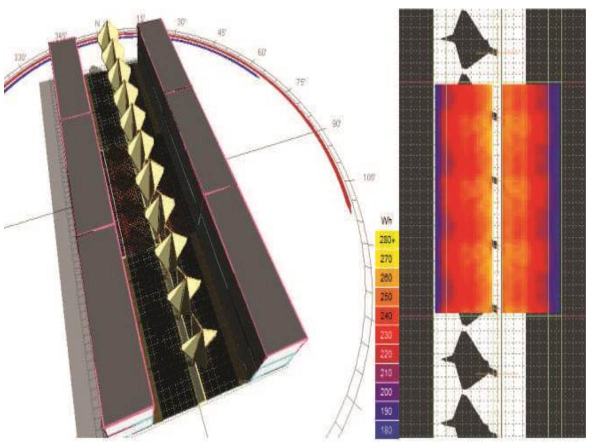


Figure 8. Incident solar radiation simulation using Ecotect

Table 4. Recommended Plants

	Columnar form	Spreading form	Creeping form
Name	Glodogan tiang (lt. Polyathea longifolia)	Tanjung (lt. Mimusops elengi)	Fikus rambat (lt. Ficus pumila)
Form	 (picture: arsip.tembi.net)	 (picture: www.panoramio.com)	 (picture: ww.academia.edu)
Preference application	At narrow street sides or median (~ 60 cm)	At wide street dividers (~100cm) and pedestrians	At windows' overhangs
Features	Easy to grow, withstand strong sun radiation, good pollutant absorption, leaves do not fall easily, roots do not destroy streets	Easy to grow, wide span branches give wide shade, good pollutant absorption.	Easy to grow and nurture, light, good pollutant absorption.
Height (m)	6 - 10	15	0.05 (thickness)
Alternative trees	Cemara angin (lt. Casuarina excels)	Mahoni (lt. Swietenia macrophyllia), Beringin (lt. Ficus Benjamina), Ketapang (lt. Terminaliacatappa), Trembesi (lt. Albizia saman), Kiara Payung (lt. Filicium decipiens), Angsana (lt. Pterocarpus indicus).	Air Mata Pengantin (lt. Antigonon leptopus).

Table 5. Simulations of Incident Solar Radiation Intensity on Gejayan St. using Ecotect

	Type of barrier (on the street median)		
	No vegetation	Columnar form tree	Spreading form tree
Information	Open street without shading devices on the street median.	Trees on street median, 8m high and 1.2m wide, 5m distant between trunks.	Tress on street median, 12m high, 5m wide, lowest branches 5m above ground, 10.5m distant between trunks.
Average hourly radiation on street surface (Wh/m^2)	295.15	255.75	230.16

Table 6. Simulations of Incident Solar Radiation Intensity of Walls using Ecotect**.**

	Without canopy		With green canopy (width = 2m)	
	West side	East side	West side	East side
Average hourly radiation on wall surface (Wh/m^2)	241.16	250.65	151.8	156.79

CONCLUSION

In warm humid climates, sun shades from live plants are more beneficial than other materials since the live plants have evapotranspiration that helps prevent the plants' temperature from rising high, thereby lowering the environmental temperature. The north-south axis corridors, or any corridors nearly aligned with that axis, have the benefit of using trees planted on their median to provide shading for the streets. Spreading form trees and columnar form trees (in a close array) can be used as cool sun shades. For east and west façades, creeping plants on pergolas will provide cool sun shades.

ACKNOWLEDGMENT

This research was made possible by the support from the Architecture Technology Planning and Design Laboratory, Faculty of Engineering, Atma Jaya Yogyakarta University, and monthly financial support through Lecture Certification Program from the Directorate General of Higher Education of Indonesia (number. 08234403106). Computer simulations were prepared by Wendy Sunarya.

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