A REVIEW OF MATERIAL COVER FEATURES FOR MITIGATING URBAN HEAT ISLAND

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Abstract
Urban Heat Island (UHI) is related to the increase of urban compared to rural temperature as the result of global phenomenon. The increase of temperature is predicted to be intensified along with the extend of urban activity in the near future. Therefore, the discussion on UHI becomes significance. This paper discusses the result of literature studies on thermal characteristics of materials that potentially used to reduce Urban Heat Island, especially in utilizing pavement and roof cover. The result of the study concludes that the reduction of UHI is determined by: 1) the high-level albedo (the ratio between the reflected heat and the absorbed heat) of material that is influenced by the color and texture of its surface; 2) The high level thermal emittance of material; 3) The lower capacity of material to store the heat. 4) The capability thermal conductivity of material surface. Recommended pavements to reduce UHI are cool pavement, reflective pavement, porous pavers, permeable pavers, pervious pavement, water retaining pavement. Roof cover materials that reduce Urban Heat Island are Cool Roof and Green Roof. The design and toughness of materials should be considered to reduce UHI.

Keywords: Urban Heat Island, material feature, thermal performance.

INTRODUCTION

Urban Heat Island (UHI) is one of the real impacts of the development of life in urban areas. UHI is a condition of temperature in the city when it is hotter than the surrounding sub-urban and rural areas. The condition of UHI is illustrated by a high temperature of the city so that it constructed the hot island (Voogt, 2002). The phenomenon of UHI has come into discussion by Luke Howard ever-since 1833 (Okay, 1982). According to US Global Change Environmental Protection Agency (2001), UHI will affect air quality, human health and energy used in the city. UHI is also one of the factors causing global warming (US Global Change Research Program, 2001).

The main factor that instigates UHI is the increase of activities occurred in urban areas. Along with the increasing of population, the needs for better city facilities supporting the activities of the population is needed. The developments will inevitably be getting more extensive, buildings will be increasingly tight, and green area will decrease. Land surface and green area in urban areas are replaced by layers of pavement, concrete surfaces, asphalt, roof tops, and building walls, which gives a rise to UHI (Buyantuyev & Wu, 2010).

Research on UHI in Indonesia has been carried out, especially in big cities in Java Island, including Jakarta, Jabodetabek (S. Effendy, 2006), Yogyakarta (Wicahyani, Sasongko, & Izzati, 2014) Surabaya (Sobirin, Fatimah,
& Rizka, 2015) and Semarang (Sasmito & Suprayogi, 2017). Based on the results of those previous studies, it is found that the phenomenon of Urban Heat Island in these cities continues to be increase. In addition, the studies concluded that UHI occurred in the highest dense development areas with less green space in some big cities in Indonesia.

UHI calculates the air and Land Surface Temperature (Zhang, Zhan, Tao, and Xinyu, 2017) by using remote satellites, in addition to figure the city surface and record the characteristics of the ground (Buyantuyev & Wu, 2010). In fact, urban ground surface (such as roads, buildings, parking lots, concrete) are mostly covered by pavement (Hung, Chen, & Cheng, 2010; Senanayake, Welivitiya & Nadeeka, 2013).

The previous studies mentioned two types of material cover (Nurul, Helmi, & Mohd, 2011), i.e.; man-made materials (roofs and pavement) and non-built-up materials (vegetation, soil, rocks, and water bodies). Forty percent of city surface is covered by pavement (Akbari et al., 2008). Road pavement is a significant contributor to increase the UHI effect in addition to other roof cover materials that have high level radiation. They impacted to the increase of urban surface temperature up to 50-60°C (Santamouris et al., 2012; Andrade et al., 2007).

Generally, conventional materials surface are source of heat. Therefore, we need to decide selectively what types of materials will be used. This paper discusses on thermal characteristics of materials that is commonly used in urban area, especially for pavement and roof cover that impacted to the increase of UHI.

METHODOLOGY

This is a literature review focusing on thermal performance features of pavement and roof cover materials used in urban area. The referred literatures are those in relation to thermal performance (albedo, thermal conductivity, and volumetric heat capacity) and material cover features (pavement and roof). The discussion was developed in the form of making comparison among the features of materials that is potentially increasing or reducing the heat level of ground and roof cover surface.

DISCUSSION

Thermal Performance of Materials Used in Urban Area

Abbas, et.al, (2017) found that the characteristics of thermal performance related to albedo, thermal conductivity, and volumetric heat capacity. While Santamouris (2012) measured two main variables of thermal material performance, namely: climatological variables (solar radiation surface temperature, thermal balance, ambient temperature, ambient humidity, wind speed, atmospheric turbulence) and optical variables (albedo, material emissivity). According to UHI concept, the exposure of solar radiation influences the increase of air and urban ground surface heat level. The solar radiation will be absorbed, reflected, transmitted or re-radiated by ground or roof cover material surface which depends on its quality in receiving solar radiation.

Solar Radiation (Heat Flux)

Solar heat radiation consists of ultraviolet (UV), visible light and infrared energy.
The radiation wave energy contributes to Urban Heat Island (EPA, 2012).

**Albedo (Solar Reflectance)**
Albedo feature of material is the ratio between the reflected heat and the absorbed heat. Albedo is influenced by the color and texture of material surface. The darker the color, the easier the material store the heat and the brighter the material, the easier it reflects the heat. The range values of Albedo are between 0 and 1 in which 0 refers to dark color material (black) that absorbs the heat perfectly, whereas 1 refers to bright color material (white). The smoother the material surface, the higher the heat (100% reflected) as illustrated in Figure 1.

![Albedo values on various city material surfaces](Source: bitsofscience.org)

Buildings and road materials, such as tar, asphalt, and bricks, have a dark surface with low albedo causing the heat to be absorbed during the day and released during the night (Karthika, et al, 2015). The use of materials with high albedo is highly recommended, because it will reduce the amount of heat radiation absorbed by the ground cover surface of urban area (Taha & Huang, 1988).

**Thermal Emittance**
Thermal emittance is the amount of energy needed by an object to release stored heat. The higher the emissivity, the more heat will be released and vice versa. When exposed to sun light, a surface with high emittance will reach thermal equilibrium at a lower temperature than a surface with low emittance because the high-emittance surface is ready to release its heat (EPA, 2012). By choosing a material with high emissivity, a lower thermal balance can occur when the absorbed heat is similar to the energy released.

**Heat Capacity**
Material heat capacity is defined as the material's ability to store the heat. Volumetric heat capacity is a combination of specific heat constant and density material. Materials used in urban area mostly have high heat capacity compared to material resistance and vegetation. Materials such as concrete or brick have high heat capacity, which will store a lot of heat during the day. Heat will be dropped and be released at night.

**Thermal Conductivity**
Material conductivity is the ability of a material as a solid object to conduct heat. Heat transportation occurs due to the differences of temperature degree. Heat will flow from a higher to a lower temperature. Because heat flows in a solid object, it will be delivered through the thickness of material over time. Related to this, Abbas (2017) found that the changing of pavement surface on thermal conductivity would have an effect on reducing its surface temperature.

**The Features of Pavement Materials**
Pavement is used for pedestrian ways, neighborhood streets, parking area, and
open spaces. The pavement temperature is influenced by radiation level and thermal characteristics. Compared to the ground cover of vegetation, asphalt, and concrete, pavement absorb a lot of heat causing UHI level to be increase (Sobirin, et al 2015). Pavement with conventional dark-colored materials will absorb 80-95% heat.

Several studies on pavement materials and the effect on UHI among others are: 1) Stempihar et al (2012) focused on thermal analysis on porous pavements; 2) Takebayasi and Moriyama (2012) compared the surface temperature of some pavement materials; 3) Santamoris (2013) analyzed cool pavements and their effects on urban heat island; 4) Li, H (2015) evaluated and compared thermal performance of several types of materials in hardness; 5) Mohajerani, Abbas (2017) reviewed thermal properties of asphalt concrete as material for strength and effect, mitigation against UHI.

According to Abbas (2017) the types of pavement materials which can be used to mitigate urban heat Island are cool pavement, reflective pavement, porous pavers, permeable pavers, pervious pavement, water retaining pavement.

Cool Pavement
Unlike conventional dark-colored pavements material, cool pavement has layered surface with additives or added pigment to reflect solar radiation. The layers are used to raise albedo on the surface by giving bright colors to reflect more heat radiation into the atmosphere. In addition, cool pavement has cooler surface temperature compared to conventional pavement. Illustration of the effect of raising albedo at surface temperature can be seen in Figure 2.

If the solar reflectance pavement surface increases from 10 to 35 %, the air temperature has the potential to decrease to 0.6 °C (EPA, 2012).

Reflective Pavement
Similar to the cool pavement, reflective surface can be made by increasing the surface albedo. In addition to the selection of bright colors, reflective surface is also necessary to regulate the roughness of its surface (Santamouris, 2013). Reflective pavement can be made by providing layers, such as reflective paint, thin bitumen sealants, or resin base on aggregate layers in pavement (Mohajerani, Abbas, 2017).

Examples of reflective pavement types of aggregate base resin can be seen in Figure 3.

![Figure 2](image1.png)  
**Figure 2.** The white colour surface (high albedo) has a lower temperature than the darker surface  
(Source: EPA, 12)

![Figure 3](image2.png)  
**Figure 3.** Surface and layer of pavement resin based  
(Source: clearstonepaving.co.uk, 2012)

A layer of cement that uses aggregates in the resin layer will create a finer pavement surface. Other layered surface pavements have high albedo and reflect, rather than absorb, more solar radiation (Doulos et al., 2004; Santamouris, 2013).

Porous Pavers
Porous pavers comprise cellular grid system, with gaps or holes between the
parts to withstand moisture and allowing rainwater to pass directly through the base of the pavement. Generally, porous paver is not recommended to be used in highly traffic roads. Porous paver illustrations can be seen in Figure 4. Gap or hole in porous paver better infused with vegetation compared to infill sand. It is because grass or vegetation has high albedo. On the other hand, grass can transpire and facilitate evaporative cooling (Qin, 2015). The transpiration of plants or evaporation of moisture from soil resulted in lower surrounding water temperature and a net cooling effect (Tian et al., 2017).

Permeable pavements effectively reduce the effect of UHI by not storing much heat during the day for re-radiation to the atmosphere (Golden and Kaloush, 2006). Permeable pavements have the lowest nighttime temperatures compared to other solutions which considered as an effective solution for mitigating UHI in tropical environments (Stempihar et al., 2012).

**Permeable Pavement**

Permeable pavements have porous top layer that divert around the pavement (Qin, 2015). The albedo and thermal properties of the surface of the porous material depend heavily on the aggregate distribution of the pavement. Solar radiation reflectance of permeable pavement is lower during the day than smooth surface pavements because of its openness and roughness structure (Golden and Kaloush, 2006; Stempihar et al., 2012; Santamouris, 2013; Qin, 2015). In addition, less dense structures will cause less heat storage. The heat transfer to the surface and subsurface layers, often results in hotter daytime temperatures (Stempihar et al., 2012; Qin and Hiller, 2014; Coseo and Larsen, 2015).

**Pervious Pavement**

Pervious pavement is a type of pavement with cavity that allows water to seep in. Concrete refers to a special type without the addition of fine aggregates, such as sand, result in a high porosity level. Pervious pavement illustrations can be seen in figure 5. A large internal cavity in the concrete allows water to flow quickly as a consequence the cooling effect of concrete can be varied.

**Water Retaining Pavement**

Water retaining pavement is a concrete pavement, for example asphalt by water. The way water retaining pavement works is by vaporization by its retained water. And water retaining pavements were developed in response to fast draining and permeable pavements, which caused negative cooling effects in the pavement (Qin, 2015a).

**ROOF COVER MATERIALS**

Nurul EM & Nasarudin (2011) and Kolokotsa et al. (2012) stated that the types of conventional roof cover materials, such as: Clay, Concrete, Metal Deck, Asbestos, and Polycarbonate Zinc Slab can be adapted to the increasing of sensible heat flux from the surrounding surface air temperature. When the roof covers is directly exposed to the sun
radiation, the heat of its surface can reach 50-60°C (Andrade et al, 2007). Several studies of roof covers types and its effect on UHI among others are: 1) study of various types of cool roof in America (Hashem Akbari and Ronnen Levinson, 2011); 2) studies the use of PCM cool roof to reduce UHI in Korea (Young Kwon Yang et al, 2017); 3) analysis of green roof surface temperature to prevent Urban Heat Island in the Mediterranean region (Piero Bevilacqua et al, 2017); 4) effect of green roof in improving microclimate and reducing Urban heat Island in India (Aparna Dwivedi and BK Mohan, 2018); 5) reviews on thermal properties of cool roof and green roof in UHI’s mitigation efforts in Singapore’s tropical climate region (Junjing The et al, 2018).

In addition, the color of roof cover materials will affect the energy consumption of buildings. Bright colors that reflect more heat will reduce heat delivered into the rooms of the building, so that the energy for cooling indoor air temperature can be reduced. The types of roof cover materials that reduce Urban Heat Island are Cool Roof and Green Roof.

Cool Roof

Cool roof reflects and emit the heat approximately from 28-33°C of roof cover surface (EPA, 2012). Similar to cool pavement, the bright painted cool roof has a high level of albedo and its surface reflect solar radiation to reduce the absorbed heat. The comparison of white color cool roof and conventional dark roof cover materials illustrated in Figure 6. Cool roof relatively better in reducing UHI than conventional roof cover material (Akbari et al, 2012; Santamouris, 2012; Junjing Yang et al, 2018). Recently, the advanced technology of Cool Roof is possible to create the varied colors by using infrared reflective pigments such as thermos chromic paints, Phase Change Material (PCM) coating. (Junjing, et al., 2018).

Green Roof

Vegetation layer of Green roof is built above the minimum planting medium of soil and membrane water proofing. Two types of green roofs are: Extensive and Intensive green roofs (Junjing, et al., 2018). An extensive green roof system uses a simple lighter weight plant such as sedum, succulent, hardy plants and other vegetation suitable for alpine environment. The extensive roof design is easy-to-maintained once it is established. While intensive green roof is made to resemble conventional garden, or park, with almost no limit on the type of available plants, including large trees and shrubs.

Green roof can potentially reduce the heat by shading and evaporating the
water. Shading Island Green roof provides shade and removes heat from the air through evapotranspiration, and reduces the temperature of the roof and the surrounding water as illustrated in Figure 7 (EPA, 2012).

Based on the previous discussion, it is agreed that UHI is considered to be a dangerous treat for the environment, in terms of the increase of temperature leading to global warming. To mitigate the effects of UHI, i.e. the reorganization of all physical aspects related to the urban design, should be done.

The design and toughness of materials should be considered to reduce UHI. There are two surface types of albedo: high and porous surfaces. The high albedo type prevents heat by reducing the absorption of sunlight. Whereas the porous albedo type will receive heat better on the rough than smooth surface. Porous type also prioritizes water to be absorbed into the material body so that the heat level will be decreased by evaporation. Research conducted by Yoshioka et al. (2007) and Yamagata et al., (2008), explains that the techniques used to reduce UHI can moist and poured road throughout the day sufficiently in order to keep the surface temperature cool.

Selecting the type of pavement material in urban planning needs to be determined based on the function of the pavement, such as pedestrian way, road vehicle, or parking area. By looking at the potential types of pavement material reducing UHI, the application can be adjusted by considering the high or low traffic on the hardness surface (EPA, 2012). Reflective pavement surface should be avoided in high traffic areas because it will potentially cause the glare. Therefore, the permeable types would be a better material for low traffic such as parking, alleyways and trails (EPA, 2012).

The using of cool or green roof material covers and design should consider the environmental factors, especially the
local climate. In the humid tropical countries, the use of green roofs can be less optimal because of the high humidity of air and soil, in addition to the complicated maintenance. Thus, cool roof that maximizes the use of coating with high albedo will be more optimal (Junjing, et al., 2018).

Reducing the surface exposure heat in order to decrease UHI level, can also be done by shadowing the solid surface (Aynsley et al, 2009; Kimpraswil DIY Office, 2006). Shadows can be formed when buildings or trees blocking the sun as they will form Urban Geometry and Urban Canyon (the dimensions and distance between buildings). The urban geometry and urban canyon will affect how much heat will be absorbed by the city surface.

The surface of pavement or roof transfers heat by air through convection. The capacity of heat can be continued flowing in line with the wind, so that the heat can be reduced. Large convection depends on the speed and the capacity of wind flow and the air temperature that hits the surface. Urban Geometry influences the characteristic of wind patterns that flows in the urban ground surface (Memon et al., 2010).

CONCLUSION

UHI is a phenomenon that threatens global urban environment. Acknowledging thermal performance material in designing a city must be followed by understanding the climate character such as sun, humidity, the wind of the region. Most of the previous studies on pavement and roof cover materials are based on sub-tropical climatic conditions. However, very few studies of material behavior in preventing UHI in tropical climates; therefore, studies related to the topic become significant.

Pavement and roof cover materials can contribute to the UHI formation, so that thermal performance analysis needs to be considered include albedo (solar reflectance), emissivity, conduction, and material heat capacity.

Reducing heat radiation formed on the pavement and roof cover surface can be applied by increasing albedo in order to maximize the reflectance and minimize the absorbed solar radiation. Furthermore, evaporative cooling can also be used for reducing the heat pavement and roofs surfaces.

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