

A Review on Mitigation Technologies for Controlling Urban Heat Island Effect in Housing and Settlement Areas

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Abstract. Urban Heat Island (UHI) has many harm impacts to urban and human life, the examples are increased building and energy consumption, increased air pollutants emissions, compromised human comfort and health, and many more. Despite UHI phenomenon and those impacts has been realized long enough by the experts along with development of major cities in the world, but its mitigation technology has not been well developed. This paper discusses few mitigation technologies for UHI phenomenon that have been developed by experts. Some mitigation technologies such as double skin façade, shading strategies, and many more are discussed in this study, include the strengths and the weaknesses of each strategy. The focus of the study is mainly on the potential of building skin engineering in which thermal conductivity, infrared emissivity, and specific heat factors. The selected case discussed are buildings made of heavy weight materials. The result in this study reveals a potential map where thermal insulation is one potential strategy to reduce the intensity of UHI through the reduction of heat emissions of heavy building materials components. By this study, improvement of the urban life in its relation to UHI are expected to occur, especially in housing and settlements area.

1. Introduction

UHI is a phenomenon closely related to the improvement of cities and also its expansions [1]. The term 'heat island' represents a region with a higher temperature (urban) than non-urbanized area around it [2]. Urban centers have lower solar reflectivity, higher solar absorption, and greater thermal capacity compared to the rural areas due to their less vegetated surfaces and darker surfaces [3]. Wanphen & Nagano [4] in their report found the temperature difference could be as high as 5-15° C between urban and its surroundings (rural). Experts and scientists has realized about Urban Heat Island impacts and have been trying to find solution to mitigate it but the mitigation technology has not been developed much. Accordingly, this study is motivated to look the mitigation technologies for Urban Heat Island, especially on Building Skin Engineering. This paper is a preliminary study which is aimed to increase urban environment because of Urban Heat Island and to discover a new alternative solution for UHI mitigation. Urban Heat Island can be detected by surface or air temperature. Figure 1 showed that commercial and residential areas are the third most areas which have the hottest temperature. It means the Urban Heat Island intensity in this area is high, and that's why we need to mitigate UHI in housing and settlement.



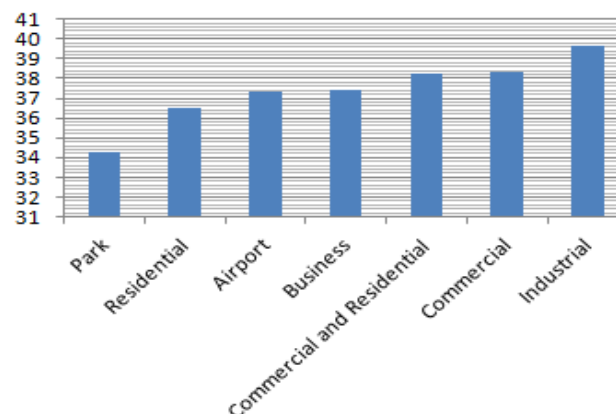


Figure 1. Daytime temperature in various land use areas [5].

The causes of UHI are identified [6] :

- Greenhouse gas emissions

Vehicles, industrial processes and the heating of buildings with fossil fuels are main sources of gas emissions, which trap solar energy in the atmosphere and warm the atmosphere.

- Gradual loss of urban forest cover

Vegetation has roles in preventing heat through evapotranspiration and shading of the ground and buildings. Loss of vegetation means loss of cooling in urban area.

- Impereability of materials

The change of ground covers from natural soils to asphalt made a problem because they can't provide water filtration or absorpsion functions, modify the path of stormwater [7, 8, 9].

- Thermal properties of materials

Impermeable surfaces and building materials influence the microclimate and thermal comfort conditions, since they absorb considerable heat during the day, which they release back into the atmosphere at night, thus contributing to the urban heat island effect [10].

- Urban morphology and city size

Urban morphology, which relates to the three-dimensional form, orientation and spacing of buildings in a city, also plays a role in the forming of Urban Heat Islands [11]. Large buildings and narrow streets can hamper good ventilation of urban centres because they create canyons where the heat generated by solar radiation and human activities accumulates and remains trapped [8]. In fact, the reduction of the sky view factor limits net radiative losses of buildings and streets [12]. In addition, urban morphology can also influence vehicle traffic and thus promote inputs of heat and air pollution from this mode of transportation [13].

- Anthropogenic heat

The production of anthropogenic heat such as heat emitted by vehicles, air conditioners and industrial activity is another factor that contributes to the development of heat islands, particularly in dense urban areas where activities are concentrated [11]. The best way to mitigate Urban Heat Island first is to know about the causes of the phenomenon explained above. After we know the causes, we could explore how to mitigate the phenomenon itself.

2. Selection of research studies

This paper reviews recent research about some various strategies to mitigate UHI effect in the urban environment. The main objective of such strategies is to map mitigation technologies for Urban Heat Island, and to find new innovative solution for UHI mitigation to improve urban life. The article had to be deep study of the heat island effect to be included in this review, its characteristics, influential factors, consequences, mitigation strategies, etc. The result of this study will reveal the possible effective strategies to mitigate UHI effect. However, it should be underlined, because of the correlation

and interrelation, some of these strategies might be overlap to each other, and it is also because some of these researches tend to imply several of the strategies simultaneously.

3. UHI mitigation strategies

For decades, the experts has been developed some mitigation strategies to face the Urban Heat Island phenomenon. Some of the strategies really has a big impact to environment. The strategies implied are focusing on the air temperature reduction or surface temperature reduction. The common mitigation strategies are explained below.

3.1. Green spaces

Based on Shashua-Bar research, the combination effects of tree shading and evapotranspiration cause a big decrease in temperature, and even produce what are referred to as cool islands within the city [14]. Varied studies have analyzed the temperature in parks and beneath trees. the overall conclusion was that green areas were cooler than areas with none greenery [15, 16]. In another research, Eliasson found air temperature difference between the city and the park can be as high as 4°C [17]. Ca et al. [18] collected field knowledge to quantify the result of a park on the summer climate in a nearby area. They analyzed ways in which to cut back the energy consumed for air con. At varied locations, the air temperature, relative humidity, and different meteorological factors were measured. The study was dispensed within the park in Tama ny, a coastal city within the metropolitan area of Tokyo. The results obtained indicated that vegetation considerably changed the city climate. At noon, the cooling was the maximum amount as 1.5°C in an exceedingly busy commercial area one km down wind [18]. The analysis analyzed over that parks and green areas might help to mitigate urban heat island effects and reduce cooling energy consumption in summer.

What is more, it had been found that such green areas additionally reduced the temperature changes made by building materials, stabilizing the temperature fluctuation caused by building materials [19, 20]. However, it had been not clear specifically however park affected the formation of the heat island. The cooling result looked as if it would rely on the dimensions of the park and therefore the seasonal radiation conditions, however there was no linear relation between the dimensions of the park and therefore the intensity of the cool island. This intensity was primarily determined by the realm occupied by the trees and shrubbery within the park in addition as by the form of the park.

3.2. Vegetations

Rosenfield analyzed with the use of vegetations, lighter colors of paving, and cooler roofs can reduce the air temperature as much as 3° C [21]. The study above combined all three aspects to reduce the air temperature. Another studies analyzed the use of vegetations and planting only can reduce air temperature between 1.3 – 1.6° C [22,23].

3.3. Green roofs

The study analyzed by Li et al showed green roof fraction has to be close to 90% and the cool roof (albedo = 0.7) fraction has to be close to 95% in order to reduce the near-surface UHI by 0.5 °C.

3.4. Albedo

Albedo is Latin, meaning whiteness. The albedo of a surface is a shard of sunlight reflected by the surface [24]. Taha in his research found by the increase in albedo and vegetation, it has impact to the reduction in the surface temperature and near-surface air temperature. This study demonstrated that the use of materials with high albedo properties decreased the radiation absorbed by building and urban structures. By keeping these sur- faces cooler, the intensity of long wave radiation was reduced. From this study, it can be concluded that by modifying albedo of the surface (0.25 to 0.40), air temperatures can be decreased as much as 4°C [25].

3.5. Pavements

Thermal balance in pavement depends of the amount of solar radiation absorbed by the pavement, the emitted infrared radiation, the heat transferred by convection to the atmospheric air, the heat stored into the mass of the material and the heat conducted to the ground [26]. Synnefa et al. [27] report that the measured surface temperature differences due to the differences in solar reflectance, reached 12 °C (between the off-white thin asphalt layer sample and the conventional black asphalt).

4. Building skin engineering to reduce air temperature

The mitigation strategies above specifically developed in macro and meso scale of urban space. The reduction of the air temperature varies between 1-3 °C. In order to mitigate the heat island more detail, the mitigation strategies could be developed in micro scale of urban space, or the building scale, which is more related to architecture scope. Building skin or envelope absorbed the heat from solar radiation, and emitted the heat to the environment. The potential of building skin engineering in which thermal conductivity, specific heat, and infrared emissivity factors could lead to the maximum reduction of air temperature and UHI intensity. Building skin engineering for UHI mitigation strategies which have been explored by experts are explained below specifically their effects to reduce air temperature.

4.1. Double skin facade

Al Kaabi [28] on his thesis examined the interaction between the urban canopy and a building with a Double Skin Façade (DSF). It has been found that the heat gains from the building envelope can be reduced by applying the DSF, the reduction of heat gains causes an enhanced energy performance and lower cooling loads. Additionally, the application of DSF can help achieve lower pavement temperature, which increases the outdoor conditions for pedestrians. In terms of UHI intensity, the application of DSF have resulted in a reduction of about 1.4 °C which is a significant enhancement to the urban environment

4.2. Tree shading strategies

Tan et al [29] indicates that the tree canopies are able to maintain the surface cooler than the air above. Ta is cooled by 1 °C at the pedestrian level (1.5 m) in the morning and by 1.5 °C in the afternoon.

4.3. Vertical greeneries : green facade and living walls

Vertical greeneries consist of two types : living walls and green facades. Green façade is a kind of green walls in which a simple structure (such as metal frames, square panels and cable systems for retaining structure) for scaffolding attached to the wall of building ,and acts such as anchor for creeping and climbing plants: vine, ivy and etc. Green facades can rely on fences and columns or be built as an independent structure. Green facade scaffolding structure can be different materials such as wood, steel (galvanized, stainless, coated), plastic or aluminum, etc., each of this materials will follow the usage , aesthetic aspects and different functions [30].

A research about cooling effect of green façade has been done by Jeffrey Price in 2010, tested the effect on West and South walls of four small buildings. The results showed the significant reduction of surface temperature, air temperature inside, building's ambient air, and also heat flux. On hot, sunny days, the green façade on the south and west sides cooled their respective ambient air temperatures by as much as 1.12 °C at 12:00 pm DST and 2.97 °C at 7:50 pm DST , respectively.

4.4. Reflective coatings

Synnefa et al in 2007 made a research which shown a cool coating applied on a road (SR 0.65) could reduce the temperature (1.2-3.7 °C). Look at figure 2 below for the comparison of building engineering method for reducing air temperature.

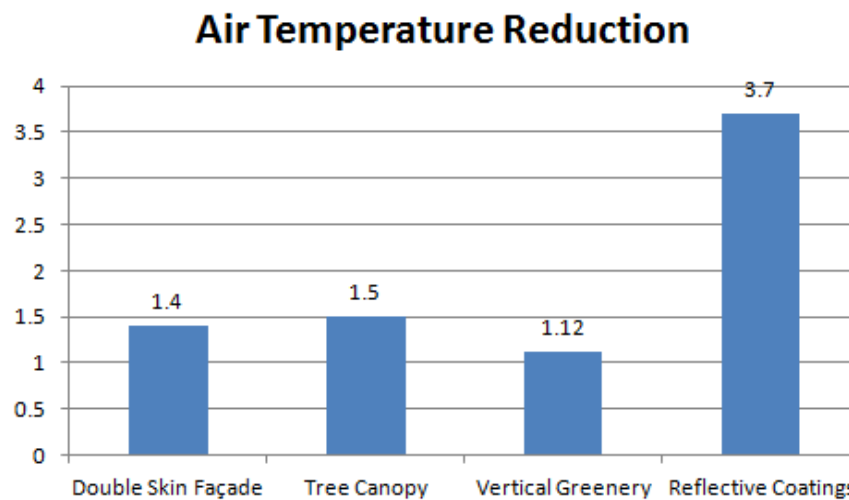


Figure 2. Air temperature reduction with several building skin engineering method.

5. Building skin engineering to reduce surface temperature

To measure Urban Heat Island, experts usually use air temperature or surface temperature. Correlated with building envelope, it is hard to use air temperature as a factor to be examined, so it would be easier to use surface temperature as a factor to be examined.

5.1. Vertical greenery system

Wong et.al [31] have examined by the use of vertical greenery system, the reduction of wall surface temperature could be maximized to 11.58 °C.

5.2. Tree canopy system

Berry et.al [32] have examined by the use of tree canopy system, the reduction of wall surface temperature could be maximized to 9 °C.

5.3. Reflective coatings

Shen et al [33] have examined by the use of reflective coatings, the reduction of wall surface temperature could be maximized to 19.9° C.

5.4. Double skin facade

Kinnane [34] have examined by the use of DSF, the reduction of wall surface temperature could be maximized to 7° C.

5.5. Thermal insulation

Ibrahim [35] experiment on uninsulated and insulated envelopes so far resulted great outcomes. With the use of thermal insulation, west wall surface temperature could be reduced up to 26°C (from 49°C to 23°C). This result means thermal insulation is one of great solution to reduce surface temperature. Look at figure 3 for comparison building skin method for reducing surface temperature.

From figure 3 below, we can conclude that thermal insulation is a great solution to reduce surface temperature. Surface temperature reduction is up to 26°C.

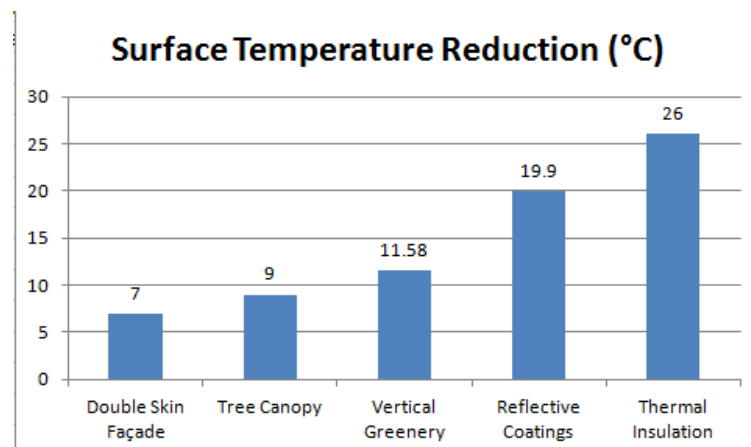


Figure 3. Surface temperature reduction with several building skin engineering method. Source : Analyzed by literature reviews.

6. Disadvantages of building skin engineering that has existed

Despite of the great reduction of ambient air temperature resulted by those building skin engineering (1.4 – 3.7° C) and great reduction of surface temperature (7-19.9°C) , they have few disadvantages. Double Skin Façade has higher construction costs, which Oesterle et al [36] describe “noone would dispute double skin façades are more expensive than single skin forms”. DSF has no clear information, positive or negatif about how its reaction in case of fire. DSF also have additional maintenance and operational cost, and there is not a very efficient way to estimate the costs [36]. DSF also have overheating problems. If the DSF system is not properly designed, air temperature in the cavity might increase and make interior space overheating. Other disadvantages of Double Skin Façade are increased structural weight and the reduction of light entering the building, because of its large size [37].

For tree shading strategies, it takes a lot of time to wait for the tree can shade the building. If the tree used for shading are imported, there are some factors which need to be considered, such as the strength of the soils, the façade of the building which is hindered by the trees. It should be considered about the type of the vegetation used as well.

Vertical greeneries also have some disadvantages. Vertical greeneries change the building façade, which affects the design of the building. From the economic perspective, the cost of vertical greeneries is expensive. The cost is between \$900 - \$1,500 per square m. Another disadvantage, it will attract biodiversity (fauna) which could damages the infrastructures. It is also need extra maintenance. Another disadvantages are : Incorrect dimensioning of the support of the vegetation, both in relation to the size of the plant and the loads will cost incident on the structure; lack of space for the plant to develop, mainly regarding the thickness of the branches, faults and poor quality of the coating, which can cause damage to the building even if the choice of the plant and the support has been appropriate [38, 39]

7. Thermal insulation as good UHI mitigation technology opportunities

With all disadvantages of building skin engineering above, we could see that we still have some room for the improvements of building skin engineering for UHI mitigation. Thermal insulation could be explored as good UHI mitigation technology opportunities. How thermal insulation could be one of potential strategy for UHI mitigation is explained below.

Physical development in big cities generally use heavy material in building envelope such as brick and concrete. This heavy material component has a high heat capacity that stores a lot of solar heat (see figure 1). This has a detrimental effect on the thermal environment, where the heat stored in the morning and afternoon is released back in the afternoon and evening in the form of heat re-emissions resulting in a hot city environment becoming hotter (see figure 2). This extreme rise in urban

temperatures resulted in the emergence of the Urban Heat Island phenomenon where city temperatures differ significantly compared to rural temperatures. This heat island phenomenon significantly affects the activity, productivity, and quality of life of urban residents so that mitigation is needed to prevent further damage [40].

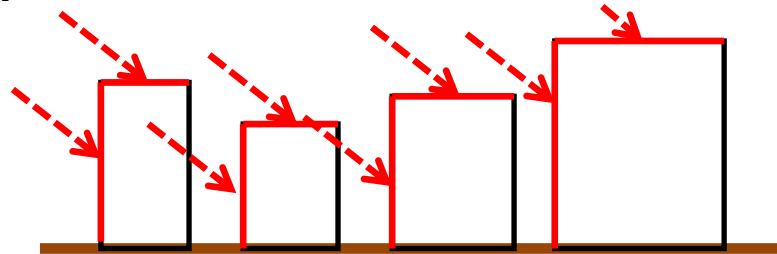


Figure 4. Heavy materials store heat from the sun on the building envelope in the morning and afternoon.

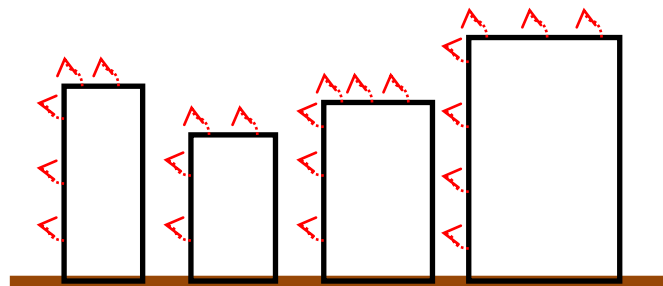


Figure 5. Heavy materials release heat emissions from sunlight through building envelopes

Existing mitigation strategies generally do not take into account the release of heat emissions (IRE / infrared emissivity) from buildings, whereas the release of heat emissions is one of the most important aspects in the formation of heat islands where the release of heat emissions by heavy building material increases the urban temperatures of hot cities. In the afternoons and evenings. For that it is necessary heat island mitigation that can intervene before heat is absorbed into the building that will break the path of heat before it is released back outside the building. In addition, there are considerations of heat island mitigation in terms of economy, time, and the appearance of the facade. As explained above, the use of double skin facade is expensive and heavy, the use of vegetation takes a long time until the tree can give the effect of shading, while the use of green facade will change the appearance of the facade that will affect the design aspects of the building. Therefore, this research tries to present heat island mitigation strategy that is fast, cheap, does not change the facade, but able to intervene before heat is absorbed by building envelope, which will influence to decrease of heat emission which is released by the building. The potential strategy proposed in this study is by providing thermal insulation attached to heavy building material sheath (see figure 3).

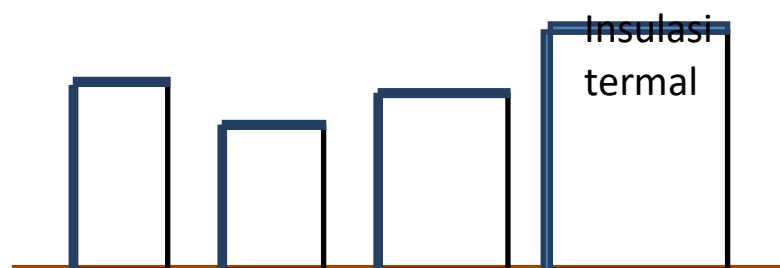


Figure 6. Thermal insulation as an intervention on the building envelope for the reduction of heat emissions of heavy building materials

From the explanation, we can conclude there are 2 important heat factors that needs to be considered for thermal insulation strategy. The factors are heat resistance and heat re-emission.

7.1. Heat resistance

Heat resistance is about how the thermal insulation could resist from the heat from solar radiation before the heat enters the heavy weight materials ($\text{m}^2\text{K/W}$). The more thickness means the less heat flow through the building and so does a lower conductivity. High thermal resistance means a good insulator, and one with a low thermal resistance is a bad insulator. The equation is Thermal Resistance ($\text{m}^2\text{K/W}$) = Thickness (m) / Conductivity (W/mK)

Thermal Conductivity measures the heat flow by conduction through a material. Conduction is the main sort of heat transfer through insulation. The lower the thermal conductivity, the performance of the material as insulation will increase. The density refers to the mass (or 'weight') per unit volume of a material and is measured in kg/m^3 .

The Specific Heat Capacity of a material is the amount of heat needed to raise the temperature of 1kg of the material by 1K (or by 1°C). A good insulator has a higher Specific Heat Capacity because it takes time to absorb more heat before it actually heats up (temperature rising) to transfer the heat.

7.2. Heat re-emission

Factors related to heat re-emission is albedo and emissivity. Albedo is the ratio between incident solar energy and reflected solar energy. The higher the albedo, the better the performance. Albedo rate depends on the combination of surfaces, material, pavements and color. Materials with lighter color will have high albedo and it will absorb less energy than materials with darker color. Materials with dark color will absorb more heat during day time and it will have high reflectance at night. Another important factor of heat re-emission is thermal emittance. It means surface ability to emit IRE (infrared radiation). Surfaces which have high emittance value will release more heat and remain cool. Many construction materials except metal have high thermal emittance value [41].

8. Conclusions

From all the reviews above we can conclude that thermal insulation could be the potential strategy to mitigate Urban Heat Island effects, by large amount of surface temperature reduction (26°C) with the use of thermal insulation [35]. With large reduction of surface temperature, the heat will not absorbed much into heavy weight materials and it will not reradiate heat much into environment as well. So, it is why thermal insulation could be potential to mitigate Urban Heat Island, by increasing the thermal resistance of the building envelope. Thermal insulation is one of the easy and effective ways of energy conservation and heat reduction available today. It offers a number of applications in residential sectors, and also commercial and industrial sectors.

To find the best thermal insulation to mitigate Urban Heat Island effects, we need to understand about 2 most important factors of thermal insulation : heat resistance and heat re-emission, and their subfactors such as thermal conductivity, thermal diffusivity, density, thickness, specific heat capacity, albedo, and emissivity. We need to explore the most combination of the factors with most advantages to reduce maximum surface temperature and air temperature.

One of the most developed thermal insulation is bio-massed insulation or natural fiber, because it is cheap and it is everywhere [42], it is easy to dispose as waste, so it will reduce negative impact to environment [43], and it has a very low thermal conductivity. So, we can begin the exploration of thermal insulation to mitigate UHI effects from pure bio-massed insulation, or mixed bio-massed insulation : lightweight concrete insulation – agriculture waste based thermal insulation.

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