



IMPACT OF ASPHALT AND CONCRETE PAVEMENTS ON URBAN HEAT ISLAND AND MICROCLIMATE INCIDENTS: A REVIEW

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Abstract: Urban heat island (UHI) is a real phenomenon and impacts negatively on urban microclimate. Findings from well documented literature reported that dark and impervious pavements surfaces are the key contributing elements to the UHI. The UHI is an incident in which surface and air temperatures increase due to retention and emittance of heat energy from pavements and other manmade hard surfaces. It is a phenomenon whereby ambient temperatures are substantially higher in cities than in rural and suburban areas due to the absorption and accumulation of heat in pavements and other physical interactions. This paper presents a thorough literature review of existing literature on the impact of conventional asphalt and concrete pavements on UHI and microclimate incidents. The work focuses on the impact of these pavements with respect to their contributions to UHI, the effect of UHI on urban microclimate, UHI mitigation measures and their associated impact. Primarily, the paper discusses and summarizes the key findings on the UHI phenomenon and its consequences with respect to its harmful effect on urban wellbeing, particularly on human thermal comfort. Several UHI mitigation measures have been proposed in the existing literature. Specific emphasis is accorded to reflective, permeable and water retentive pavements. However, using a combination of different techniques is deemed as the most effective strategy for reducing the impact of UHI. This work suggests further works on UHI mitigation measures for varying seasons and localities around the world to establish the best possible solution.

Key words: Asphalt and concrete pavements; UHI; Microclimate; UHI causes and impact; UHI mitigation measures

1 Introduction

A native soil could be satisfactory or fairly strong to serve as a riding surface for vehicles, however, depending on the type, the native material may have some shortcomings. These may include the discomfort to move on when dried due to dust or soaked, which may result in muddy surface. Likewise, it loses strength when soaked. These situations necessitate the need for firm and comfortable surface for vehicular and pedestrians' movements. Pavement is a constructed horizontal surface structure of reasonable depth supported by an in-situ natural material (soil) used as ways for vehicular movements, parking, and pedestrians' walkways, and other purposes. The Cambridge Systematics Incorporated (CSI, 2005) defined pavements as on-ground structures used for riding, parking and walking.

Pavements are constructed using different materials depending on their intended purpose, and availability of materials and funds. The conventional types of

pavements are asphalt concrete and Portland cement concrete. However, at times, a combination of asphalt and concrete are used as a composite pavement structure. The asphalt concrete pavement, also referred to as flexible pavement is built with asphalt concrete as hot-mix asphalt (HMA) or warm-mix asphalt (WMA) consisting of a mixture of bitumen (or tar) and aggregates. This category is simply referred to as asphalt pavement. The Portland cement concrete pavement, also referred to as rigid pavement is constructed with a concrete, which comprises of Portland cement mixed with water and aggregates. This class is commonly referred to as concrete pavement. The conventional types are however not limited to asphalt and concrete pavements; as road mixes, bituminous surface treatment and macadam construction are equally regarded as other classes of pavements (CSI, 2005). These are commonly thin and are mixed in place. They are as well used on roads and streets with light traffic.

For main arterials with considerable traffic volumes, asphalt and concrete pavements are the most common type of pavements used. Irrespective of asphalt or concrete pavement, the structure is expected to perform certain key functions, which includes the structure's ability to bear and distribute traffic loads over an area so that the bearing capacity of the native material or subgrade is not exceeded. It is also to provide a smooth, skid resistant and non-dusty surface as well as protect the substructure against the adverse effect of weather conditions. Both asphalt and concrete pavements are well known in satisfying these functional requirements.

Globally, the most commonly used pavements materials are asphalt concrete and Portland cement concrete (Ibrahim *et al.*, 2018). Burnt brick block has also been used as paving material and recently, the use of mud (soil-based) concrete block is gaining attention as paving material (Galabada *et al.*, 2020; Udawattha *et al.*, 2017). However, asphalt and cement concretes are the mostly used construction materials for continuous slab-based pavement (Murugan *et al.*, 2016). Likewise, for block pavement technology, concrete is the commonly used material for roadway and other applications (Rahman *et al.*, 2020). In spite of the satisfactory performance of both asphalt and Portland cement concrete as paving materials, they are however, been blamed for considerable contribution to higher surrounding temperatures (Akbari, 2009; Benrazavi *et al.*, 2016; Buyung and Ghani, 2017; Chen *et al.*, 2019; CSI, 2005; Hendel, 2020; Lee *et al.*, 2010; Qin, 2015; Ramakreshnan *et al.*, 2018; Tan and Fwa, 1992). The effect is more pronounced in urban areas where the land cover is substantially made of asphalt and concrete materials (Akbari, 2009; Benrazavi, *et al.*, 2016; Chen, *et al.*, 2019; Hendel, 2020; Li, 2012; Qin, 2015; Ramakreshnan, *et al.*, 2018).

When pavements are exposed to solar radiation, part of the radiation is reflected into the air, while some is absorbed by the pavements, which in turn lead to rise in the pavements' temperatures resulting in higher temperatures in urban relative to surrounding rural areas (Benrazavi, *et al.*, 2016; Carnielo and Zinzi, 2013; Chen, *et al.*, 2019; Hu *et al.*, 2017). According to Qin (2015), conventional impervious asphalt and concrete pavements have huge thermal inertia, making them absorb and store solar radiation, negate cooling through evaporation, and raising urban temperature higher than that of rural areas (Ismael *et al.*, 2024; Oke *et al.*, 2017; Wang *et al.*, 2021). The difference between the urban air temperature relative to the surrounding rural area is referred to as UHI (Carnielo and Zinzi, 2013; Chen, *et al.*, 2019; CSI, 2005; Hendel, 2020; Qin, 2015). Galabada, *et al.* (2020) defined UHI as an incident in which surface and air temperatures increase due to retention and emittance of heat energy

from pavements and other manmade hard surfaces. Carnielo and Zinzi (2013) referred to UHI phenomenon as the increase in urban air temperature compared to surrounding rural areas.

The impact of UHI was first recognized by a British meteorologist; Luke Howard in the 19th century (Mills, 2008; Oke, 1982). Howard (1833) evidently established that that urban air temperatures are usually higher than in its surrounding rural and suburban areas. Over a century after, other studies (Chandler, 1967, 1970; Oke, 1974, 1979) affirmed the assertion in Howard's study and most recently supported by others (Chen, *et al.*, 2019; Faragallah and Ragheb, 2022; Hendel, 2020; Oke, *et al.*, 2017; Qin, 2015; Wang, *et al.*, 2021).

Findings from many studies affirmed that the effect UHI effect caused by the asphalt and concrete pavement materials surfaces is attributed to their low solar reflecting power or low albedo (Akbari, 2009; Anting *et al.*, 2017; Benrazavi, *et al.*, 2016; Carnielo and Zinzi, 2013; Chen, *et al.*, 2019; CSI, 2005; Hendel, 2020; Kinouchi *et al.*, 2003; Lee, *et al.*, 2010; Lima Jr *et al.*, 2022; Qin, 2015; Ramakreshnan, *et al.*, 2018; Udawattha, *et al.*, 2017; Wijeyesekera *et al.*, 2012). The impact is also as a result of the fact that these materials are highly impervious as such, they lack water absorption capacity, which could assist in cooling their surface through evaporation. Hence, they tend to absorb heat easily and subsequently release it to the surrounding. This also results in higher temperature of the surrounding environment. To some extent, even porous asphalt contributes in elevating surrounding temperature, though it exhibit the lowest night-time temperatures compared with other paving materials having a similar or higher albedo (Stempihar *et al.*, 2012).

Hence, the concern for better environment called for the need of eco-friendly paving materials for roadways, parking, and walking facilities. Specifically, searching for pavement materials that can enhance the cooling effect of surrounding temperature via the use of cool pavement technology. Earlier studies (CSI, 2005; Hendel, 2020; Lee, *et al.*, 2010; Mendonca, 2009; Ramakreshnan, *et al.*, 2018; Udawattha, *et al.*, 2017; Zhao *et al.*, 2014) asserted that cool pavement (resulting in low surrounding temperature) can be achieved through the use of pavement materials with satisfactory surface reflectance and permeability. This is because, materials having good reflectance reduces the solar radiation absorption by pavement's surface. Likewise, pavement materials with good permeability assists in cooling the pavement through evaporation. Conventional asphalt and concrete pavement surfaces have poor reflectance power as well as highly impervious, which make them absorb considerable amount of solar energy and subsequently release it to the microclimate with resultant rise in the surrounding

temperature. This is in contrast to the characteristics of natural materials' surfaces, specifically, earth or soil, which has good reflectance power and moisture-trapping capability that allow it absorbs solar energy, releases water vapour (through evapotranspiration) and in turn make the surrounding air cooler (Galabada, *et al.*, 2020; Udawattha, *et al.*, 2017). Earth is an important construction material, which follows the native settings (Alcoforado, 2006) as such it aids evapotranspiration much better than asphalt and concrete surfaces (Udawattha, *et al.*, 2017; Udawattha and Halwatura, 2018).

Based on the documented literatures reported herein, it is obvious that conventional asphalt and concrete pavements' materials have poor reflectance capacity or low albedo (Lima Jr, *et al.*, 2022) and considerably impervious. As a result of these characteristics, these materials cause a significant rise in surrounding temperature, especially in urban areas where substantial land cover is made up of these materials.

It is therefore most desirable to search for eco-friendly pavements construction materials with cooler surface temperatures in an effort to mitigate high urban temperatures. This could be achieved through the use of materials with good reflectance power (high albedo), better heat transfer characteristics, and satisfactory permeability. Native soil was identified as having these characteristics (Galabada, *et al.*, 2020; Udawattha, *et al.*, 2017). Santamouris (2013b) and Galabada, *et al.* (2020) affirmed that asphalt, cement concrete and brick concrete pavements absorb more solar radiation and emit far more to the environment than native soil's surface. This necessitates for shift from the conventional pavement materials that extensively contribute to UHI towards cool pavement technology. Cool pavement is referred to as pavements engineered to minimize their surface temperature as well as their impact to UHI (Hendel, 2020).

Therefore, the current study attempts to review the impact of conventional asphalt and concrete pavements on UHI and microclimate incidents. The paper focuses on the impact of asphalt and concrete pavements with respect to their contributions to UHI, effect of UHI on urban microclimate, cool pavement technology and its benefits, UHI mitigation techniques and their associated impact.

2 Terminologies

Solar radiation: This is the amount of radiant energy emitted by the sun.

Albedo: The term albedo is referred to as the proportion of solar radiation reflected by a horizontal surface, which depends on the spectral composition of the incident radiation. (Hendel, 2020). Carnielo and Zinzi (2013) defined an albedo as the ratio of reflected solar radiation to the total solar on a surface and is

regarded as an indicator of the reflection power of a pavement surface. An albedo value of 0% implies that a surface has no reflecting power at all (all radiation is absorbed or none is reflected) as is the case with perfectly black surface, while an albedo of 100% indicates total reflecting power (perfect reflection) as for perfectly white surface (Chen, *et al.*, 2019).

Urban Heat Island: It is an incident in which surface and air temperatures increase due to retention and emittance of heat energy from pavements and other manmade hard surfaces (Galabada, *et al.*, 2020). It is a phenomenon whereby ambient temperatures are substantially higher in cities than in rural and suburban areas due to the absorption and accumulation of heat in pavements and other physical interactions (Carpio *et al.*, 2020). Carnielo and Zinzi (2013) defined UHI phenomenon as the increase in urban air temperature compared to surrounding rural areas.

Cool pavement: This is referred to as a category of pavements engineered to minimize their surface temperature as well as their impact to UHI (Hendel, 2020). The United States Environmental Protection Agency (USEPA) refers cool pavement as paving materials that reflect more solar radiation, enhance evaporation, or have been otherwise modified to remain cooler compared to conventional pavements (Qin, 2015).

3 Asphalt and Concrete as Conventional Pavement Materials

Pavement is a critical structure in various aspects of transportation; including riding private car, transit, freight, parking and walking. It is as well used for other purposes; such playgrounds and squares. Pavements made of asphalt, concrete and other materials account for a substantial proportion of the land cover in many urban areas and is expected to increase over time (Akbari *et al.*, 1999; Chen, *et al.*, 2019; Golden, 2004). Studies established that within the last two decades, dark and impervious pavements, mostly made of asphalt and concrete used for roads and streets, parking, walkways, playgrounds, and so forth account for 30 to 45% of land surface cover in urban areas (Akbari *et al.*, 2001; Cheela *et al.*, 2021; CSI, 2005; Lee, *et al.*, 2010; Qin, 2015; Rose *et al.*, 2003; Zhang *et al.*, 2021). This implies that urban development is well associated with changes in natural land cover, in which pavements account for a substantial proportion.

Though asphalt and cement concretes are the most popular materials used pavements (Ibrahim, *et al.*, 2018) with satisfactory records of of structural performance, however, they are associated with some weaknesses with respect to negative environmental

effect, especially in urban areas. Conventional impervious asphalt and concrete pavements have huge thermal inertia, making them absorb and store solar radiation, hence, they negate cooling through evaporation, and lead to elevated urban temperature higher than that of surrounding rural areas (Cao *et al.*, 2015; Qin, 2015). Other studies established that when asphalt and concrete pavements are exposed to solar radiation, part of the radiation is reflected into the air while more is absorbed by the pavements, which in turn lead to rise in the pavements' temperatures resulting in UHI effect (Benrazavi, *et al.*, 2016; Carnielo and Zinzi, 2013; Chen, *et al.*, 2019; Hu, *et al.*, 2017).

Pavement facilities contribute significantly to UHI effect (Carnielo and Zinzi, 2013; Haselbach *et al.*, 2011; Qin, 2015; Rosheidat and Bryan, 2010; Synnefa *et al.*, 2011; Wan *et al.*, 2012). Many studies reported that UHI effect raises urban temperatures relative surrounding rural areas in the range of 2 °C to 8 °C (Akbari, *et al.*, 2001; Goldreich, 2006; Huang *et al.*, 2008; Kolokotroni *et al.*, 2007; Krishnan, 2007; Rosenzweig *et al.*, 2005; Santamouris, 2007; Taha, 2000; Yusuf *et al.*, 2014).

This negative environmental effect associated with asphalt and concrete pavements' surfaces is attributed to their low reflectance ability of solar energy, low albedo as well as being highly impervious (Anting, *et al.*, 2017; Benrazavi, *et al.*, 2016; Carnielo and Zinzi, 2013; Chen, *et al.*, 2019; Hendel, 2020; Kinouchi, *et al.*, 2003; Lee, *et al.*, 2010; Qin, 2015; Ramakreshnan, *et al.*, 2018; Udawattha, *et al.*, 2017; Wijeyesekera, *et al.*, 2012). It appears that selection of pavement's material is independent of environment (CSI, 2005), suggesting that earlier researches on pavement materials focused more on the structural performance requirements, without paying adequate attention to the environmental issues, particularly global warming (Jamshidi *et al.*, 2019).

Many studies highlighted the effect of conventional pavements surfaces on raise in urban temperatures, some of which are summarized herein. According to Benrazavi, *et al.* (2016), in tropical climate paved surfaces with poor reflectance capacity can cause an increase in urban air temperatures to as high as 40 °C. It was asserted that towards the end of 21st century, urban areas' temperatures influenced by UHI will rise by 5 °C (Faragallah and Ragheb, 2022; Oke, 1976). Vujovic *et al.* (2021) stated that on the global scale, it was projected that urban growth could raise air temperatures by up to 3 °C. For instance, Krishnan (2007) stated that Putrajaya (Kuala Lumpur, Malaysia) city's temperature is 5 °C hotter than other Malaysian cities due to urbanization and UHI effect. Also, an average gain in surface temperature of 8.4 °C was recorded in Kuala Lumpur between 1997 and 2013 (Yusuf, *et al.*, 2014). Thus, rapid growth of

urbanization, which is associated with substantial increase in pavement cover significantly contributes in worsening the impact of UHI (Ramakreshnan, *et al.*, 2018). In Seoul, Korea, air temperature increased by an approximate of 1.7 °C over a period of 56 years from 1962 to 2017 with significant contribution due to urbanization (Hong *et al.*, 2019). Likewise, in Melbourne, Australia, urban growth and changes in land cover including paved surfaces raised the city's surface and air temperatures in the ranges of 1.9 – 5.4 °C and 0.75 – 2.8 °C, respectively (Imran *et al.*, 2019). Further, Tu *et al.* (2016) reported that urban expansion in Nanjing, China from 2000 to 2012 caused a considerable increase in the city's temperature due UHI effect.

It is thus evident that the problem of UHI effect exists around the world, of which conventional impervious asphalt and concrete pavements are key contributing elements. Hence, rise in air temperature causes harmful effect to the environment and negatively impacts urban areas life quality with attendant rise for air conditioning and electricity demands adding to air pollutants issues as well greenhouse gas emissions (Gray and Finster, 2000; Vujovic, *et al.*, 2021). The effect of UHI reduces the thermal comfort of urban residents (Fahed *et al.*, 2020; He *et al.*, 2021; Parker, 2021; Sharma *et al.*, 2021). It also causes a general decline in the urban environmental quality (Ballinas and Barradas, 2016; Henao *et al.*, 2020). On the other hand, UHI results in high urban energy demand to cushion the effect of urban high temperature rise due to UHI (Kubilay *et al.*, 2020; Yuan *et al.*, 2017). Shahmohamadi *et al.* (2011) and Heaviside *et al.* (2017) reported that UHI causes many other heat-related health difficulties.

In order to mitigate UHI effect, it is essential to implement the use of cool pavement, at least in areas of less structural requirements such as light traffic roadways, parking lots, walkways and so forth. This can be achieved through the use of pavement materials that exhibit enhanced heat transfer and cooling reflectance and satisfactory permeability. Udawattha, *et al.* (2017) and (Galabada, *et al.*, 2020) identified native soil exhibiting these characteristics as asphalt, cement concrete and brick concrete pavements surfaces absorb far more heat and emit much more to the surrounding environment than bare native soil (Galabada, *et al.*, 2020; Santamouris, 2013b). Other advantages of using earth or native soil as paving material is its abundant availability, low cost, reduction of waste generation as well as less danger to the environment. Hence, this study attempts to examine the potential of using earth concrete block for improved heat transfer and cool pavement.

4 Conventional Pavements and Urban Heat Island

Pavement is an artificial land cover that is constructed as a horizontal surface structure supported by the native soil. It is used as ways for vehicular movements, parking, and pedestrians' walkways, and so forth. The Cambridge Systematics Incorporated (CSI, 2005) defined pavements as on-ground structures used for riding, parking and walking. The primary function of a pavement is to receive and transmit loads safely to the underlying native soil.

Pavements are constructed using different materials depending on their intended purpose, and availability of materials and funds. The conventional types of pavements are asphalt concrete and Portland cement concrete. However, at times, a combination of asphalt and concrete are used as a composite pavement structure. The asphalt concrete pavement, also referred to as flexible pavement is built with asphalt concrete as hot-mix asphalt (HMA) or warm-mix asphalt (WMA) consisting of a mixture of bitumen (or tar) and aggregates. This type of pavement is commonly referred to as asphalt pavement. The Portland cement concrete pavement, also referred to as rigid pavement is constructed with a concrete, comprising of mixture of Portland cement, aggregates and water. This class is generally referred to as concrete pavement.

Worldwide, the commonest used pavements materials are asphalt concrete and Portland cement concrete (Ibrahim, *et al.*, 2018). Moreover, burnt (clay) brick block has also been used as paving material and most recently, the use of mud (soil-based) concrete block is gaining attention as paving material (Galabada, *et al.*, 2020; Udawattha, *et al.*, 2017). Asphalt and cement concretes are the most common construction materials for continuous slab-based pavement (Murugan, *et al.*, 2016). However, for block pavement technology, concrete is the commonly used material for roadway and other applications (Rahman, *et al.*, 2020). In spite of the satisfactory performance of asphalt and cement concrete as paving materials, they are however, been blamed for significant contribution to higher surrounding temperatures (Akbari, 2009; Benrazavi, *et al.*, 2016; Buyung and Ghani, 2017; Chen, *et al.*, 2019; CSI, 2005; Hendel, 2020; Lee, *et al.*, 2010; Qin, 2015; Ramakreshnan, *et al.*, 2018; Tan and Fwa, 1992). Their surfaces absorb and store solar radiation, and subsequently release it to the environment (Qin, 2015). The effect is more pronounced in urban areas where the land cover is substantially made of asphalt and concrete materials (Akbari, 2009; Benrazavi, *et al.*, 2016; Chen, *et al.*, 2019; Hendel, 2020; Li, 2012; Qin, 2015; Ramakreshnan, *et al.*, 2018).

This process leads to an incident referred to as UHI effect whereby surface and air temperatures increase

due to the retention and emittance of heat energy from pavements surfaces (Galabada, *et al.*, 2020). Hence, the surrounding urban air temperature rises higher than that of the surrounding rural area with attendant implication of an unpleasant urban microclimate. In an effort to minimize the impact of UHI and global warming, the use of cool pavement has been demonstrated as an effective mitigation strategy (Hendel, 2020; Santamouris, 2013b). The following subsections present a review on some existing literatures relating to conventional pavements' impact on UHI and the effect of UHI on urban microclimate. It also comprises of issues on cool pavement technology and the benefits associate with cool pavement.

5 Impact of Pavement Land Cover on Urban Heat Island

Pavements provide transport links in our cities as roads and are also applied to diverse array of surface structures; pedestrians' walkways, parking lots, squares, and so forth. Within the last decade, these structures cover large portion of urban surface area, typically, 30 – 45% (Akbari, *et al.*, 2001; CSI, 2005; Lee, *et al.*, 2010; Rose, *et al.*, 2003) and are identified as primary contributor to UHI, especially the roads pavements (Mohajerani *et al.*, 2017). For the fact that urbanization is well associated with manmade activities; including changes in natural land cover, especially with pavements, it means that pavements surfaces cover is expected to increase as well as their contribution to UHI effect. It was demonstrated that increased urbanization being associated with change in native land cover using use artificial hardscapes, particularly paved surfaces is the major cause of UHI (Mohajerani, *et al.*, 2017) demonstrated.

A lot of studies reported blamed pavement surfaces as the main contributor to UHI effect. Santamouris (2013b) stated that pavements are the significant UHI contributors. This is well attributed to their substantial geographical coverage in our cities and the low albedo associated with them (Synnefa, *et al.*, 2011). A study was conducted in Kota Samarahan area on the impact of road pavement surfaces on UHI. The study examined four types of pavements (asphalt, concrete, permeable, and industrialized building systems (IBS) Storm Pave). Finding from this study revealed that pavement surfaces contribute a lot to air pollution and UHI effect; because, they have high solar energy absorption due to their large solar radiation storage capacity (Ibrahim, *et al.*, 2018). They tend to absorb heat during the day and then gradually release it back into the environment at night (Katzschner, 2010). Asphalt pavement and other dark surfaces in urban environments are the primary causes of the UHI (Calkins, 2012). The asphalt pavement absorbs large

amount of solar radiation rather than reflecting it, elevating the temperatures the pavement surfaces and ambient air.

The properties of conventional pavements' material cause them to absorb and store large amount of heat than natural vegetated land cover. Likewise, the impervious nature of most pavements reduces cooling due to evaporation in comparison to native vegetated ground. As a result, pavements become substantially hotter than ambient canopy temperature and emit this excess heat into the environment throughout the day as well as the night (CSI, 2005). This situation would as well contribute the effect of UHI with its associated environmental implications.

In an investigation regarding the state-of-art on cool pavements technology, Santamouris (2013b) reported that pavements represent a large fraction of urban areas and contributes significantly to development of UHI. Though UHI can be affected by several factors, such as urban population density, spacing and buildings height, heat generated by vehicles, geographic location and vegetative cover, the dark pavement surfaces are the significant contributors to UHI due to their low albedo (Chen, *et al.*, 2019). Carnielo and Zinzi (2013) studied the optical and thermal characteristics of cool asphalts for mitigation of urban temperatures and building cooling demand. They discovered that the main cause of UHI is modification of native land surface in urban areas, typically pavement surfaces, characterized by high solar radiation absorption, impermeability and thermal properties. These characteristics enhance energy storage and subsequent emission of heat to the urban microclimate.

Modification of native land surface through the use of conventional pavements alters the surface energy balance, which makes pavement surfaces absorb heat, its subsequent release to the atmosphere and thus contribute to UHI. The pavements' materials properties, particularly, their low albedo make them to absorb and store a substantial amount of heat energy than the natural vegetated land cover. According to Pomerantz *et al.* (2003) fresh asphalt concrete absorbs an approximate of 95% of solar radiation, representing an albedo (solar reflecting power) of only 5%. Furthermore, their impervious nature reduces cooling through evaporation compared to native surface. As a result, pavements become considerably hotter than ambient temperature and radiate this excess heat into the environment throughout the day and into the night (CSI, 2005). Other studies on mitigation of UHI caused by paved surfaces affirmed that pavements surfaces used for roads, parks, walkways, parking lots, etc are the main contributors to UHI phenomenon (Rosheidat and Bryan, 2010; Wan, *et al.*, 2012). Haselbach, *et al.* (2011) and Tukiran *et al.* (2017) equally reported that pavements are one of the major

artificial hardscapes contributing to the development of UHI.

An investigation conducted by Benrazavi, *et al.* (2016) in Putrajaya, Malaysia, on the effect of pavement materials on surface temperatures in tropical environment, it was discovered that pavements surfaces exhibit high surface temperatures, with asphalt pavement having the highest impact. Pavements' dark surfaces and impervious characteristics make to serve as thermal inertia. During summer, paved surfaces absorb and store solar radiation with attendant effect of negating cooling by evaporation. This process makes them contribute significantly to the UHI effect. Buyung and Ghani (2017) demonstrated similar assertion of the impact of conventional pavements on UHI development. Still with respect to a typical Malaysian city, Hashim *et al.* (2007) conducted in Selangor on mapping of UHI using a remote sensing approach. Finding from this study revealed that the growing areas around Kajang, Cheras and Bandar Baru were found with highest surface temperature as result of intense thermal energy responses of pave surfaces such as asphalt concrete.

Furthermore, Mohajerani, *et al.* (2017) asserted that asphalt concrete is one of the most common pavement surfacing materials and equally a significant UHI contributor. They reported that a densely graded asphalt concrete has a low albedo and high volumetric solar radiation storage capacity, which makes its surface temperatures as high as 60 °C or more during summertime. This claim is well consistent with another finding based on a study conducted in Putrajaya, Malaysia, which reported an asphalt concrete surface temperature of 60.4 °C (Benrazavi, *et al.*, 2016). In another study conducted in Japan by Takebayashi and Moriyama (2012) on surface heat budget of different pavement materials for UHI mitigation, it was discovered that day time temperature of conventional asphalt surface was found to be 20 °C higher than native grassy land cover. The increase of paved surfaces in our cities account for larger proportion of elevated temperatures per unit volume relative to any other artificial material or structure (Golden and Kaloush, 2006).

Based on the assertions by various studies, it is evident that conventional pavements characterized by dark and impervious surfaces extensively contribute the development UHI as well as the advancement of its associated implications in our urban areas. The following subsection discusses the impact of UHI on urban microclimate.

6 Effect of Urban Heat Island on Urban Microclimate

The UHI phenomenon, which is referred to as the increase in urban air temperature compared to

surrounding rural areas (Carnielo and Zinzi, 2013) is considered as a worldwide issue that threatens the operation and habitability of urban environments (Mohajerani, *et al.*, 2017). It is a climatic phenomenon caused by the modifications to climate as a result of changes in the form and composition of land surface and atmosphere (Ibrahim, *et al.*, 2018). Growth in UHI due to rise in changes on the natural land surface is increasingly becoming a further and complex environmental issue because of its devastating effect on human health (Galabada, *et al.*, 2020). The UHI effect is negatively affecting the living standard of urban dwellers (Grimmond *et al.*, 2010).

The major effect of UHI on the environment is that it causes an elevation in urban ambient temperatures (Lee, *et al.*, 2010). For instance, it was observed that UHI effect raised urban surface and air temperatures compared to those of surrounding rural areas, in the range of 1 °C to 3 °C (Akbari, *et al.*, 2001). Many studies conducted at varying altitudes confirmed the adverse environmental effect of UHI and its intensities can be up to 12 °C (Carnielo and Zinzi, 2013). Moreover, some other studies reported that UHI effect raises urban temperatures in the range of 2 °C to 6 °C (Goldreich, 2006; Huang, *et al.*, 2008; Kolokotroni, *et al.*, 2007; Rosenzweig, *et al.*, 2005; Santamouris, 2007; Taha, 2000). In Sri Lanka, Galabada, *et al.* (2020) discovered that asphalt pavement surface was found to be 17.63 °C hotter than natural ground surface, while cement concrete was 7.38 °C hotter.

With respect to Malaysia, some literatures documented the effect of UHI on urban microclimate. In a tropical regions like Malaysia, at times temperatures in urban areas can reach up to 10 °C hotter than surrounding rural areas (Shaharuddin *et al.*, 2006; Sin and Chan, 2004). Specifically, Krishnan (2007) went to the extent of comparing Putrajaya city's temperature relative to those of other urban areas. It was discovered that the Putrajaya's temperature is 5 °C hotter than other Malaysian cities due to urbanization and UHI effect. Likewise, Yusuf, *et al.* (2014) reported that an average gain in surface temperature of 8.4 °C was recorded in Greater Kuala Lumpur (GKL) between 1997 and 2013.

Based on the representative reported literature herein, it is evident that UHI has a negative impact on our urban microclimate or environment, which is a resulting effect of continuous changes in cities' native land surface. Specifically, as a result of using man made hardscapes such as dark and impervious pavement surfaces. These surfaces absorb huge thermal energy, store it, and subsequently release it to the environment causing an elevation in the urban air temperature. This situation threatens the operation and habitability of urban environments (Mohajerani, *et al.*, 2017) because, slight changes in the average earth's temperature can cause great changes in climate and

perhaps, a dangerous weather (Gustavsson *et al.*, 2001). It therefore essential to make effort towards mitigating the negative impact of UHI on our environment. One of the measures to mitigation of UHI is the use of cool pavement technology, discussed as follows.

7 Cool Pavement Technology and Its Benefit

Studies have shown that conventional dark and impervious pavements are the key contributors to UHI, which cause significant rise in urban ambient temperatures. For instance, it was reported that asphalt surface temperature in urban areas can be as high as 60 °C or more (Benrazavi, *et al.*, 2016; Mohajerani, *et al.*, 2017). Likewise, cement concrete pavement is also identified as a key contributor to UHI as its surface temperature was found to be 7.38 °C higher than that of ground surface (Galabada, *et al.*, 2020). The negative impacts cause to our environment through the use of conventional dark and impervious pavements compelled the need for alternative paving materials, which gave rise to cool pavement.

The United States Environmental Protection Agency (USEPA) refers cool pavement as paving materials that reflect more solar radiation, enhance evaporation, or have been otherwise modified to remain cooler compared to conventional pavements (Qin, 2015). Several studies interpret a component of this definition to mean that a cool pavement must be able to suppress its daily maximum surface temperature relative to asphalt concrete (Higashiyama *et al.*, 2016; Jiang *et al.*, 2016; Mohajerani, *et al.*, 2017; Qin, 2015; Toraldo *et al.*, 2015; Zheng *et al.*, 2015) Nevertheless, for simplicity and better understanding, cool pavement is referred to as a category of pavements engineered to minimize their surface temperature as well as their impact to UHI (Hendel, 2020).

According to Hendel (2020), cool pavements have been proposed and studied for decades with the aim of countering UHI. On this basis, it means that the major objective of cool pavement can be regarded as a strategy for mitigation of UHI. Benrazavi, *et al.* (2016) demonstrated that one way to combat the issue of UHI is by using paving materials that absorb less amount of heat and provide lower surface temperatures. This suggests the use of materials with high solar energy reflection (high albedo) and considerable permeability in order maintain lower surface temperature. Natural soil or earth-based materials were identified as having these characteristics (Galabada, *et al.*, 2020; Udawattha, *et al.*, 2017).

Santamouris (2013b) and Galabada, *et al.* (2020) affirmed that asphalt, cement concrete and brick concrete pavements absorb more solar radiation and emit more to the environment than natural soil's

surface. This necessitates for shift from the conventional pavement materials that extensively contribute to UHI towards the use of eco-friendly materials for cool pavement.

According to CSI (2005), cool pavements can be achieved with existing paving technologies and may not require new materials. Possible means for making a cool pavement that have been studied to date are; increased surface reflectance (through the use light coloured material or painting of dark surface pavements with white or other lighter coloured materials) and increased permeability. Mohajerani, *et al.* (2017) reported other mechanisms of cool pavement technology with respect to reflective and evaporative capacity of a paving material. They claimed that the use of reflective pavements is one of the most studied and cost-effective mitigation measures for combatting the UHI effect by reducing the pavement's surface temperature, since it is easier to vary the albedo of a pavement than its thermal inertia. On the other hand, evaporative pavements enhance cooling of the pavement surface through water evaporation when they become exposed to solar radiation.

In terms of benefits, cool pavement has been a good strategy for UHI reduction, hence, it contributed to the general benefits of UHI mitigation and global warming as well. It also decreases for demand and use energy and enhances air quality (CSI, 2005; Qin, 2015). It also contributes towards the shift from conventional pavements to sustainable pavement structures. Thus, the use of cool pavements is deemed as a key strategy for UHI mitigation and reduction urban thermal discomfort as well as the impact of UHI on microclimate Wang, *et al.* (2021). The pavement related UHI mitigation strategy approaches and some of their associated impacts as reviewed from existing literature are summarized in the following section.

8 Urban Heat Island Mitigation Measures

Due to the incidence of urban thermal discomfort as a result of UHI effect, which negatively impact on urban microclimate, cool pavements are essential measures for mitigating the negative incidences (Kousis and Pisello, 2023). This could be achieved through the use of available cool pavement technologies. Some of the key techniques include; reflective pavements, permeable pavements, and evaporative pavements.

Cool pavements design approach has been commonly used to increase pavement surface's albedo in order to improve their permeability, reflectivity, porosity and water retentive capability. The of reflective pavements is one of most cost effective mitigation actions for combatting the effect of UHI by reducing the pavement's surface temperature (Chen *et al.*, 2025; Mohajerani, *et al.*, 2017; Rossi *et al.*, 2014). It is

usually much easier to vary the albedo of a pavement's surface compared to its thermal inertia. Thus, increasing albedo is deemed as the simplest technique to reduce the maximum daily pavement's surface temperature. Hence, the use of reflective coating can even be applied to existing pavements. Basically, to make a pavement more reflective, its colour and surface roughness are changed (Mohajerani, *et al.*, 2017; Santamouris, 2013a). Earlier studies claimed that UHI effect can be mitigated by pavement surfaces whiter, or as light-coloured as possible (Mohajerani, *et al.*, 2017; Santamouris, 2013a). By making a pavement's surface a light-coloured, it decreases the amount of solar radiation to be absorbed as well as enhances the pavement's capacity to reflect solar radiation into the atmosphere. Usually, light-coloured materials and smoother surfaced pavements have a higher albedo. Consequently, they reflect more solar radiation than absorbed (Santamouris, 2013a). Commonly, a reflective paint can be applied on pavement surfaces to increase their solar radiation reflective performance.

Similarly, evaporative and water retentive pavements used to minimize the effect of UHI on microclimate. This is due to the ability of these pavements to cool themselves through water evaporation. Likewise, water retentive, permeable and porous pavements eliminate finer particles within their structure, hence, increases the air voids within the structure. The increase in the amount of air voids within the pavement allows water to pass through the voids via seepage or surface runoff. Absorption of solar radiation causes heat convection from the pavement to the atmospheric air. Movement of water within the pavement saturates the pavement, which reduces emission of heat, as part of the absorbed solar energy vaporizes into the atmosphere (Hassn *et al.*, 2016). As thermal exchanges heat the pavement through solar radiation to a certain temperature, water evaporation within the voids causes the pavement to cool (Mohajerani, *et al.*, 2017; Santamouris, 2013a). A larger amount of air void in pavement, especially asphalt reduces its thermal conductivity, hence, lowers its specific heat capacity. It was demonstrated that the rate of increase in pavement's surface temperature was higher for dry asphalt pavement with a high amount of air void than for dry one with a lower void. (Hassn, *et al.*, 2016). This implies that low thermal conductivity adversely affects a dry pavement's ability to dissipate heat. Conversely, the rate of increase in surface temperature was lower for wet asphalt pavement with a higher amount of air void. Under wet conditions, a pavement with higher water content diverts higher solar energy to evaporate the water than a pavement with a higher conductivity and heat capacity but with lower amount of air void. Interestingly, this supports a fundamental concept in

porous pavement design methodology; that the ability of a pavement to retain water for longer duration increases its cooling ability.

9 Conclusion

UHI is a real phenomenon and impacts negatively on urban areas. It is therefore essential to make the most needed effort towards mitigating its associated negative impact on our environment. Based on documented literature as reported herein, it is evident that the problem of UHI effect exists around the world, of which conventional dark and impervious asphalt and concrete pavements are key contributing elements. These pavements as key contributing elements, which advance the UHI associated negative impact on our urban microclimate. These surfaces absorb huge thermal energy, store it, and subsequently release it to the environment causing an elevation in the urban air temperature. This situation threatens the operation and habitability of urban environments, as slight changes in the average earth's temperature can cause great changes in climate and perhaps, a dangerous weather. There has been a persistent need to reduce the impact of the UHI, due to its harmful effect on the wellbeing in urban areas. The rapid growth of urban environments and the increased use of hardscapes, heat absorbing surfaces make a substantial contribution to the UHI. Several UHI mitigation measures have been suggested within the existing literature. Key among the proposed measures are; the use of cool pavements, which include reflective pavements, permeable pavements, and water retentive pavements. Further, using a combination of several techniques is deemed as the most effective strategy for reducing the impact of the UHI. Currently, further works are most needed on UHI mitigation measures across varying seasons would be useful to establish the best possible solution. Because of the wide variation among different localities around the world, solutions should be targeted to meet the specific needs of different cities

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