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EVAPORATIVE PAVEMENTS AS AN URBAN HEAT ISLAND (UHI) MITIGATION STRATEGY: A REVIEW

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ABSTRACT

There has been a rise in ambient temperature, known as the Urban Heat Island effect, due to the continued replacement of natural surfaces, increases of buildings, paved surfaces and construction materials used in urban areas. There are direct relationships between the level of comfort on the outdoor environment, energy, and urban heat islands. Prior studies focused on aspects such as reflective pavements, cool pavements, and albedo of reflective pavements. However, there is a paucity of research on evaporative paved surfaces for hot humid environs, especially in countries with tropical rainforests. The evaporative pavements then called permeable pavements, are ideal for environs that receive adequate rainfall. The study seeks to close the gap via a desk literature review survey by exploring the compatibility of systems with evaporative pavements in an attempt to alleviate the impacts of Urban Heat Island at the micro-level.

Disciplinary: Architectural Sciences.

1. INTRODUCTION

A significant percentage of the land area in urban areas is covered with multiple pavement types, including parking areas, streets, plazas, sidewalks, as well as playgrounds. According to Gartland (2012), pavements have the potential of decreasing the heat island impact related to the use-phase of pavements within a context of the local climate and urban density. The traditional impermeable pavements, particularly those made of impervious asphalt, generate high temperatures at the surface, ranging between 65-80ºC during hot summers, hence leading to high temperatures on the near-surface air. Consequently, the high temperature on the near-surface air results in negative effects related to the heat island impact during the hot climates, which in turn decreases the level of human comfort, deteriorate water and air quality and result in increased energy consumption to cool vehicles and buildings (Hashem et al., 2001). Researchers have been keen on the development of cool

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pavement technologies to mitigate the effects of Urban Heat Islands (UHI), mostly by enhancing the surface reflectivity of pavements, called albedo (Hashem et al., 2001; Gartland, 2012). It is important to appreciate that the effects of higher temperatures on the pavements are not necessarily negative; by all accounts, the importance of the effects varies from location to location, as well as seasons. During the hot climate and high pavement temperatures generating negative effects, the opposite is true during the cold weather, and in cold climatic zones, heat islands can benefit occupants and building owners by decreasing the heating energy costs and mitigating human thermal discomfort (Aflaki et al., 2014; Manteghi et al., 2019).

2. THE UTILIZATION OF PAVEMENTS AS AN URBAN HEAT ISLAND (UHI) MITIGATION STRATEGY

It is estimated that pavements account for 20-40% of the land area of a typical city (Qin, 2015). The long-wave emission from the pavement during the night is intercepted by the adjacent building walls, hence retaining the heat absorbed in the pavement. The adjacent buildings in the urban areas also repress the adventives turbulence. The inadequate heat drainage ensures that there is warmer near-surface air, which leads to night time UHI (Kusaka et al., 2001; Li et al., 2013).

There has been a steady rise of studies exploring the idea of utilizing cool pavements as a mitigating measure towards Urban Heat Island UHI. There are varied thermo-psychical traits considered in each paving material. A mixture design comprises of varied materials, such as Portland cement or asphalt, air voids, aggregate gradation and alterations like polymers, fibers, or crumb rubber. Scientists are convinced that the best parameter of mitigating against Urban Heat Island is surface reflectivity. However, there is a belief that the level at which absorption of solar energy occurs can be greatly influenced by the porosity of a pavement. Thus, the ability to insulate the ground and diminish the impacts of urban heat islands can be enhanced by the utilization of materials with a high percentage of permeable materials. Conversely, the voids facilitate the evaporation of infiltrated water thus resulting in a cooling effect (Haselbach, 2009; Pourshams et al., 2013; Mostofa and Manteghi, 2020). The contribution to UHI by pavements is more complex when compared to the material type and reflectivity of the surface. Additionally, the impacts are greatly dependent on the area’s local climate, as well as the built environment of the pavements.

According to Benrazavi et al. (2016), pavement surface air temperature was significantly reduced in under shade place relative to near water or open space. In addition to appreciating the fact that albedo (reflectivity) has a significant role in the temperature of pavements surface, caution should be exercised when utilizing a single parameter in describing the contribution of pavements to UHI or for a designation of “cool pavement”. The literature illustrates that higher reflectivity is not necessarily exhibited in open void structures, but they have an evaporative cooling effect and insulating impacts, leading to lower surface temperature at night as opposed to the traditional materials with higher reflectivity (Haselbach et al., 2011; Pourshams et al., 2013). The potentiality of pavements is influenced by a number of thermal properties, where albedo is an essential contribution, but not the only element for mitigation (Yang et al., 2016). Moreover, different pavement structures in terms of thickness and materials have the likelihood of possessing identical surface temperature in the entire day, as evidenced in the ASU Phase I modeling. (Benrazavi et al., 2016; Stempihar et al., 2013). A three-pronged approach, comprising of 1) cool pavements, 2) urban vegetation and forestry and 3) green roofs and cool roofs, with a view to mitigating UHI has been developed in the US Environmental Protection Agency (EPA, 2008). As has previously been stated, pavements have a significant role when it comes to heat island, however, they can also be considered as part of the solution if they are efficiently designed.

3. COOL PAVEMENTS

Cool pavements are defined as a range of emerging and recognized technologies and materials (EPA, 2008). The aforementioned technologies and materials are known to prospectively diminish the surface temperature of pavements, as well as emit heat to the atmosphere relative to traditional pavements. Currently, the term cooling pavements denotes paving materials that enhances the evaporation of water, stimulates the reflection of more solar energy, or modified to promote a cooler surface relative to conventional pavements. Notably, the aspect of "remain cooler" is taken to mean cool pavements that facilitate the emission of less sensible heat to the air as opposed to the traditional types of pavements. Kolokotsa et al. (2018) found that in all aspects, cool pavement reported lower temperatures than conventional pavement, either in under shaded or under unshaded spots. Essentially, a cool pavement is deemed so because it has the potential to restrain surface temperature.

Cool pavements can essentially be categorized into:

- Reflective pavements
- Evaporative pavements

Based on the research and literature on cool pavements, the potential cool pavement technologies and impact assessment reported in the literature are summarized in Table 1.

3.1 EVAPORATIVE PAVEMENTS

Paving systems, such as parking lots, walkways, and roads can be designed to restrain water, and thus facilitate evaporative cooling. Pavements that holds off water to a certain extent remains cool the partition less absorption of solar into thermal conduction as opposed to pavements. Heat energy is required in evaporation of water that leads to the change of water to gas. For this process to occur, heat energy needs to be absorbed from the environment, and subsequently cooled down. Evaporative cooling thus decreases pavement temperature, as well as the air temperature. Pavements that hold off the water can be grouped into permeable pavers, pervious pavers, and porous pavers (Mullaney & Lucke, 2014; Qin, 2015). Essentially, conventional pavements that are deemed permeable include previous cast concrete pavements, pervious concrete pavements, asphalt pavements, as well as permeable interlocking concrete pavements are deemed ideal for highway shoulders, city streets, and parking lots (Hunt & Collins, 2008; Li et al., 2013).

3.2 POROUS PAVEMENTS

There are internal holes within porous pavers that serve as the channel through which water is filtered through. Generally, such pavers have a cellular grid system with holes that are loaded with sand, grass, dirt, or gravel for purposes of holding off moisture. According to Mullaney and Lucke (2014), the loaded area of the pavement ranges from 20-50%. The particles in such mix designs are smaller than No. 30 sieve (600 microns) that are diminished with a view to allowing a structure that is

Table 1: Summary of literature relevant to cool pavements from 2000 to 2019

No	Author (year)	Title	Cool Pavement Type	UHI	Energy Use	Water Quality	Stormwater	Thermal Comfort	Durability	Economic	Environmental
1.	Pomerantz et al. (2000b)	The effect of pavements' temperatures on air temperatures in large cities	1	√	X	X	X	X	X	X	X
2.	Pomerantz et al. (2000a)	Cooler reflective pavements give benefits beyond energy savings: durability and illumination	1	X	X	X	X	X	√	X	X
3.	Ting, et al. (2001)	Preliminary evaluation of the lifecycle costs and market barriers	1	X	X	X	X	X	X	√	X
4.	Pomerantz et al. (2003)	Examples of cooler reflective streets for urban heat-island mitigation: Portland cement concrete and chip seals	1	√	X	X	X	X	X	X	X
5.	Golden & Kaloush (2006)	Meso scale and micro scale evaluation of surface pavement impacts on the urban heat island effects	1	√	X	X	X	X	X	X	X
6.	ITO (2006)	Study on pavement technologies to mitigate the heat island effect and their effectiveness	1	√	X	X	X	X	X	X	X
7.	Lin et al. (2007)	Seasonal effect of pavement on outdoor thermal environments in subtropical Taiwan	1	X	X	X	X	√	X	X	X
8.	Kaloush et al. (2008)	The thermal and radiative characteristics of concrete pavements in mitigating urban heat island effects	1	√	X	X	X	X	X	X	X
9.	Furumai (2008)	Recent application of rainwater storage and harvesting in Japan	2	X	X	√	√	X	X	X	X
10.	Yilmaz (2008)	Determination of temperature differences between asphalt concrete, soil and grass surfaces of the City of Erzurum, Turkey	1	√	X	X	X	X	X	X	X
11.	Mallick (2009a)	Harvesting energy from asphalt pavements and reducing the heat island effect	1	√	X	X	X	X	X	X	X
12.	Mallick et al. (2009b)	Reduction of urban heat island effect through the harvest of heat energy from asphalt pavements	1	√	X	X	X	X	X	X	
13.	Nakayama & Fujita (2010)	The cooling effect of water-holding pavements made of new materials on water and heat budgets in urban areas	2	√	X	X	X	X	X	X	X
14.	Starke et al. (2010)	Urban evaporation rates for water-permeable pavements	2	X	X	√	√	X	X	X	X
15.	(J. T. Kevern, Haselbach, & Schaefer, 2012)	Hot weather comparative heat balances in pervious concrete and impervious concrete pavement systems	1 & 2	X	X	X	X	X	X	X	X
16.	Hui (2012)	Evaluation of Cool Pavement Strategies for Heat Island Mitigation Evaluation of Cool Pavement Strategies for Heat Island Mitigation	1	√	X	X	X	X	X	√	√
17.	Qin (2015)	A review on development of cool pavements to mitigate urban heat island effect	1	√	X	X	X	√	X	X	X
18.	Cortes et al. (2016)	Evaluation of water retentive pavement as mitigation strategy for urban heat island using	2	√	√	X	X	X	X	√	√
19.	Battista & Pastore (2017)	Using Cool Pavements to Mitigate Urban Temperatures in a Case Study of Rome (Italy)	1	√	X	X	X	X	X	X	X
20.	Kyriakodis & Santamouris (2017)	Using reflective pavements to mitigate urban heat island in warm climates - Results from a large-scale urban mitigation project	1	√	X	X	X	X	X	X	X
21.	Liu et al. (2018)	A new structure of permeable pavement for mitigating urban heat island	2	√	√	X	X	X	X	X	X
22.	Kolokotsa et al. (2018)	Cool roofs and cool pavements application in Acharnes	1	√	√	X	X	X	X	X	X
23.	Zheng et al. (2019)	Analysis on Environmental Thermal Effect of Functionally Asphalt Pavement	1	√	X	X	X	√	X	X	X
24.	Xie et al (2019)	Laboratorial investigation on optical and thermal properties of cool pavement	1	√	X	X	X	X	X	X	X

Note: Cool pavement type 1= Modify material Pavement; Cool pavement type 2 = Evaporative/ Permeable Pavement.

open-graded. Essentially, such a mixture is consistent in a minute percentage of aggregates (Pourshams-manzouri et al., 2013). The aggregate sizes of porous pavers nonetheless are larger. The Federal Highway Administration (FHWA) stipulates that the aggregate size of large air voids is between 3-10 mm, within a context open-graded mixes (Liu et al., 2010; Pourshams et al., 2013). The utilization of gravel, dirt, or soil as infill in a system makes render the cooling effect negligible, making it equable with concrete pavement from a thermal perspective. The utilization of grass as infill fosters the process of transpiration, as the roots permeate moisture from the deep soil to the surface that subsequently evaporates and cools the pavement (Wayne et al., 2010; Mullaney & Lucke, 2014; Takebayashi & Moriyama, 2009). Mullaney and Lucke (2014) stated that porous pavers consist of grass paving or reinforced turf, open-ended paving grids with grass, and Geocells with grass. The observed temperatures of porous pavements are exhibited in Table 2.

3.3 PERMEABLE PAVEMENT

Permeable pavements are regarded as an alternative cool pavement type that are associated with several environmental advantages, such as decreasing the discharge of pollutant load to receiving waters, diminishing water run-off during storms, recharging underground water, and enhancing water quality (Hunt & Collins, 2008; Jones et al., 2010; Kayhanian et al., 2010; Li et al., 2013). Also, permeable pavements could enhance the thermal environment outdoors via evaporative cooling (Hisada et al., 2006; Kevern et al., 2009). This would facilitate the reduction of pavement temperature, and during hot days, the subsequent air temperature via the absorbed latent heat change of water from liquid to gas in the event there is water on the pavement. It is via convection that permeable pavements are cooled. Permeable pavements can be constructed using both concrete and asphalt with an open grid mix of aggregate that is larger. Consequently, the lower part should rest on a layer of crushed stone that would facilitate the flow of water through it. This is opposite to the conventional pavements permeable pavements, making it cooler, given the heightened surface area exposed to air. The evaporation of water is facilitated by the porous quality, hence its decrease in temperature. There are other permeable pavements that are non-conventional, such as vegetated permeable pavements like concrete grid pavers and grass pavers that utilize metal, concrete lattices or plastic for support and allowing vegetation or grass to grow in the interstices (EPA, 2008). As opposed to conventional permeable pavements, the utilization of vegetated permeable pavements is ideal for alleys, trails, and parking lots with low traffic volumes. Additionally, they do well in climatic regions that have sufficient moisture to allow for the growth of vegetation or alternatively support the process of irrigation. In a bid to provide additional cooling effect and decrease the temperature of the pavements, vegetated permeable pavements integrate the processes of transpiration and evaporation.

3.4 PREVIOUS PAVEMENTS

The material used to make previous pavements is porous, as the name suggests, for purposes of allowing water infiltration to the soil. Previous pavers, like porous pavers, consist of a large volume of pore spaces for purposes of facilitating evaporation and act as a buffer for temperature. There are studies that view previous pavers as a kind of cool pavement for hotter regions (Pourshams et al., 2013; Schaefer et al., 2006). The previous paper is regarded as a special concrete, whose porosity is on the higher level, which allows the infiltration of water as opposed to the water passing around. The ingredients used to make previous concrete include asphalt or concrete paste and single-graded aggregates (Kevern & Schaefer, 2008; Kevern et al., 2005; Qin et al., 2015).

If the interval concrete cavity is large and thus able to drain water. Syrrakou and Pinder (2013) noted that previous concrete that allows water to permeate is 10^{-8} -10^{-10} m^2 (~9.7- 0.0097 cm/s). It was also noted that previous pavers do not store the percolated water, as the pavement systems readily support draining. However, there is limited information on the thermal properties of previous concrete.

Table 2: Performance observation at a different type of evaporative pavements.

Pavements	Type	Performances
Porous pavers (Vegetated permeable pavements)	Reinforced turf or grass paving	Cool the surface by evapotranspiration. The evaporative rate is about 243% higher than open-jointed paving blocks.
	Plastic geocells with grass	Cooling the ground surface because the spacing between blocks fosters evapotranspiration.
	Open-celled paving grids with grass	Reduce sensible heat release approximately 100–150W/m^2 during the day and about 50 W/m^2 at night (compared to a nearby asphalt surface). May cool temporarily but the grass can die during long spells during hot weather because of water deplete and/or of heat stress from the surrounding concrete. Interlocking with grass is 2.61 °C lower than asphalt pavement and 1.61 °C lower than concrete paver interlocking.
Permeable pavers (Non-vegetated permeable paver)	Open-jointed paving blocks	Concrete brick, concrete pavement stones, and pavers with infiltration cells have similar temperatures. These three previous pavers are cooler than asphalt pavement at daytime but warmer at nighttime.
	Permeable clay brick pavements	-
Pervious paver	Pervious cement concrete	Porous concrete is as hot as dark asphalt pavement on sunny summer days due to the low reflectance. Pervious concrete behaves thermally similar to normal concrete for days with less of precipitation but performs evaporative cooling after rain. Pervious concrete has a higher surface temperature than normal concrete during daytime but lower temperatures during nighttime.
	Pervious asphalt concrete pavement	Pervious hot-mix asphalt pavements have the highest predicted daytime surface temperatures & lowest nighttime temperatures. The surface temperature of pervious asphalt pavement was 4-6 °C higher than that of dense graded asphalt pavement. Pervious asphalt pavement has a cooling effect during the wetting period but aggravates the UHI effect during drying spell.

Note :Details refer to: Kevern et al. (2012), Lee et al. (2010); Li (2012), Lin et al. (2007), Lucke & Beecham (2011), Morgenroth (2010), Starke et al. (2011), Stempihar et al. (2012), Suleiman et al. (2006), Syrrakou & Pinder (2013).

Similarly, there are few studies focusing on the reflectivity of previous concrete (Haselbach et al., 2011; Kevern & Schaefer, 2008). Given that the surface of the previous pavement is rough, the albedo is less than normal compared to normal concrete, and as such, its absorption of solar irradiation is higher (Haselbach et al., 2011; Kevern & Schaefer, 2008; Qin, 2015). The solar reflectance index of concrete made previous pavements, as observed by Haselbach and Boyer (2014), being 14 compared to 37 in pavements made of the conventional concrete (Haselbach et al., 2011; Qin, 2015). There was no precise measurement in reference to the previous concrete and its thermal properties. When compared to the traditional concrete, it is widely known that pervious concrete has lower thermal inertia, but nonetheless, there has been no measurement reported on this. Additionally, there is little known about the heat convection of previous concrete. Given that when compared to traditional concrete, previous concrete is rougher, it is estimated to have a higher convective coefficient, and thus could be potentially cooler in windy weather conditions as opposed to conventional concrete (Qin & Hiller, 2013). The porosity of previous concrete is reported to be

15-30%, and many times higher (Kevern et al., 2009; Kevern & Schaefer, 2008; Wang et al., 2006). In a context where the temperature gradient is adequately large, then there may be convective cooling, where buoyancy is driven inside the cavity. Thus, evaporation in previous concrete rarely contributes to the reduction in surface temperature, except on occasions where it is re-wetted during the most ideal period.

3.5 WATER-RETAINING PAVEMENTS

Pervious concrete allows for fast infiltration of water such that there is no desirable water retained for evaporative cooling. This results in water-retentive pavements that primarily hold the water at its top layer. Water retaining pavements can either be made of cement or asphalt. Literature refers to such pavements as water-retentive, water-holding, water-retaining, watered, and other identical terms. There is a variance in the evaporative capacity and pore structure of permeable pavements and water-retentive pavements, as illustrated in Table 3. The table shows the permeability (m^2) of both waters retentive and permeable pavements, which in this case is similar. Consequently, the porosity of the permeable and water retentive pavements is comparable where the latter is (10^{-11}-10^{-13} m^2), one or two magnitudes lower than the former, at (10^{-8}-10^{-11} m^2) (Karasawa et al., 2006; Nakayama & Fujita, 2010; Qin et al., 2015). For the purpose of holding a large amount of water, the fillers of water-retentive pavements are embedded within the concrete. There are varied forms of fillers, including peat moss, bottom ash, blast-furnace slag, hydrophilic fiber, and others that are water absorbent (Karasawa et al., 2006; Kinoshita et al., 2012). A pavement that is water retentive can retain 0.15–0.27 g/cm^3 (~15 kg/m^3) of rainwater when the surface is sufficiently wet, depending on the filler material used (Qin, 2015; Yamagata et al., 2008). The absorption rate is twice that of the absorption of permeable concrete in Table 3. Consequently, it can evaporate for a longer period of time, due to the fact that the absorption rate is higher. Moreover, the pore structure of the filler in water-retentive pavements can use a capillary force to absorb water from the base when the evaporable water near the surface is exhausted (Kinoshita et al., 2012). A block that is water retentive can absorb over 70% of it when water is poured on the dry surface of the block for a period of thirty minutes (Akira et al., 2011; Karasawa et al., 2006). Given its high rate of absorption, pavements that are water retentive are expected to remain cool for a lengthy period relative to previous and permeable pavements. There are scientists that are keen on exploring the evaporation capacity of pavements that are water retentive. This can be achieved by replenishing the pavements with wastewater. This was done in cities such as Osaka and Tokyo, where water-retentive pavements are sprinkled with wastewater to increase its evaporative cooling (Furumai et al., 2008; Qin, 2015; Starke et al., 2010). A large scale experiment in this regard has been conducted in Tokyo at Shio Site, where water-supplied pipes are installed right next to the pavement and automatically sprays water. The pavement in this context stays cool when contrasted to the planting zones, owing to the sprinkling reclaimed water (Starke et al., 2010; Yamagata et al., 2008). The cooling of water retentive pavements can also be enhanced by the utilization of novel pore structure designs and high absorptive filler (Karasawa et al., 2006; Okada et al., 2008).The evaporation rate of water-permeable pavements are not well documented, and a substantial portion of stormwater infiltrates into the ground, which in turn leads to diminished rates of evaporation relative to natural soil (Asaeda & Ca, 2000; Starke et al., 2010).

Table 3: Comparison of permeable pavements and water-retaining pavements.

Pavement type	Porosity (%)	Permeability (m^2)	Absorption height (%)	Water retaining amount (g/cm^3)	Evaporative cooling duration	Mainly pore size distribution (μm)
Permeable Pavement	15-30	10^{-8}-10^{11}	20-40	0.06-0.10	1-2 days	0.4-50
Water-retaining Pavement	22-43	10^{-11}-10^{-13}	>70	0.15-0.27	One week	0.03-400

Note: absorption height is a parameter defining the capillary force, detail refers to Karasawa et al. (2006), Nakayama & Fujita (2010), Qin & Hiller (2013).

4. IMPROVEMENT OF CONVECTION BETWEEN THE AIR AND PERMEABLE PAVEMENTS

It is via convection that heat is transferred from the pavement to its surroundings. The convection rate is dependent on the air temperature and velocity passing over the surface, the roughness of the pavement, and the pavement's total surface area that is exposed to air (EPA, 2008). There are some permeable pavements that have surfaces that are rougher and consist of additional air voids when compared to the traditional pavements, such as pervious concrete pavement, previous block pavers, and previous cast pavement. The roughness and additional air voids enhance the effectiveness of the surface area exposed to air, which in turn develops circulation turbulence within the pavement. In this context, the University of California Pavement Research Centre (UCPRC) proposes the utilization of previous cast pavements for the purpose of stormwater management (Jones et al., 2010; Li, 2012). The proposed previous cast pavements are made of concrete that is dense-graded and consists of air holes that drain water and facilitate effective convection, thus allowing the pavement to stay cooler relative to other types of pavements. As opposed to utilizing an open-graded mix, previous cast pavement utilizes standard dense-graded Portland cement concrete that is cast in place or has precast holes. To this end, they have a structural capacity per unit thickness that is relatively higher when compared to previous concrete mixes. Nonetheless, caution should be taken when designing holes, as they should have sufficient robustness, facilitate adequate drainage of water, and ensure that it could facilitate safe usage for motor vehicles, motorcycles, bicycles, and pedestrians. Similar ideas were observed in literature with regards to the cooling effect (Li, 2012; Wang et al., 2010). Notably, the cooling effect and convection are enhanced by surface roughness, but it also has the potential of diminishing the net solar reflectiveness of the surface (EPA, 2008).

4.1 PERMEABLE PAVEMENTS AND THERMAL COMFORT

People usually experience an environment that is hot during the summer, especially in hot climates. When the temperature goes beyond ideal levels, it causes general discomfort in parking lots and streets, thus prompting the use of air conditioning in vehicles and buildings. This discomfort could transform into respiratory difficulties, exhaustion, non-fatal heat stroke, heat cramps, and other heat-related diseases. Thermal comfort can be enhanced by decreased pavement surface and diminished near-surface air temperature that can be potentially realized by encouraging outdoor activities (Li, 2012; Nikolopoulou & Lykoudis, 2007).

There are studies that have indicated that irrigation can aid in the reduction of permeable pavement surface temperature during the day, hence minimizing the impact of heat island and further enhancing thermal conflict (Li et al., 2013). The effect of cooling is heavily reliant on the availability of pavement surface temperature and is likely to disappear should there be a decrease in water levels. For irrigation to work, one approach that can be employed is using an urban landscape runoff. For instance, the water utilized for vegetation in parks and boulevard medians can be used during the summer and in the late afternoon within the context of permeable pavement. This strategy is applicable during the hot season, where the heatwave for the following day can be mitigated by doing the work the previous night with the chief aim of enhancing thermal comfort. The water retention capacity of water retentive pavements can be enhanced using materials that are water retentive, such as slag, pea gravel, water-retentive fiber, and fly ash, with the purpose of lengthening the effective time of cooling and enhancing the cooling effect of watering (Karamanis & Vardoulakis, 2012; Pyun et al., 2010; Tomotsugu, 2012). When impermeable pavements are sprinkled on the water at mid-day, the cooling effect is enhanced, but only for a short period since upon evaporation taking place, the cooling will be diminished (Li et al., 2013). This is in contrast to permeable pavements being added on water, as it prolongs the cooling effect with there being enough water for evaporation to take place throughout the day. This is further buttressed by the fact that permeable pavement has lower surface temperature during the night compared to the impermeable pavements in both dry and wet weather conditions (Nakayama & Fujita, 2010; Okada et al., 2008; Tomotsugu, 2012). The permeable pavements thus have the additional benefit of providing a solution to nighttime heat or island impact within urban areas, especially during hot summers.

The implication made here is that irrigating/watering can sufficiently reduce the surface temperatures of pavements. Moreover, evaporation of moisture helps increase the cooling effect of pavements as long as there is adequate water irrigation from the urban landscape. Findings denote that keeping water near the pavement surface by sprinkling water or injecting water to the surface enhances the rate of evaporation, which improves the cooling effect. The capillary impact is dependent on the structure and contents of the air void in the surface materials, and air voids connectivity, distribution, and sizes.

5. DISCUSSION

The reduction of environmental effects in urban areas is probable if there is proper pavement design. In China, (Liu et al., 2018) confirmed that the evaporation-enhancing permeable pavement could significantly subsidize UHI mitigation, and was 9.4 °C cooler than conventional permeable pavement. There is a significant reduction of moisture availability at the surface when the stored water evaporates, hence hampering continued evaporation (Aida & Gotoh, 1982; Qin, 2015). There is a need to accurately model this resistance in a bid to predict the evaporative cooling of pavements that are evaporative and identify the ideal time frame for replenishing the pavements that are water retentive. With the coupled CFD-PT model, it was confirmed that water retentive pavement, as a pavement material for the main street, can cause a reduction in the ground surface temperature (Cortes et al., 2016). The cooling of evaporative pavements could also be enhanced by painting permeable concrete pavements with light-colored paints, while reflective paints can be used for water-retentive pavements (Akagawa et al., 2008; Qin, 2015). Cooling in pavements that are water retentive or permeable occurs due to the retained water at the pavement layer evaporating. Filling the pavement with agents that are water-holding can thus enhance the pavements' rate of water retention. Consequently, the availability of water heavily determines the thermal performance of water-retentive and permeable pavements and the ranges of influence of porous materials evaporative cooling due to their differences in thermal and moisture transport properties (Kubilay et al., 2019). The evaporative pavements are ideal for humid and rain areas, where water is abundant. The near-surface heat island can be mitigated via the use of permeable pavements while enhancing air quality and thermal comfort. Permeable pavements have a lower thermal impact on the near-surface air compared to impermeable pavements. Adequately designed permeable pavements can potentially capture all stormwater pavements devoid of creating surface overflow, facilitate the flow of heavy truck traffic, and enhance the pavements' thermal performance. Theoretical research is needed for purposes of modeling the availability of surface moisture and determining the optimal time for water replenishment on pavements. Future studies are also expected to add on to the reduction of canopy air temperature, decrease thermal stress, as well as loading heat in adjacent buildings relative to evaporative pavements (Manteghi et al., 2016; 2018).

6. CONCLUSION

There are several researchers that have attempted to document, comprehend, and solve the challenge of urban heat islands. To this end, innovative technologies and systems have been developed and suggested in the quest to reduce the flux of sensible heat to the atmosphere from paved surfaces and varied urban structures such as buildings. This study provided an overview of the problem and suggested probable solutions based on available literature. Nonetheless, the implementation of the proposed strategies in cities is still far from being executed due to multiple reasons. The constraints can be overcome via further research and development, with the purpose of promoting sustainable cities. Pavements that are water retentive and permeable are the most ideal for humid and rainy areas, as such areas have an abundance of water. When compared with traditional materials, laboratory tests confirmed that the new generation of permeable materials reported lower surface temperature. However, the availability of water is the sole driver in the thermal performance of water retentive and permeable pavements. There is a need for further exploration of alternative pavement systems with probable composite materials, such as pavements with a high albedo and are permeable. Additionally, there is need for further research on the thermal traits of evaporative pavement systems in local climates with tropical rainforests. Ultimately, literature on thermal performance is scarce, with monitoring only reported by a few projects.

7. AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding author.

8. ACKNOWLEDGEMENT

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