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INFLUENTIAL FACTORS OF WATER BODY TO ENHANCE THE URBAN COOLING ISLANDS (UCIs): A REVIEW

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ABSTRACT

In the current growth of urbanization, problems especially anthropogenic heat emissions are emerging. Urban Heat Islands (UHI) are one of the major causes of environmental problem and it exacerbates the cities' living environment heat conditions critical to human health. Various factors affect the urban thermal environment, which is closely linked with UHI as well as the outdoor thermal comfort. These factors include buildings density, urban landscaping and water bodies. Water bodies are one of the significant components of the core surface. Water influence the urban thermal environment of the surrounding through its cooling effect, either through evaporation or heat transfer between the air and water. This review paper comprehends the factors that facilitate the water bodies cooling effect in order to achieve urban cooling island to mitigate UHI.

Disciplinary: Architectural Sciences.

1. INTRODUCTION

Urban development is one of the key forms of land cover change that has profoundly affected the surrounding environment. Trees are cut down and as a result, natural vegetation cover is basically substituted by paved surfaces in the throes of urbanization. For ornamental or recreational purposes, open spaces are preserved. Transformation and urbanization of the earth's surface to urban application is an indication of massive changes in global usage of the land, affecting the environment considerably (Manteghi et al., 2015; Weng & Yang, 2004). The microclimate that is experienced in urban valleys is far from which is experienced in the suburban areas because of the dissimilarities of the valley surfaces (Manteghi & Mostofa, 2020). The Public body that lies between the urban space and the building can considerably influence the energy consumption of the urban buildings, the outdoor and the indoor microclimates as well as thermal comfort for the pedestrians. Insufficient moisture, as well as vegetation covers for evaporative cooling that is experienced in urban space, leads to a variety of urban problems entailing urban heat islands. Urban climate researchers have

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proposed a number of viable urban development concepts and techniques that embolden the addition of pleasant outdoor spaces and energy-efficient buildings by designing for solar radiation, temperature, and humidity (Syafii et al., 2017; Gaitani et al., 2014). In contrast to the urban heat island, areas that having low temperatures when contrasted with their surroundings are called UCI (Urban Cooling Islands) (Lee et al., 2016). The impact of UCI is generated by trees shadow or green and water space evaporation (Rosenzweig et al., 2006). Water spaces for example stream, river, and lakes in specific have a significant aspect in creating urban cool islands because water spaces have higher evaporation rates than green spaces. Therefore, water spaces have the role of cooling islands in urban areas as a result of the temperature difference of their adjacent environment (Hathway & Sharples, 2012; Sun & Chen, 2012). As UCI comprises the shaded area, green and water space to improve the UHI, we will more precisely focus on the parameters that influence to increase evaporation of water bodies. The urban water bodies are highly capable of mitigating the temperature of urban environment by reducing the consumption of energy, enhancing outdoor thermal comfort including its positive effects on UHI (Urban Heat Island) (Manteghi et al., 2016). Due to the flat surface and the large heat capacity, water body is useful to form an "air duct" for the urban climate regulation and as an important solution of urban climate change responding as well as improving the outdoor environment (Zeng et al.,2017).

Despite the fact that many studies have confirmed the effectiveness of water bodies in the reduction of air temperature, though very few review papers of how different variables influence the cooling effect of water bodies. However, conducting such studies in real urban settings comes with many shortcomings due to the complexities and heterogeneity of the pertinent road surface materials and building, resulting to difficulty in isolating the individual effects of every influential variable for instance, configuration, surface area, shape and position (Manteghi et al., 2016). Responding these inquiries might support us to adopt more suitable indicators to quantify the microclimate regulation services of water spaces, and could provide us with useful measures for urban landscape design. It is therefore required in understanding these parameters, which may be beneficial to designers and planners. The purpose of this paper is talking over the influential parameters of water bodies and finding further ranges for the study.

2. COOLING EFFECTS OF WATER BODIES

Water features that are found in the urban zone influence the micro-climate atmosphere of the encompassing regions positively when natural cooling from evaporative process is required during the hot radiant day. Generally, the rise in water availability boosts evaporation, including the related uptake of latent heat that gives an extra daytime cooling effect. Air temperature over or close to waterways is completely different from that over land due to differences in the way water cool and warmth. Water bodies are the best safeguards of radiation since they reveal very slight thermal response. A good number of researches claimed that water bodies or water feature evaporative cooling is still one of the best ways of passive cooling for cities (Manteghi et al., 2015; Shafaghat et al., 2016; Völker et al., 2013). Whatever the case, evaporative cooling may not work perfectly in hot and humid regions because of the high humidity (Manteghi et al., 2018).

The microclimates around waterways in a variety of past investigations have been discovered to have reduced the air temperatures as compared to the surrounding urbanized areas (Manteghi et al., 2019). It has been acknowledged during the hot season in Japan, the air temperature difference between the river and the city was between 1–3° C (Syafii et al., 2017). Observations were similarly, proven that the cooling effect of a small river in the Sheffield (UK), with an average temperature difference of approximately 1°C during the hot season. It was discovered that a large pond in Fukuoka, Japan had a 3° C cooling effect that extended up to 400 m (Hathway & Sharples, 2012). In addition, small size water bodies can have a horizontal cooling effect (Chen et al., 2006; Syafii et al., 2017). Another research revealed that even a 4 m^2 pond is capable of reducing the air temperature in its surroundings (Syafii et al., 2017; Robitu et al., 2004). The Ota River cooling effect in Hiroshima, Japan was discovered to reach up to 5° C directly above the river and disseminated about 100 m from the river banks (Hathway & Sharples, 2012). However, in urban areas, the climatic effects of a water body depend on the direction and speed of the predominant wind, and the water surface area.

UHI mitigation in policy has revealed that even a small body of water can lead to a cooling effect of 1°C in temperatures reduction and the only way in which these cooling effects can be improved by carefully designing the surrounding areas. The reestablishment of water through the planned incorporation of porous surfaces, like porous paving, or the presence of water bodies, including rivers or ponds, is capable of lessening the UHI by returning the floor moisture availability to the same values as those in rural areas. The water evaporation process has been studied, and the cooling results for a variety of cities demonstrated with models recommended for a variety of sites (Hathway & Sharples, 2012). Generally, suggestions emphasis including green space to counter the high temperature but urban water spaces, or all surface waters within a city, are also considered as a possible variable for UHI mitigation. According to Völker et al., (2013) the influence of different microclimate zones on UHI mitigation by water bodies, the resilient result was monitored in tropical climates and wetlands revealed the strongest effect average temperature difference of 2 K.

The accessibility of water contributes to an operative latent heat sink, and evaporative cooling leans towards weakening the layer of surface and additional increases mixing. These characteristics affect the water bodies' surface temperature to be cooler than the land. Enriched evaporation is capable of lowering the air temperature, hence mitigates the process of UHI, and therefore achieves thermal comfort for inhabitants.

It is observed that cooling distribution for the water body exhibits seasonal and diurnal variations. A good example is the study of a river in Sheffield (UK), which the cooling impact of the river was likely to be maximum before noon, and during the hot days representing ~2 K over the river and in the buffer between the land and the river, showing 1.5 K. However, no considerable cooling was observed at night (Hathway & Sharples, 2012; Jin et al., 2017; Wong et al., 2012).

Although all mentioned studies have reported the practicality of water bodies in the air temperature reduction, researchers have limited knowledge of the way a variety of parameters are affecting the cooling effect. In table 1, we can perceive that many researchers worked with the features of a water body that have impact on UHI as well as thermal comfort. With the help of this table, research gap, as well as scope for future studies, can be identified. Very few investigations have been carried out on the parameter that influences the cooling effect.

Table 1: Summary of Literature Review from the Year 2010-2019

No.	Authors	Title	Region	Scale	Method	PET	UHI
1	Xu et al., (2019)	Evaluation of energy-saving potential of urban green space	Sub-tropical	Micro climate	ENVI-met	X	√

		and its water bodies					
2	Gajjar & Devi*, (2019)	Assessment of Role of Water Body on Thermal Comfort in Ahmedabad, India	Tropical	Microclimate	Field Measurement	√	X
3	Cai et al., (2018)	Do water bodies play an important role in the relationship between urban form and land surface temperature?	Sub-tropical	Micro climate	Field Measurement		√
4	Zeng et al., (2017)	The Impact of Water on Microclimate in Lingnan Area	Sub tropical	Microclimate	Numerical Simulation	X	√
5	Jin et al., (2017b)	Effect of water body forms on microclimate of the residential district	Temperate	Microclimate	Envi-met Simulation	X	X
6	Du & Li, (2017)	The Effect of Pearl River on Summer Urban Thermal Environment of Guangzhou	Sub tropical	Microclimate	Remote Sensing Image and Simulation	√	√
7	Syafii et al., (2016)	Experimental Study on the Influence of Urban Water Body on Thermal Environment at Outdoor Scale Model	Temperate	Microclimate	Experiment study with Equipment	X	√
8	Hongyu et al., (2016)	Research on the cooling island effects of water body: A case study of Shanghai, China	Sub tropical	Microclimate	Remote Sensing Image and Regression Analysis	X	√
9	Manteghi et al., (2015)	Water bodies an urban microclimate: A review	Tropical	Microclimate	Review Paper	X	√
10	Yang et al., (2015)	The impact analysis of water body landscape pattern on urban	Sub tropical	Microclimate	Regression Analysis	X	√
11	Steeneveld et al., (2014)	Refreshing the role of open water surfaces on UHT	Temperate	X	Study with Equipment	X	√
12	Li & Yu, (2014)	Mitigation of urban heat development by cool island effect of green space and water body	Subtropical	X	Regression Analysis	√	√
13	Theeuwes et al., (2013)	Modeling the influence of open water surfaces on the summertime temperature and thermal comfort in the city	Sub-Tropical	Mesoscale	Meteorological Model	√	X
14	Hathway & Sharples, (2012)	The interaction of rivers and urban form in mitigating the Urban Heat Island effect: A UK case study	Temperate Maritime	Mesoscale	Investigation Examine	X	√
15	Sun & Chen, (2012)	How can urban water bodies be designed for climate adaptation?	Temperate	Micro climate	Investigation and Analysis	√	X
16	Wong et al., (2012)	Influence of water bodies on outdoor air temperature in a hot and humid climate	X	Microclimate	Investigation and Analysis	√	X
17	Xu, et al., (2010)	Evaluation of human thermal comfort near urban waterbody during summer	Sub-Tropical	Microclimate	On-site Measurement and Calculation	√	X

2.1 WATER BODIES EFFECT IN URBAN MICROCLIMATE

In particular ways, urban environment modifies the urban microclimate. The structure and the geographical location of the city, building materials, regional meteorology, geometrical configuration, vegetation, and water lead to significant consequences on the urban microclimate

(Robitu et al., 2006). Therefore to improve urban climate, a number of policies have been recommended: higher albedo, more vegetation Akbari, et al. (2001), or water bodies that favor the evaporative cooling (Du & Li, 2017). Evaporative cooling is one of the most proficient ways of passive cooling for buildings and urban spaces in warm zones (Robitu et al., 2006). Syafii et al., (2017) recommended water facilities like fountains or waterfall, with the aim of creating favorable urban microclimate. The air temperature measurements on the leeward side underlined a temperature reduction about 3K during the water vaporization period from 14 p.m. to 15 p.m. which could be felt up to about 35 m of the water system. By shading the urban surface by trees and the presence of water bodies the urban microclimate thermal environment enhances. Most of the time, evapotranspiration and evaporation are related to the heat transfer between air, water, and vegetation. Wind function is very important in the process; in the vicinity of vegetation and surfaces, it supplants the saturated air with drier air. Water features, like water walls and ponds in Singapore, are capable in air temperature reducing up to 1.8° C in sunny clear days (Syafii et al., 2017).

Theeuwes et al. (2013) discovered that bigger lake is likely to have a higher influence in the city with the respect to the direction of wind, whereas smaller lake is equally distributed, despite the fact that they have a smaller cooling effect that may have a lot of impact on a considerable proportion of the city (Theeuwes et al., 2013). A research utilizing numerical simulation study reveals that beside the ability to reduce the air temperature the presence of water bodies are capable of reducing the consumption of energy Robitu et al., (2003) and it will also offer enhanced outdoor thermal comfort with further vegetation, (Manteghi, 2015; Robitu et al., 2006).

Hatway & Sharples (2012) investigate humidity and temperature between August and April in 12 sites, which are located at outstanding remoteness from a minor river that strolls through the metropolis of UK, in places of a variety of urban street particularly in an open street, an open rectangular, and a closed road or entirely enclosed with the use of homes. It resulted in reduction average of 1°C in temperatures that are above 20° C. During the daytime, cooling just took place and varied from 0.25 to 1.82° C. In May, the impact was also great from 1.01 to 1.82° C, instead of June which is from 0.25 to 0.98° C and was expected to be attributable of water in temperatures that are high during the summer months. Furthermore, Sun & Chen, (2012) investigate the state inside the sixth ring-road of Beijing, through a range of 2000 km^2 and the particular water bodies should have positions separated by 1500 m or more between each other. Finally a total of 197 water bodies were nominated under the above benchmark. This examination confirmed the fact that the water bodies have a remarkable cooling effect, particularly at ambient air temperatures that are high. Sun & Chen, (2012) demonstrate that water bodies with surrounding built-up land are correlated with stronger cooling effects. The other way, more irregular urban geometry and more distance from the downtown center tended to have less cooling intensity. In hypothetical simulation with ENVI-met and (Ray Man) from Manteghi et al., (2016) illustrate that buildings hight to the width of the street (H/W) aspect ratio of urban geometry has influence on water bodes cooling effect. The study found that urban setting with deep canyon,e.g (H/W>1) and wider river width is more comfortable. With greater plant life, the open streets to the river joined with banks of rivers, led to extra powerful cooling, that turned sustainable over an additional distance. For instance, an open road was 1.2° C cooler compared to a closed street (Hathway & Sharples, 2012). However, the urban geometry that surrounds the corridor of the river is very vital as compared to the mere absence. The consequences of cooling can be more suitable by considering more carefully the design of a city.

2.2 COOLING EFFECTS OF WATER AREA

Previous research confirms that water scale has a considerable impact on its surrounding microclimate. As reported by Sun & Chen (2012) water bodies with larger area has a cooling intensity of 34 % and cooling efficiency of 44%. The thermal environment impact of water area in conjunction with moistening and cooling is more apparent as compared to that of converting water intensity. In a positive volume, the intensity and area of the water have a modifiable feature of regional weather. In accordance with the study of urban water change in layout by the area of water is distributed into four occupies of 4%, 8%, 12% and 16% which is a representation of the proportion of China city's water distribution (Li et at., 2008). Given that the research concerning impact of urban water on the microclimatic and model parameterization simulation illustrates the fact that 2 km^2 water is capable of cooling the 1 km environment range by 0.6 ° C, as well as the area of single water below 0.25 km^2, has a minor effect to the environment (Zeng et al., 2017).

Syafii et al. (2017) found that the temperature difference, though, does not certainly be guided by the increased ratio of pond size. In this investigation, the cooling benefits between the big pond and the small pond are merely the 0.3° C improvement on average though bigger pond has four times a large surface area than the small pond. Conversely, afterward in the night, the large pond has a tendency to warm the air more than the smaller pond (Syafii et al., 2017). As a result of its larger surface area and bigger thermal capacity, the big ponds contribute to absorbing and accumulation more heat during the daytime. As the water area increases, the impact on the locality surroundings also increases, therefore leading to the water location growth, and hence typically increasing the wind velocity from zero to between 1- 0.2 m/s. As the water area increases, the degree of decline of change curve increases from 0.39 ° C to 0.2 ° C (Zeng et al., 2017). The water temperature of the 400 m^2 water body can also be reduced by 0.2 °C and the air temperature of 1600 m^2 water body can be lessened by 0.39 °C and over the 400 m^2, water rises by 0.08 m/s, and over 1600 m^2, it is possible that water is augmented by 0.13 m/s (Zeng et al., 2017). With the increase of the water area, the latent heat of water evaporation rises, leading to increasing the wind velocity and decreasing the temperature of water central area. As the area of the water rises in the urban microclimate, the water cooling effect also upsurges.

Modern researches confirm that features like area, shape, etc., can also greatly influence the intensity of cooling effect (Sun & Chen, 2012). The cooling efficacy (distribution and magnitude) of water bodies is affected by the spread and size of spaces. Theeuwes et al. (2013) put up a mesoscale replica of hypothetical water bodies replicated in a city that is idealized. From the study, it is clear that the reasonably large water bodies exhibit a maximum cooling effect to downwind areas as well as the neighboring boundaries. In addition, the width importance of certain water bodies was examined with a review in Beijing's water bodies that emphasized urban river width as the most important variable that affects the riparian zone's temperature and the humidity. They were able to discover that when the width of the river was >40 m, it was obvious that there were stable and significant impacts of increase in humidity and decrease in temperatures of the neighboring urban areas (Zhu et al., 2011). Again it is discovered that a 35 m wide river led to a drop of 1–1.5 ◦C ambient temperature (Hongyu et al., 2016).

The temperature and humidity of the air are also affected by the depth of the water. When the water depth increases, it enhances the heat preservation effect of water, cooling effect in summer as well as the warming effect in winter (Peng et.al., 2013; Zeng et al., 2017). The cooling effect is also affected by the shape of water. Through the technique of GIS spatial analysis and thermal infrared information processing conferring to the research with the ETM+ remote sensing data and SPOT5, that the water surface temperature is lower than linear river in urban thermal environment, which indicate that the surface water has better a cooling effect (Yue, 2013; Zeng et al., 2017). Concerning a variety of climate impacts of water depth which is derived from mathematical model, the shallow water has a particular warming impact due to the reflectivity which is different than the water-primarily role of cooling effect when the water depth is more than 0.5 m (Zeng et al., 2017).

3. WATER COOLING ISLAND (WCI)

The water cooling island discovered by Cao et al., (2010); Chang et al., (2007); & Hongyu et al., (2016) confirmed that it was apparent for water cooling island effect to be found in the water body. Water evaporation permit ambient atmosphere to fascinate latent heat and considerably decrease the air temperature, so water bodies are considered as urban cooing island in order to act as an important local climate regulating service (Amani-Beni, et al., 2018). As linked with prior researches, this section discovered that water body geometry has greatly affected to create Water Cool Island.

According to the theory of ground surface heat balance, the water body affects the ambient temperature of the neighboring environment apart from corresponding to reasonably lower surface temperature. In line with the preceding research, wetland, city parks, and green space considerably affect the intensity of water cooling effect (Cao et al., 2010; Chen et al., 2014; Sun & Chen, 2012). Four descriptors which are proportion green land (PG), geometry of water body that is water area (WA), land shape index and proportion impervious surfaces (PI) are applied in quantifying the relations between WCI effects and water body characteristics.

The water cool island alleviates the temperature variation between water bodies and its surroundings, with the use of water vapor and temperature exchange in the horizontal direction. Improving the surrounding microclimate condition is very important. The formation of local circulation is easier with the improved green land area, leading to bigger impacts on the thermal environment of the water body's surroundings. Waterbody can, therefore, absorb heat from ambient temperature. Expansive impervious surfaces surrounding the water body increase the temperature of the water body itself apart from increasing the temperature around, weakening the water cooling effects outcomes. In a situation that the percentage of impervious surfaces increased, the proportion of green land improved, the distance between the edges of the water body and the water area changed, therefore the outcomes of water cooling effect will increases.

Through evapotranspiration and shading, vegetation mostly affects the meso- and microclimate (Andrade & Vieira, 2007; Georgi & Dimitriou, 2010; Oliveira et al., 2011). The vegetation shading effect reduces the incident shortwave radiation resulting in surface and ground temperatures that are lower. The effectiveness of shading relies on plant geometry for instance density and crown shape. Through evapotranspiration, plants also have a cooling effect. Instead of increasing the sensible heat flux like the air temperature, solar energy is transformed into latent heat through changing of water from liquid to gas. In climate studies, comparative assessment of both together is not common despite the fact that water space and green space is often emphasized as to provide considerable ecosystem services (Hathway & Sharples, 2012; Völker et al., 2013). A very good example is presented by research of three lakes and six parks in Chongqing, China (humid subtropical). Little analysis is offered in description of the synergistic processes concerned, especially for conditions where both green space and water space are resolutely incorporated as green and water infrastructure. A good example is a study of 20 streams in Washington (USA) that emphasized the impact of riparian vegetation in decreasing the net radiation balance of rivers by lessening the frequency of contact between solar radiation and wind flow. They discovered that within one winter, clear-cutting of this vegetation raised air temperature above the streams by up to 4 K and that conserved vegetated buffers offered some security in opposition to air temperature increases mid-summer, whereas even superior protection was realized in summer, both late and early. Following the removal of such riparian vegetation, vapor density at a stream might rise as higher air temperatures result in more evaporation and augmented rates of transpiration from the left behind riparian vegetation, with the assumption that adequate airflow to evacuate the air that is moist. This corresponding rises in the atmosphere and the moisture reductions from the surface of watercourses may probably have a demeanor on the confined water-cycle (Gunawardena et.al., 2017). In all of these studies it is going to be better to further liven up the urban design by co-modeling the thermal advantages of water and green infrastructure design in conjunction with the outcomes on all additional services of eco system, psychological aspects included, which is relevant. With respect to the eco-psychological advantages and design, accomplishing the right character and balance of green and water infrastructure essentials would particularly appear to be important (Kellert et al., 2011). In all redevelopment and urban development situations, contributions of water space and green space to urban cooling have to be taken into consideration and assessed with the use of a modeling framework that is systematic.

4. DISCUSSION

Due to their capability of promoting an impact of cooling through heat transfer and evaporation between the air and water, water bodies aid the changes in the neighboring thermal environment. Impact of cooling effect of urban water bodies is a remarkably complex procedure, but it is certain that some parameters as size of water body, solar radiation angle, evaporation rate, albedo of water and surrounding area, climate condition, wind speed, water, and air temperature influence the cooling capability (Amani-Beni et al., 2018; Hathway & Sharples, 2012). From some studies, it is obvious that the water cooling effect rises as the water surface area increases and the impact of wind speed on the water is that it raises the water area. There is a strong affiliation between the water surface, wind direction, and building positioning. As compared to the water depth changes, the impact of thermal environment that is created by the water area rises as the water area increases. In order to boost the impact of water on thermal environment, the area covered by the water body can be changed. A water body that lies in an urban environment can considerably decrease the temperature of the ambient air with suitable solar radiation and wind speed. The utilization of water spaces in the context of urban areas is, therefore, one of the important strategies of advancing the urban thermal environment and at the same time in promotion of diverse advantages of urban areas. Positive cooling effects are promoted by extensive use of water bodies. In order to accomplish this, resourceful distribution and design of water spaces to make sure those advantages of microclimate are attained maximum.

5. CONCLUSION

For the case of urban water bodies, increasing the size of the water body with a very simplified shape is appropriate for more UCI intensity and temperature difference. With increasing the water area and presence of green space, the UCI effects could increase significantly. The area size is a vital element in the water bodies that facilitates the reduction of air temperatures. The potential of urban water bodies to mitigate the surrounding temperature has various benefits including the reduction in levels of energy consumption, improved thermal comfort of pedestrians in outdoor environments and creation of urban cool islands. This review paper offers a great opportunity to come up with guidelines for upcoming design developments in consideration of the following points. (1) The urban water bodies' installation configurations should be designed carefully. Although water body inclusion in an urban environment provides the cooling effect, equally it can raise the humidity of the surrounding resulting in increased pedestrian discomfort. (2) The water bodies' orientation should be carried out with respect to the prevailing winds so as to enhance optimal levels of cool air distribution. (3) The location of the water bodies is also significant to ensure that there is no excessive shadowing of a water body from the nearby buildings. In fact, such buildings may reduce significantly the water bodies' cooling effect by decreasing the energy required to facilitate the process of evaporation.

6. AVAILABILITY OF DATA AND MATERIAL

Data can be made available by contacting the corresponding author.

7. ACKNOWLEDGEMENT

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