A QUEST IN URBAN MICROCLIMATE; REVIEW ON THE IMPACTS OF STREET DESIGN ON URBAN CANYON'S AIRFLOW

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Abstract - Urban climate is a significant topic on climate, both locally and globally. There are numbers of aspects that affect it such as urban morphology, density, the possessing of urban surfaces and the vegetation spread. The urban environment alters micro-climate in various ways. Therefore, an increasing interest can be seen in microclimate concerns as they resemble significant factors in order to achieving sustainability among the cities, where numerous inhabitants lives in. The role of Canyon street morphology is very important in urban microclimates as often more than a quarter of urban areas are covered by streets. As the amount of airflow in urban canyons are impacted as by geometry and orientation of streets, the effects of designing streets on urban microclimate with emphasizing the effects of streets geometry (H/W ratio) and their orientation on airflow in an urban canyon will be studied in the manners of present literature and evidences. Scholars have evidently illustrated that geometry and orientation of a street are the major principles that should be considered in order to creating a suitable microclimate at pedestrian scale in an urban canyon.

Keywords - Urban Microclimate, Street Design, Urban Canyons, Airflow

I. INTRODUCTION

One of the most dominant factors that influence open spaces microclimate in cities is urban morphology. Various urban forms provide different microclimates which their comfort situations differ for pedestrians. Furthermore, the urban microclimate is likewise vital mostly through its impacts on urban air quality. Cities are reactive to urban climate unsteadiness and changeability and able to alter their own climates. A critical characteristic that impacts domestic and global climates and accordingly urban livability is urban climate (Srivanit& Kazunori, 2011) (Huang et al, 2008). The first person who proposed considering the impacts of urban form on microclimate was Howard (Howard, 1833).Moreover, the first researchers who study the correlation among architects and urban designers in the aspect of climatologic, which is concentrating on the interactions among building and microclimate design were Olgyay and Oke (Olgyay, 1963) (Oke, 1988).

There are few factors that affect the urban open spaces microclimate such as geometry, urban density, the greenery, water levels and the surfaces possession. The incorrect application of former noted factors adds to the environment harshness and consequently increases the temperature in urban regions that is higher than suburbs. This phenomenon is known as Urban Heat Island (UHI) (Oke, 1988). Very fast increases of urbanization, urban development and rise of population have led to city induced climate alteration, significant impacts on public health, growing interest among scholars to overwhelm the adverse impacts of urbanization on cities thermal condition. The phenomenon of "Urban heat island" (UHI) is the most evident phenomenon between the climatic manifestations of urbanization. Additional studies have been done in order to comprehend the UHI characteristics, important parameters, causes and effects of it and to file the intensity of this phenomenon in different geographical locations of the planet (Arnfield, 2003) (Ghiaus et al, 2006). Heat trapping by urban geometry, urban surfaces properties, replacement of greeneries which is caused by widely constructed surfaces cover and the anthropogenic sources of heat are known as major reasons of UHI creation (Bourbia&Boucheriba, 2010) (Arnfield, 2003). Latest studies have led to the improvement of technological measures in order to construct an urban area that is thermally comfortable (Akbari et al, 2008) (Sanatamouriset al, 2012). Amid the measures, it seems that urban geometry is very promising in amending urban climate. Therefore, designing urban streets is very important as it is essential for formation of the urban climate. The urban streets are various in the manners of geometry as defined by height/width ratio (H/W) and length/width (L/W) also the orientation that is defined by its long axis. These factors affect the amount of produced emission and absorption of urban ventilation directly, which have considerable influence on variations of temperature within both streets and surrounding environment (UHI) (Shashua Bara & Hoffman, 2003). This research evaluate and study the current literature and evidence in order to understand the effects of designing streets on the urban microclimate with precise consideration of the impacts of geometry of streets (H/W ratio) and orientation on airflow in urban street canyons.

II. METHODOLOGY

This research systematically reviews the studies on the impacts of geometry of streets on airflows in

urban canyons and illustrates the impact of geometry manipulation (over changing the orientation and the aspect ratio (H/W)). The research is founded on information and data that are collected from bibliographical studies and associated proofs. The first part of the paper reports the studies on the urban microclimate and street canyon design. The second part of the paper presents the researches on the street design's impacts on airflow.

III. URBAN MICROCLIMATE AND STREET CANYON DESIGN

Many scholars believe that at a micro scale, the geometry of urban open spaces is the most related factor which is liable for variation of microclimate (Putrajaya, 2000) (Oke, 1982). Accordingly, streets unique geometric characteristics are called as "street canyons" due to their geometrical forms that resembles natural canyons (Nicholson, 1975). Likewise to natural canyons, urban canyons have a tendency to channel the wind and also they play a significant role in improving wind speed and dispelling excessive heat from urban regions. Wind is a significant factor in outdoor environments as it impacts thermal comfort of pedestrians (Memon& Leung, 2010) (Yang & Li, 2011).

Oke terms an "urban street canyon" as the "basic geometric unit which can be reasonably approximated by two-dimensional cross-sections, neglecting street junctions, and assumes that buildings along the canyon axis are semi-infinite in length." As urban canyons can be seen as two-thirds of urban spaces in a city, they are very important in the manners of radiative balance an outdoor thermal comfort (Oke, 1992) (Oke, 1998). Geometry of urban canyon is considerable as it is responsible for saving up to thirty percent of consumed energy in retailed and commercial buildings and nineteen percent in buildings with residential function (Rooney et al, 1998). Additionally, aspect ratio is one of the main factors of canyon geometry determination, which can be explained as the ratio between the average height (H) of the canyon walls and the canyon width (W) (Oke, 1998). If the aspect ratio of a canyon is below 0.5, it is called as a shallow street canyon. However, if the aspect ratio is 2, it is called as deep street canyon. (L) Stands for the length of canyon which indicates the road distance among two major intersections dividing the street canyon into short (L/H=3), medium (L/H=5) and long (L/H=7) (Ahmed et al, 2005).It has been proved that the street canyon geometry and orientation impact both indoor and outdoor environments, solar access outside and inside of the buildings, the penetrability to airflow for urban ventilation and also the ability of cooling the entire urban system (Ali-Toudert& Mayer, 2006). Thus, the street design affects the thermal comfort at both pedestrian and global scale of urban buildings energy usage. From climatic perspective, the major difficulty of designing streets for designer is when the seasonal internal and external needs differ from each other. For example, sun protection in summer from the sun and solar admittance in winter are needed. Theoretically, these indicate density and wideness respectively to the sky (Ali-Toudert&Mayer, 2006).

Referring to the most associated studies, street canyon geometry's factors (height/width ratio (H/W)) and the orientation of street are the most related urban factors accountable for the microclimatic alters in a street canyon (Todhunter, 1990). These mentioned factors straightly impact the potential of airflow at street level, solar access and consequently urban microclimate (Arnfield& Mills, 1994) (Nakamura &Oke, 1998). Even though, there have been lots of traditional and modern architectural attempts to design urban streets referring to climate, measurable data that is founded on scientific approaches about finding the best street design is needed in order to having a regulation about the climate comfort (Asimakopoulos et al, 2001) (Hawkes, et al, 2002).

IV. STREET DESIGN'S IMPACTS ON AIRFLOW

Air movement is an important component of climate that influences the urban region's thermal performance (Van Esch et al, 2012) (Knowles et al, 1980). Urban airflow arrays are identified by the interface among and upcoming wind with the human-made environment. The airflow formation within a street canyon is necessary for human health, external and internal thermal comfort, quality of air, buildings energy effectiveness and consequently, providing a proper urban microclimate (Memon& Leung, 2010). For example, the airflow's cooling impact, specifically at night, can diminish impacts of urban heat island phenomenon. Many studies suggest that the pattern of a prevailing districted wind is altered when it flows through a built environment (Al-Sallal& Al-Rais, 2012).

Therefore, designing street canyon and built environment is a major factor in formation of urban airflow patterns.The air above urban regions can be classified into major layers: urban canopy layer and urban boundary layer. The urban canopy layer is a layer that is placed below roof tops in spaces among buildings and it is affected by solar energy that is absorbed via building facades and ground. Heat transmission, contaminant emission, transpiration and evaporation and contemporary urban expansions in general are the major parameters that impacts air temperature in urban boundary layer (Thomas&Fordham, 2003). As there are obstacles such as buildings and trees, airflow in the urban canopy layer is more impassable comparing to airflow in the urban boundary layer. Hence, the airflow in urban canopy layer is slower in canopy layer than in the nearby country sides (Okeil, 2010). Urban boundary layer that creates a secondary

circulation feature delivers airflow in an urban canyon that is significantly impacted by orientation and geometry of street (H/W and L/W) (Nakamura &Oke, 1998). "As the airflow in the urban boundary layer is nearly normal to street axis, three airflow regimes, which each of them has its own characteristics, could be taken place according to the aspect and building ratio (H/W) and (L/W) (Fig. 1), the isolated roughness regime; the wake interference regime; and the skimming regime" (Okeil, 2010). Alteration from a regime to another regime occurs at critical merging of H/W and L/W (Rooney et al, 1998).

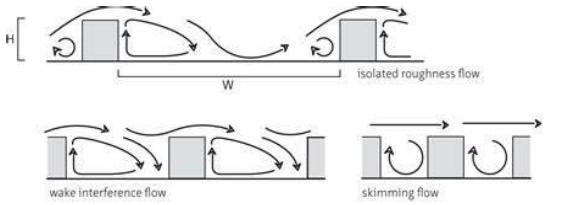


Fig.1. Airflow regimes over an range of barriers the core flow features associated with each (Oke, 1988) (Arnfield, 2003) (Memon& Leung, 2010)

The secluded roughness regime occurs among building that are well-spaced, when there is no interface among leeward flows and windward, likewise to a wind movement around a secluded blockade. By raising the H/W ratio, the concerned wakes are resulted in a wake interference regime. More rising of H/W ratio, can lead to isolation of street canyon from circulating air in the urban boundary layer and consequently, a stable circulatory vortex is made in the canyon. This steady circulatory vortex conducts a skimming regime that is the most repentant urban regions (Yoshida et al, 1990/91). Hence, it can be understood that the airflow in deep street canyons is slower comparing to the ones which are united or shallow.

In many studies, the effects of street design on airflow have been considered. For example, Johansson (Johansson, 2006) studied the effects of geometry of street on airflow. It has been studied in Morocco as case studies with actual site measurements for over one and half years. Deep and shallow street canyons that have aspect ratio of 9.7 and 0.6 respectively were analyzed in details. The outcomes showed a clear correlation among street canyon geometry the microclimate within an urban canyon (1.7m). This research illustrate that the speeds of wind are less and steadier in deep canyon (0.4 m/s) in either seasons of summer and winter. On the other hand, the average wind speed of shallow street canyon is 0.7 m/s in summer and 0.8 m/s in winter.

There has been another study that is conducted by Al-Sallal and Al-Rais (Al-Sallal& Al-Rais, 2012) in Dubai, it has been evident that narrow street canyons (4 meter and less) could raise the speed of wind passing through it, leading to a better performance which is passive cooling before making eddies at bending angles. As the speed of wind was higher (5 m/s), wind became deeper inside the old-styled narrow streets and it creates a better potential for thermal comfort. Most areas (49-57% of the studied criteria) with street canyons aspect ratio of 2-0.67 had wind velocities that have a range of light to mild breeze.Furthermore, several scholars studied measures of the effects of heights of buildings on the airflow within the street canyon.

Accordingly, Priyadarsini and Wong (Priyadarsini& Wong, 2005) initiate that if a few blocks of high-rise towers placed strategically, the speed within the street canyon will be improved when the airflow is either parallel or perpendicular to the canyon. Additionally, the temperature degree was less when tall buildings were located in a street canyon. By locating some of these high-rise building, the speed amplified by up to ninety percent for parallel flow and the temperature is lowered by up to one Celsius degree. For the flow that is perpendicular, the speed is raised up to ten times more and the temperature is reduced by 1.1 Celsius degree.

Furthermore, Robins and Macdonald found out that further wakes make extra air exchange and U-shaped vortices can take place by designing a few high-rise buildings amid surrounding buildings which are limited in the urban canopy layer(Robins & Macdonald, 1999). High-rise buildings that are upstream would convey more vertical flow up from the street canyon to the urban boundary layer. On the other hand, buildings that are downstream would provide extra vertical flow down from the urban boundary layer into the urban canopy layer. Moreover, creating proper openings among streets and courts helps to advance air exchange within the urban canopy layer. In addition, it has been evidently showed by Chan et al. (T. Chan et al, 2001) who found out that better ventilation can be provided by various building heights. Thus, tall buildings do not necessarily can be function as barriers. Additionally, they also discovered that better combination of air can be achieved by an urban canyon that is wider and street geometry ought to be restricted to threshold value for skimming flow and the maximum relative canyon length ratio L/H must not be more than 5.Besides the orientation and geometry of streets, the street configuration could impact the airflow at canopy layer. Straight streets that are parallel to each other would provide air drive into and within the urban regions. Lack of greenery and adequate covers in straight streets can lead to severe heat (in hot-dry climate) or cold (climates that are cold-dry) wind blows into the streets because of air movements that are straight (Santamouris et al, 1999) (Fig. 2). Slim and winding streets decrease either cold or hot winds reduce the impact of winds that are stormy (Fig.3). This outline is appropriate for towstressful climates (hot-dry and cold-dry) (Santamouris et al, 1999).

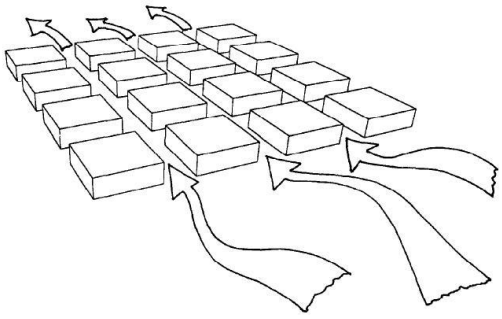


Fig. 2 Straight and parallel streets advance airflow into and within a city (Santamouris et al, 1999)

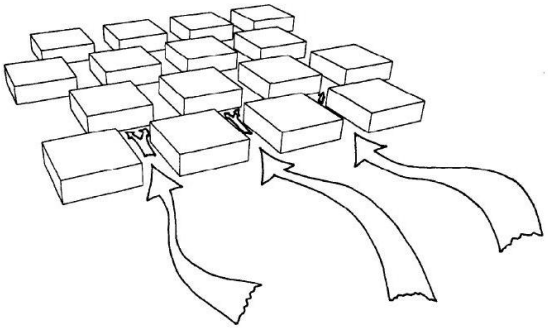


Fig. 3Narrow and winding streets lead to slower airflow (Santamouris et al, 1999)

V. CONCLUSION

Streets design is a major subject in an international goal for an environmental urban design as streets covers around a quarter of urban areas. The streets' geometry (H/W & L/W ratios) orientation impacts the airflow in urban canyon in a direct way and thus thermal comfort at pedestrian scale. A street that is wider can create better combination of air and hence better-quality airflow in urban canyon. Additionally, more adequate ventilation could be taken place in a street with different building heights. Street orientation considerably affects the diurnal and seasonal form of streets surface irradiative contamination and it is more influenced on vertical surfaces of the street. Consequently, designing urban streets, in order to create an adequate and proper microclimate in urban regions in a way that provide appropriate airflow is significant and necessary. This could impact global-scale climate and building usage of energy.

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