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Influence of Geometry and Orientation on Flank Insolation of Streets in an Arid Climate City

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Abstract: Problem statement: Whilst at the design stage the various aspects of design impact must be taken into account, the incident solar radiation, insolation, is a key to many environmental aspects of street canyons. In this regard, the configuration of an urban street has a decisive role in magnitude of the solar radiation which it receives on its flank. This study aimed the influence of geometry and orientation of urban street canyon on flank insolation in an arid climate city. **Approach:** This study approached numerical simulation and employs a computational programme to carry out a 2D simulation within Urban Canopy Layer; (UCL). To enhance the resolution, the simulation condition is based upon accumulative hourly insolation on the daily-basis sun movement for the both solstices as the two extreme days of the year. **Results:** Geometry has an inverse influence on flank insolation and streets approaching deeper canyons would have lower insolation in both summer and winter. The orientation influence on insolation is to be seen with the season. In winter, orientation effect is analogous to geometry impact and higher inclined canyons would have lower insolation on their flank. In summer, increase in orientation causes variation in flank insolation of which the variation trend is not in the same direction. **Conclusion:** This study showed that both geometry and orientation influence the solar radiation incident on the street flank and therefore ought to be considered in the design stage where the designers can take full advantages. The increase in geometry or orientation towards deeper canyon and higher inclination respectively, yield insolation reduction excluding for the orientation influence in summer that causes insolation variation.

Key words: Geometry and orientation, flank insolation, urban street canyon, numerical simulation

INTRODUCTION

The Impact of the sun on the climate particularly for subtropical cities is prominent. Incident solar radiation, insolation, comprising direct and diffuse radiation on a given surface is of great deal as a lot of further decisions in the design process for different purposes highly depend upon it. From the urban street canyon point of view, its impact on pedestrian thermal comfort (Oka, 2006; Parlmutter *et al*., 2007), surface energy budget and radiative exchange (Arnfield and Grimmond, 1998; Harman *et al*., 2004), solar access (Arnfield, 1990; Morello and Ratti, 2009) and pollution dispersion (Huang *et al*., 2005; Zhanga *et al*., 2007) is discussed. Yet, to what extent the canyon itself affects the receiving solar radiation has not been explored.

Insolation on a sunlit horizontal surface is a function of latitude, time of the year and hourly sun altitude (Jones, 2003). Improved models also take into account the height of location from the sea level (McQuinston *et al*., 2000). In urban areas, the modeling of solar radiation is discussed (Robinson and Stone, 2004) where dealing with urban street canyons requires consideration of air pollution, cloudiness of sky and shading effect (Kreider *et al*., 2002). Among these, the clearness index and pollution density are off the control of the designer while shading can be controlled. Shading on a flank might be caused by trees as well as opposite flank. Shading of trees to provide thermal cooling is pleasant (Shashua and Hoffman, 2004), however, as vegetation is scarcely available in arid climate, shading is mostly cast by opposite flank. Therefore in arid cities, shading of street and subsequently insolation intensity rely on aspect ratio (H/W or geometry) and azimuth (orientation) of a canyon without trees.

Studying geometry and orientation of street canyons for the design purposes is the issue which recently has gained importance. It has been investigated to improve design quality towards a climate-friendly design through various aspects inter alia healthier air to breathe (Taseiko *et al*., 2009), outdoor thermal comfort

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(Ali-Toudert and Mayer, 2006) to underpin outdoor activities, wind flow and ventilation (Offerle *et al*., 2007; Hanga *et al*., 2009) and canyon thermal conductivity (Panao *et al*., 2009) for energy conservation purposes. But influence of geometry and orientation of a canyon on the insolation is not clear and well-established. This study aims to investigate to what extent the canyon itself affects insolation. The outcome of study provides a platform not only for urban design purposes but also addresses design issues within building scale such as heat gain (Li and Lam, 2000) and facade PV installation (Yun and Steemers, 2009).

MATERIALS AND METHODS

The study approaches numerical simulation and seeks the magnitude of solar radiation striking flank of the street canyon. A two-dimensional simulation is undertaken by the aid of a computer programme called Ecotect to carry out the simulation process. The selection is due to the integrity of the software that provides all the necessary tools in one programme that considerably leads to save time and effort. It also facilitates producing weather files for any desired location by support of another programme called WeatherTool. High resolution and ability to assess outdoor climate are among the other reasons for the selection of this programme.

Since this study aims to understand the influence of geometry and orientation of street canyon, series of street canyons each varying in aspect ratio or azimuth are modeled. The examined models vary in five equal steps between 0.7 and 6.7 in terms of aspect ratio and from 0°, East-West (EW), to 90°, North-South (NS), in terms of azimuth (Fig. 1). Then, analogous to the undertaken approach by Muhaisen (2006) and Muhaisen and Gadi (2006) all models are evaluated in solstices 22nd June and 21st December as the two peak days representing summer and winter time respectively. Modeling of the street canyon is based on Oke (1988) model, having two symmetrical and continuous flanks with no opening along the street and within urban areas.

The selected city: The city selected as the case study is the city of Yazd located at 32°20'N in the central plateau of Iran (Fig. 2). Based on Koppen-Geiger climate classification map (Kottek *et al*., 2006) the city is in arid climate located between two deserts and characterized with low annual precipitation (Yazdi and Khaneiki, 2006). The high fluctuation in seasonal variations as well as diurnal and nocturnal temperature is due to solar radiation (Haghparast-Kashani *et al*., 2009).

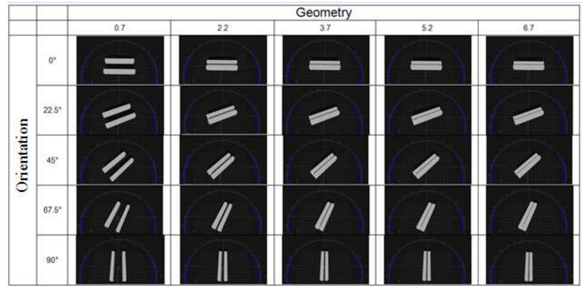

Fig. 1: Matrix of cases comprising canyons varying in geometry and orientation

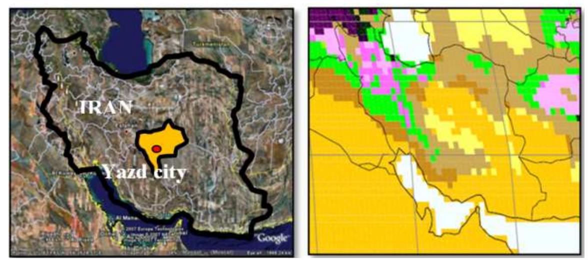

Fig. 2: Left: Iran and Yazd province and Right: Climate of Yazd city (Haghparast-Kashani *et al*., 2009)

The selection of the case study is on grounds of the following characteristics of Yazd city which fit properly in the employed model's characteristics:

- The continuous urban fabric forming a continuous street canyon flanks
- The even canyon flanks usually with no fenestration
- The plain surface flanks, generally with no gallery and colonnade
- The city clean atmospheric condition with low amount of pollution
- The city's sky that is rarely clouded
- The remote location far from pollutant industrial zones
- The desert surroundings which is away from woods and water currents to affect city climate
- The very poor vegetation particularly in street canyons

RESULTS

The influence of geometry: The influence of geometry for summer and winter time is shown in Fig. 3 and 4.

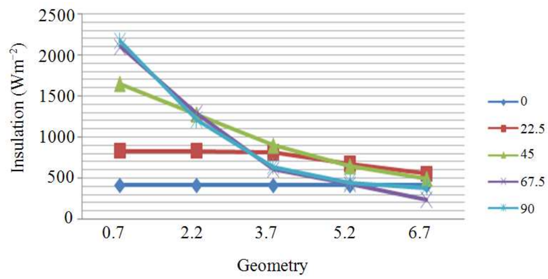

Fig. 3: Geometry impact in summer

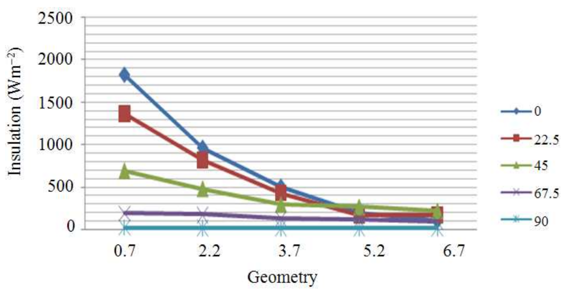

Fig. 4: Geometry impact in winter

Geometry impact in summer: Figure 3 shows that geometry of street canyon affects the summer insolation. The shallower canyons receive more radiation rather than deeper ones due to shading effect of one flank on the other. As canyon become deeper the shading effect is more significant.

The EW canyons are exceptions because those streets always are sunlit and hence are of the same insolation magnitude. The deeper the canyon, the lower the insolation they receive. Thus the shallowest canyon, where there is no shade, has the highest insolation and insolation of the deepest canyon is the lowest due to the shading. For shallower canyons the insolation plummets at the H/W = 3.7 specifically for those with higher inclination and the intensity of reduction decreases afterwards toward H/W = 6.7.

Geometry impact in winter: Figure 4 shows the influence of geometry on insolation in winter. Shading extensively affects the winter insolation due to the lower altitude of the sun.

Excluding the NS canyon, all canyons characterizing with the geometry between 0.7 and 3.7 maintain a drastic influence of shading while the reduction trends lessen towards H/W = 6.7. The fact that the insolation of NS canyon is not tended to vary with variation of geometry is due to the shading effect as the flank is shaded at all times.

The influence of orientation: The influence of orientation for summer and winter time is shown in Fig. 5 and 6.

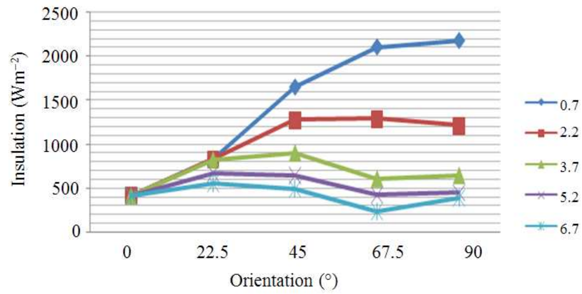

Fig. 5: Impact of orientation in summer

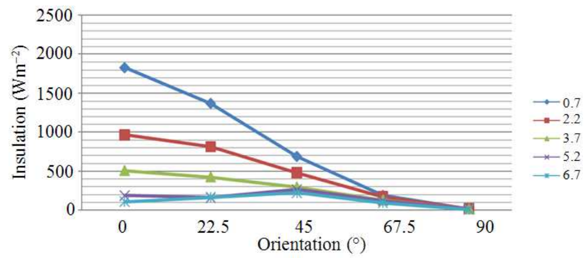

Fig. 6: Impact of orientation in winter

Orientation impact in summer: Figure 5 shows the impact of orientation on insolation in summer. The increase in inclination from EW orientation toward NS results in insolation variation which is dependent. Generally, streets with higher orientation have higher insolation in summer.

Two conspicuous orientations are EW and 67.5 in which the former one is regardless of the geometry and hence all canyons with this orientation have the same insolation and the latter is one where a significant insolation drop for deeper canyons is discernible. Notwithstanding these specific orientations, the increase of inclination from EW is associated with augmentation of insolation. This fact is more significant for those with the higher aspect ratio. Increase of inclination from EW in summer leads to distinguish differences in insolation. Overall, insolation from EW toward NS differentiates though at EW is equal.

Orientation impact in winter: Figure 6 shows the influence of orientation on insolation in winter. The canyons having orientation in the proximity of EW canyon receive more radiation than those approaching NS canyon. In this sense, flank insolation at EW orientation corresponds to the aspect ratio of that street whereas at NS is of the same magnitude regardless of the aspect ratio. Excluding the slight rise for the deeper canyons at 45°, NE-SW direction, the isolation declines from EW toward NS in winter.

The drastic drop in insolation for canyons approaching NS direction is due to shading effect causing lack of direct radiation as the bigger constitute of solar radiation.

DISCUSSION

Geometry influence: Figure 3 and 4 show the influence of geometry on flank insolation on two extreme time of a year for winter and summer solstices. Geometry and insolation have inverse relation i.e., increase in geometry yields decrease in the insolation. In summer, the insolation magnitude overall is higher than winter time. For both seasons, the flank insolation is discernable at lower geometries and the trend shrinks toward street canyons characterized with higher geometries. Street canyons shallower than 3.7 are much intended to insolation reduction due to the geometry increase whereas the tendency diminishes towards deeper canyons of which insolation varies in smaller range due to the obstruction of sky dome.

Orientation influence: Figure 5 and 6 illustrate the impact of orientation on insolation of canyon flank in summer and winter. The orientation in summer and winter affects the insolation in two different fashions. Increase of inclination from EW towards NS causes insolation augmentation in summer and insolation declination in winter. This is to say that higher inclined canyon in summer as well as lower inclined canyons in winter show more tendency to orientation impact. The insolation of EW canyons in summer is the same and variation of geometry has no effect on that. This is akin to flank insolation at NS street canyons.

CONCLUSION

The influence of geometry and orientation of street canyon on its flank insolation in an arid climate city is sought. Both geometry and orientation of canyon influence the incident solar radiation striking on the street’s wall. In both summer and winter, increase in geometry results in insolation declination that is due to shading cast by the opposite flank and the sun’s position in the sky. Orientation affects flank insolation in two different fashions. In summer canyons approaching the NS direction from the EW are associated with insolation variation with particular augmentation for shallower canyons and reduction for deeper ones. In winter the trend is analogous to the geometry influence, showing insolation reduction when orientation is more inclined.

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