BACKGROUND LITERATURE

At the micro level, building geometry shows an intimate relationship with air temperature, and Oke (1976) states that the thermal climate at the canopy layer depends on the characteristics of the individual site and not on the temperature at boundary layer. The height-to-width ratio and the street orientation with respect to solar radiation, was found to have a great influence on the timing and magnitude of the energy regime of the individual urban surfaces (Nunez and Oke 1977). Oke (1981) states that the rate of cooling at the street level depends on two parameters: the Height – width ratio (H/W, street geometry) – the ratio of typical height of the buildings to typical width of the neighbouring streets and the sky view factor - the fraction of the sky hemisphere visible from a location at the street level in an infinitely long urban street canyon. Arnfield (1990) compared the effects of urban geometry and thermal properties of the construction materials and found that the canyon geometry is the predominant factor and the thermal properties of the materials enhance the differences in the cooling rates generated by different street geometries. The canyon radiative geometry contributes to a decrease in the long-wave radiation loss from within the street canyon due to the complex exchange between buildings and the screening of the skyline and decreases the effective albedo of the system, because of the multiple reflection of short-wave radiation between the canyon surfaces (Oke et al 1991). Ahmed (1994) found a decrease in air temperatures by 4.5K with an increase in the H/W ratio from 0.3 to 2.8, in the hot humid city of Dhaka, Bangladesh, in summer. Also, the aspect ratio and the street orientation determines the time of exposure to direct solar radiation and the occurrence of extreme heat stress (Ali-Toudert and Mayer 2006). Shashua-Bar (2006) indicated that the thermal effects of built form, vegetation and colonnades, in streets and in courtyards depend on the envelope ratio (i.e.,), the overall geometry factor. Johansson and Emmanuel (2006) analyzed the influence of street canyon geometry on the outdoor thermal comfort in Colombo, Sri Lanka and the study revealed that the differences in air temperatures were higher during the day, especially in the afternoons when compared to the night and a maximum difference of 7^{o}C was found between sites.

It is difficult to predict the actual thermal sensation of humans because of the varying climatic conditions in the outdoors and the changes in the personal factors such as the clothing and activity level. PET – a universal outdoor thermal comfort index (Jendritzky et al 1990, Matzarakis et al 1999), is defined as the "Physiologically Equivalent Temperature at any given place (outdoors or indoors) and is equivalent to the air temperature at which, in a typical indoor setting, the heat balance of the human body (work metabolism 80 W of light activity, added to basic metabolism; heat resistance of clothing 0.9 clo) is maintained with core and skin temperatures equal to those under the conditions being assessed" (Mayer and Hoppe 1987).

The field of research pertaining to outdoor thermal comfort conditions especially at the street level is relatively new. Matzarakis and Mayer (1998) investigated the thermal component of different urban microclimates in Freiburg, Germany and found that the heat stress levels of the human beings depend mainly on the shading effects and clothing factors. Ali-Toudert et al (2005) found that the heat stress in unobstructed locations is high, when compared to sheltered urban sites in Beni-Isguen, Algeria. Ali-Toudert and Mayer (2006) found the dependence of thermal comfort on the design of the street, including geometry, orientation and other design strategies, such as the galleries and horizontal overhangs. Gulyas et al (2006) examined the outdoor thermal comfort conditions in the complex urban environment of Szeged, Hungary using the RayMan model and found a difference of 15^{o}C to 20^{o}C in the PET index due to the radiation differences in sites that were shaded differently by buildings. Emmanuel and Fernando (2007) insisted that the mitigation strategies adopted by urban designers should be based on human comfort (determined by both MRT and air temperature), rather than on simply attempting to control air temperature alone. Lin et al (2010) indicated that low SVF and sufficient shading with tress and buildings can improve the thermal comfort during summers. Bourbia and Boucheriba (2010) highlighted the importance of street design in Constantine-Algeria and found a difference of 3–6^{o}C in air temperatures between the streets with varying geometry. Also, the wind speed reveals a significant impact in the relationship between the MRT and the SVF, even though solar access has a strong relationship with SVF than the wind speed (Kruger et al 2011). The study on the seasonal effects of urban street shading by Hwang et al (2011) revealed that shading effects provided different thermal sensation at different seasons and suggested that improvement of comfort conditions in urban streets

(E-W) of locations 2 & 4 were same (H/W = 0.5), their thermal recordings varied upto 3.28^{o}C at 14.00hrs, due to presence of vegetation at location 4. The N-S oriented streets at location 1 & 5, also experienced significant thermal differences of about 2.3^{o}C at 14.00hrs, attributed mainly due to the presence of significant vegetation at location 5.

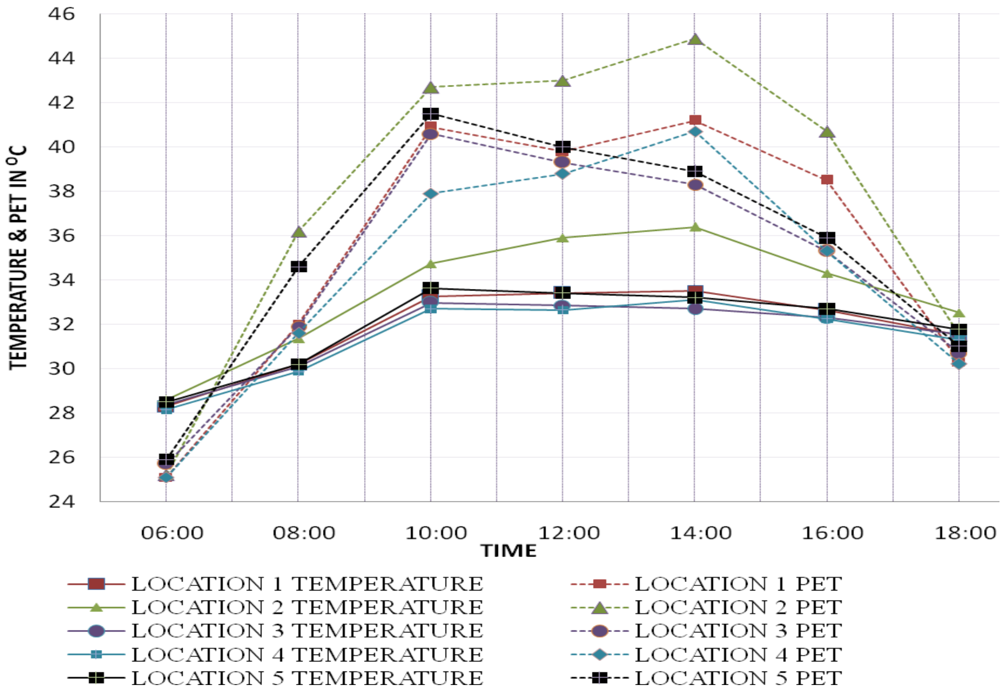

Figure 3 Air temperature and PET variations at various locations

Street geometry, The variations in air temperatures with respect to height to width ratio increases gradually from 8.00hrs (1.1^{o}C) to 14.00hrs (3.7^{o}C) and reduces from 18.00hrs reaching almost similar temperatures at 6.00hrs. The H/W ratio is inversely proportionate to air temperatures and PET values, i.e., higher the H/W ratio lesser the air temperatures and PET values. Thus the study reveals that narrow streets are comfortable during daytime due to internal shading of buildings in hot humid climates, thus improving the outdoor comfort conditions.

The comfort conditions expressed by PET values were higher than the air temperatures by 8.5^{o}C during daytime (8.00hrs to 16.00hrs) attributed to the presence of intense solar radiation. In the absence of direct solar radiation, the human thermal sensations represented by PET values were lesser than the air temperatures upto a maximum of 3.39^{o}C lesser than the air temperatures. Analysis also revealed higher variation in PET values when compared to temperature differences at location 2 & 3 at 14.00hrs. For a temperature difference of 3.7^{o}C between location 2 & location 3 at 14.00hrs, PET differences of 6.6^{o}C existed at the same locations. This indicates that even slight variation in air temperatures can have a significant impact in the comfort conditions (PET) during daytime.

Location 2 experienced the maximum temperature and PET values at 14.00 hrs owing to its E-W orientation of the street, H/W ratio of 0.5, SVF of 0.623 and absence of vegetation. Also the concrete pavements and absence of shading by trees and buildings added to the discomfort. Almost all the five locations were above the upper limit of discomfort of 33^{o}C as stated by Ahmed (1994), during daytime (between 07.00 hrs and 17.00hrs). The temperature in the PET index increases with the increase in ambient air temperatures and the difference between the same is as high as 8.5^{o}C at 14.00hrs. At 6.00hrs the PET was lesser than the air temperature by 3.05^{o}C at location 4 which recorded the minimum temperature. This clearly reveals that the outdoor thermal comfort index has a significant impact with direct solar radiation. PET index during night time was comfortable and was well within the upper limit of comfort (33^{o}C) and was also lesser than the ambient air temperatures.

Questionnaire Survey and PET Analysis

The questionnaire survey revealed that the respondents experienced the heat stress during daytime as the PET varied from 34.6°C to 44.9°C between 8.00hrs and 16.00hrs. The thermal sensation at locations 3 & 5 was almost tolerable at 14.00hrs due to internal shading by buildings and trees. The N-S orientation of these locations had a significant impact on the thermal sensation. Location 1 which was also oriented in N-S direction experienced higher discomfort due to its street geometry with SVF of 1. The thermal perception of the respondents was too warm at locations 1 & 2 due to the absence of internal shading. Also the reflective nature of the abutting buildings had a significant impact on the thermal sensation in the above locations. In general the thermal perception at locations 1, 2 & 4 were not satisfied and the users experienced heat stress. The overall conditions inside the campus are acceptable for the users near the locations 3 & 5 due to the N-S orientation and the presence of vegetation, thus providing a tolerable environment at these locations.

CONCLUSION

The air temperature and the PET trends in the campus revealed that the nights were comfortable when compared to day. During daytime, all the streets were uncomfortably hot with the PET values well above the upper limit of the comfort zone. As the daytime comfort was found to have a significant correlation with the street geometry (SVF), presence of vegetation and orientation, the study indicates the significance of improving the daytime comfort in the campus, by stipulating appropriate built geometry and orientation in the new developments in campus. Also if the concept of internal shading is adopted in the existing built form, it can improve the comfort conditions to a significant level. Based on the study, recommendations pertaining to some of the aspects of built form have been suggested to improve the outdoor thermal comfort conditions at the campus.

- N-S oriented streets are comfortable when compared to E-W orientation. If E-W orientation is essential in the design, then appropriate shading of streets through shaded corridors, projected balconies, and vegetation can improve the pedestrian comfort considerably in campus.
- Shading through vegetation significantly reduced air temperatures and PET values during daytime irrespective of the orientation.
- Narrow streets oriented in the N-S direction reduced the heat stress during daytime as they reduce the time of exposure to direct intense solar radiation. Also the internal shading of buildings accelerated the comfort conditions at pedestrian level.

NOMENCLATURE

PET	=	Physiologically Equivalent Temperature (°C)
H	=	Height of building (m)
W	=	Distance between buildings in a street canyon (m)
SVF	=	Sky View Factor
OUT_SET*	=	Outdoor Standard Effective Temperature (°C)
SET*	=	Standard Effective Temperature (°C)

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