Assessment of Thermal Comfort in Urban Street Canyons

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ABSTRACT

Urban Street Canyons are the open spaces between buildings, having various microclimates. A dense urban fabric may provide solar shading to pedestrians within deep street canyons; on the other hand they may also become “heat traps” due to reflection and reduced albedo, diminished night sky radiation and substantially reduced ventilation. The microclimate in street canyons influences the thermal environment. Thermal environment is of prime importance, which influences the people’s comfort conditions in outdoor spaces. An attempt to study urban street canyons in Chennai city, India, has been made using PET (Physiological Effective Temperature) using Rayman 1.2 model. Field measurements were carried out for streets with varying canyon geometry and orientation in two sites (residential and commercial). Comfort conditions of streets with varying orientations and aspect ratio were compared. The study confirmed that a shallow urban canyon was warmer than a deeper one. In shallow urban canyons small increases of air velocity had little influence on thermal comfort level. On the other hand, a deeper urban canyon with lower air velocities maintained tolerable comfort levels, mainly because of the cooling effect from the reduction in solar penetration to the street level. The deeper canyons provided better thermal comfort. For optimum shading the best street orientation and street geometry for urban canyons were analyzed. Design guidelines for designing better urban environments were formulated.

KEYWORDS: Street Canyons, PET, comfort conditions, aspect ratio.

1. INTRODUCTION

Urbanization tremendously changes the landscape of an urban area and results in distinguished climatic conditions termed the “Urban climate”. Luke Howard (1833) carried out the first scientific study of inadvertent urban climate modifications. (H.Landsberg, 1981). He compared the temperature of a city weather station with that of a rural station and found that the city station was warmer. The warmth of cities in contrast to their rural surroundings is termed as “Urban Heat Island” (UHI), a term according to Landsberg (1981) coined by Gordon Manley (1958). Research on UHI phenomenon includes (Oke 1988), (Chandler.T.J, 1976), (Jauregui, 1997). (Akbari et al, 1992). This has revealed a series of causal relationship between urban factors and climate. Urban geometry and thermal properties of urban surfaces have been found to be the two main factors influencing urban climate. (Oke 1987, Arnfield 2003). At neighbourhood and smaller scales urban geometry affects the most (Todhunter 1990, Arnfield 1990). The urban geometry of a city is characterized by the “urban canyon” which is defined as the three-dimensional space bounded by a street and the buildings that abut the street. The Urban canyon layer (UCL) is the layer of atmosphere where most life occurs: from ground up to the mean height of roofs (Oke 1982). Urban canyons restrict the sky view and free movement of air. It also causes multiple reflection of solar radiation. Urban canyon geometry is specified by the height of building / width of street (H:W) ratio, known as aspect ratio. Terjung and
Louie (1974) were among the first to suggest that the urban/rural daytime temperature anomaly is largely attributable to the aspect ratio. In the hot humid environment of Dhaka, Bangladesh, Ahmed (1994) found that on an average the daily maximum temperatures decreased, by 4.5 K when the H/W ratio increased from 0.3 to 2.8. Studies indicate that the street-level thermal comfort depends largely on the aspect ratio. Also the comfort condition outdoors dictates the usage of outdoor spaces in an urban environment (Nikolopoulou et al., 2001). However, urban climate and outdoor thermal comfort are generally given little importance in the planning and design processes. (Evans 1996, Eliasson 2000).

The aim of this paper is to assess the thermal comfort in urban street canyons in a hot humid city of Chennai, India. This is done by comparing urban street canyons in two locations Methanagar (residential) and Pycrofts Junction (commercial) in Chennai, India. The study is based on field measurements of air temperatures, wind speed and relative humidity. Thermal comfort is assessed by calculating the Tmrt (Mean radiant temperature) and Physiological equivalent temperature (PET) using Rayman 1.2 model. (Matzarakis 2002).

2. THE CITY OF CHENNAI AND STUDY AREAS

Chennai-Madras, one of the four metropolitans of India, is the capital of the southeastern state of TamilNadu. It lies between 12.9° and 13.9° N and between 80.9° and 80.19° E. The coastal city of Chennai experiences hot humid climate throughout the year with out extreme seasonal variation. The maximum temperatures in summer is around 40-44 °C and the minimum temperatures in winter is around 19-22 °C. Varying microclimates exists within the city due to changes in built environment. Two sites (Methanagar - residential and Pycrofts Junction - commercial) representing typical street canyons were considered for this study.

3. METHODOLOGY

3.1 Site Selection

A residential area in Methanagar and a commercial area in Pycrofts junction were chosen for the study to assess the impact of canyon geometry and orientations on comfort conditions. The residential area has a dispersed urban form with two to three storey buildings with aspect ratio varying from 0.33 to 1.8. The buildings have setbacks on all sides of the plot. Most of the streets on N-S are shaded by vegetation. The commercial area has a compact urban form with four-storey to five-storey structures with aspect ratio varying from 0.5 to 1.67. Most of the buildings directly abut the street with no setbacks. The geometric characteristics of the measurement locations in the two sites are given in Table 1.

3.2 Field measurements

Air temperatures, relative humidity and wind speed were measured at both residential and commercial sites on 4th April 2007. In the residential area the measurements were taken four times a day and in the commercial area the measurements were taken three times a day.

3.3 Assessment of thermal comfort

The thermal comfort was assessed for varying street canyons in both the sites by calculating PET (Physiological equivalent temperature) and Tmrt (Mean radiant temperature) expressed in °C with the field measurements of air temperatures, relative humidity and wind speed using Rayman 1.2 model. The measurements were taken at a height of 1.2m above ground level. The thermo-physiology of the human body (age, sex, height, weight, clothing insulation, physical activity) has been considered.
Table 1 Geometric characteristics of the measurement locations in the two sites

<table>
<thead>
<tr>
<th>Site</th>
<th>Location</th>
<th>Building height</th>
<th>Street width</th>
<th>H/W ratio</th>
<th>Orientation</th>
</tr>
</thead>
<tbody>
<tr>
<td>MethaNagar</td>
<td>A</td>
<td>6</td>
<td>8</td>
<td>0.75</td>
<td>E-W</td>
</tr>
<tr>
<td></td>
<td>B*</td>
<td>6</td>
<td>9</td>
<td>0.67</td>
<td>E-W</td>
</tr>
<tr>
<td></td>
<td>C</td>
<td>3</td>
<td>9</td>
<td>0.33</td>
<td>E-W</td>
</tr>
<tr>
<td></td>
<td>D</td>
<td>9</td>
<td>12</td>
<td>0.75</td>
<td>E-W</td>
</tr>
<tr>
<td></td>
<td>E*</td>
<td>9</td>
<td>5</td>
<td>1.8</td>
<td>N-S</td>
</tr>
<tr>
<td></td>
<td>F*</td>
<td>6</td>
<td>5</td>
<td>1.2</td>
<td>N-S</td>
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<tr>
<td></td>
<td>G</td>
<td>9</td>
<td>12</td>
<td>0.75</td>
<td>N-S</td>
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<tr>
<td></td>
<td>H*</td>
<td>6</td>
<td>12</td>
<td>0.5</td>
<td>N-S</td>
</tr>
<tr>
<td>Pycrofts Junction</td>
<td>A*</td>
<td>9</td>
<td>15</td>
<td>0.6</td>
<td>E-W</td>
</tr>
<tr>
<td></td>
<td>B</td>
<td>7.5</td>
<td>15</td>
<td>0.5</td>
<td>E-W</td>
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<tr>
<td></td>
<td>C</td>
<td>12</td>
<td>15</td>
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<td>D*</td>
<td>15</td>
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<td>I</td>
<td>12</td>
<td>9</td>
<td>1.33</td>
<td>N-S</td>
</tr>
</tbody>
</table>

* Locations with vegetation

4. RESULTS AND DISCUSSION

4.1 Microclimate at street level

4.1.1 Air Temperature

The measured air temperatures $T_a$ in all urban streets for E-W and N-S orientation in residential area are shown in Fig 1. The E-W oriented streets experienced higher air temperatures than N-S oriented streets. The air temperature of E-W street canyons increased as the day progressed and reduced in the evening. Whereas in N-S street canyons the air temperature reduced from morning till 10.45am and then increased marginally during late afternoon and reduced in the evening. Fig. 2 represents $T_a$ in urban street canyons of commercial area. The air temperatures of both E-W and N-S oriented street canyons increased from morning to afternoon and then reduced in the evening. N-S canyons were slightly warmer than E-W canyons.

4.1.2 Humidity and Wind speed

The relative humidity in E-W and N-S canyons in the residential area and commercial area are shown by Fig 3 and Fig 4 respectively. The RH in the residential area increased gradually in N-S canyons and in E-W canyons the variations were minimal. In the commercial area the RH increased in both N-S and E-W canyons and reached the maximum in the evening. Lesser aspect ratios experienced higher humidity in E-W and N-S canyons at both sites. The wind velocity was higher in E-W canyons than N-S canyons. In deeper canyons the velocity was higher contributing to the tolerable outdoor comfort conditions.

4.1.3 Mean Radiant Temperature and Physiological Equivalent Temperature

The $T_{mrt}$ in the commercial area reduced with increasing aspect ratios. The maximum difference of 4.2°C existed in the morning and it was minimal in the evenings. The impact of orientation on $T_{mrt}$
was negligible. In the residential area E-W orientation experienced higher $T_{mrt}$ when compared to N-S canyons.

Fig: 1 Ta (air temperature) at 1.2m above ground in the middle of residential street canyons on a summer day

Fig: 2 Ta (air temperature) at 1.2m aboveground in the middle of commercial street canyons on a summer day

Fig: 3 RH (Relative Humidity) at 1.2m above ground in the middle of residential street canyons on a summer day

Fig: 4 RH (Relative Humidity) at 1.2m aboveground in the middle of commercial street canyons on a summer day

Fig: 5 PET calculated using Rayman 1.2 Model for a residential area on a summer day

Fig: 6 PET calculated using Rayman 1.2 Model for a commercial area on a summer day

Fig: 7 Residential Location D

Fig: 8 Residential Location E

Fig: 9 Commercial Location A
The PET in all urban streets for E-W and N-S orientation in the two sites is shown in Fig 5 and Fig.6. In the residential area the PET values increased considerably in the E-W canyons during day and in N-S canyons the variation was minimal. The E-W and N-S canyons experienced similar PET’s in the commercial area. The PET reduced with increasing aspect ratios and N-S orientation were better in terms of comfort.

4.2 Impact of Canyon geometry and Thermal Comfort Analysis

Deeper canyons with higher aspect ratio were better when compared to shallow canyons in terms of comfort. However during early mornings deeper canyons act as heat traps due to multiple reflections. The comfort analysis was done based on the PET values. The thermal sensation in tropical climate and the grade of physiological stress was arrived using PET values (Hoppe, 1999) using Rayman 1.2 model (Matzarakis 2002).

4.2.1 East-West oriented Streets

In the residential area, the E-W streets experienced strong heat stress in the afternoons with PET values higher than 30°C. In the mornings and evenings moderate heat stress were experienced with PET values between 26°C to 30°C. All locations experienced similar physiological stress irrespective of the street geometry through out the day. The thermal sensation was better with higher aspect ratio. In the commercial area during morning (10.30am) the thermal sensation was better in locations D(0.8) and E(1). At 2.30pm and 5.30pm the thermal sensation at all locations remained same irrespective of aspect ratios. The physiological stresses at all locations were uniform during each measurement period. Strong heat stress was experienced during 10.30am and 2.30pm and moderate heat stress experienced at 5.30pm.

4.2.2 North-south oriented Streets

The N-S streets of residential area experienced better thermal sensations with increased aspect ratios. At 7.30am location E experienced very hot thermal sensation while other locations were hot. But during 10.45am, 4.00pm and 6.15pm location E experienced slightly warm and warm thermal sensation and other locations experienced hot thermal sensation. Through out the day strong heat stress was experienced in all locations. In the commercial area all locations experienced very hot thermal sensation with PET exceeding 40°C except at 5.30pm, where it was slightly warm with PET ranging from 28°C to 32°C. Strong heat stress was experienced all through the day but in the evening moderate heat stress was experienced.

5. RECOMMENDATIONS

Thermal comfort is very difficult to achieve in hot humid climates but considerable amount of improvement is possible with better street geometry and orientation. Based on the findings of the study, it is clear that N-S orientations are better than E-W orientation. Deeper canyons provide better outdoor thermal comfort than shallow canyons. Presence of vegetation in street geometry increases the comfort conditions and enhances the usage of outdoor spaces considerably.

6. CONCLUSIONS

The study indicates the dependence of thermal comfort on canyon geometry. Both aspect ratio and orientation were found to have a considerable influence on the street thermal environment and the thermal sensation of people. Further study on diurnal and nocturnal situations in street geometry and thermal storage of materials can lead to better street designs and improved urban environment.
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