Urban Built Form Geometry manipulation and its importance in Outdoor Thermal Comfort analysis

Dr. Debashish Das

Assistant Professor
Department of Architecture,
Jadavpur University, Kolkata,India

***Abstract*—Climate change concerns are the most important areas of research for the twenty-first century and though it is very difficult, rather impossible to culminate all these ideas into one direction, it is clear that small contributions from various fields of study can be of utmost importance for mitigation of urban heat island in cities..This understanding needs scientific approach towards its mitigation and in this regard various research works have been put forward by various researchers and scientists in different fields.When we talk of quality of life of people we generally focus on living conditions inside the buildings but we tend to forget that we also spend much of our time outside- between the buildings. It is in these open spaces like streets, parks, etc. much social interaction takes place like pedestrian movement, outdoor shopping, siting on park seats,etc.These spaces are also the hub for any kind of social, cultural and economic activities. The impact of urban built form geometry on outdoor thermal comfort was researched for mitigating the heat island effects in urban areas. In this study the built form geometry manipulation of various urban canyons were analysed for achieving desired comfort level for pedestrian movement, outdoor activities, social gatherings, playing etc.**

***Key Words*—Built Form Geometry, Urban Microclimate, Outdoor Thermal Comfort**

I. Introduction

The influence of urban geometry in processes such as the trapping of both incoming solar radiation and outgoing long-wave radiation, generation of anthropogenic heat,etc. are common factors [1]**.** So the study of urban built form plays an important role on the variation of air and street surface temperatures in the canopy layers in urban areas.The variation in the urban built form types also reduces the openness of the sky also known as *sky view factor*, changing the conditions of penetration, absorption and reflection of the solar radiation at urban canopy layer [2].

So the changes in the urban structure is one of the main reasons of urban heat islands and characterizing the sky view factor and urban density is a way to parameterize its intensity [3][4].The microclimatic aspects which are affected by urbanization are temperature, humidity, precipitation, wind speed, solar radiationsetc.In the case of temperature, there can be rise in the minimum daily temperature or the maximum temperature can also change. The wind speed can reduce up to 20% and there can be increase in number of calm periods. The solar radiation gets trapped in the dense urban forms and the rise in temperatures or urban heat island can be observed [5] [6]. Some studies in tropical areas suggests that microclimatic changes due to urbanization are substantial and the anatomy of tropical heat islands bears a close resemblance to that of temperate climates [7].

II. Objectives of the study

- To study the aspects of urban built form geometry which modifies the microclimate of urban street canyons
- To analyse the aspects of urban microclimate which impacts the outdoor thermal comfort.
- To suggest modifications in the urban street canyon geometry for achieving the desired level of outdoor thermal comfort in warm humid climates

III. Aspects of UrbanBuilt Form Canyon Geometry

Urban form refers to the physical form of urban areas in three dimensions at a variety of scales.Built form typically implies urban form in three dimensions, at the scale of individual buildings. Urban built formin this study typically implies the built form of individual building or group of buildings in an urban area in three dimensions.

i. Urban Street Canyon (Height/Width Ratio)

The urban canyon, which is a simplified rectangular vertical profile of infinite length, has been widely adopted in urban climatology as the basic structural unit for describing a typical urban open space, i.e. filtered from irrelevant nonclimatic aspects. From these studies, basic knowledge on street microclimate was gathered[8][9][10].Basically, the height-to-width ratio (H/W) and street orientation were found to be the most decisive features affecting the microclimate of the urban street canyon. This includes the energy balance of the urban canyon,the potential of irradiation of canyon facets (i.e. floor and walls),the surface temperature,the amount of energy transported into the urban canopy layer by the sensible heat flux, which increases for sunlit surfaces and leads to a higher air temperature close to them,the potential of wind flow at street level, which sharply decreases in the urban street canyon.Thepotential of solar access inside the buildings and, by implication, the sitelayout and urban density are also directly related to the vertical street profile and orientation of the urban street canyons.

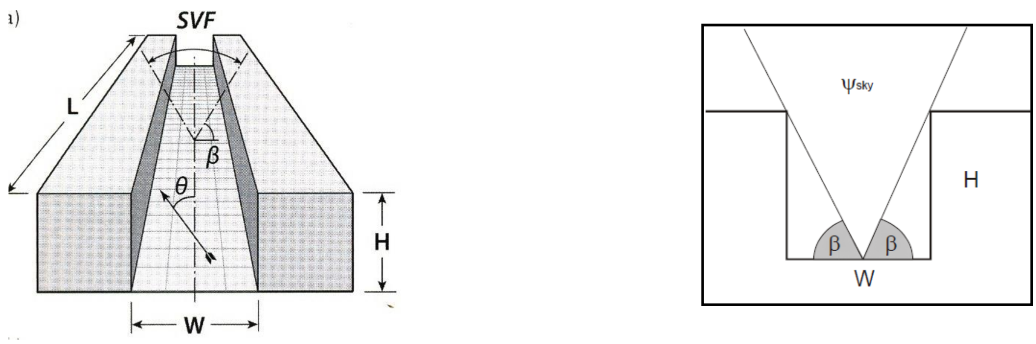

Fig.1: Urban Canyon (H/W Ratio) &Sky View Factor (ψsky) =Cos β
Source: Based on Oke (1987)&Erell, E. et al,2011

ii. Sky View Factor of Urban Street Canyons

The sky view factor (SVF) (ψs) is a geometrical concept that describes the fraction of the overlying hemisphere occupied by the sky [2]. The sky view factor (SVF) is often used to describe urban geometry [11][12].Energetically, SVF is the ratio of the radiation received (or emitted)by a planar surface to the radiation emitted (or received) by the entire hemispheric environment [13]. It is a dimensionless measure between zero and one, representing totally obstructed and free spaces, respectively [2].The urban geometry variations can change the sky view factor and its different impacts can be analysed [14].

iii. Orientation of Urban Street Canyons

Indoor solar gain is a challenging issue in urban context, where the main difficulty is thereduction of the potential of solar irradiation due to the effects of sun obstruction from thesurroundings. The concept of *solar envelope* initiated by [15][16] was a firstattempt to resolve this problem and shows how the urban forms are shaped according toarchitectural purposes.Basically, the solar envelope can be defined as the largest volume on a plot, which allowssolar access to all adjacent parcels to useful sunshine times.

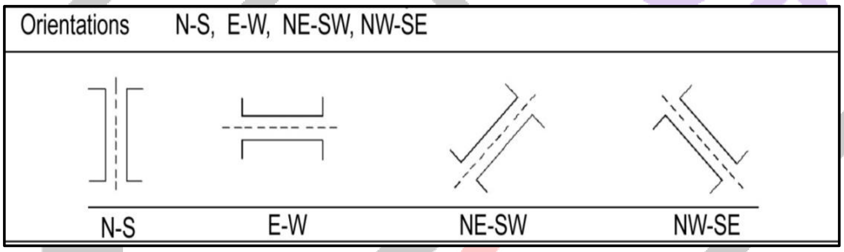

Fig2. :Different orientations considered for the study

Source: Author

iv.Urban Canyon Wind Flow

As with heat, studies of wind in urban canyons include both modeling and observation. Wind in urban street canyons is important for dispersing heat and pollutants.Understanding wind in these canyons relies on basic principles of fluid dynamics.

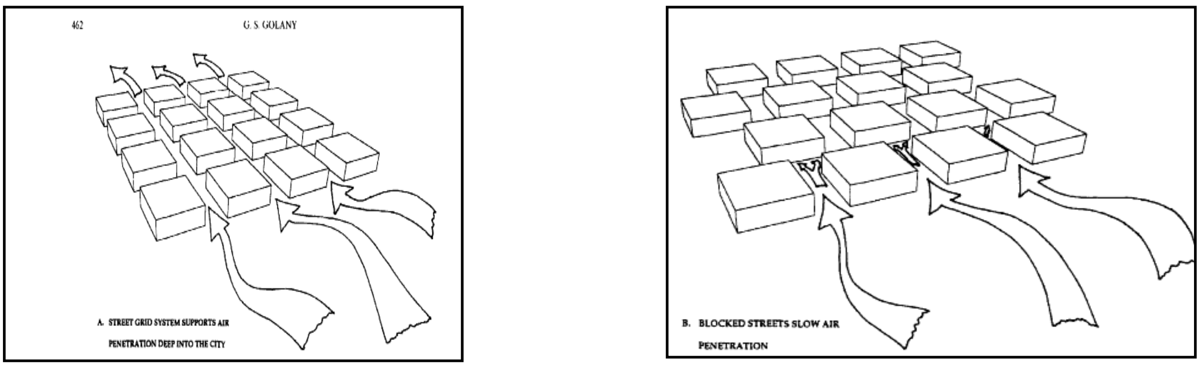

Fig 3. : Street Design and orientation influence the design of wind penetration into the city especially at its peripheral zone
Source: G.S Golany, 1996 [17]

v. Urban Canyon Geometry Types

The generic built forms were formed based on the building bye laws of Kolkata Municipal Corporation.The width of the street was taken as 3m wide and the front set back as 1.2m

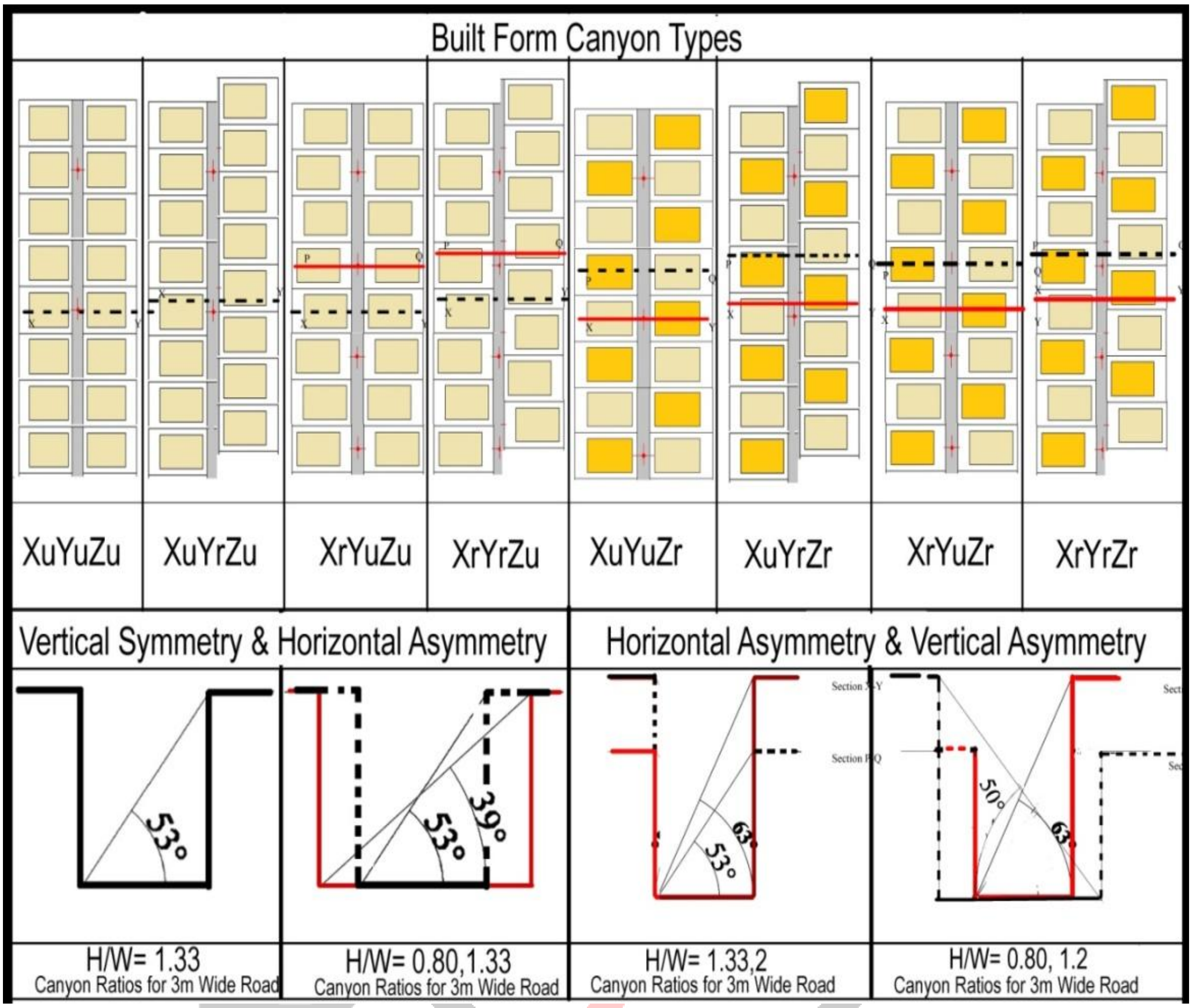

Fig4.: Generic Built Form Types for 3m Wide Road

Source: Author

IV. Urban Microclimatic Aspects for Outdoor Thermal Comfort

The thermal comfort inside the blocks has been well studied and explained in various literature but studies on outdoor thermal comfort in humid climate of tropical areas are few. The study focussing on the dependence of outdoor thermal comfort on building geometry can be of importance because in tropical areas people spend enough time outside for various activities.

i. The Mean Radiant Temperature

Tmrt or mean radiant temperature is defined asthe uniform temperature of a surrounding surface giving of black body radiation (emission coefficient= 1) which results in the same radiation energy gain of a human body as the prevailing radiation fluxes which are usually very varied under open space conditions". Tmrt can be either obtained by direct measurement of all relevant radiation fluxes or by calculations of the short-wave and long-wave radiation fluxes. The *T*mrt is defined as the 'uniform temperature of an imaginary enclosure in which the radiant heat transfer from the human body equals the radiant heat transfer in the actual non-uniform enclosure[18]

ii. Predicted Mean Vote

While comfort sensation indoors is well documented [18] [19] , assessing comfort outdoors is by far less well understood. Basically, comfort assessment methods applied outdoors have been adjusted from those originally conceived for indoors.The PMV (predicted mean vote) model is probably the best know biomet model. Based on Fangers [19] model, it relates the energy balance of the human body to the personal comfort feeling of persons exposed to the corresponding climates

IV. Case Studies- Core City Area -Kolkata

The generic built forms were formed based on the building bye laws of Kolkata Municipal Corporation.The width of the street was taken as 3m wide and the front set back as 1.2m. The points at which the measurements were carried was selected on the basis of its orientation (in this case North-South and NESW) , road width varying from 1.3m to 5m, built form types with horizontal and vertical uniformness and randomness. In the college street the street canyon in mainly continuous type with no side setbacks. The whirling psychrometer was used to measure the dry bulb temperature (DBT) and the wet bulb temperature (WBT). The relative humidity was calculated using the conversion chart from the DBT and WBT data. The wind speed was measured at the centre of the street canyon using the thermo anemometer.The thermal comfort analysis for the street canyon was done by using Raymansoftware to calculate the mean radiant temperature and PMV (predicted mean vote) . The weather data file for kolkata was inbuilt in the software.The measurements for the points P1 to P9 were done at the centre of the street at a height of 1.2 m from the ground

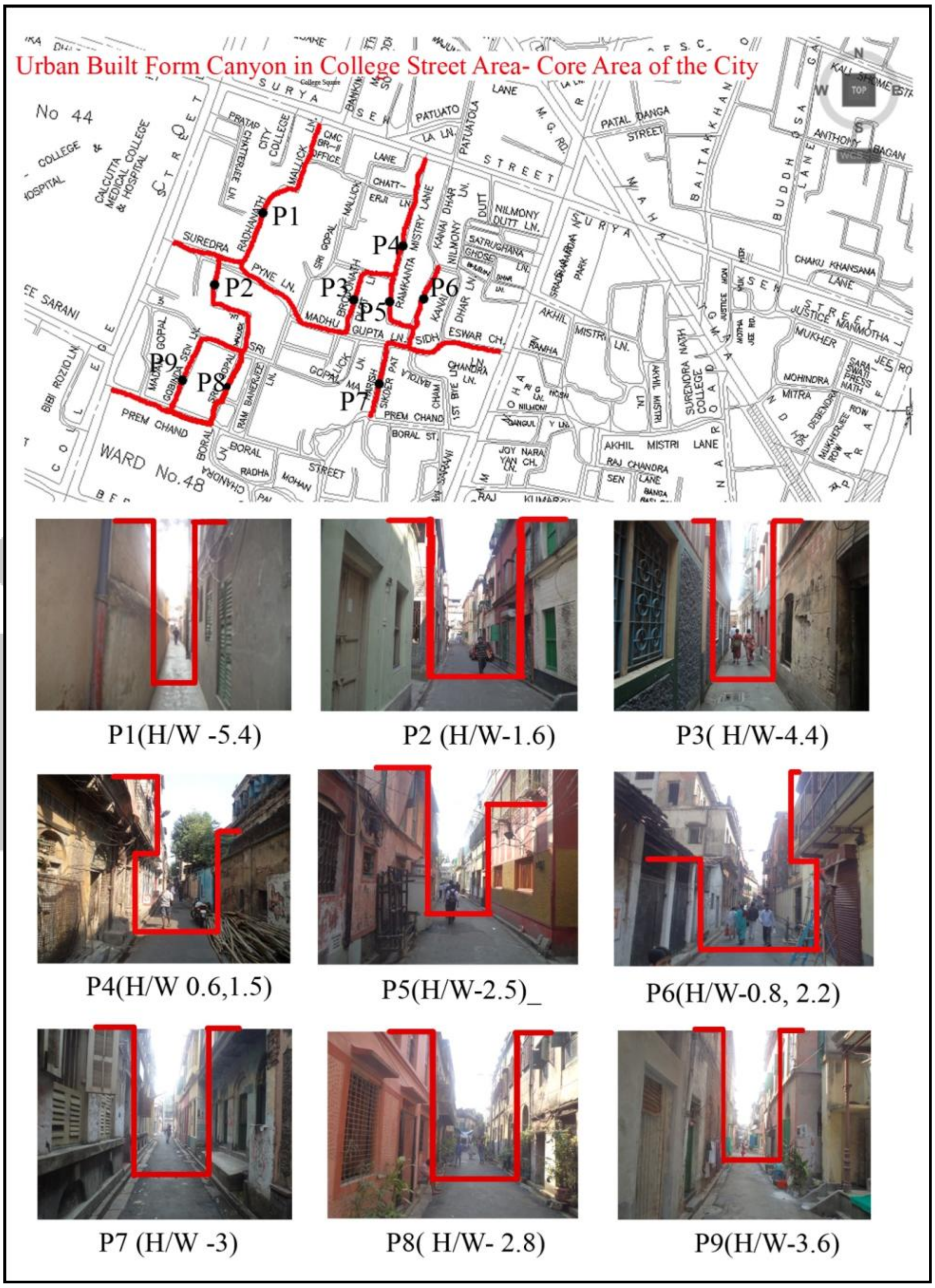

Fig.5 :Urban Built Form Canyon Geometry aspects f or case study area

Source: Computed by Author

Table 1: DBT, WBT and Wind Speed measured at the centre of the street canyon for the case study area

Site/ Point	Street width	Aspect Ratio (H/W)	Built Form Type	Orie-ntation	Wind Speed (m/s)	DBT (in° C)	WBT (in° C)	RH %age) (Calcu-lated)	MRT (in° C)	PMV (Value range
P1.	1.3	5.4	XuYuZu	NE-SW	1.6	34	29.5	71	46.3	+3.6
P2.	4.3	1.6	XuYuZu	N-S	0.8	35	29	68	48.2	+4
P3.	1.8	4.4	XuYuZu	NE-SW	1.4	34.5	29.5	68	46.9	+3.7
P4.	4.8	0.6,1.5	XrYuZr	NE-SW	0.9	33	29	73	46.4	+3.5
P5.	4.4	2.5	XuYuZu	N-S	1.3	35	29	63	47.4	+3.8
P6.	5	0.8, 2.2	XrYuZr	NE-SW	1.4	32	28.5	76	44.9	+3.2
P7.	3.5	3	XrYuZu	N-S	1.1	35	29.5	65	47.7	+3.9
P8.	4	2.8	XuYuZrv	NE-SW	1.4	33.5	29	70	46.1	+3.5
P9.	2.5	3.6	XuYuZu	NE-SW	1.5	34	29.5	71	46.4	+3.6

Source: Collected &Computed by Author

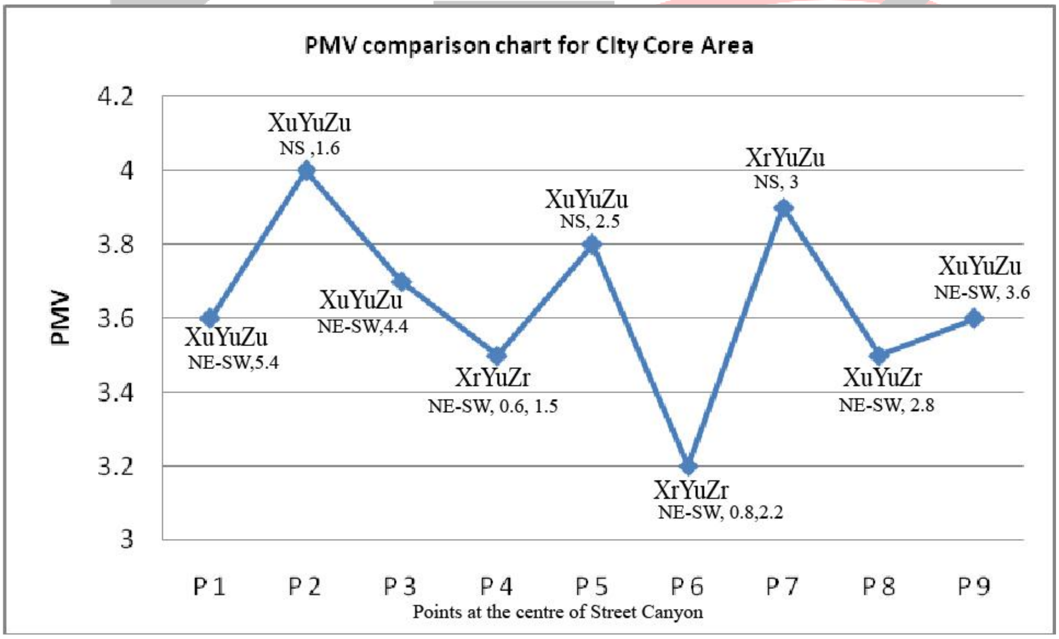

Fig.6 : Comparison of PMV values for City Core Area at 11a.m. for different built form types

Source: Computed by Author

V. Observations and Recommendations

1. The above graph shows that NE-SW orientation is more preferable as compared to other orientations.
2. The XrYuZr built form type, i.e randomness is X axis and in Z axis is more preferable. The randomness in X axis can be achieved by alternating the setbacks and randomness in Z axis can be achieved by alternating the FAR.
3. The point 2 which is built form type XuYuZu , shows that uniformness in street canyon is less preferable as it has higher PMV value or more thermal stress outdoor.
4. So for achieving desirable thermal comfort level outdoor for continuous type of street canyon, NE-SW is the best orientation and uniformness in building geometry should be avoided and more randomness in built form geometry is preferable.

References

[1] Emmanuel, R. (2005) 'An Urban Approach to Climate-Sensitive Design- Strategies for the Tropics'.

[2] Oke, T.R. (1981): 'Canyon geometry and the nocturnal urban heat island: Comparison of scale model and field observations'. Int. Journal of Climatology 1, 237-254.

[3] Oke, T.R. (1987) 'Boundary Layer Climates' 2nd editionRoutledge.

[4] Sakakibara, Y., (1996), 'A numerical study of the effect of urban geometry upon the surface energy budget', Atmospheric Environment, Vol. 30, 3, 487-496.

[5] Chandler, T.J. (1976). 'Urban Climatology and its relevance to Urban Design',WMO Technical Note No. 149, Geneva: World Meteorological Organization.

[6] Ali-Toudert, F., Mayer, H. (2006) 'Numerical study on the effects of aspect ratio and solar orientation on outdoor thermal comfort in hot and dry climate', Building and Environment 41: 94-108.

[7] Nunez, M. – Oke, T. R. (1977)'The energy balance of an urban canyon'. J. Appl. Meteorol. 16. pp. 11-19.

[8] Todhunter, P. E.(1990)'Microclimatic Variations Attributable to Urban Canyon Asymmetry and Orientation', Physical Geography 11. pp. 131-141.

[9] Santamoouris, M. (ed.) (2002) 'Energy and Climate in the Urban Built Environment'. London: James and James Science Publishers.

[10] Ali-Toudert, F., Mayer, H. (2005) 'Thermal comfort in urban streets with trees under hot summer conditions', Proc. 22th Conference on Passive and Low Energy Architecture (PLEA), Beirut, Lebanon. 13-16 Nov. 2005, Vol. 2. pp. 699-704.

[11] Svensson, M.K., (2004), 'Sky View Factor analysis- implications for urban air temperature differences'. Meteorological Applications, 11(3): 201-211.

[12] Upmanis, H., (1999): 'The influence of sky view factor and land use on city temperatures' In Upmanis, H.: Influence of Parks on Local Climate. Earth Sciences Centre, Göteborg University A 43, paper 3

[13] Watson, I.D. and G.T. Johnson (1987). 'Graphical estimation of sky view factors in urban environments', Journal of Climatology, 7:193-197

[14] Bradley, A. V., Thornes, J. E. & Chapman, L. (2001), 'A method to assess the variation of urban canyon geometry from sky view factor transects',Atmospheric Science Letters, 2(1-4), 155-165

[15] Knowles, R.L. (1981). Sun Rhythm Form, Cambridge, MA: MIT Press.

[16] Knowles R.L. (2003): 'The solar envelope: it's meaning for energy and buildings', Energyand Buildings 35: 15-25.

[17] Golany, *G.* (ed.) (1982). Design for arid regions. Van Nostrand Reinhold, New York.

[18] ASHRAE (2001b): Chapter 13 – Measurements and instruments. In: Handbook of Fundamentals. American Society for heating Refrigerating and Air Conditioning, Atlanta:13.26 –13.27.

[19] Fanger, P. O.1970. Thermal comfort. Danish Technical Press, Copenhagen.

[20] Höppe, P. (1999): 'The physiological equivalent temperature - a universal index for theBio-meteorological assessment of the thermal environment', Int. J. Biometeorol. 43:71-75.