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INFLUENCE OF BANGALORE'S CANYON GEOMETRY ON THE INTRA-URBAN AMBIENT AIR TEMPERATURE

Statement of the problem. The present study attempts to unravel the impact of urban canyon geometry on ambient air temperature. Twelve stations based on pre-defined land-cover features were selected for the study.
Results and conclusions. The percentage distribution of these land-cover features across each observatory was determined for a 'Radius of Influence' of 250m. This was achieved with the analysis of Satellite Images, using Google Pro software's inbuilt 'polygon' tool. Also at these locations, ambient air temperature was continuously monitored using sensors equipped with automated data-loggers, between January–April 2013. It was found that the highly urbanised and industrialised stations always showed an increasing trend for the maximum, minimum and mean air temperatures, while the rural stations, and those within city but with a distinct green patch depicted a reverse trend. At these stations, Theodolite surveying was then carried out to determine the 'Sky View Factor' and 'Aspect Ratio'. Eventually, the results were assessed for statistical relationships between urban geometry and air temperature, with the application of Correlation. Upon analysis, briefly it was found that higher the sky obstructions, greater were the air temperatures, and generally it could be concluded that 'Sky View Factor' and 'Aspect Ratio' shared a negative relationship with the ambient air temperature. These statistical inferences drawn would play a vital role in developing guidelines for city planners.
Keywords: heat, urban, urbanization, aspect ratio, sky view factor.

INTRODUCTION

A typical urban canyon is a basic urban surface unit comprised of the walls of adjacent buildings, the ground (street) between, and the air volume enclosed within. It can be visualised as a relatively narrow street with buildings lined up continuously along both sides [1]. Commonly used indicators to describe this typical urban geometry are, the 'Sky View Factor' and 'Aspect Ratio'. 'Sky View Factor' indicates the ratio of the radiation received (or emitted) by a planar surface from the sky to the radiation emitted (or received) from the entire hemispheric radiating environment [2]. Regardless of the technique employed, the output is basically a value between 0-1 [3]. 'Aspect Ratio' is also regarded yet another most important factor governing intra-urban air temperature differences. It can be defined as the ratio of the height of the canyon to its width. The H:W ratio describes how tightly or loosely spaced buildings are with respect to their heights.

Urbanization marked by 'Urban Canyons', leads to unavoidable changes in land-use patterns and inadvertent environmental consequences [4]. Several researchers have tried to establish relationships between canyon geometry and the climate of cities. S.V.F. as one of the most important parameters in urban climatology has been established to have a strong correlation of the S.V.F. with net long-wave radiation [5]. S.V.F. taken from the ground has been shown to give slightly better correlation with air temperature than those taken at sensor level [6]. Compared to studies linking air temperature with S.V.F., relatively only a few approaches has been found in literature survey with respect to Aspect Ratio. However, there have been no conclusive findings that highlight the true nature of correlation for canyon geometry with ambient air temperature. While some have shown good relationship, other studies showed the opposite.

OBJECTIVES

The scope of the present study envisages recording and comparing the temperature patterns in the 12 urban stations of differing land-use characteristics for the period of study. It also includes measurement of 'Sky View Factor' and 'Aspect Ratio' for 12 different urban canyons within a 'Radius of Influence' (R.O.I.) of 250m for Bangalore city, and eventual measurement of the results. Finally the study attempts to establish statistical relationships between 'Sky View Factor' and 'Aspect Ratio', with the air temperature values recorded from the 12 stations.

EXPERIMENTAL METHODOLOGY

While researching for literature review, it was found that most of the studies were carried out in a single urban canyon. By doing so, comparisons for the thermal conditions in urban canyons with different geometrical characteristics are not feasible. The present study works to overcome these limitations with an intensive statistical investigation by increasing the number of variables within the framework of research. The same was achieved by carrying out the study in different stages, beginning with identification of potential stations within the study area. This was followed by land-cover mapping using Google pro software.

Further the sensors and radiation shields were commissioned at stations, and the climatic data was collected on-site. Simultaneously theodolite surveying was carried out to estimate S.V.F. and H:W determination.

Correlation analysis concluded the statistical analysis. Table 1 displays the characteristics of stations.

Table I

Name of the Station	Location in the City	Classification	Category
Vaderahalli Village	North [Outskirts]	Agricultural	Rural
Bhuvaneswari Nagar	North-East	Residential	Sub-Urban
Vijay Nagar	West	Residential	Urban
Chamarajpet	Central	Commercial	Urban
Bommasandra Industrial Area	South-East [Outskirts]	Industrial - Transportation	Semi-Rural
Peenya Industrial Area	West	Industrial	Urban
B.T.M. Layout	South	Residential	Urban
Frazer Town	Central	Residential	Urban
R.T. Nagar	Central	Residential	Urban
Devasandra	East [Outskirts]	Residential	Semi-Urban
Nimhans	South	Commercial	Urban
B.E.M.L.	East	Industrial	Urban

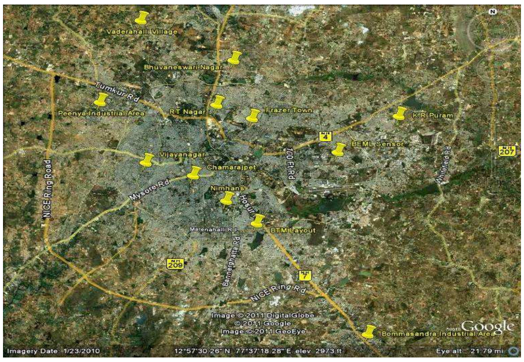

Fig. 1. Geographical location of each station

Fig. 2. Google Image of Peenya Industrial area

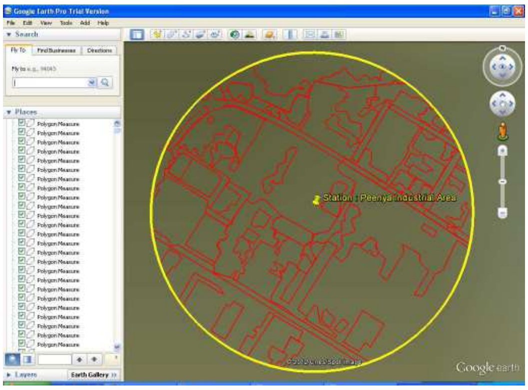

Fig. 3. Outline Demarcation screenshots

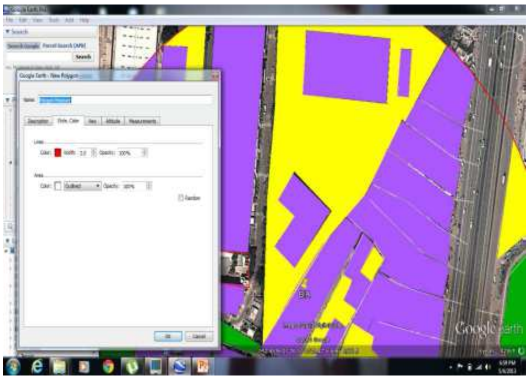

Fig. 4. Land-use % analysis screenshot

All the stations were located about the same elevation and latitude. The observational points were so chosen, so as to ensure adequate representation of the station. While Figure 1 showcases their physical location, Figure 2 to 5, depicts via screenshots the process involved in Google Pro software for analysing % of each land-use pattern. Figure 6, eventually shows the pie chart for the result. The previous images have showcased only Peenya Industrial area, as a random pick, among the 12 station, for the present paper. As can be observed from the Figure 7, for each station was theodolite surveying was undertaken for measurement as depicted in Figure 8. The Sky View Factor and Aspect Ratio values for the present study were obtained from the analytical method of Oke (1988) [3].

This was however subjected to a slight author desired modification. In the actual method suggested by Oke (1988), only 2 elevation angles (Equations 1, 2, 6 and 7) to the top of buildings were measured normal to the axis of streets in both directions, using a 1.5m high theodolite. These were modified to consider parallel elevation angles (Equations 1, 2, 6 and 7), to finally develop an empirical model for S.V.F. (Equation 5) and H:W (Equation 10) respectively.

$$X_1 = (1 - \cos \alpha_1)/2 \qquad \text{Eqn. 1.}$$

$$X_2 = (1 - \cos \alpha_2)/2 \qquad \text{Eqn. 2.}$$

$$X_3 = (1 - \cos \alpha_3)/2 \qquad \text{Eqn. 3.}$$

$$X_4 = (1 - \cos \alpha_4)/2 \qquad \text{Eqn. 4.}$$

$$S.V.F. = [(1 - (X_1 + X_2)) + (1 - (X_3 + X_4))]/2 \qquad \text{Eqn. 5.}$$

$$H_1 = (\tan \alpha 1 \times W_1) + 1.5 \qquad \text{Eqn. 6.}$$

$$H_2 = (\tan \alpha 2 \times W_2) + 1.5 \qquad \text{Eqn. 7.}$$

$$H_3 = (\tan \alpha 3 \times W_3) + 1.5 \qquad \text{Eqn. 8.}$$

$$H_4 = (\tan \alpha 4 \times W_4) + 1.5 \qquad \text{Eqn. 9.}$$

$$H = (H_1 + H_2 + H_3 + H_4)/4 \qquad \text{Eqn. 10.}$$

Fig. 5. Final view after land-use mapping

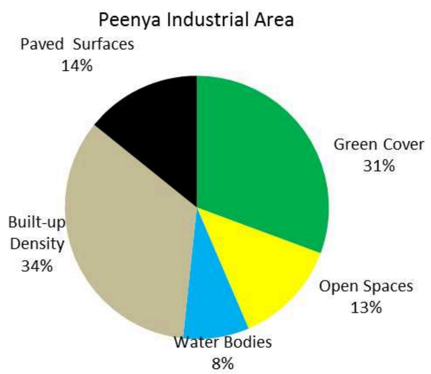

Fig. 6. Resultant existing Land-use classification

Fig. 7. Theodolite Surveying

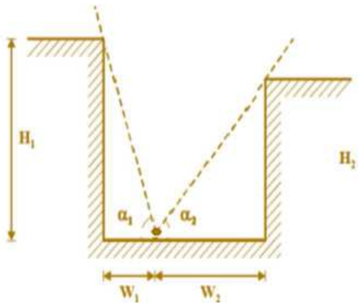

Fig. 8. Angle Measurement from Theodolite Surveying

Results and Discussion

There was a distinct daily and monthly variation in ambient air temperature from one station to another, w.r.t. both maximum and minimum values. While at the urban stations there was peaking of rise and falls; the rural stations and others did not exhibit any sharp turns. The same can be confirmed from Figure 9.

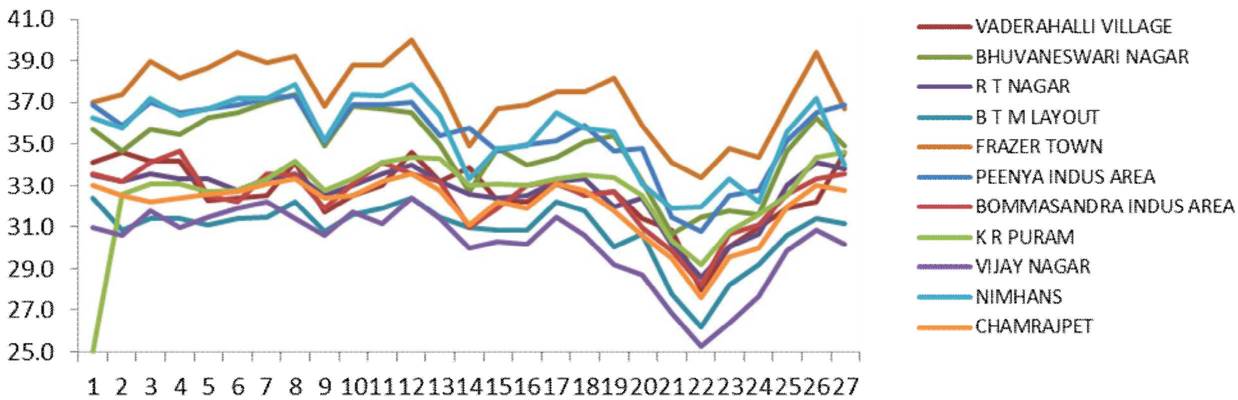

Fig. 9. Day-wise variation of Maximum Air temperature across all the stations during April 2013. (Sample set)

When compared to all stations, the plot reveals that the maximum and the minimum temperatures have increased at a greater rate in the congested urban centres (e.g. Frazer Town, R. T. Nagar, etc.) than the rural stations (Vaderahalli Village) having more natural features. From the climatic data collected, it was evident that the urban centres got heated up faster on average in the morning than the rural environs. They also stayed warmer throughout the evening due to the additional heat they had stored during the day. Hence it may be confirmed that the urban centres continued to show warming signs and this may be attributed to the continuous heat contamination, as derived from human activities such as central heating systems.

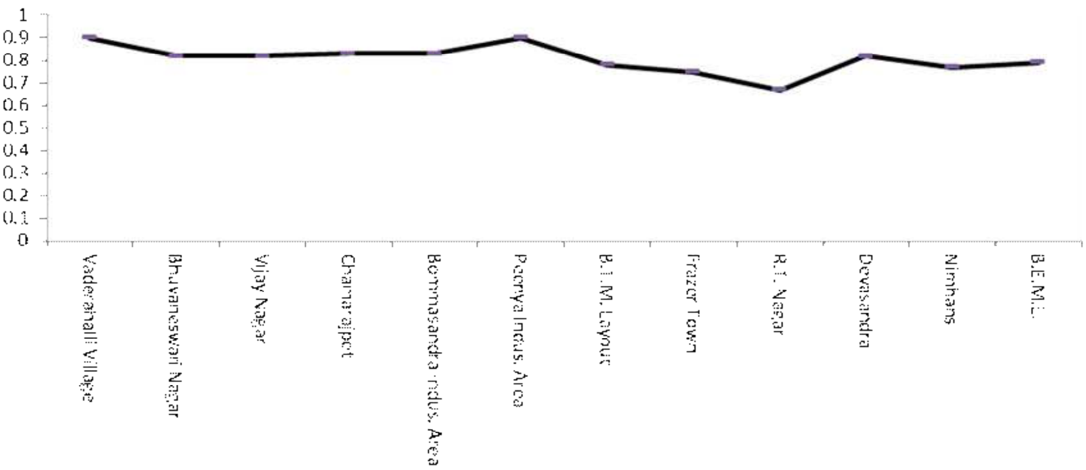

Fig. 10. S.V.F. variation across all the stations

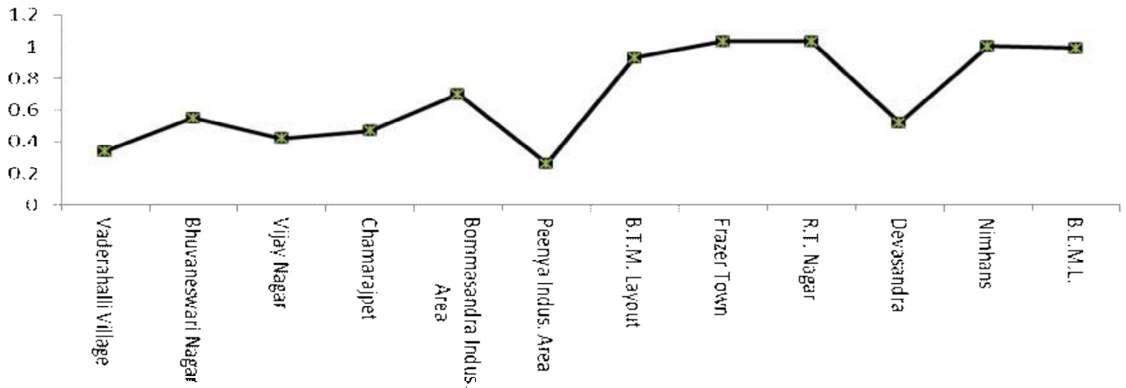

Fig. 11. H:W variation across all the stations

Upon considering all the contributing cells, when the representative S.V.F. was extracted for an entire station from the net sum S.V.F., it was found that it was highest in Vaderahalli Village with a value of 0.8. This can be credited to the vast open spaces which were more in % distribution than the built-up spaces. Most of the stations barring Chamarajpet, B.T.M. Layout, Frazer Town and Vijay Nagar, had a moderate S.V.F. close in the range of 0.5-0.6. Taking the case of Frazer Town as an example, the reason why it had a low 'Sky View Factor' was due to its rampant unplanned development evident from its narrow street canyons.

On the other hand, other stations that projected a moderate S.V.F. was that despite the heavy built-up density, their width of road was sufficiently higher. This can be verified from Figure 10. When 'Aspect Ratio' is considered, the study found lowest H:W values for rural and sub-urban stations such as Vaderahalli Village, Bommasandra Industrial Area, Peenya Industrial Area and Bhuvaneswari Nagar respectively.

The reasons supporting this claim may be credited to the less number of multiple residential units, or a single stretch of a building unit largely reduced when averaged by the net count. Few stations such as Chamarajpet, B.T.M. Layout, R.T. Nagar and Nimhans depict higher values owing to their high density building spaces, while B.E.M.L. has a moderate value compared to all. This was due to its distinct open-spaces cover which is about 1/4th of the net R.O.I. This can be also observed from Figure 11.

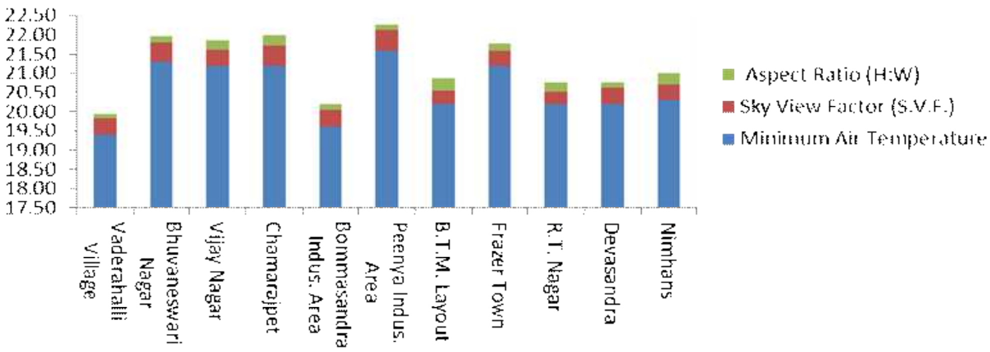

Fig. 12. Comparison of variation in 'minimum' air temperature across all the stations w.r.t. their canyon geometry

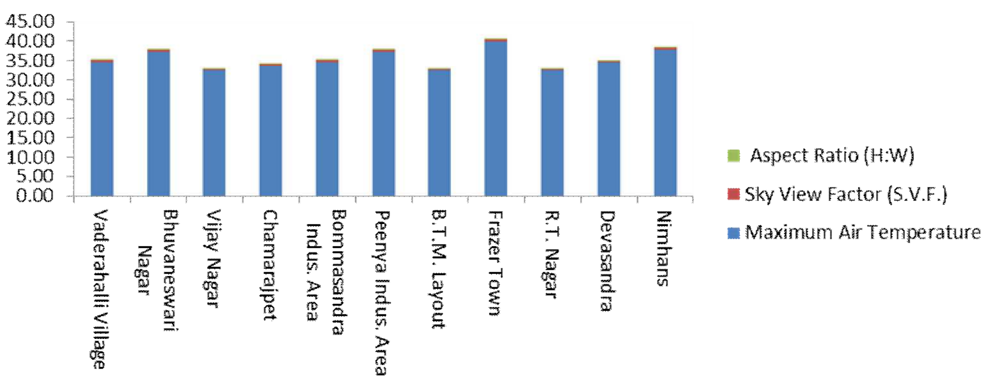

Fig. 13. Comparison of variation in 'maximum' air temperature across all the stations w.r.t. their canyon geometry

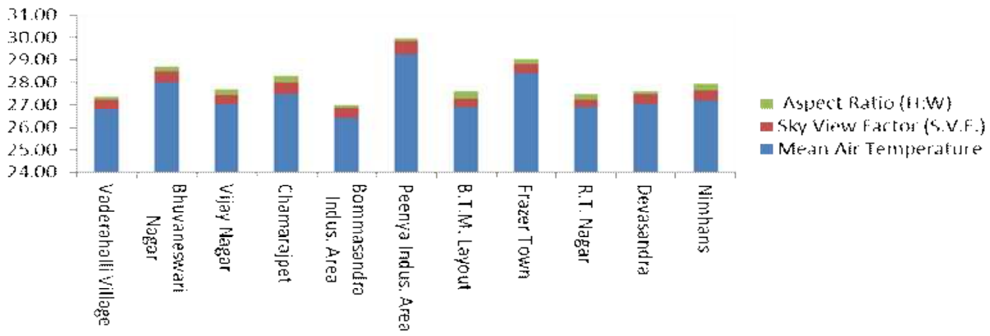

Fig. 14. Comparison of variation in 'mean' air temperature across all the stations w.r.t. their canyon geometry

To statistically highlight the results of Correlation analysis carried out on 'maximum', 'minimum' and 'mean' of ambient air Temperature (extracted from data collected over the study period at each station) along with the respective S.V.F. and H:W., it may be realised that for correlation with 'maximum air temperature', a moderate positive relationship was obtained with the Pearson's Correlation Coefficient (r) as 0.38. Further the coefficient was obtained as +0.51, when the correlation analysis was carried out for 'minimum air temperature'. These findings have been highlighted in figure 12 to 14. To support the charts, it may be re-understood that for instance, Vaderahalli Village which had the largest 'average open surface' exposed to the sunrays during the daytime shall absorb more sunrays than those stations with limited S.V.F like Frazer Town. In return, during the night time, there are more chances for the heat trapped during daytime to be dissipated more effectively in the case of Vaderahalli Village; and not Frazer Town which has a high H:W ratio, as a result of which it becomes increasingly isolated in terms of heat exchange with the atmosphere above. In other words, 'Aspect Ratio' plays an important role in reheating urban streets after sunset. This ratio invariably may also influence the wind fluid which might blow away the heat from streets, since deeper the canyon, the lesser will be the radiative losses.

To conclude, though the statistical analysis confirms that the urban canyon geometry alone may be inadequate to represent the complex thermal phenomena, and yet it may added that, irrespective of the strength of the relationship, the moderate value of coefficient clearly demarcates that the geometrical properties of buildings are perhaps the most obvious distinctions between urban and rural landscapes, and this has been showcased very distinctly in the previous 3 charts. Hence, to conclude there is a possible and probable relationship that exists between the urban canyon geometry and air temperature which needs further in-depth probing. The cause of moderate and weak relationships might be due to the fact that, the external parameters which have not been included in the study such as wind speed, wind direction (or any other parameter) might have influenced the climatic parameters with more intensity than the 'canyon geometry' or also probably in synergy with them. Both of these cases were beyond the scope of present study. Yet another reason for a weak and contradictory result may be because the present study considered the daily temperature dataset as a single population. However, this result now propels the need to consider latter researches to engage temperature dataset to be divided into day-time and night-time temperatures.

LIMITATIONS AND SCOPE OF FUTURE STUDY

The present study was conducted for only a brief period of 4 months; hence the result is susceptible to seasonal influences. Also the practical estimation of canyon geometry for an entire urban environment using a theodolite is never an easy task, and is subjective to uncontrollable factors limiting the data collection process. The studies that are planned as a continuation to the present study may include more parameters such as wind speed, orientation, albedo etc. The study should also consider more air temperature values to strengthen the statistical claims. Research must be conceptualised to correct the canyon geometry assessing method when vegetation data is present.

CONCLUSIONS

Urban and rural areas differ significantly in their microclimate, duly linked to building geometry, and surface material properties. The present study provided a review of the intra-urban 'air temperature-canyon geometry' relationship. The highly urbanised and industrialised stations indicated an increasing trend for the minimum, maximum and mean air temperatures. The rural stations and those within city spaces having more natural landscapes generally had a lower ambient air temperature. A logically modified approach in terms of practical and analytical measurement was presented in determination and representation of S.V.F. and H:W for the present urban scenario. The stations with higher canyon geometry features had a cooler environment than those with lower values, and hence they exhibited a negative relationship with the ambient air temperature. The results obtained by correlation analysis indicated a fairly moderate relationship between canyon geometry and air temperature, and hence may be claimed as a useful and effective tool in urban planning.

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