ONLINE CALCULATOR FOR EVALUATING SITE PLANNING IMPACTS – EXPERIENCE OF DEVELOPING HEAT ISLAND TOOL FOR GRIHA LD

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ABSTRACT

Urban Heat Island (UHI) has been an alarming issue in the context of sustainable urban development. About 0.8 to 2 K higher mean air temperature was observed during the field studies conducted by the authors. With this experience, authors of this paper have developed an empirical formula based 192 parametric simulations using ENVImet tool to estimate the change in microclimate air temperature due to site level development. The paper presents the sensitivity analysis of the empirical formula generated out of parametric simulations; and discusses its applicability and incorporation with Green Rating for Integrated Habitat Assessment for Large Developments (GRIHA-LD)'s online calculator for estimating site-planning impacts on the local air temperature. The sensitivity of the model based on parametric simulation was found to be low as the decrease in mean temperature was only upto 1K. Further, the paper also presents the validation of online calculator customized using already existing STEVE's model for GRIHA-LD in India.

INTRODUCTION

The heat island effect is studied at the site level to observe the effects of hard paved surfaces, roofs and urban vegetative cover. It is well documented that low reflectance of building materials and urban geometry are two major sources as far as building contribution is considered to the heat islands (R Giridharan et al, 2007; Maria Kolokotroni & Renganathan Giridharan, 2008; E Scott Krayenhoff & James A Voogt, 2010).

Thermal interactions between the built environment and surrounding atmosphere define urban microclimatic temperatures. In a dense urban scenario, vegetation, reflective building roof and pavement surfaces significantly improves microclimate and reduces the cooling energy demand in buildings (Figure 1). This also implies a sense to encourage passive cooling by altering microclimate and improve indoor conditions in hot climates. Increasing reflectance of urban surfaces using cool roofs and pavements lowers the temperatures when the trapping of reflected radiation and the outflow of the absorbed solar radiation into the atmosphere decrease. However, reflective pavements need be considered cautiously in a dense urban scenario as higher cooling loads were observed due increased larger ground albedo (Neda Yaghoobian & Jan Kleissl, 2012). From the field measurements carried out by C Deb et al, it is understood that Building height to width ratio (H/W) and the ground coverage (built-up and green) are the two most important site characteristics that would influence the microclimate. (C Deb & A Ramachandraiah, 2011). Along with these two variables, surface albedo is another critical variable that determines the reduction in heat Islands (Maria Kolokotroni et al, 2008). Thus, reduction of heat islands with improved microclimate because of all the three variables would result in better outdoor comfort and reduction in air conditioning load.

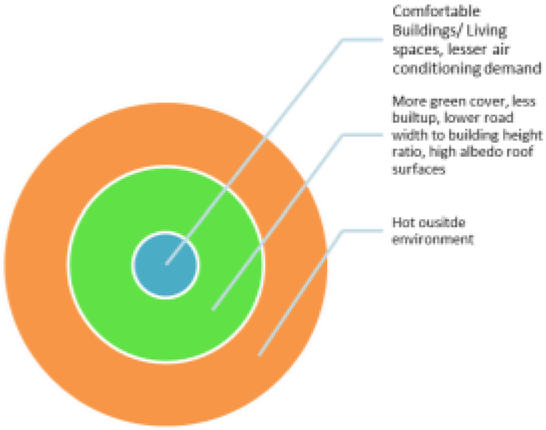


Figure 1. Model for improved urban microclimate in a new development scenario

Field measurements help to provide accurate data and a wholesome understanding of mitigating heat islands in an urban environment. Steve et al, present correlation between several of these variables (Steve et al, 2009) based on the extensive field measurements carried out as part of his doctoral work. His work presents sensitivity analyses of air temperature prediction models developed based on the data collected from the field measurements. There are also a few other tools developed/ being developed across the globe to predict or evaluate microclimate and urban weather conditions (Sebastian Huttner & Michael Bruse, 2009, Mark F. Jentsch et al, 2008, Viktor Dorer et al, 2013, Bruno Bueno et al, 2012).

Field studies conducted by Minni Sastry et al in the city of Bangalore (Minni Sastry et al, 2013) observed about 0.8 to 2K difference in mean air temperature from the city centre to surrounding rural area. With this background, authors of this paper conducted 192 parametric simulations for Bangalore climate using ENVI-met tool in order to develop an empirical formula with the above mentioned variables namely, built up vs green density, street geometry and roof surface reflectance. The first part of this paper discusses the methodology and sensitivity analysis carried out to test the empirical formula generated out of ENVI-met parametric simulations. The second part of this paper presents the analysis on customization and evaluation of STEVE's model for its integration with an online calculator for GRIHA LD in India.

METHODOLOGY

The urban microclimate as defined by World Meteorological Organisation (WMO) refers to the climate effects defined by individual buildings, trees, roads, streets, landscape and vegetation etc...,; its horizontal extent can be taken up to hundreds of meters. It is also observed that an area within 50m radius can be considered as significant area of influence and for studying microclimate (Maria Kolokotroni et al, 2008, Steve et al, 2009). The following sections present the methodology and approach for the two tasks described in the paper.

ENVI-met Parametric Simulations

ENVI-met is a three- dimensional computer modeling tool that simulates surface-plant-air interactions within urban environments. The software uses calculation of fluid dynamic characteristics such as air flow and turbulence, thermodynamic process that takes place at the ground surface, walls, roofs and plants. Simulation output of ENVI-met has been validated with the field monitored results by various authors (Mohd Fairuz Shahidan et al., 2012; Anisha Noori Kakon et al, 2009; Kiran Kumar D EV S & Minni Sastry, 2013)

Hypothetical urban configurations that represent different urban density scenarios were defined with an area of extent, 100m X 100m for the parametric simulations. Four site configurations (in plan) with four different road to building height ratios (in section) and with four different roof surface reflectance were simulated using ENVI-met tool to generate local level air temperature data. Figure 2 illustrates various configurations of site, buildings (both in plan & section) to achieve different combinations of microclimate parameters defined for the exercise. The input file for simulation was developed by defining Bangalore's geographical position (77° 34'E and 12°58' N). Initial temperature and relative humidity were given as per the study day conditions selected in the parametric case. Wind velocity and direction of 1.5 m/s, from the South West direction was assumed. Conventional building material characteristics (low reflective RCC slab for roof and plastered brick masonry for wall) were defined in the input file. Output parameters like minimum, maximum and average temperature were defined at this stage with the interval of 1hour for a 24 hours cycle of the study day. The input file was further edited to develop the building geometry as well as the roof reflectance as per each parametric case selected. Building material characteristics are identical for all the buildings in the simulation model. It is important to note that ENVI-met cannot study the impact of anthropogenic heat flux; thus it ensembles the current simulation exercise where this parameter is improbable.

The resolution of cells or the grid size in the ENVI-met model was defined as 0.5 m X 0.5 m. The tool adjusts the sun position for the day of simulation as defined in the input data. All the 64 cases developed with different combinations of site, building configuration and roof reflectance (four Built up to Green ratio; four building height to road width ratio; four roof reflectance) were simulated on three typical days of the year (equinox, summer and winter solstices) for different solar exposure scenarios. One of the difficulties with ENVI-met version 3.1 is that it takes a lot of processor and memory (RAM) to run the simulation and to store the result generated on hourly basis. Four desktop computers with i3 processor and 2GB RAM were used simultaneously day and night for about 24 days. Data collected in the 192 ENVI-met simulations were statistically analysed.

STEVE's model

Steve et al developed an empirical model for predicting air temperature to evaluate the impact of site level developments (Steve et al, 2009). The model (Equations 1) for average temperature (Tavg) for a given site extent in Singapore has been developed and validated based on long-term field measurements between the period of September 2005 and March 2008. Independent variables used in the models are daily temperature at reference point, average of daily solar radiation (SOLAR), percentage of pavement area over R 50m surface area (PAVE), average height to building area ratio (HBDG), total wall surface area (Wall), Green Plot Ratio (GnPR), sky view factor (SVF) and average surface albedo (ALB).

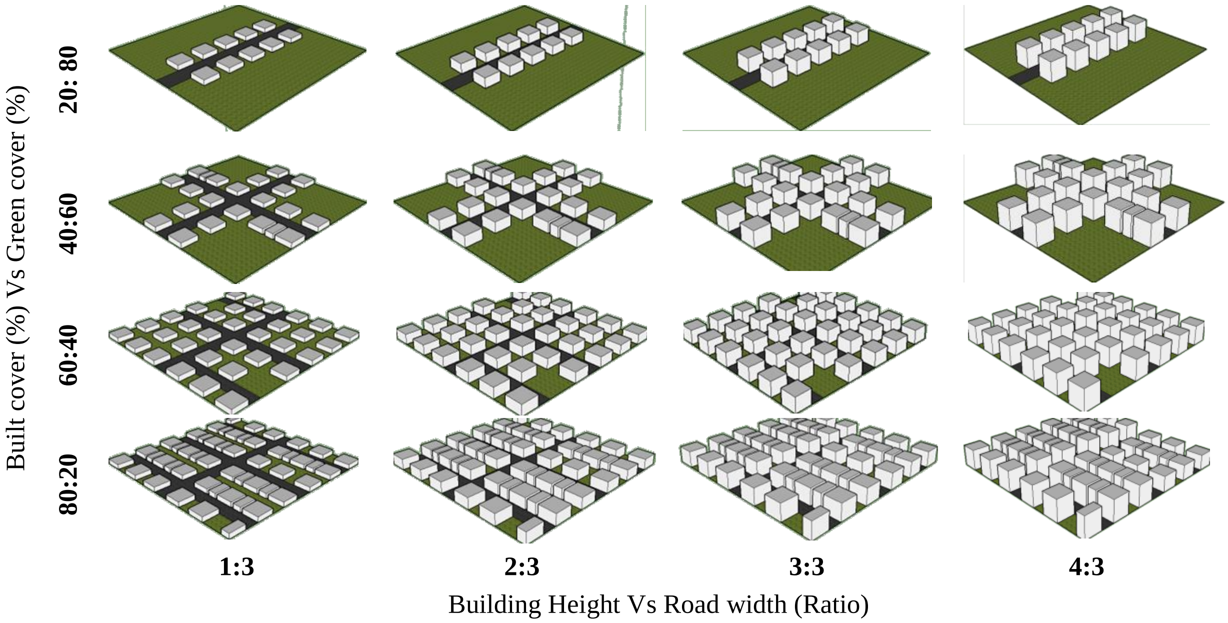


Figure 2. Different parametric cases considered for ENVI- met simulations

Tavg (°C) = 2.347 +0.904Ref Tavg +5.786E-05 SOLAR total (W/m2) +0.007 PAVE (%) -0.06 GnPR-0.015 HBDG + 1.311 E-05 WALL (m2) + 0.0633 SVF – Equation 1

It is important to note that, this empirical formula has been developed to predict average air temperature of a single point (location), the effect of which is assumed to be in the range of 50m radius. It was observed in the sensitivity analysis carried out using the model that groundcover (PAVE and GnPR) are the most significant variables. It was also understood that the as built-up area decreases, reduction in mean air temperature increases. Roof surface reflectance was found not to be very significant in STEVE's model. The impact of anthropogenic heat was not studied in the model as a variable; to certain extent, this may be valid as the measurements were done within the university campus where anthropogenic heat due to traffic could be significantly minimal.

Online calculator for GRIHA LD

GRIHA Council (earlier Association for Development and Research of Sustainable Habitats) launched the GRIHA rating for Large Developments (GRIHA LD) in February 2013. The rating was designed to assess the environmental impacts of large area developments. The rating assesses environmental impacts on the areas viz., Site planning, Energy, Water and wastewater, Solid Waste management, Transport, Social.

In the Site Planning section, a calculator was developed to estimate the impact of site planning, building layout, green cover distribution etc. on the ambient outdoor temperature. The two models described in the above sections were tested for its integration with online calculator of GRIHA LD. The STEVE's model was found to be better in terms of its accuracy to analyse the effect of site planning as well as building and landscape layout on outdoor temperature. Therefore, a calculator was developed, based on the STEVE tool, for the GRIHA LD site planning section.

RESULTS AND DISCUSSIONS

Sensitivity Analysis of air temperature model developed based on ENVI-met simulations

The results of ENVI-met simulations consist hourly maximum, minimum and average temperatures for the selected day for each of the 64 parametric cases. Regression analysis was carried out to get the relation between the resultant temperature and the independent parameters considered in the simulations. Equations 2 presents the empirical model resulted out of the 192 parametric simulations.

Max. Temperature= 1.29Ref T Avg-0.03Ref Sol SOLAR (W/m2) + 0.55Ground Cover-0.19R/W to Height-0.26*Roof Albedo-2.18 - Equation 2

The difference between this model and the Steve's model is that it considers the impact (in 2D) of the development under the independent variable "Ground cover" which takes in to account of both built cover and green cover. It was also deliberated that the paved areas, road surfaces and building roof surfaces are accounted in the built cover. In order to simplify the model, the impact of development (in 3D) was assumed to be studied under the parameter "Road width to Building height ratio" as against to HBDG and SVF considered in Steve's model. A good relation has been described between SVF and analytical results for building height to road width ratio (CS B Grimmond et al, 2001). Other parameters like reference air temperatures, solar radiation and roof albedo were the same as in the Steve's model.

Sensitivity analysis of the model shows the influence of each micro climatic variable on the change in resultant air temperature. Independently, each of the variables has linear correlation with some direct functional relationship. The variable, roof reflectance came out to be insignificant in case of the average and minimum temperature. However, in contrast to STEVE's model, maximum temperature turns out negatively significant. This probably implies that a high reflectance will reduce the maximum temperature and not so much the minimum and average temperature. Average temperature appears to have a negative relationship with the Roof Surface Temperature and Road Width to Height ratio.

The model was further analysed for its sensitivity in predicting change in temperature. Maximum temperature increased by only 0.5 K when the built cover (roads, pavements & building roofs in plan) percentage increased from 10% to 90% with respect to the overall site. When the road width to building height ratio increases by about eight times, average temperature was found to be decreased up to 1K. The sensitivity of the model based on parametric simulation was found to be low and hence it was not suggested to integrate with the online heat island calculator for GRIHA LD. Previous studies (Wong Nyuk Hien et al, 2012) also support that ENVI-met simulations under predicts the temperature when compared to STEVE's model. Thus, STEVE's model was further analysed and tested for Indian climatic conditions.

Validation of STEVE's model for Indian context

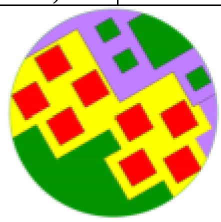
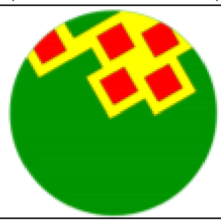
Extensive analysis was done using STEVE's model for its adaption to Indian context and this section presents the evaluation of the model. The GRIHA LD online calculator is based on this model to predict the average Temperature depending on the site level developments. For the online calculator in GRIHA LD, equation 1 predicting the average temperature was selected.

A sample site level development was selected and three different land-use patterns (zones) were identified in the same. These three zones were selected to represent the following scenarios

- Medium density, Low rise development with over 70% hard paved area
- Medium density, Medium rise development with over 70% hard paved area; and
- Low density, Low rise development with less than 30% hard paved area

Since the STEVE's model, analyses the effect of built form at the centre of a circle of radius 50m, data was extracted from each zone encompassed within a circle of radius 50m. The data assumed for the analysis is given in the table 1

Table 1: Three typical Scenarios of site level development considered for testing STEVE's model

Scenarios of site level development	URBAN 1 urban area – medium rise (Ground + 3 structure)	URBAN 2 urban area – high rise (Ground + 9 structure)
Area representation		
Site Area (m^2)	7854	7854
PAVE (%)	70	70
GnPR*	0.75	0.75
HBDG	0.002	0.002
WALL (m^2)	5184	12960
SVF	0.42	0.18
Scenarios of site level development	NON URBAN 1 suburban area – medium rise (Ground + 3 structure)	
Area representation		
Site Area (m^2)	7854	
PAVE (%)	30	
GnPR*	1.75	
HBDG	0.0035	
WALL (m^2)	3240	
SVF	0.9	

*GnPR =(Total Tree Leaf Area + Turf Area) / Area of Circle (site = 50 m radius), where
Total Tree Leaf Area = No. of trees x Canopy Area x LAI
LAI (Leaf Area Index) varies from 0 to 6where 0 depicts barren site and 6 depicts extremely dense vegetation

GnPR (Green Plot Ratio) and LAI (Leaf Area Index) are crucial components of the calculation. Based on our calculations and data sourced from earlier studies (Mohamad Fahmy et al, 2010), it was estimated that LAI ranges from 0 to 6 with 0 being a barren surface and 6 being an extremely dense tree. There were calculations done for both urban and non-urban building scenarios with trees of varying LAI and canopy radius. Thus, it was calculated that without green walls, the LAI should not exceed the value 7. In the three scenarios, based on these assumptions the

GnPR was calculated for both Urban – 1 & 2 and Non-Urban case. For the Urban Cases, GnPR estimated to be 0.75 and for Non-Urban case, it was 1.75.

The above three scenarios were run in the calculator for 14 different cities of India. The cities (Table 2) represent different climate zones across various latitudes of India. All climates except cold climate were considered in this exercise. The analysis was conducted for the three typical days – 21st May, 21st March and 21st December. (21st May was selected over 21st June to ensure that all cities are analysed for non-monsoon skies). The weather data (ambient temperature and daytime average radiations) was considered from the standard weather files (TMY2).

Table 2. List of cities modelled for testing STEVE's model

New Delhi	Mumbai	Chennai
Hyderabad	Pune	Dehradun
Bengaluru	Kolkata	Indore
Trivandrum	Ahmedabad	Jodhpur
Guwahati	Amritsar	

The aforementioned data were calculated using equation 1 for all three scenarios mentioned in Table 1. The results of this exercise are presented in Table 3. It was observed that the resultant local temperature vary with change in reference air temperature. The equation provided satisfactory results as long as mean ambient temperature fell in the range of 20 °C to 30 °C.

Table 3. Reduction in air temperature using GRIHA LD calculator based STEVE's model for 14 Indian city climates

Temperature Parameter (K)	21^{st} May	21^{st} March	21^{st} December
Urban Average	0.02	0.53	1.13
Non-Urban Average	-0.05	0.46	1.05
Urban Max	0.64	1.49	2.06
Urban Min	-0.48	0.02	0.49
Non-Urban Max	0.48	1.33	1.89
Non-Urban Min	-0.50	0.00	0.47

The results for 21st March for the city of Bengaluru were compared with actual field monitored results observed by Minni Sastry et al, (Minni Sastry et al, 2013). The comparison of these results is presented in Table 4.

Table 4. Comparison of results from GRIHA LD calculator and Field Results

Ambient Average temperature (°C)	Increase in Temperature Observed Bangalore field studies (K)	Estimated increase in Temperature using GRIHA LD Calculator (K)
24.8	1.5	0.95
23.6	1.5	1.03
23.3	2	1.2

The incremental difference between the actual observed increase in temperature and that predicted by the GRIHA LD calculator was consistent. It was thus concluded that the difference in temperature could be accounted due to anthropogenic heat sources, or other variables not considered in the calculator.

CONCLUSIONS

An attempt was made to develop a simple empirical model based on parametric simulations using ENVI-met. The sensitivity the model was found lower compared to the STEVE's empirical model, which was developed based on actual field monitored results. Both the models do not consider anthropogenic heat as a variable to study the impact of heat island; thus using these models is limited to new site level developments. STEVE's model when tested for different city climate scenarios was found satisfactory and thus it has been integrated with the online calculator available for GRIHA tool for large developments. Although both the tools could not predict the actual temperature difference, they would be useful to assess the sense of impact with new campus level developments.

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