Sensitivity Analysis Tool

A Tool for designing better building

Parametric modeling- Thermal simulation- Regression analysis

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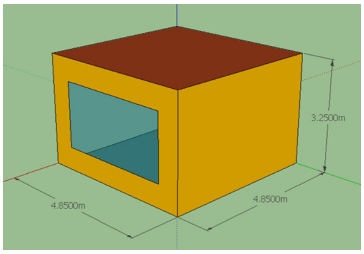
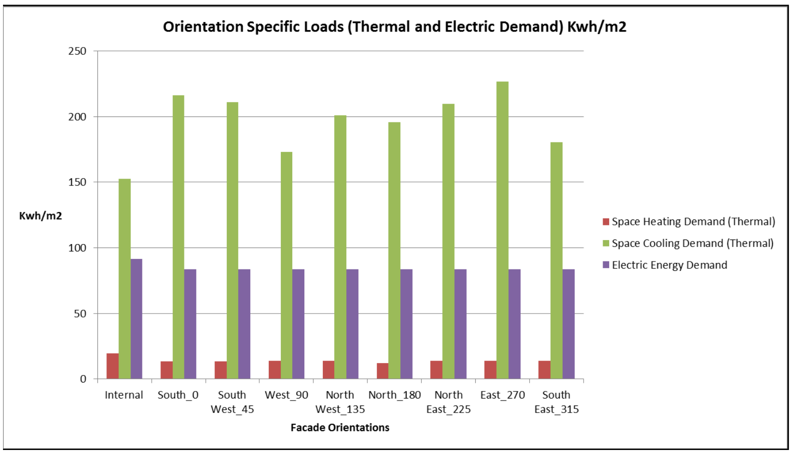


180	180	180	180	180	180
90	Int	Int	Int	Int	270
90	Int	Int	Int	Int	270
0	0	0	0	0	0



ABSTRACT:

Buildings contribute for more than 80 per cent of GHG emissions (IPCC, 2007), and are extremely vulnerable to climate change impacts. Most modern buildings have highly controlled and conditioned indoor climates, irrespective of the outdoor climate regime and at the expense of energy consumption. Need of the hour requires a new focus on creating buildings that are comfortable and healthy for the occupants yet also energy efficient.

Climate influenced building design, thus provide a comfortable space that is energy efficient as well. The issues to climate influenced building designs are less knowledge on climate responsive strategies for building massing and design, dependent on system for loads of a building (systems vs design) and replicating western building practices and designs in not so similar climate regime.

Thus, architects and designers are to be informed about the various building parameters and their effect on building energy at conceptual design stage" - create less energy demand and climate responsive designs. The sensitivity analysis tool informs Designers on "Design and its impact on loads" and so the degree of closeness of building design to climate increases. Other impacts from the tool include reduction in time and effort on Building Energy Simulation (BES) at later design stages and less design changes at a later design stage.

INTRODUCTION:

Sensitivity Analysis Tool is a passive design decision making tool that uses simple regression equations employed in the conceptual design stage. This approach provides quantitative insight into the level of influence of each parameter under scrutiny, informing about changes altering, enhancing, or having only minor effect on performance. The framework in definitive provides the design team with means to balance design intentions with performance aims.

At the early stages of design process,indoor climate rarely plays a predominant role in driving design; despite decisions taken at that schematic/ conceptual design stage having dramatic influence on performance (H¨onger et al. 2009).Outcomes of this research project include a set of simple regression equations that can be used at preliminary design stages to quantify heating, cooling and electricity loads of a proposed building design.

Assuming a linear regression model between the building parameters and the loads, the generated equations are embedded in a macro enabled excel sheet to generate, an interactive tool for different building footprints.

Energy simulation is a powerful computational tool that equips a user to model the building as a system to visualize its complex interactions with its outdoor space/ climate regime (Morbitzer CA. 2003). Impact on cost and energy is largest at conceptual design stage, yet energy simulation is seldom performed during the early stages of design (Krygiel .et.Al, 2008). Simplified simulation methods or a simplified user interface could enable more effective energy estimation by reducing the number of required inputs, thereby making the process more intuitive for designers, reducing the burden associated with constructing an energy model, and allowing for faster generation of results.

The accuracy of these results at the conceptual design stage, does not make much sense but the effect of capturing the influence of parameters on the loads, make the process more interesting by informing the designers the effectiveness of their design both aesthetically (Qualitatively) and energy profiles (Quantitatively).

LITERATURE REVIEW:

The difficulty to understand and digest the quality of results by designers non-experts in simulation raises a simple question on the overall scheme [Ibarra and Reinhart 2009], especially since the final building performance is direct impact to choices made at early design stage. One way of overcoming this issue, is through hierarchy of tools (Hensen 2004): simplified tools or subset/simple interface to expert-level tools.

Sensitivity analysis aims to assess the influence of uncertainties in input data on a given model output. These techniques can be categorized in two different sets: global sensitivity methods, which aim at capturing the influence of a given set of input parameters over the whole parameter space, and local sensitivity analysis, which by altering one parameter value at a time, computes sensitivity around a given point of interest (Saltelli et al. 2008)

Parametric analysis can be used to some extent to give a range of potential outcomes given uncertainty in the model input parameters. However performing a parametric analysis that includes all of the unknown design parameters requires significant time and resources. Several prior studies have attempted to identify which simulation parameters have the most impact on building performance (Domınguez- Munoz F., 2010) (Hopfe C., 2009) (Breesch H., 2010) (De Wit S., 2001). These studies focused primarily on simulation variables rather than the building design parameters that are likely to evolve throughout the design process.

To make building energy simulation a useful design tool, the analytical methods and resultant model outputs must be made relevant and simple to the design decisions at hand. In early design stages, energy simulation is useful for comparative analysis of multiple design schemes. In addition, energy simulation tools can facilitate a broader search of the design space by allowing parametric analysis of a whole building or a single room, floor, or façade. The results should relate energy performance to key design parameters under consideration. Such an approach would offer meaningful energy-related feedback related to design choices.

IPCC. 2007, Chapter 6, Residential and commercial1 buildings, Coordinating Lead Authors, Mark Levine (USA), Diana Ürge-Vorsatz (Hungary).

Morbitzer CA, 2003 - Towards the Integration of Simulation into the Building Design Process. Thesis; University of Strathclyde, Energy System Research Unit, Department of Mechanical Engineering

Krygiel .et.Al, 2008 - Krygiel E, Nies B. Green BIM: successful sustainable design with building information modeling. Indianapolis: Wiley

H¨ONGER, C., BRUNNER, R., MENTI, U.-P., AND WIESER, C, 2009. Climate as a Design Factor, vol. 1 of Laboratorium. Quart Verlag, Luzern, CH.

HENSEN, J. L. M. 2004. Towards more effective use of building performance simulation in design. In Developments in Design & Decision Support Systems.

SALTELLI, A., RATTO, M., ANDRES, T., CAMPOLONGO, F., CARIBONI, J., GATELLI, D., SAISANA, M., AND TARANTOLA, S. 2008. Global Sensitivity Analysis, the Primer. Wiley.

Domınguez-Munoz F. Cejudo-Lopez J.M., Carrillo- Andres A. 2010. Uncertainty in peak cooling load calculations, Energy & Buildings.

Hopfe C. 2009. Uncertainty and sensitivity analysis in building performance simulation for decision support and design optimization, PhD thesis. Technische Universiteit Eindhoven

Fig-1: Delhi, India (Composite Climate)

28.6100° N, 77.2300° E

ADVANTAGE AND LIMITATIONS OF STUDY:

Advantages:

Reduces the iterative changes on design needed on a later design stage
Reduces the time and effort on Building Energy Simulation (BES) at later design stages
A quick tool to analyze the extent of degree of closeness of building design to climate

Limitations:

Daylighting simulation was not considered simultaneously into the thermal simulation. This would affect both heating, cooling and electricity demand of the space
The building foot print size should be a multiple of 5 (as the single zone shoebox shape is 5*5*3.25 m3)
Limited building parameters (five) considered for the equations.
Rectangle/square and triangle footprint shapes
Regression Analysis was performed assuming linear relationship between the parameters and the loads. This would not always match the reality.

CLIMATE INFO:

Delhi, India (Composite Climate)

Delhi lies in the landlocked Northern Plains of the Indian Subcontinent (Fig-1). Its climate is greatly influenced by its proximity to the Himalayas and the Thar Desert, causing it to experience both weather extremes. Delhi has 5 distinct seasons, viz. Summer, Rainy, Autumn, Winter and Spring

The climate of Delhi is a monsoon-influenced humid subtropical (Köppen climate classification Cwa) with high variation between summer and winter temperatures and precipitation. (Fig-2, Fig-3 and Fig-4)

Summers start in early April and peak in May, with average temperatures near 32 °C (90 °F), although occasional heat waves can result in highs close to 45 °C (114 °F) on some days and therefore higher apparent temperature. The average temperatures are around 29 °C (85 °F), although they can vary from around 25 °C (78 °F) on rainy days to 32 °C (90 °F) during dry spells.

Fig-2: Outdoor Temperature Statistics
New Delhi, India (Composite Climate)

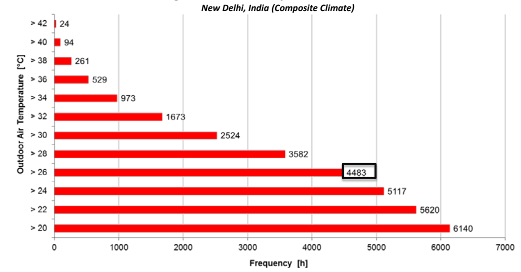


Fig-3: Outdoor Humidity Statistics
New Delhi, India (Composite Climate)

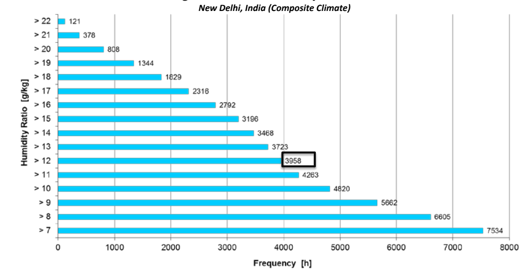
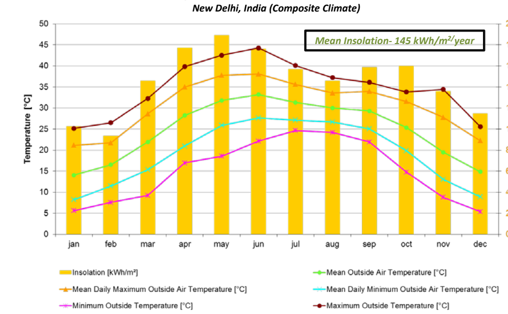


Fig-4: Solar Insolation Statistics
New Delhi, India (Composite Climate)



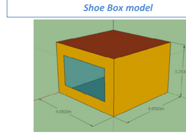
SIMULATION AND VARIANTS DEFINITION:

The siumation was performed considering the following base conditions for the geometry , operational parameters and facade details . (Fig-5 and Fig-6)

This shoe-box design of 5*5*3.25 was then simulated with multiple variants considering 5 building parameters as the key factors, they include orientation, shading factor, window to wall ratio, glazing type and area/ person their variations were studied for influencing the building loads.

Fig-5: Geometry, Material and Operational parameters

Geometry:
4.85 X 4.85 X 3.25 m3
Shoe Box model



Opaque Façade: 0.219 m, U value- 0.250 W/m2K

Glazed Façade :
Option-1: Double- U Value-1.24 W/m2K, G value- 0.642
Option-2: Triple Façade- U Value-0.59 W/m2K, G value- 0.451

Base Operational Parameters:
(Deg Celsius)

Heating Set point- 20 ºC
Cooling set point- 26 ºC
Max ACH (Natural Ventilation)- 3 ACH
Mechanical Ventilation (Occupancy Schedule: 09-17 Hrs.)
Set point- 19 Winter, 22 Summer

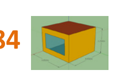
Fig-6: Variants Definition

Orientation	Shading Factor	Window to Wall Ratio	Glazing Type	Area (m2)/person
0	0	33	Double glazing with one low e	5
45	30	66	Triple glazing with 2 low e	10
90	60	100		
135	90			
180				
225				
270				
315				

8 ✖ 4 ✖ 3 ✖ 2 ✖ 2

8*4*3*2*2= 384 combinations

No of Variants (Each Climate) is 384



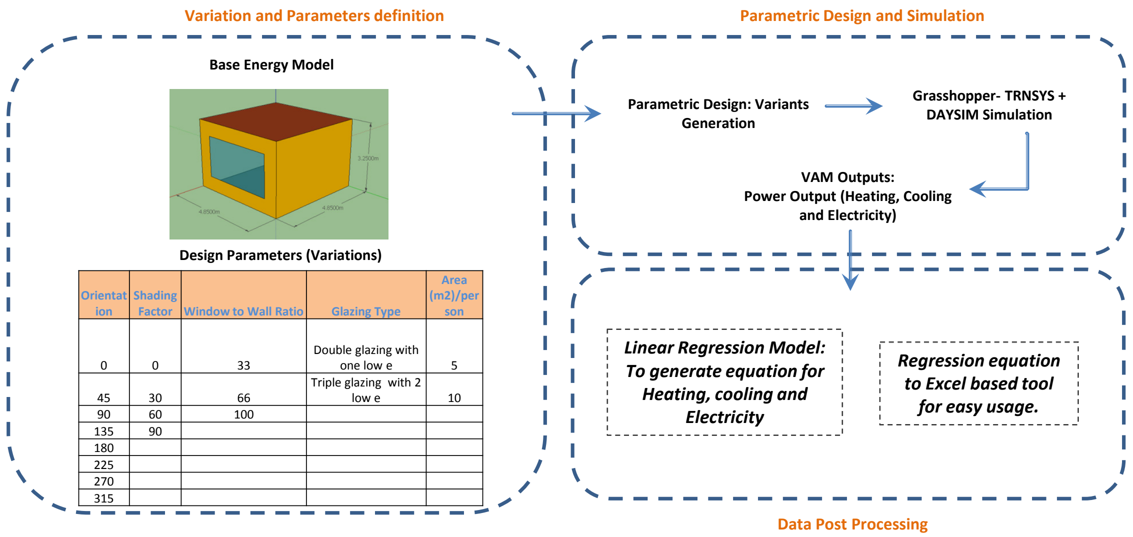
METHODOLOGY/ FRAMEWORK:

The methodology adopted for performing this parametric study was linking multiple softwares like TRNSYS (Thermal simulation software) and Daysim (Daylighting simulation) thhrough middle software Grasshopper. Thus a grasshopper script (with fortran) was used to create the linkages between the various simulation platforms. (Fig-7)

Also, the parametrization of various input combinations to generate the input files for various parameter combinations was generated using excel VB coding.

The generated patch was the run multiple times (384 times) as per the comninations with Delhi's IWEC climate data. The results of some special cases are discussed further.

Fig-7: Project framework and post processing

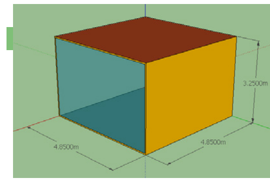


SIMULATION RESULTS:

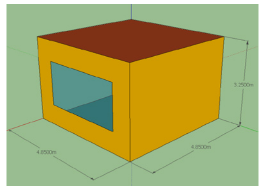
Since, Delhi is not a heating (demand) dominant climate. The analysis of the simulation results have been from the cooling load and electricity demand for the space. The following are some of the simulation results from the various 384 cases, which are interesting to understand the impact of the parameter on the cooling and electricity loads.

The window to wall ratio has a direct impact on the cooling load, as the solar gains reduces through having smaller windows. The loads curves for the 3 different Window to wall ratio of 33%, 66% and 100% and variations with façade direction is shown below. The North façade does not get direct solar gains from the sun and so has least cooling loads. (Fig-8)

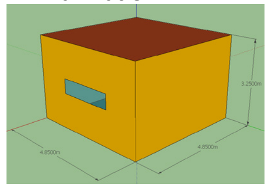
Fig-8: Window to Wall Ratio's influence on cooling demand (kWh/m2)



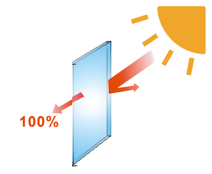
Window to Wall Ratio :100%



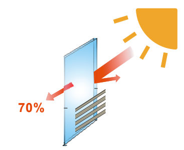
Window to Wall Ratio :66 %



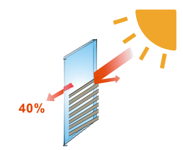
Window to Wall Ratio :33 %



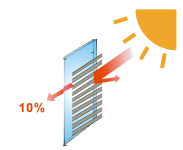
Shading Factor- 0%



Shading Factor- 30%

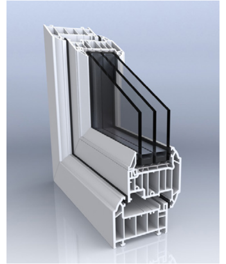


Shading Factor- 60%



Shading Factor- 90%

Double Glazing
U Value-1.24 W/m2K

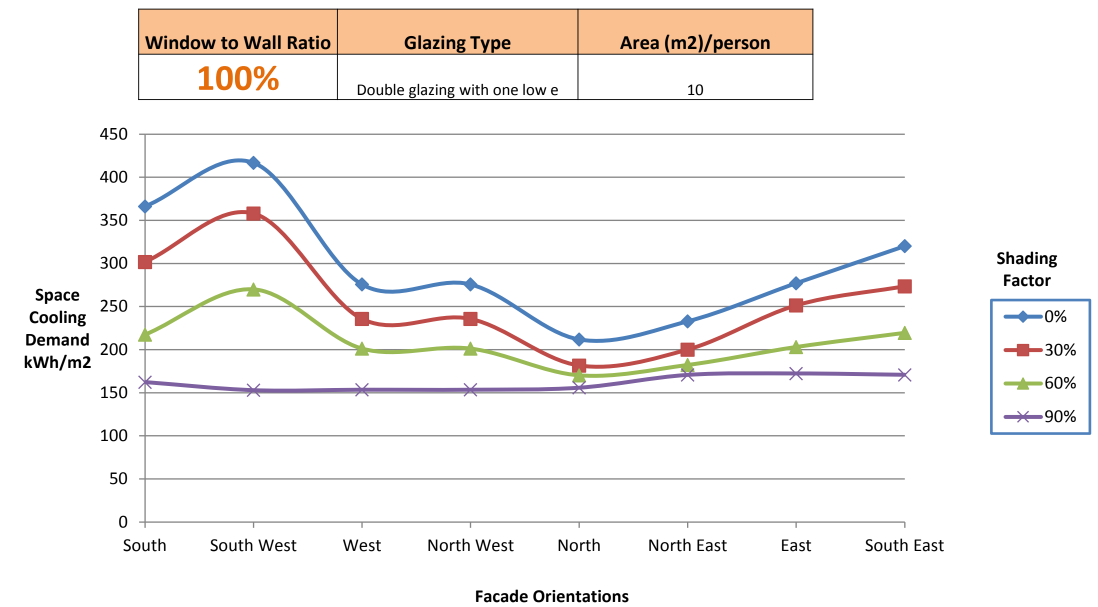


Triple Glazing
U Value-0.59 W/m2K

Shading Factor's effect on Loads:

The shading factor's impact on the cooling load follows the profile as shown above. The shades make sense more on the south, south west and west orientations. The indirect solar gains on the north and north east make shade effective. (Fig-9)

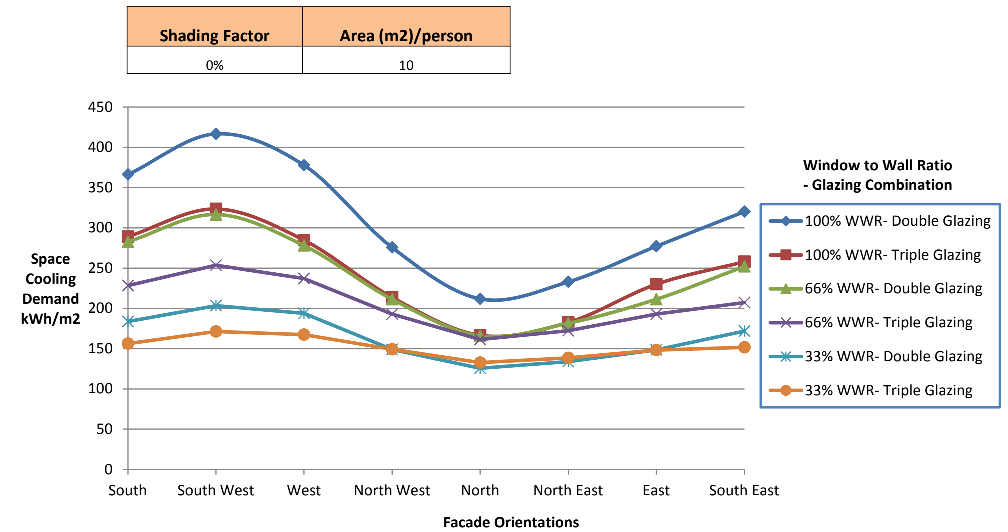
Fig-9: Shading Factor's influence on cooling demand (kWh/m2)



Glazing type effect on Loads:

Glazing type affects the solar heat gains through the U-Value of the glazing. One interesting thing is to look at the two curves 100%WWR-Triple glazing and 66%WWR-Double glazing has the same load profiles closely matching to each other. This gives the flexibility for the designer or architect to decide on what he actually needs based on other factors like view through window, cost etc. (Fig-10)

Fig-10: Glazing Type influence on cooling demand (kWh/m2)

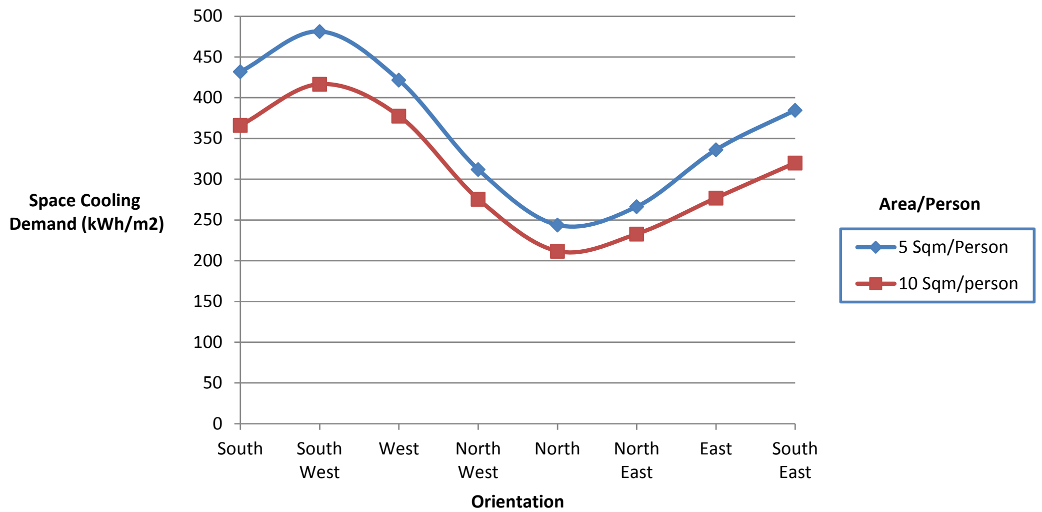


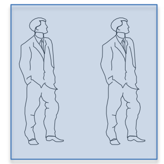
Area/person's effect on Loads:

Area/person has direct impact on cooling load and also on the electricity demand of the space, with less area/person means more people, more internal loads and so the elevated cooling loads and also electric loads. This helps in zoning of the spaces for different purposes as per the usage.. (Fig-11 and Fig-12)

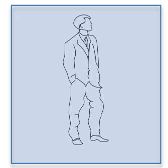
Fig-11: Area/ Person influence on cooling demand (kWh/m2)

Shading Factor	Window to Wall Ratio	Glazing Type
0	100%	Double glazing with one low e



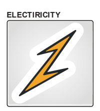


5 sqm/Person

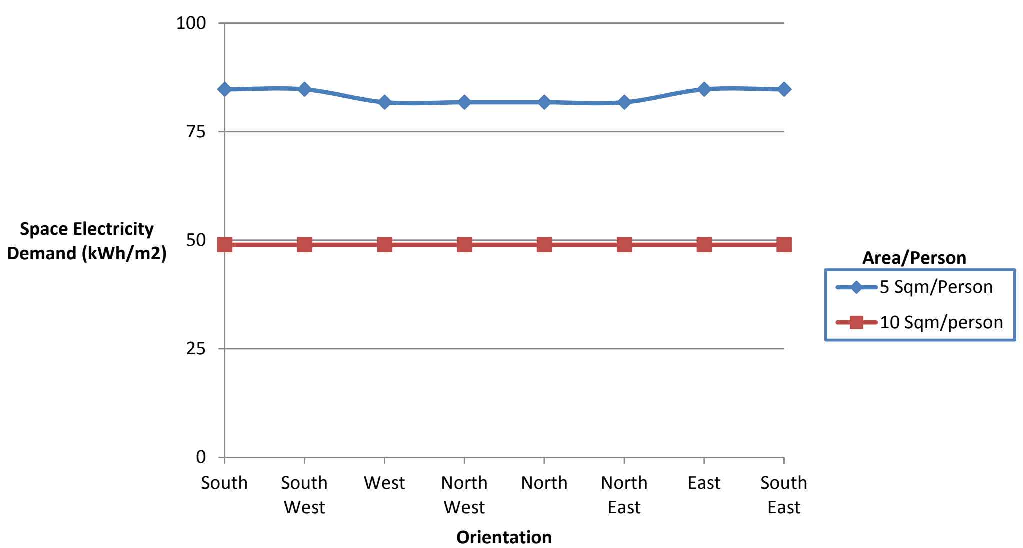


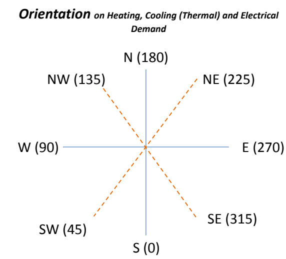
10 sqm/Person

Fig-12: Area/ Person influence on electricity demand (kWh/m2)



Shading Factor	Window to Wall Ratio	Glazing Type
0	100%	Double glazing with one low e





Orientation's effect on Loads:

TThe cooling load is the dominant load for the space. Orientation's effect on the loads could be seen to follow the graph discussed with the WWR or the Shading factor profile of maximum loads in South, southwest and west and reducing gradually due to less direct solar exposure in the North façade. Assuming a COP for heating and cooling of 3 and 4 respectively, we can convert all the loads in the primary energy of electricity. (Fig-13) and Fig-14

Fig-13: Orientation's influence on heating, cooling (Thermal) and electrical Demand (kWh/m2)

Shading Factor	Window to Wall Ratio	Glazing Type	Area (m2)/person
0%	100%	Double glazing with one low e	10

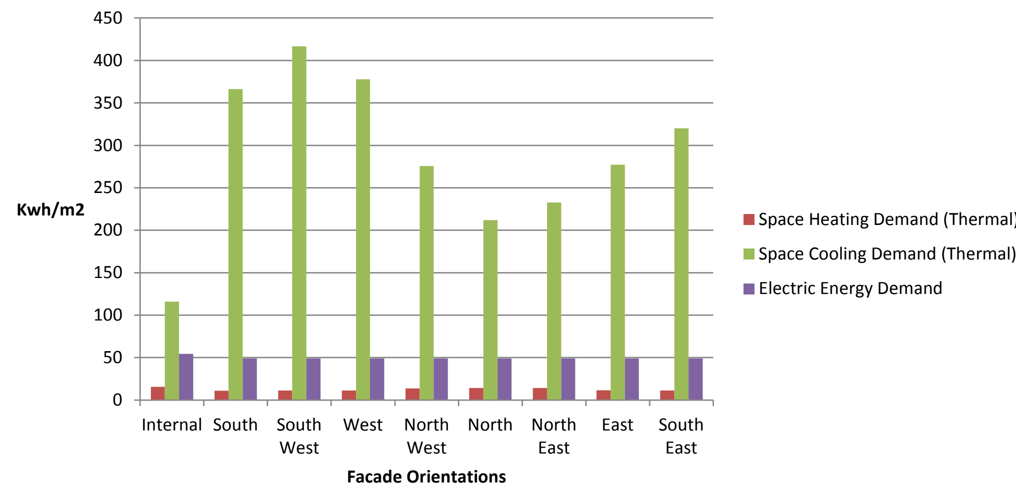
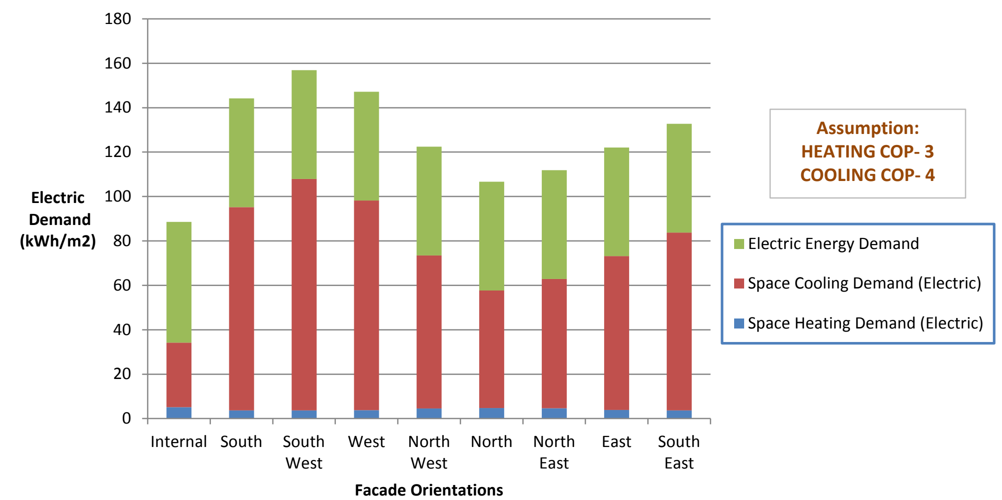


Fig-14: Orientation's influence on Combined Electric Energy Demand (kWh/m2)

Shading Factor	Window to Wall Ratio	Glazing Type	Area (m2)/person
0%	100%	Double glazing with one low e	10

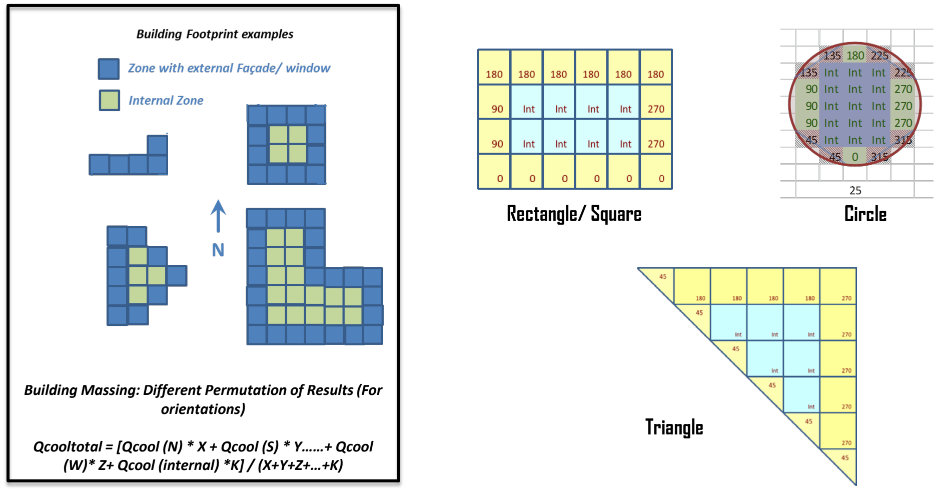


SINGLE ZONE TO BUILDING FOOTPRINT:

The shoebox model of 5*5*3.25 could be multiplied into forming different building foot prints as per the site specification and the number of zone required internally as well. The combinations of the shoeboxes could help us understand the possibilities of extending the learnings to larger and more common building footprints. (Fig-15)

This approach increases the applicability of learnings into more closer to reality. Some of the common building footprints as shown below like rectangle, square, circle and triangle etc. This helps us understand the best possible footprint and the orientation for the current climate/ site context with comparative results as a decision making tool at early, conceptual design phase.

Fig-15: Building Footprints



REGRESSION ANALYSIS AND EQUATION FORMULATION:

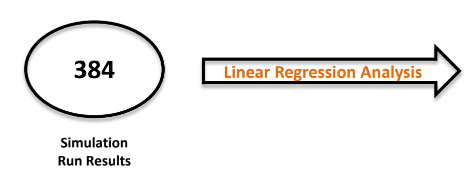
A regressing analysis, is the easiest way to ascertain the relationship and the extent of relationship between independent variables on the dependent variable.

Thus by analyzing the 384 cases and their results, we had generated the pattern or the extent of influence of the factors on the dependent variables Heating, cooling and electricity demand.

For the internal zones, the factors that influence the loads are just area/person. The following are the results of the regression analysis to get the coefficients for the independent variables on the dependent variable. (Fig-16)

Fig-16: Regression Coefficients

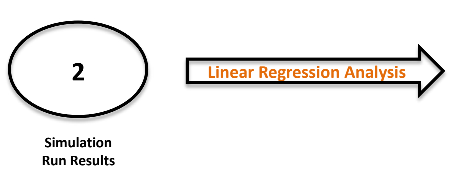
External Zones



Dependent Variables

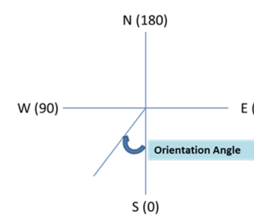
	Heating (Thermal)	Cooling (Thermal)	Electric (Electric)
Intercept	13.9467	221.7451	119.3328
Orientation	0.0016	-0.1135	-0.0001
Shade	0.0011	-0.9290	0.0003
WWR	-0.0016	1.2374	0.0006
Glazing	0.2057	42.8218	0.0501
Sqm/Person	-0.2974	-10.4469	-7.1224

Internal Zones



Dependent Variables

	Heating (Thermal)	Cooling (Thermal)	Electric (Electric)
Intercept	23.18775	249.74582	128.7594
Sqm/Person	-0.769254	-13.315802	-7.43292



Orientation Angle (From True South)

The equations thus formed through regression analysis on the simulation results for various cases of the parameters variation on the dependent variables. This could be very complex for non-engineers, especially designers to apply and understand the effect.

Thus the need for the hour was to translate the equations into a more interactive means, that could be easily applied and that, has real time results and visualizations that could help convey the message to the designers on the betterment of their design. (Fig-17)

Fig-17: Regression Equations- External and Internal Zones

External Zone

Space Heating Demand (kWh/m2) = 13.9467 + (**Orientation** * 0.0016) + (**Shading Factor** *0.001148)+(**Window to Wall Ratio** * -0.0015527)+(**Glazing** * 0.2056)+(**Sqm/person** * -0.29736)

Space Cooling Demand (kWh/m2) = 221.74 + (**Orientation** * -0.113490) + (**Shading Factor** *0.92903)+(**Window to Wall Ratio** * 1.2373)+(**Glazing** * 42.8218)+(**Sqm/person** * -10.4469)

Space Electricity Demand (kWh/m2) = 119.33 + (**Orientation** * -0.000123) + (**Shading Factor** *.000299)+(**Window to Wall Ratio** * 0.0006)+(**Glazing** * 0.05006)+(**Sqm/person** * -7.1225)

Internal Zone

Space Cooling Demand (kWh/m2) =279.0139 + (**Sqm/Person** * -13.315)

Space Heating Demand (kWh/m2) =23.18775+ (**Sqm/Person** * -0.7693)

Space Electricity Demand (kWh/m2) =128.759 + (**Sqm/Person** * -7.4329)

COMPLEX EQUATION TO INTERATIVE TOOL:

Since, understand the applicability of the learnings into to various building footprints, we need to identify the sensitivities of the building parameters on the loads. Their extent of influence on the loads, in a very crude way at this early design stage. Understanding this, would help designers think on the critical aspects of their design and what their influence . This is the approach of Integrated Design Process, that would help the design process to be more concrete, well informed and less variations at a later design stage.(Fig-18 and Fig-19)

Fig-18: Tool Input (Façade specific)

Building Foot Prints	Rectangle	Triangle
Length of Façade 1 **(Mandatory Input)**	0	30
Length of façade 2 **(Mandatory Input)**	0	30
Orientation of façade 1 wih respect to South	0	25
Façade Properties	Different Properties for facades	
South Façade		
Shade Fraction (0 to 100%)	90	
WWR (0 to 100%)	50	
Glazing (U value of the Glazing W/m2K)	0.79	
Area/ Person (m2/Person)	5	
Construction (U Value of Wall)	0.3	
West Façade		
Shade Fraction (0 to 100%)	90	90
WWR (0 to 100%)	30	30
Glazing (U value of the Glazing W/m2K)	0.6	0.6
Area/ Person (m2/Person)	5	5
Construction (U Value of Wall)	0.3	0.3
North Façade		
Shade Fraction (0 to 100%)	80	80
WWR (0 to 100%)	100	100
Glazing (U value of the Glazing W/m2K)	0.79	0.79
Area/ Person (m2/Person)	10	10
Construction (U Value of Wall)	0.3	0.3
East Façade		
Shade Fraction (0 to 100%)	50	50
WWR (0 to 100%)	60	60
Glazing (U value of the Glazing W/m2K)	0.6	0.6
Area/ Person (m2/Person)	5	5
Construction (U Value of Wall)	0.3	0.3
Internal Zone		
Area/ Person (m2/Person)	5	5
Construction (U Value of Wall)	0.3	0.3
COP For Heating	3	
COP For Cooling	4	

Fig-19: Building Footprints
(Generated user inputs and orientation angle)

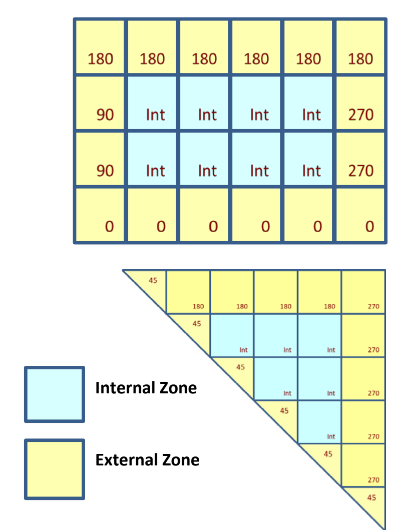


Fig-20: Orientation Specific Loads (Thermal and Electric Demand) Kwh/m2

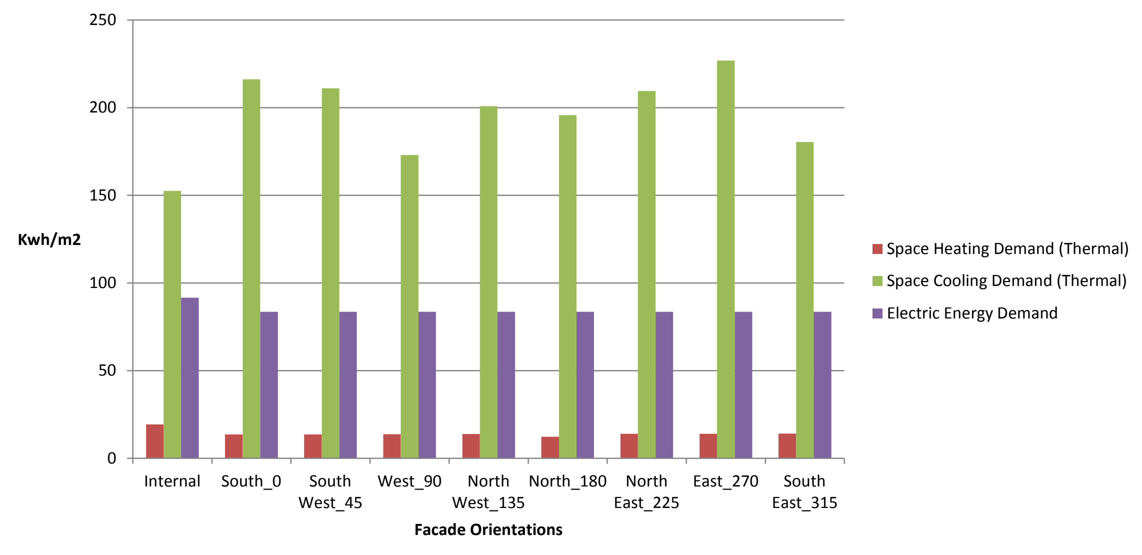


Fig-21: Orientation Specific Loads (Electric Demand) Kwh/m2

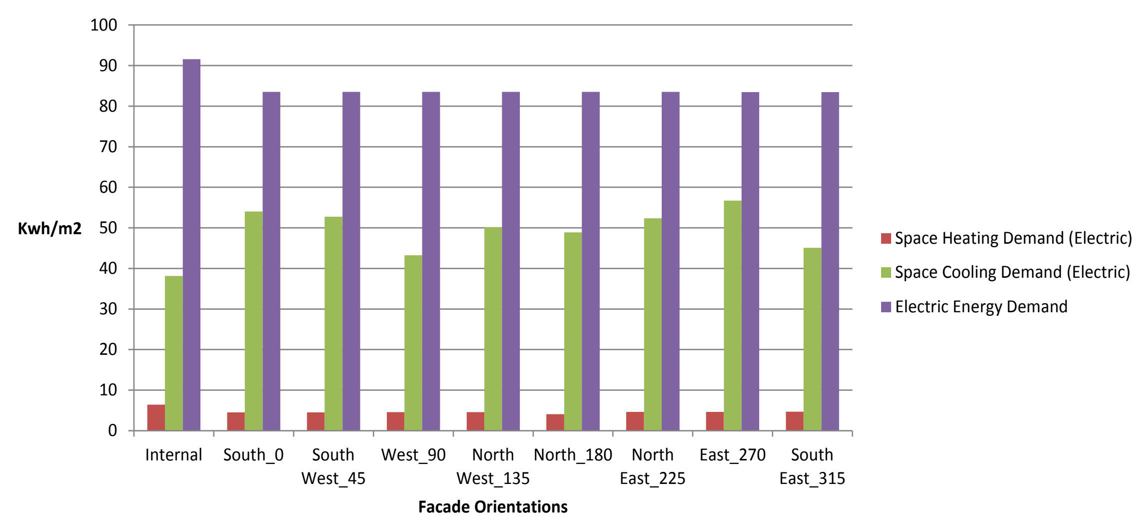


Fig-22: Real Time Demand statistics for building footprints

Kwh/m2	Space Heating Demand (Thermal)	Space Cooling Demand (Thermal)	Space Electric Demand (Electric)
Total	15.11788885	190.6755681	78.81435735
Kwh/m2	Space Heating Demand (Electric)	Space Cooling Demand (Electric)	Space Electric Demand (Electric)
Total	5.039296283	47.66889203	78.81435735

CONCLUSION:

Thus this interactive tool is generated for New Delhi climate and could help designers to think in right directions, in the early massing stage itself for the building design that could be best fit for the climate context. Reduced cooling, heating and lighting loads as the key benchmarks that could be used to compare the various alternative designs or massing forms. This is much more improved way of inculcating

climate influenced design to the designer's to understand the effect of the building parameters on the building energy. These kind of interactive tools are much more important to inform the designers about the influence of their design on building operations and also these improve the normal intuitive and thumb rules that are normally considered during the building design.

Tool Outputs:

- Influence of building parameter's on building energy- **Sensitivity of parameters**
- Interactive **Building footprint and load profile generation**
- **Real time demand statistics** as per dynamic user parameter inputs

WAYFORWARD/FUTURE ACTIONS:

The tool has to be still tuned to include some key elements like daylighting simulation input to influence the thermal simulation. Also include more building parameters. The long term follow-up for the tool are also listed above.

Immediate:

- Include **more flexible and user defined building footprints** (Circle, L shaped etc.)
- Formulate the tool **for 2 more climates (Germany and Singapore)**
- Consider **Cost as one of the parameters** for building form and energy

Long Term:

- Trying to include the **neighboring/ surrounding context for formulating the regression coefficients**
- **Include equations for Natural Ventilation and Daylighting potential**
- Analyze **comfort and loads** simultaneously