

Thermal performance of a building envelope - An evaluative approach

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ABSTRACT

The extremes of climate pose a challenge to the building elements, and the "building skin" or the "building envelope" has to bear the brunt to the most. Thus, its design and treatment for better thermal performance is extremely significant in the present scenario of energy deficiency. In the composite climate zone of India, the primary factor affecting the thermal comfort in the buildings for most of the time in a year is the solar radiation. In response to extremes of solar radiation, an air-conditioned building consumes 55% of its total energy demand for the purpose of maintaining indoor comfort conditions. It indicates that the solar/thermal performance of a building envelope needs to be reviewed if energy efficiency targets have to be addressed by the architects. This paper aims to examine the role of thermal performance evaluation approach for a building envelope in taking design decisions during the building design stage. The methodology adopted for the research is to calculate the thermal performance of building envelope of a hypothetical case study representing a typical fully air conditioned office building in New Delhi, which lies in the composite climate zone of India. The thermal performance has been evaluated for various architectural design parameters related to building envelope design. The considered parameters are, Surface area-to-volume ratio(S/V), Orientation, Size, Shading of windows and material efficiency. the thermal performance evaluation has been done by using the Envelope Performance Factor (EPF) calculation equation, as given in Energy Conservation Building Code (ECBC), 2007. The findings shall help the architects to gain an insight into using this evaluative approach in the design decision making stages.

Key words: Thermal Performance, Building Envelope, Energy Efficiency, Envelope Performance Factor(EPF), Energy Conservation Building Code(ECBC)

1.0 BUILDING ENVELOPE

Building envelopes have always been designed and constructed as shields to the extremities of prevailing climates. The building envelopes were designed to be responsive to climate by providing large thermal masses and small openings. But the scientists of 19th century, discovered and explained the concepts of building physics of materials used in the building envelope. This was the time in 1828, when Jean Claude EngenePelet, termed the thermal conductivity of a material as K-value (now U-value) to explain its property of permeability to heat. This development paved ways for the inclusion of thermal insulation of external walls, which was seen to improve the indoor comfort conditions by excluding the incoming solar radiation. [1]The 20th century developments introduced new materials and technologies which widened the scope of design options in building envelopes. [2]

But as a result, buildings came up with large areas of windows which led to uninterrupted ingress of solar heat causing discomfort in the interiors. Such enormous amounts of solar heat gains had to be countered with the use of artificial means of cooling, which in turn increased the energy consumption of buildings. [1]The Oil Embargo and global oil crisis of 1970s, compelled the policy makers to make efforts for energy conservation in all sectors. [3]Since then, the design of building envelope has also come under the scanner for the scope of energy efficiency by using various measures.

2.0ROLE OF BUILDING ENVELOPE IN ENERGY SAVINGS

At present, a typical office building in India has an electricity consumption level of more than 200 kWh per sq. m. The integration of energy efficiency in the design of such buildings has shown an energy saving potential ranging from 20% - 40%, thus bringing down the per sq. m. energy consumption levels to 120 - 160 kWh. The energy efficient designs have also exhibited the potential of reducing the overall power demand of India to the tune of approx. 25% by the year 2030. [4]

Hence, the role of building envelope design and its thermal performance can be linked directly to the energy savings potential. For achieving these targets, there is a need to evaluate the connection of energy efficiency measures with the thermal performance of a building envelope.

2.1 Components of a Building Envelope

A building envelope or the façade of a building can be categorised into Opaque and Transparent Components. The Opaque components comprise of Walls, Roofs, basement walls and doors which are not glazed, whereas, the Transparent components consist of Windows, ventilators, skylights and completely glazed and half glazed doors.

2.1.1 Opaque Components

These components form the major part of a building envelope. Therefore, their surface area, thickness, selection of materials, colour and finishes are very important so as to limit the ingress of amount of heat gain. The thermal transmittance of materials of opaque components is generally described as U-value with units as W/m^2K . It is preferable to have low U-value materials for better thermal performance of an envelope component.

2.1.2 Transparent Components

These components consist largely of windows with glazing, which act as a medium of visual connection with the outdoors and to permit daylight into the interiors. But windows are most vulnerable to the solar heat gains and transmit a huge amount of solar radiation if suitable energy efficiency measures are not taken into account. The glazing properties are described in terms of Solar Heat Gain Coefficient (SHGC) and U-value of complete fenestration systems (including frame and glass). SHGC values are taken between 0 and 1, which indicate the heat resistance capacity of a glass. Lower SHGC and U-values are generally preferred for energy efficiency. The other term associated with glazing properties is the Visible Light Transmittance (VLT) which varies between 0 to 1 and depicts the clarity of glass for daylight transmittance. The glasses having high VLT can although lead to glare issues. [5]

3.0 BUILDING ENVELOPE DESIGN FOR BETTER THERMAL PERFORMANCE

The thermal performance of a building envelope can be improved by incorporating the design principles given in books, best practices guides and energy conservation codes. Hegger et al, have given the methodology to Reduce Heat Transfer and Incoming Solar radiation along with the geometric optimisation of the building envelope. [1] The “Energy Conservation Building Code, User Guide” (2009) and “Handbook on Energy Conscious Buildings” (2006) ask for Increasing Thermal Resistance, Thermal capacity, Shading, decreasing exposed Surface Area, and introducing buffer spaces for reducing solar heat gains. [5,6] Reshma et al, have highlighted the importance of Orientation, Optimising Massing and Fenestration sizes for decreasing the solar heat loads. [4] Koenisberger et al, in the book “Manual of Tropical Housing and Buildings”, have summarised the design objective of reducing solar gains by adopting Passive Design strategies. [7] Baruch Givoni, with his book titled “Housing, Climate and Comfort”, has advised to increase thermal capacity of the envelope components for accomplishing the objective of Reduced Heat Gain. [8] It can be summarised that the common objective/principle of improving the thermal performance of a building envelope is to “Reduce the Solar Heat Gain”. The corresponding common architectural interventions recommended by the authors in this regard are: - Orientation, Building Configuration, Shading of Windows and Thermal Efficiency of Components of a building envelope.

The Design recommendations for a composite climate, can be summed up as given below: -

1. The most preferred orientation is North-South, so that the longer facades of building face North and South directions.
2. The Surface Area to Volume (S/V) ratio of a building envelope should be on lower side to ensure compactness. [9]
3. The proportion of windows in walls facing various directions need to be optimised. This proportion is termed as Window-to-Wall (WWR) ratio.
4. Appropriate shading devices should be provided on windows in various directions.
5. Thermal insulation of opaque and transparent components should be preferred. [1]

4.0 THERMAL PERFORMANCE EVALUATION

The data related to envelope geometry, material properties, window proportions and shading can be used to understand and compare their contribution towards the thermal behaviour of a building. [10] The method of thermal performance evaluation of building envelope used in the present research is that of the mathematical equation as given in Energy Conservation Building Code (ECBC), 2017. The equation is used to calculate the Envelope Performance Factor (EPF) of a building envelope, which is the sum total of EPF of all its components, i.e., Roof, Walls and Fenestrations/Windows. [11]

$$EPF_{Total} = EPF_{Roof} + EPF_{Wall} + EPF_{Fenest}$$

$$EPF_{Roof} = C_{Roof} \sum_{s=1}^n U_s A_s$$

$$EPF_{Wall} = C_{Wall,Mass} \sum_{s=1}^n U_s A_s + C_{Wall,Other} \sum_{s=1}^n U_s A_s$$

$$EPF_{Fenest} = C_{1Fenest, North} \sum_{w=1}^n U_w A_w + C_{2Fenest, North} \sum_{w=1}^n \frac{SHGC_w}{SEF_w} A_w$$

$$+ C_{1Fenest, South} \sum_{w=1}^n U_w A_w + C_{2Fenest, South} \sum_{w=1}^n \frac{SHGC_w}{SEF_w} A_w$$

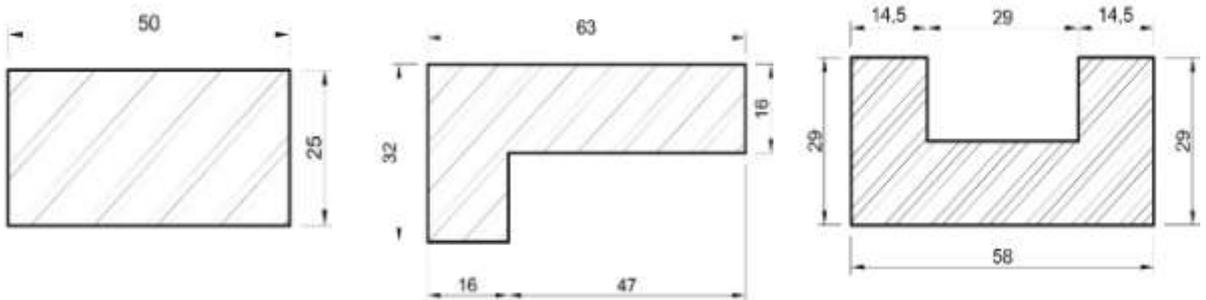
$$+ C_{1Fenest, East} \sum_{w=1}^n U_w A_w + C_{2Fenest, East} \sum_{w=1}^n \frac{SHGC_w}{SEF_w} A_w$$

$$+ C_{1Fenest, West} \sum_{w=1}^n U_w A_w + C_{2Fenest, West} \sum_{w=1}^n \frac{SHGC_w}{SEF_w} A_w$$

- EPF_{Roof} Envelope performance factor for roofs. Other subscripts include walls and fenestration
- A_s, A_w The area of specific envelope component referenced by the subscript “s” or for windows the subscript “w”.
- SHGC_w The solar heat gain coefficient for windows (w).
- SEF_w A multiplier for the window SHGC that depends on the projection factor of an overhang/ side fin.
- U_s, U_w The U-factor for the envelope component referenced by the subscript “s” / “w”
- C_{Roof} A coefficient for the “Roof” class of construction.
- C_{Wall} A coefficient for the “Wall”.
- C_{1Fenest} A coefficient for the “Fenestration U-Factor”
- C_{2Fenest} A coefficient for the “Fenestration SHGC”

Values of “C” for Composite Climate zone are taken from ECBC 2017 as given below:

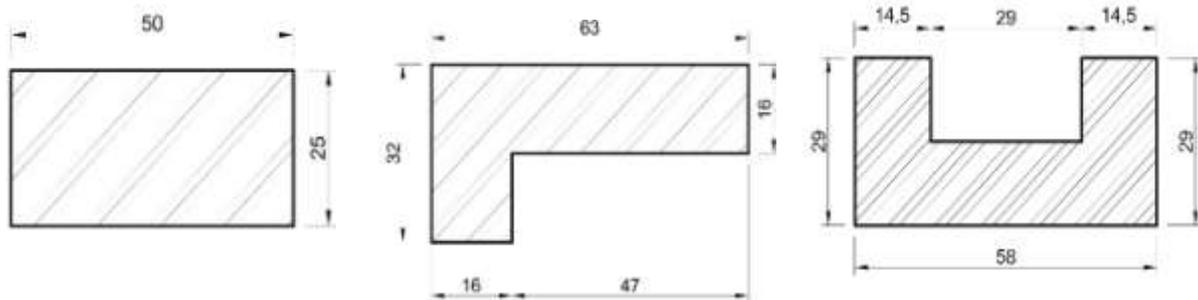
	Value as per ECBC 2017 for Composite Climate
C _{Roof}	14.93



C _{Wall}	5.39
C _{1Fenest}	0.33 (North), -2.3 (South), -1.17 (East), -0.74 (West)
C _{2Fenest}	81.08 (North), 221.07 (South), 182.64 (East), 182.11 (West)
U _s (Roof)/ U _s (Wall)	0.33/ 0.63
U _w	3.0
SHGC _w	0.5 (North), 0.27 (Non North)
SEF _w	Calculated as per the design of the shading device

Area of Building = 5000 sq. m.
 Overall Aspect Ratio = 2:1
 Height of building = 16 m
 Number of floors = 4
 Building Footprint = 1250 sq. m.

Window size = 4m x 3m
 Orientation = North-South
 (Recommended Orientation for Composite Climate as per SP-41)
 WWR = 40%
 (Max. permissible value as per recommendations of ECBC 2017)



Three types of building shapes have been taken to find out the effect of shape on Thermal performance of building envelope. Six glazing proportions have been taken by varying the proportion of glazing on all the four walls. Type I and Type IV have predominantly North glazing, Type II and Type V have predominantly South glazing, Type III is having equal glazing proportions on all sides and Type VI has predominantly East- West glazing. The shading devices in all directions have been designed as per the recommendations given in SP-41. [12]

SHAPE A- RECTANGLE S/V RATIO: 0.18	SHAPE B- L SHAPE S/V RATIO: 0.21	SHAPE C- U SHAPE S/V RATIO: 0.22
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The Architectural parameters to be compared for Conventional and ECBC cases are as mentioned in the Table 1.

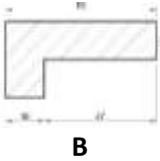
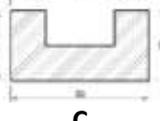
CASES	SHAPES	GLAZING PROPORTION TYPES		SHADING	MATERIALS
					U-VALUES (W/m ² K)
Conventional case without shading	 A	I	N-60%, S- 40%, E- 0%, W- 0%	NORTH: Vertical fins + Horizontal overhang 0.54 m	Conventional Case: U _{wall} = 2.1 W/m ² K U _{roof} = 2.34 W/m ² K U _{fen} = 4.786 W/m ² K SHGC: 0.692
		II	N-40%, S- 60%, E- 0%, W- 0%		
Conventional case with shading	 B	III	N-25%, S-25%, E- 25%, W-25%	SOUTH: Horizontal overhang 0.86 m	
		IV	N-50%, S- 30%, E- 10%, W-10%		
ECBC case without shading	 C	V	N-30%, S- 50%, E- 10%, W-10%	EAST WEST: Combination of Horizontal overhang and vertical fins 1.19 m	
ECBC case with shading		VI	N-0%, S- 0%, E- 50%, W-50%		

Table 1: Description of Architectural parameters considered for envelope thermal performance evaluation for 3 shapes

EPF calculations

Table 2: EPF calculations for all the glazing proportions and for 3 shapes without any shading devices to trace best glazing proportion cases

SHAPE	CASE	ORIENTATION- NORTH SOUTH WWR- 40%						Better envelope performance potential (Best as compared to worst)
		EPF CALCULATIONS WITHOUT SHADING						
		I(Dominant North)	II(Dominant South)	III(All Directions)	IV (Dominant North)	V(Dominant South)	VI(Dominant East West)	
A S/V: 0.18	Conventional	158593	174785	177154	153534 (Best Case)	169726	187620 (Worst Case)	+18%
	ECBC	58500	60662(Worst Case)	59205	54825 (Best Case)	56987	58829	+10%
B S/V: 0.21	Conventional	187672 (Best Case)	207996	210616	192876	213158	224063(worst Case)	+16%
	ECBC	71749	74462(Worst Case)	72494	71540 (Best Case)	74248	72164	+4%
C S/V: 0.22	Conventional	199272 (Best Case)	221199	224408	204941	226868	238579(worst Case)	+16%
	ECBC	77031	79959(Worst Case)	77986	76828 (Best Case)	79755	77477	+4%
Shape A having lowest S/V Ratio depicts best thermal performance potential of 18% - 22% when its best case was compared to the best performing cases of other two shapes having higher S/V Ratios								

SHAPE	CASE	ORIENTATION- NORTH SOUTH WWR- 40%						Better envelope performance potential (Best as compared to worst)
		EPF CALCULATIONS WITHOUT SHADING						
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The EPF calculations have been done for the reference building firstly considering it as a conventional building using conventional materials for the envelope and subsequently for ECBC compliant building using envelope materials with low U-Values. The first step of calculations was performed for the six types of glazing proportions for both cases with no shading on the windows. The results are given in Table 2. Thereafter, the best cases of glazing proportions were taken forward for EPF calculations with the provision of shading devices on them. The results are given in Table 3.

SHAPE	ORIENTATION- NORTH SOUTHWWR- 40%						Better envelope performance potential (With provision of shading)
	EPF CALCULATIONS						
	CONVENTIONAL CASE			ECBC CASE			
	BEST CASE	WITHOUT SHADING	WITH SHADING	BEST CASE	WITHOUT SHADING	WITH SHADING	
A S/V: 0.18	IV	153534	119977	IV	54825	40367	22% - 26%
B S/V: 0.21	I	187672	151193	IV	71540	49220	19% - 31%
	IV	192876	139921				
C S/V: 0.22	I	199272	159841	IV	76828	53335	20%- 31%
	IV	204941	149468				

5.0 ANALYSIS OF FINDINGS

The results for thermal evaluation of building envelope for the various architectural parameters can be summarised as: -

1. Surface area-to-volume (S/V) ratio

The shape A (Rectangle) having lowest S/V ratio has shown the best thermal performance potential of 18%-22% over the other shapes having larger S/V ratios (Table 2), for both conventional as well as ECBC cases. This indicates that the architectural parameter of S/V ratio plays an important role in improving the thermal performance of a building envelope with or without the use of efficient/low U-value materials.

2. Glazing Proportions

It is clearly evident that the envelopes having North dominated glazing proportions (i.e. 50%-60% of total WWR on North façade) perform far better in comparison to those in other cardinal directions. It further shows that the orientation plays a significant role in the building envelopes constructed in conventional materials (16%-18% better thermal performance potential) whereas, the role of glazing orientation in case of envelopes with efficient/low U-value materials is not that much significant (4%-10% better thermal performance potential).

3. Shading Devices

The impact of shading was studied on the best cases identified in Table 2, so as to evaluate their thermal performance potential. The results have shown that the thermal performance of a building envelope can be improved up to the tune of 26% in Rectangular buildings and up to 31% in L and U shaped buildings by the provision of shading devices.

6.0 CONCLUSIONS

The evaluation of thermal performance of a building envelope design helps in decision making by architects/building designers regarding various architectural parameters. The thermal performance of building envelopes for three shapes was calculated using the Envelope Performance Factor (EPF) equation. The findings of the present study have established the role and need of integrating thermal performance evaluation approach for a building envelope in design stage. It has also been established that a compact building having lower S/V ratio, with North dominant glazing and appropriate shading has better thermal performance as compared to other shapes considered in this study, and its thermal performance can be further enhanced with the use of low U-values envelope materials. The optimised

Orientation, WWR, glazing proportions and shading devices must be incorporated in totality in a building envelope design process so that its thermal performance can be improved to the maximum. Such an approach can lead to lower energy by the buildings so as to address the energy efficiency targets.

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The pessimist sees difficulty in every opportunity. The optimist sees the opportunity in every difficulty.

~ **Winston Churchill**