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## Optimizing Building Performance for Energy Efficiency in Cooling Buildings Sustainably

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**ABSTRACT:** Building fabric plays important role in reducing cooling loads for air conditioning and thus affect energy use intensity in buildings. Despite several national and state policies to reduce energy consumption in form of energy conservation building codes and standards, green building rating systems and other incentives, still excessive use of glass in buildings is proliferating pan India with high energy used in neutralizing building heat, irrespective of climatic context. The study examines various approaches to limit building fabric heat gain such as overall thermal transfer value, envelope performance factor and other prescriptive requirements of energy codes. The paper discusses various design parameters responsible for heat transfer in buildings. Further emphasis is on monitoring thermal conditions of buildings to assess building fabric heat gain from calculated or predicted values realistically and thus adjudge various design parameters of building envelope, particularly in a warm or composite climatic context.

**Keywords-**Energy use, Design parameters, Overall thermal transfer value (OTTV), Building fabric heat gain factor, Envelope performance factor.

### 1. INTRODUCTION

Keeping in view of recent commitments of reduction of green house gases by 30-35% by 2050 over 2005 levels and increasing gap between demand and supply of energy, demand side management of energy is significant to reduce consumption of electricity and consequently cut off carbon emission by desired levels. India's domestic energy consumption has increased from 80 TWh in 2000 to 186 TWh in 2012, and constitutes 22% of total current electrical consumption (Central Electricity Authority, 2013). With Indian economy moving up the growth trajectory of growth, urbanization to the tune of 40% people living in cities and contributing to 75% of India's Gross domestic product by 2030 and two third of built fabric is yet to be constructed by 2030 (GBPN, 2014, HPEC, 2014), energy consumption in business as usual scenario is expected to increase by four folds from 650 kWh in 2012 to 2750 kWh by 2050. Using a very aggressive policy strategy, the increase in electricity consumption could be just curtailed to 1170 kWh per household in 2050 (GBPN, 2014). Buildings contribute significantly

as much as 40% of total energy used in buildings. Whereas the other consumers of energy such as transport, industry, power generation have adopted technology for economy and efficiency in energy consumption, buildings have been sluggish in adopting energy efficiency measure and demand side management due to lack of awareness in various stakeholders including urban local bodies, professional architects, developers and owners.

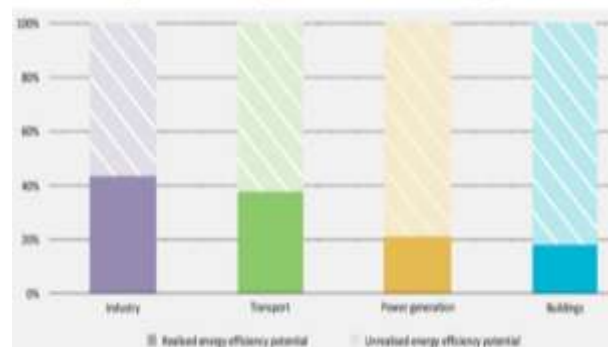


Figure 1 Untapped potential of buildings in energy efficiency

Figure 1 shows that more than 80% of energy efficiency potential in buildings are currently unrealized in existing policies (IEA, 2014).

It is also seen that due to population growth and higher urbanization rate, higher comfort expectations, indoor life style and increasing use of air conditioning to restore the thermal comfort, there is a huge potential to reduce energy consumption in buildings at a relatively lower cost than reforms in other sectors like transportation and manufacturing. Moreover in absence of grid supply, use of 100% captive power generation has caused our cities almost unbreathable and at the same time, one can experience higher temperature in cities due to higher density, vehicular emission and urban heat island effect. Air conditioning just adds to heat by rejecting the heat to outdoors, also leading to rise in temperature. Design of building fabric or envelope has a significant sensible load to be cooled and consequently impact on energy consumption in air conditioning of buildings. Architects are primarily responsible for designing building envelope, its form and geometry. This research paper explores recent concepts of limiting building fabric heat gain so as to have less cooling loads for buildings, particularly suitable for warm climates like our country.

## 2. DESIGN PARAMETERS OF BUILDING FABRIC HEAT GAIN

Various factors which affect the built environment and heat transfer are Climatic zone, Site microclimate, building form and orientation, selection of building materials, window to wall ratio and solar reflectance of the materials and as well as building typology requiring more ventilation rate.

Prajapati and Nayak (2006) has delineated various passive solar techniques to reduce heat gain and promote heat loss in different warm climatic zones. In climatic zones, when the climatic conditions are temperate or moderate like Pune or Bangalore, cooling loads are relatively less as compared to hot and dry climate or composite climate. In warm and humid climate, latent loads to remove excess moisture in humid air start dominating over sensible loads and account for increased cooling loads. Passivehaus homes in Europe consume as little as energy of 15kwh/m<sup>2</sup>/yr for cooling homes in summer in southern European countries. Sustainable energy can be saved by appropriately planned building keeping in view natural features and microclimate of the site. The formation of heat island and inversion effect can be avoided by site landscaping, tree cover or using land forms to channelize wind. Landscaping can help mitigate urban heat island effect, reduce ambient air temperature by 2-3<sup>o</sup>C and can help in reducing direct solar radiations

from heating up building surfaces. It can also provide much needed shade in tropical summers and sun, when required in winters without any fixed elements of architectural shading devices. Green roofs, vertical gardens, green walls, balcony gardens, reduce heat ingress in building and thereby reduce cooling energy demand considerably.

Building aspect ratio, form and orientation plays major role in combating heat by reducing exposed area to solar radiations through appropriate orientation. By building form and orientation the need for cooling, heating and lighting can be minimized, reducing the demand for energy. Building form can be chosen in such a way that it shades its surfaces due to its form. Self shading can be effectively designed by due to projections, recesses in façade, massing and blocking. Study of solar diagram, shading studies and computation of Shading Fraction of different orientations and effectiveness of solar shading devices in a façade can greatly minimize the energy demand in building. Shading Fraction represents ratio of the area of wall shaded to total surface area of wall for a given date and time in a particular latitude. Also zoning within the buildings for instance providing for service cores on west direction or using less occupied zones on less favorable orientation can be effectively explored by designed at no additional cost and material resource.

Building heat gain concept is largely dependent on selection of materials, their air to air thermal transmittance and penetration of solar radiations through transparent fenestrations. Factors responsible for heat gain through building envelope are conduction of heat through envelope, solar heat gain through transparent components and air changes for heat exchange. The primary elements affecting the performance of a building envelope are composite construction of materials and their resistance, thermal capacity or mass, solar reflectance of finishes, color and surfaces and position of insulation whether exterior wall insulation or over deck insulation. Comparison of commonly used different building materials is illustrated in Figure 2, showing timber having lowest U value and single glazing highest U value. For fenestrations factors such as thermal conductance, wall to window ratio, shading coefficient, shading are important to reduce solar gains.

Maximum heat gain by conductance is through roof in buildings as they receive significant solar radiation and play an important role in heat gain/ losses. Appropriate surface treatment, reflective insulation or over deck thermal insulation and air cavities in roof and walls reduce heat transmission into the building.

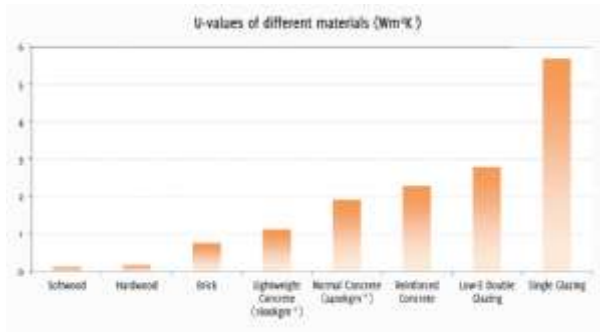


Figure 2 Comparison of U values of different materials

Solar radiations are strongest form of gains which require no medium, but transparent materials to pass through. That is why design of windows and Wall to Window ratio (WWR) play a major role in total solar gains of the building (Figure3). ECBC has prescribed WWR upto 40% maximum with SHGC 0.25 and WWR upto 60% maximum with SHGC 0.20, thereby indicating use of high performance glass, when WWR is between 40-60%. Also trade off is required between visible light transmittance and solar heat gain coefficient of glass. Use of low e glass, double glazing with air or argon gas is recommended to reduce solar gains through glass.

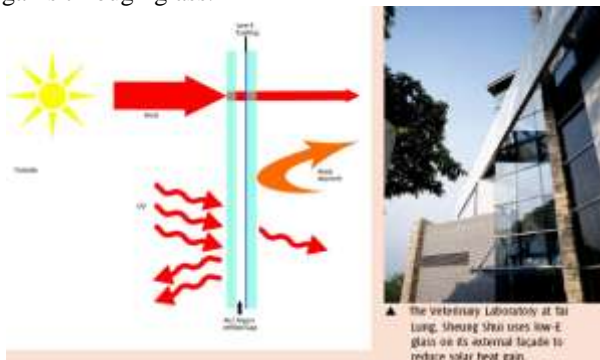


Figure3 Solar radiations through glass form major source of heat.

Energy Conservation Building Code 2006 has prescribed limiting values for thermal conductance (U values) for opaque elements, thermal mass, air tightness, surface reflectance (cool roofs) and SHGC factor for fenestrations along with wall to window ratio and shading for different climatic zones as illustrated in Table 1. Various other innovative measures can be used for enhanced thermal comfort and reducing air conditioning load of buildings such as use of double skin facades, double glazed windows, trombe wall systems, evaporative cooling, earth air tunnels, wind towers, use of lattice screens, green roofs or green facades or automatic solar shades or blinds to cut sun or admit daylight.

Table 1 : ECBC prescriptive values to control heat gain for different climates.

Climate zone	Max. Solar Heat Gain Coefficient (SHGC) Value		Max Glazing U-value *	Overall Wall Assembly U-value	Overall Wall Assembly U-value	Overall Roof Assembly U-value	Overall Roof Assembly U-value
	WWR <40%	WWR <60%	W/m²K	Day time buildings	24 hr building	Day time buildings	24 hr building
				W/m²K	W/m²K	W/m²K	W/m²K
Composite	0.25	0.20	3.30	0.440	0.440	0.409	0.261
Hot and dry	0.25	0.20	3.30	0.440	0.440	0.409	0.261
Warm and humid	0.25	0.20	3.30	0.440	0.440	0.409	0.261
Moderate	0.40	0.30	6.90	0.440	0.440	0.409	0.409
Cold	0.51	0.51	3.30	0.352	0.369	0.409	0.261

Source : ECBC User Guide 2007

Recently several innovative techniques such as double skin facades have been employed by designers to achieve energy efficient building. Double skin facades essential consists of two layers of walls with air cavity 1.2 to 2.0 m wide having integrated external shading devices. Double skin facades offer advantages that it allows adequate daylight and reduces mechanical heating and air-conditioning load by flushing out the heat due to solar radiations falling on building envelope. Computational fluid dynamic studies can help in designing the ventilation cavities to minimize heat ingress to building and at the same time ventilating building.

Apart from conduction and radiation, heat load in building is due to convection or ventilation of buildings. Natural ventilation is required to maintain fresh air for health and thermal comfort and has a direct impact on energy used in buildings. Various form of natural ventilation like stack ventilation, single or cross ventilation can be achieved by design and distribution of windows, using wind tower, courtyards, air scoop, passive energy downdraft evaporative cooling (PDEC) etc. Two stage indirect cooling or pre cooling air by earth air tunnels or spraying water with mist in courts, passive energy downdraft evaporative cooling (PDEC) etc. can be used to cool the buildings sustainably and reduce load on air conditioning plant.

It is very important to maintain requisite air changes in a given space otherwise it take no time to catch up Sick- building syndrome in buildings, reducing productivity and efficiency of people. Building codes worldwide lay down standards for ventilation. The Indian building code (IS:3362) measures ventilation provided in construction buildings in the form of number of 'air change per hour' or ACH. An air change is the ratio of volume of outside air allowed in the room

to the volume of the room in one hour. This air change is necessary to remove effects of combustion due to cooking, chemicals from paints and adhesives, printers and computing equipment in offices, and for replacing carbon dioxide with oxygen. While in living rooms the minimum ventilation standards may require only 3 air changes per hour, this requirement increases to 6 air changes per hour in kitchens due to the heat and fumes produced by cooking.

However, this treated fresh air (TFA) for pollutants and dust particles form significant load on air conditioning building. Energy efficiency should not be compromised at the cost of fresh indoor air quality. Air tightness is important factor to reduce infiltration loads in buildings. The attention should be paid to seal the windows air tight and have vestibules or air conditioning locked lobbies for avoiding losses of conditioned air.

### 3. CONCEPT OF OVERALL THERMAL TRANSFER VALUE (OTTV)

The concept of overall thermal transfer value or OTTV exists in several countries with warm climate. The use of OTTV as a building fabric heat gain for air conditioned buildings can be traced back to 1975 by the ASHRAE (ASHRAE, 1989). It has been incorporated in several countries such as Singapore, Hong Kong, Thailand, Sri Lanka and Pakistan and have evolved standards in their building codes. The OTTV standards are constantly being upgraded to improve building envelope sensitively in a climatic context rather than blatant use of glass being used even in residential buildings for sake of aesthetics and eliminated shading devices from building vocabulary. The concept and definition of OTTV involves accounting for effect of conductance of different components of building envelope i.e. roof and walls and windows coupled with orientation factor and shading fraction as well as solar heat gain coefficient of windows of different orientations, thus can be easily calculated and understood by most architects and owners in a simple way without going into complex process of building simulations.

The OTTV is defined as

$$OTTV = \frac{\sum Q}{\sum A} = \frac{Q_{wc} + Q_{gs}}{A_w + A_f}$$

Q = Total rate of heat transfer through envelope  
A = Gross area of building envelope (m<sup>2</sup>)

$$Q_{wc} = A_w \cdot U_w \cdot \alpha \cdot TD_{eq}$$

$$Q_{gs} = A_f \cdot SC \cdot ESM \cdot SF$$

A<sub>w</sub>, A<sub>f</sub> = wall and window area (m<sup>2</sup>)  
U<sub>w</sub> = U-values of wall (Wm<sup>-2</sup>K<sup>-1</sup>)  
α = solar absorptivity of wall  
TD<sub>eq</sub> = equivalent Temperature Difference (K)  
SC = Shading Coefficient of the glazing  
ESM = External Shading Multiplier  
SF = Solar Factor (Wm<sup>-2</sup>)

As heat transfer is direct function of the temperature difference of ambient air and conditioned space, the concept of OTTV serves as good indicator of impact on energy use in cooling the building, without getting in to complex predicted calculations of Energy performance calculations.

The greatest advantage of the OTTV index is that it can measure performance of a building as a single numerical index, without the use of a simulation program. The predetermined coefficients make the computation of OTTV index for any building in any of the climates very easy as any architect or building designer can use it with a simple computer spreadsheet program. OTTV is also a performance based index as it allows the building designer to make trade-offs between different envelope parameters such as U-value of opaque wall (U<sub>w</sub>), solar absorptance of opaque wall surface (α), U-value of window glass (U<sub>f</sub>), window to wall area ratio (WWR) and shading coefficient of window glass (SC).

### 4. ENVELOPE PERFORMANCE FACTOR

Another method used in building energy codes to control building fabric heat gain is Environmental Performance Factor (EPF). The resultant EPF is sum total of Envelope performance factor of individual components i.e. roof, walls and fenestrations including skylight. This method can be used in trade off option as defined in Appendix D of Building Envelope Trade off method (Prescriptive Method) for code compliance of buildings as per Energy conservation Building Code (ECBC)2007, thus offering flexibility to designers.

The trade-off method sets values for individual building parts and / or for parts of the installations, akin to the prescriptive method. However, in meeting a general standard for efficiency, a trade-off can be made between the efficiency of some parts and installations such that some values are exceeded while others are not met. The trade-off is generally made in simple terms. Trade-off can be made between U-values for the building shell or between building shell and the energy efficiency requirements for heating and cooling installations. The trade-off model provides more freedom and flexibility than the prescriptive method.

to do by hand or in a simple spreadsheet

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

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

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

$$EPF_{Fenest} = C_{1Fenest, North} \sum_{W=1}^n SHGC_W M_W A_W + C_{2Fenest, North} \sum_{W=1}^n U_W A_W +$$

$$C_{1Fenest, NonNorth} \sum_{W=1}^n SHGC_W M_W A_W + C_{2Fenest, NonNorth} \sum_{W=1}^n U_W A_W +$$

$$C_{1Fenest, Skylight} \sum_{s=1}^n SHGC_s M_s A_s + C_{2Fenest, Skylight} \sum_{s=1}^n U_s A_s$$

where

$EPF_{Roof}$  : Envelope performance factor for roof. Other subscripts include walls and fenestration.

$A_s, A_w$  : The area of a specific envelope component referenced by the subscript "s" or the window the subscript "w".

$SHGC_w$  : The solar heat gain coefficient for windows (w). SHGCs refers to skylights.

$M_w$  : A multiplier for the window SHGC that depends on the projection factor of an overhang or awning.

$U_s$  : The U-factor for the envelope component referenced by the subscript "s".

$C_{Roof}$  : A coefficient for the "Roof" class of construction.

$C_{Wall}$  : A coefficient for the "Wall".

$C_{1Fenest}$  : A coefficient for the "Fenestration I".

$C_{2Fenest}$  : A coefficient for the "Fenestration II".

Table 2 Envelope performance coefficients for composite climatic zone

	Daytime occupancy		24 Hour occupancy	
	U factor	SHGC	U factor	SHGC
Mass walls	6.01	-	13.85	-
Curtain walls	15.72	-	20.48	-
Roofs	11.93	-	24.67	-
North windows	-1.75	40.65	-4.56	58.15

In criteria under Energy, among other benchmarks, The GRIHA Version 2015 (2016) has specified building envelope peak heat gain factor so as to curb the blatant use of glass in building facades omnipresent across the country as per Table 3.

Table 3 Building Envelope Peak Heat Gain Factor

GRIHA Thresholds for Building Envelope Peak Heat Gain Factor W/m <sup>2</sup>	
Climate	Threshold
Composite/Hot & Dry	40
Warm and Humid	35
Moderate	30

Source: ( GRIHA Version 2015, 2016)

It has also separately prescribed EPI benchmarks for residential buildings/Hostels as 50 kWh/ m2/year in moderate climates and 70 kWh/ m2/year in composite, warm & humid and hot and dry climate zones in the

country. One has to demonstrate through simulations that project EPI is below GRIHA benchmark and additional reduction in EPI are awarded points 2,3,5,7,10 for reducing EPI 10 %, 20%, 30%, 40%, 50% from benchmark respectively.

## 5. MONITORING BUILDING PERFORMANCE FOR BUILDING FABRIC HEAT GAIN

There is a huge potential to reduce cooling load and hence carbon foot print by monitoring building performance with regard to building fabric heat gain and energy conserving measures.. In practice, there is a dearth of quantified data on thermal performance ,occupant comfort user perception and behavioral responses in relation to energy consumption to even designed energy efficient green buildings. Rarely do energy audits or energy performance evaluations take into account thermal performance of buildings as well as occupants' comfort and their aspirations as to how the building ought to perform. The provision of feedback, to occupants, operators and designers, is seldom recognized as a key element to the successful use, implementation and design of buildings.

As proposed in part 11 to National building Code of India 2005(SP:2007) to incorporate a new part 11 Approach to Sustainability), Subsequent to commissioning and handover stage of building to the owner, Regular Monitoring of the performance shall be carried out which will provide information whether set environmental performance and targets have been met or not. Attributes of building performance tracking(Measurement and Verification include

- Monitoring of technical and energy performance after occupancy, to ensure performance targets during operation of building by energy metering for energy consumption pattern by end use.

b) Conducting Occupant survey annually for obtaining feedback from users for identifying possible areas of improvement and implementing rectifications accordingly.

Use of data loggers to measure and monitor ambient air temperature, and humidity can give idea of building fabric heat gain in a particular day, month, season or annual basis. Also one can find out building fabric heat gain peak loads. The monitoring of temperature and humidity in inside buildings can help in exploring whether solar gains predicted in design / simulations/ simple spread sheets is akin to the one observed on real time basis.

## 6. CONCLUSIONS

This research paper explores approaches in calculating building fabric heat gain so as to have less cooling loads for buildings, particularly suitable for warm climates like our country. Effect of different building materials and thermal insulations, quantification of heat gain can lead to optimization of building envelope. Concept of OTTV as used in several countries and recently by GRIHA v5 2015 is extremely useful concept to limit blatant use of glass for sake of aesthetics in the composite climatic context of India. Envelope performance factor is a similar approach used in ECBC 2006 to calculate building envelope performance, but it does not give any absolute numbers as an indicators. There is a need to monitor thermal performance of buildings for understanding behavior of building fabric heat transfer from calculations to be validated by measurements of thermal comfort parameters. Various approaches used in OTTV, EPF or monitoring can help in reducing energy demand in case of air conditioned spaces and also help in choosing retrofitting measures to be taken in both naturally ventilated and as well as conditioned spaces. Building fabric heat gain data can serve as a useful tool for designers to understand comparative studies of behavior of different components of building envelopes with different materials, thermal mass different geometrical considerations, surface to volume ratio, orientation, use of shading devices etc.

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