GREEN BUILDING ENVELOPE DESIGN BY TRADE-OFF METHOD-AN OVERVIEW AND A CASE STUDY

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Abstract

Building consumes considerable amount of energy and leaves 'carbon foot prints'. In ancient days, zero energy materials like stone, soil, thatch / leaves and unprocessed timbers were used in construction, whereas, considerable amount of energy is being utilized for the production of modern materials. The envelope of a building transmit solar infrared rays inside buildings and cause discomfort to the occupants which inturn requires considerable energy for enhancing the comforts of occupants to the desired level. Use of low thermal resistance materials (ie less U-factor) in construction industry will provide not only comfortability but also save energy. In this contexts, various design approaches in green buildings is helpful to the Engineers, Architects in the planning and construction of energy- efficient buildings. This paper highlights the use of various thermal resistance materials, and the various approaches in the design of green buildings. A simple case study is presented to show the steps used in the design of green buildings by the trade-off method and to highlight the usefulness and flexibility of the method.

Key words: Green Building, Thermal resistance, Thermal conductivity, Trade-off method, Building envelope.

I. INTRODUCTION

In ancient days, buildings were constructed with zero energy material like stones, soil, thatch / leaves and unprocessed timber etc. Energy is required for manufacturing modern construction materials (ie bricks, metals, lime and lime–based products, inorganic binders like pozzolanic materials, Portland cement and steel, plastic and plastic products). As the Indian construction industry moved away from the zero energy materials to modern materials, it became unavoidable to spend more energy and natural resources. As the Indian construction industry is the largest producer of materials when compared to any other industry including agriculture, the higher utilization of energy in construction sector will eventually release higher Green House Gases (GHGs). In India, the construction industry consumes 33% of electricity in which residential sector consumes 25%, whereas, the commercial sector consumes 8%. The construction sector is also responsible for 30% of GHG emissions. Well developed countries like US and in the EU it has been mandated that sustainability in buildings be considered in the planning, design and construction phases where as in India even awareness is lacking on the energy efficiency parameters and design of buildings. Hence, in this paper a brief overview of desirable properties of thermal resisting building materials, some of the standard thermal resisting materials used, compliance approaches for designing green buildings have been highlighted. The design of a green building envelope by the 'trade-off method' and its usefulness has been highlighted by a simple case study projects the integrated approach to design envelope in green building. India is a electricity deficit country which will overcome to build energy saving buildings according to ECBC provisions which provides comfort to people with minimum energy use and thereby saving money.

II. BUILDING ENVELOPE AND HEAT TRANSFER IN A BUILDING

The building envelope refers to the exterior façade, and is comprised of opaque components and fenestration systems. Opaque components include walls, roofs, and opaque doors, whereas, fenestration systems include windows, skylight, ventilators and doors that are more than one-half glazed. The envelope protects the buildings interiors and occupants from the weather conditions and shields from other external factors, such as, noise, air pollution etc. Envelope design is responsible for the visual and thermal comfort of the occupants. Heat from the Sun is transferred to building / building envelope in three ways: conduction, convention and radiation. Conduction is the transfer of heat by direct contact of particles of matter within a material or materials in physical contact, whereas, convection is the transfer of heat by the movement of fluid (ie air or gas or liquid). Radiation is the movement of energy / heat through space without relying on conduction through the air or by the movement of air. The electromagnetic waves which are emitted from the surface of the sun known as solar radiation/short wave radiation, have wave length in the range of 0.3 to 2.5 microns, and consists of three components: ultra violet (UV), visible (Visible to human eye) and solar or near infrared. The solar infrared is responsible for the transfer of heat in the buildings, when it comes in contact with a building, and this phenomenon is known as solar radiation heat transfer.

III. THERMAL RESISTANCE OF BUILDING MATERIALS

Conducive heat transfer through the building envelope also depends upon the conductivity of the building materials used. Different materials offer different thermal resistance to the conduction process. Hence it is important to establish overall thermal resistance R-value and heat transfer coefficient (referred as U-factor) which is also termed as thermal transmittance. Thermal resistance (R) is proportional to the thickness of materials of construction and inversely proportional to its conductivity. The building envelope comprising of different layers and hence the total thermal resistance (R_T) is calculated by Eqn. (1).

$$R_T = R_{si} + R_t + R_{se} \qquad ...(1)$$

Where, R_t is the thermal resistance of the component in the wall/roof; $R_t = R_1+R_2+\ldots\ldots+R_n$; R_{si}-interior surface thermal resistance & R_{se}-exterior thermal resistance. ECBC user guide provides the values of surface film resistance (R_{si} and R_{se}) based on direction of heat flow and the thermal resistance of unventilated layers between surfaces with high emittance (ie thickness of air layer Vs thermal resistance). As the thermal resistance (R) is also the reciprocal of thermal conductance (U) (ie R = 1/U), U-factor or $U=R_T$.

A. Types of thermal resistance materials

Thermal resisting building materials are used to protect the occupants from heat and cold. These materials are generally porous and their properties are governed not only by their porosity, but also by the nature of pores open or closed, their distribution and size. Materials with a greater number of fine, closed and air-filled pores are the best thermal resisting materials and the bulk density of these materials is usually below 7000 N/m^3. The low heat conductivity of these materials is due to the air-filled pores. The thermal resisting materials should be protected against the moisture since the coefficient of heat conductivity of water is about 25 times higher than that of air. The choice of thermal resistance materials is based on the following parameters: cost of materials, area to be covered, standard of resistance required and cost of heating or cooling. Good quality of thermal resisting materials are: reasonably fire proof, does not absorb moisture, higher resistance against the attack of insects and do not undergo deformation. Some of the standard thermal resisting materials used in construction industry in India are: rock wool, slag wool, fiber board, flexible blankets, saw dust, wood shavings, cork board slabs, mineral wool slabs, aluminum foils, products of cement concrete with light weight aggregates, gypsum boards, asbestos cement boards, chip boards, foam glass, gasket cork sheet and foam plastic etc. Now a days, the extruded polystyrene (XPS), polyurethane foam (PUF) and expanded polystyrene (EPS) is used in most of the buildings in India and in well developed countries like US & EU as thermal resisting materials. The thermal resistance and thermal conductivity of some of the common building and insulating materials are commonly available in standard text books (for example: Engineering materials by S.C. Rangawala) Heat is lost or gained through the wall or fenestration (ie windows, skylights, ventilators and door that are more than one-half glazed) by conduction, convection and radiation, when there is a temperature difference between the inside and outside of a building. The U-factor is the rate of heat flow through one square meter of building component (ie through wall or fenestration) when the difference in temperature between the inside and outside of a building is 1°C. Thermal resisting building materials possesses lower U-factor (ie the thermal conductivity is low). In India the climate zones in which the buildings are located are classified into five zones, namely: composite; hot and dry; warm and humid; moderate and cold. The recommended values of U-factor and thermal resisting values (R-value) for wall, roof and fenestration are provided in ECBC user guide, July 2009.

IV. COMPLIANCE APPROACHES FOR DESIGNING GREEN BUILDINGS

Three compliance approaches are used for designing green building, namely: (i) prescriptive method, (ii) whole-building performance method (iii) trade-off method.

A. Prescriptive Method

This approach specifies the minimum energy efficiency parameters for various components and systems of the proposed building. It covers building envelope, HVAC systems, service hot water and pumping, lighting systems, electric power. This method requires little energy expertise. However it is a rigid approach.

B. Whole-building Performance Method

This approach allows code compliance for optimizing the energy usage in various building components and systems. It also covers building envelope, HVAC systems, service hot water pumping, lighting system and electric power. This approach is more complex than the prescriptive method. However, it offers considerable flexibility in design and requires an approved, computer software program to model a proposed design and compare it with the standard design of the building.

C. Trade-off Method

This approach is a system-based one. The thermal performance of the individual envelope components can be less but the overall performance complies with ECBC provisions. This approaches offer more flexibility. However, it applies to building envelope only. To that extend this method has a limitation. Of the three methods, trade-off method can be used if one is concerned with the design of 'building envelope' only, due to its inherent advantage. Hence, in this paper trade-off method has been selected to illustrate the design of a green building (envelope) by choosing a simple case study.

V. DESIGN OF BUILDING ENVELOPE BY TRADE-OFF METHOD

In this method, the envelope performance factor shall be calculated using the following equations.

$$EPF_{Total} = EPF_{Roof} + EPF_{wall} + EPF_{Finest} \qquad ...(2)$$

$$EPF_{Roof} = C_{Roof} \sum_{s=0}^{n} U_s A_s \qquad ... (2\ (a))$$

$$EPP_{Wall} = C_{Wall\ Mass} \sum_{r=1}^{n} U_E A_E \, C_{Wall\ other} \sum_{s=1}^{n} U_s A_s \qquad ... (2\ (b))$$

$$EPF_{Fenest} = C_{1\ Fenest\ North} \sum_{w=1}^{n} SHGC_W M_W A_W +$$

$$C_{2\ Fenest\ North} \sum_{w=1}^{n} U_w A_w +$$

$$C_{1\ Fenest\ Non\ North} \sum_{w=1}^{n} M_w + A_w +$$

$$C_{2\ Fenest\ Non-North} \sum_{w=1}^{n} U_w A_w +$$

$$C_{1\ Fenest\ sky\ light}\ SHGC_S M_s A_s +$$

$$C_{2\ Fernest\ sky\ light} \sum_{r=1}^{n} U_s A_s$$

ECBC user guide provides the values of coefficient C for main walls, curtain walls & others, roofs, north windows, non-north windows and skylights. The 'M' multiplication factor can be calculated for overhangs and side fins using the following equation: $M = a.PF^2 + b.PF + 1$

Where a & b are coefficients for overhang and side fins, which depend on the orientations, namely: north, south or east/ west. The standard values are given in ECBC user guide. The abbreviations in Equations. 2, 2 (a) to 2 (b) are described below:

EPF_{Roof}	:	Envelope performance factor for roofs. Other subscripts include walls and fenestration
A_s, A_w	:	The area of a specific envelope component referenced by the subscript "s" or for window the subscript "w"

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

M_w : A multiplier for the window SHGC that depends on the projection factor of an overhang or side fin

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"

$C_{1\ Fenest}$: A coefficient for the "Fenestration 1";

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

VI CASE STUDY

The use of trade-off method for the design of a building envelope is illustrated by a simple chosen case study described below. For the case study, a building of size: 50 m length, 30 m breadth, 3 m height and having fenestration of 10 sqm on each façade was chosen. The building was assumed to be located in a hot and dry climate zone. The energy performance factor (EPF) for roof assembly, wall and fenestration were calculated using the equations for trade-off method, described earlier (in section V). The total energy performance factor is the sum of the EPF of roof assembly, wall and fenestration. The step by step procedure for calculating EPF has been worked out and given in Appendix-A. The case study clearly projects that if the U-factor for roof is kept higher, as one option, then, the U-factor of wall can be improved (ie U-factor can be reduced) for complying with the ECBC code. In the same way the U-factor for other alternative such as change in SHGC or change in U fenest can be also be explored. Thus, the in-built flexibility in the method can be taken advantage to obtain tailored solutions for each individual buildings.

VII. CONCLUDING REMARKS

Desirable properties of thermal resisting building materials, some of an standard thermal resisting materials used in construction industry have been highlighted. A brief overview of the compliance approaches for designing green building, and the merits and limitation of trade-off method for the design building envelope, the equations used for calculating the envelope performance factor (EPF) have been highlighted. It is hoped that his paper will create awareness in construction industry and occupants for the use of energy efficient (Thermal resistance) building materials in buildings. If the energy efficient buildings are constructed by using the thermal resisting envelope materials, it will considerably reduce the electricity demand and there by save energy for future use.

VIII. REFERENCES

[1] Bureau of Energy Efficiency, Govt. of India, 2009, "Energy Conservation Building Code (ECBC)", user guide, July.

APPENDIX – A

Calculation showing ECBC compliance using trade-off method

Description and location of building:

Build size: 50 m length, breadth 30 m, 3 m height, having 10 m^2 fenestration on each façade (North), 30 m^2 (Non-north)

Location: Hot and dry climatic zone

Step 1: Determination of upper limit of envelope performance factor (EPF) for wall, roof and fenestration using prescriptive values:

(a) $$EPF_{Roof} = C_{Roof} \sum_{s=1}^{n} U_s A_s = 10171.17$$

(b) $$EPF_{Wall} = C_{Wall,\ Mass} \sum_{r=1}^{n} U_s A_s +$$

$$C_{Wall\ other} \sum_{r=1}^{n} U_s A_s = 3170.1$$

(In this case it has been assumed that there is no curtain wall)

(c) $$EPF_{Fenest} = C_{1\ Fenest\ North} \sum_{w=1}^{n} SHGC_w M_w A_w +$$

$$C_{2\ Fenest\ North} \sum_{N=1}^{n} U_w A_w +$$

$$C_{1\ \text{Fenest Non North}} \sum_{w=1}^{n} SHGC_w M_w A_w +$$

$$C_{2\ \text{Fenest Non North}} \sum_{w=1}^{n} Uwubw A_w +$$

$$C_{1\ \text{Fenest sky light}} \sum_{w=1}^{n} SHGC_s M_s A_s +$$

$$C_{2\ \text{Fenest skylight}} \sum_{s=1}^{n} U_s A_s = 821.98$$

(Assuming there is no skylight and no shading device used on windows)

EPF_{Total} = EPF_{Roof} + EPF_{Wall} + EPF_{Fenest} = 10171.17 + 3170.1 + 821.98 = 14163.25

Step 2: Determination of EPF of proposed building using actual U-factors and SHGC.

Assuming that in place of using U Roof of 0.261, the roof of proposed building has U-factor of 0.3.

$EPF_{roof\ new}$ = 25.98 × 0.3 × 1500 = 11691

Similarly, if U-factor of wall/fenestration and SHGC are different from the prescriptive requirement, new $EPF_{Wall,}$ EPF_{Fenest} are to be calculated. In this case, let us first assume that the wall and fenestration meet the prescriptive requirements.

The EPF of proposed building is:

$EPF_{Total\ new}$ = 11691 + 3170.1 + 821.98 = 15683.08

Step 3: Comparison of EPF through perspective route and EPF_{new} through actual specifications show that the later is higher than the $EPF_{perspective}$. Hence, the building is not complying with the ECBC.

Step 4: Now even with the roof having inferior U-value (0.4 against the requirement of 0.261), the EPF is to be brought down to the level of $EPF_{perspective}$ i.e. 14163.25, in this case. This may be done by several options related to wall or fenestration.

In the example given above, through back calculation, it can be found that for bringing down the EPF_{new} to the level of $EPF_{prescriptive}$ = 14163.25 and with EPF_{Roof} being 11691 and no change in fenestration, (EPF_{Fenest} = 821.98), the maximum EPF_{wall} can be:

$EPF_{wall\ new}$ = 14163.75 − 11691 − 821.98 = 1650.77

Step 5: For the target $EPF_{Wall\ new}$ = 1650.77, the required U_{Wall} new can be calculated through back calculation.

$$EPF_{\text{wall}} = C_{\text{Wall}} \sum_{i=1}^{n} U_s A_s$$

$$U_{\text{wall}} = \frac{1650.77}{15.01 \times 480} = 0.23$$

This means that due to certain limitation, if in place of having U-factor of roof equal to 0.23, it is kept as 0.3, as one options, U-factor of wall can be improved from 0.44 to 0.266 for complying with the code. Similar to the method of calculating revised U-factor for wall, other alternatives such as change in SHGC or change in U_{Fenest} can also be explored. It is important to note that change in specification through 'trade-off method' would vary from case-to-case and therefore need to be calculated separately for individual building and for individual solution.

D. Sandanasamy Presently working as Principal, Karaikal Polytechnic College, Karaikal and engaged in research in the area of green building concept and energy efficient design of buildings. Has nearly 23 years of experience in teaching in Civil Engineering. Has published nearly 10 papers in reputed conferences at National/ International level. Research areas include: green building concept, energy efficient design of buildings, green ratings of buildings.