Residential Characterization

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1. Executive Summary

As India is moving rapidly towards sustainable development there is a tremendous need for the good energy efficient policies. Especially when one looks at the Building Energy Sector, as it contributes to one-third of the whole energy consumption. The Ministry of Power, Govt. of India has taken an initiative towards developing and implementing the Energy Conservation Building Code in 2007, which was further been revised in 2016 with considerations for residential sector along with other building typologies. It sets certain standards for building energy conservation for building envelope, HVAC, etc. That help design energy-efficient buildings, promising huge savings in future energy consumption.

Since there is lack of acts that mandate ECBC implementation at State or at ULB level, it's difficult to observe its impact on a larger scale. The demonstration of large-scale benefits would help decision makers to achieve wide-scale implantation of this code. Following the same line of thought, this study focuses on residential characterization of ECBC at city/state levels.

This study tries to use Overall Thermal Transfer Value (OTTV) as performance criteria other than the Energy Performance Index (EPI). As EPI only shows the energy usage index of that building, but it lacks the ability to define which factors in the building are leading to higher energy consumption. Whereas OTTV directly talks about the thermal performance of the building envelope. It provides huge opportunity to play with wall construction and window material, envelope design, WWR, building orientation, etc. to provide the most efficient building envelope with minimal cost.

The study demonstrates literature resources to determine OTTV, as well as has attempted to develop an online web-based tool for calculation of OTTV, also known as OTTV Calculator.

2. Introduction

ECBC (2016) is based on multiple building typologies pre-defined in the National Building Code (NBC). NBC applies to residential buildings also. Several organizations such as the Central Public Works Department (CPWD), Housing and Urban Development Corporation (HUDCO) and National Housing Board (NHB) have prepared guidelines for energy efficient or sustainable residential design. Periodically, various state and national level organizations have released residential guidelines related to redevelopment after a natural disaster, or slum rehabilitation or low-cost mass-housing. The recent Indo-Swiss bilateral project also published guidelines specifically focused on thermal comfort and energy efficiency in the residential sector. The Global Building Performance Network, PRAYAS and NHB have conducted studies to understand residential energy consumption. CARBSE also contributed to build on to this collective knowledge to provide a comprehensive understanding of the residential sector in India vis-à-vis issues pertaining to energy efficiency.

Initially, the proposed work focused on secondary sources to study residential typologies, construction practices, design parameters and campus level planning. The first phase of the activity was focused on identification of guidelines, mandates, and players in housing sector along with mapping of agencies, their contribution, roles, and responsibilities laid down by them and for them. The literature on the history of mass housing in India and the state of affairs involved were studied. It also included the study of Pradhan Mantri Awas Yojana and Housing for all mission. Roles and responsibilities of ministries at Central, State, Municipal Corporations, Municipalities were analyzed. Role of HUDCO, HSMI and such other institutions had been studied. Role of private developers in Affordable housing in Partnership has been studied.

Existing status of Ahmedabad City based on four verticals of Pradhan Mantri Awas Yojana – "In situ" Slum Redevelopment, Affordable Housing through Credit Linked Subsidy, Affordable Housing in Partnership and Subsidy for beneficiary-led individual house construction was studied.

It had extracted information from national and state level programs. It also covered configurations by economic groups and in urban and rural context. The study attempted to bring out inferences focused towards climate responsiveness, thermal comfort, electricity consumption and integration of renewable energy. By identifying research and information gaps, this work proposed to advance the understanding of climate responsiveness, thermal comfort, electricity consumption and integration of renewable energy in residences and to offer a good foundation for the residential energy conservation work in future.

CARBSE was supposed to deliver outcomes such as (i) nature of energy efficiency codes or guidelines for residential buildings, (ii) the various energy efficiency performance metrics that could be explored to enable implementation and enforcement of energy efficiency codes and (iii) the way the issues of code implementation and enforcement be addressed when it comes to the residential sector. The study would help BIS and BEE in devising a framework for residential energy efficiency codes.

In the context of BEE developing residential code, CARBSE has helped SDC-BEEP team to technically evaluate code approach based on over all thermal transfer value. Due to the rapid development of residential code at BEE, CARBSE team had placed constraints on original work plan under SSEF project. To assist BEE role out residential code, CARBSE team took up an activity to develop early design stage computational tool to help building owner and architects to evaluate their design against proposed residential code. First, a CSV format based tool was developed. Later CARBSE team was hoping to integrate it with a graphical user interface such as Google Sketch-up. And hence an online tool was developed to calculate Overall Thermal Transfer Value (OTTV) based on various equations followed by different countries.

3. Literature Review

The American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) in 1975 were the first body to introduce the OTTV method. A number of countries like Singapore, Hong Kong, Malaysia, Thailand, etc. have adopted mandatory requirements on energy conservation for buildings as shown in Figure 1.

Sr. No.	Country	Year	Status	OTTV (walls)	OTTV (roof)
1.	Singapore	1979	Mandatory	45 W/m^2	45 W/m^2
2.	Malaysia	1989	Voluntary	45 W/m^2	25 W/m^2
3.	Thailand	1992	Mandatory	45 W/m^2	25 W/m^2
4.	Philippines	1993	Voluntary	48 W/m^2	---
5.	Jamica	1992	Mandatory	55.1 – 67.7 W/m^2	20 W/m^2
6.	Hong Kong	1995	Mandatory	Tower – 35 W/m^2 Podium – 80 W/m^2	

Figure 1 History of OTTV

Source: Vijayalaxmi, J. "Concept of overall thermal transfer value (OTTV) in design of building envelope to achieve energy efficiency." Int. J. of Thermal & Environmental Engineering 1.2 (2010): 75-80.

Overall Thermal Transfer Value (OTTV): How to Improve Its Control in Hong Kong, Sam C. M. Hui says to achieve sustainability and economic competitiveness, it is important for Hong Kong to promote energy efficiency in buildings and control building energy consumption. The OTTV standard is the first step towards this objective; the second step and so on are urgently needed. The success of the building energy standard depends on the will of the Government to persist with the policy, the back-up of research and development, and the co-operation of the professionals to accept any initial inconvenience. It is hoped that a more comprehensive building energy standard integrating all aspects of architectural and building services designs can be developed in the coming future.

*Green Building Assessment Based on Energy Efficiency and Conservation (EEC) Category at Pascasarjana B Building Diponegoro University, Semarang, Rahayu Indah Komalasari, P. Purwanto, S. Suharyanto*demonstrated that green building is a concept in which development should be implemented with environmental principles, start from design, construction, operation, and management. There is one of two prerequisites which is not met criteria due to the unavailability of the electrical sub-meter system. Total OTTV is 32.95 W/m2 which is eligible below the maximum standard in Indonesia. Lighting and vertical transportation have met the benchmarks as an electrical energy saving equipment. The air condition system is not fulfilling the criteria due to the percentage of COP that under the minimum standard. So did the natural lighting, from direct measurement it could not meet the standard. The criteria for ventilation and climate change impact already meet the standard of each criterion. The last, for the bonus criteria, could not be achieved due to the unavailability of the renewable energy system in this building. Therefore, the total points that Pascasarjana B Building earned from all criteria are 10 points. This means that the building achieved 38.46% of total category points.

Optimizing Building Performance for Energy Efficiency in Cooling Buildings Sustainably, Ar. Neeti Garg, Dr Ashwani Kumar, Dr. Satish Piprralia and Dr. Parveen Kumar 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. The concept of OTTV as used in several countries and recently by GRIHA v5 2015 is an extremely useful concept to limit the 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 indicator. There is a need to monitor thermal performance of buildings for understanding behaviour 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 the 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.

An OTTV-based energy estimation model for commercial buildings in Thailand, Surapong Chirarattananon, Juntakan Taveekun postulates on the cooling requirement and energy consumption of the four types of commercial buildings are shown in this paper to be respectively verified through parametric runs using the DOE-2 program and validated by energy audit reports of real buildings. The relationships postulated are simple and natural even though the dynamic relationships between the driving forces and resultant energy-related terms in a building are complex. It is expected that the results would contribute towards energy conservation efforts, both in works related to energy code compliance and in energy monitoring efforts.

American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Standard 90 in 1975 was first to propose the OTTV requirement. The general OTTV equation is used in the United States, Singapore and other parts of Southeast Asia.

The general equation, for OTTV calculation, for external walls consists of three major components:

a. Conduction through the opaque wall, Q_{wc}.
b. Conduction through window glass, Q_{gc}. And
c. Solar radiation through window glass, Q_{gs}.

$$OTTV = \frac{Qwc + Qgc + Qgs}{A}$$

Where, A = Total wall area, (m^2)

$$OTTV_w = \frac{(A_w . U_w . TD_{eq}) + (A_F . U_f . \Delta T) + (A_F . SC . SF)}{(A_w + A_f)}$$

- Where, A_w , A_f = wall and window area (m^2) ; A = A_w + A_f
  U_w,U_f = U – Value of walls and window (W/m^2. K) W/m^{2}°C
  TD_{eq} = equivalent Temperature Difference (K)°C
  SC = Shading Coefficient of window glass
  SF = Solar Factor (W/m^2)
  ΔT = Temperature difference between exteriors and interiors design condition (K)°C

- For Equivalent Temperature Difference, TD_{eq}:

Table 1 Equivalent Temperature Difference as per ASHRAE Standards

Wall Construction – mass per unit area		**TD_{eq}**	
Lbs/ft²	**Kg/m²**	**F**	**°C**
0 – 25	0 - 125	44	24.5
26 – 40	126 - 195	37	21.0
41 – 70	196 - 345	30	17.0
71 and above	346 and above	23	13.0

Source: ASHRAE Standard 90 – 1975

Later further addition was done to these equations in *ASHRAE Standard 90A – 1980,* for roofs/ceilings as follows:

$OTTV_R$

In SI Units (W/m^2):

$$26.8 \geq \frac{(U_R * A_R * TDeq_R) + (434.7\, A_S * SC_S) + (U_S * A_S * \Delta T_S)}{(A_R + A_S)}$$

In Conventional Units ($Btu/h.ft^2$):

$$8.5 \geq \frac{(U_R * A_R * TDeq_R) + (138\, A_S * SC_S) + (U_S * A_S * \Delta T_S)}{(A_R + A_S)}$$

- Where,
  U_R = the thermal resistance of all elements of the opaque roof/ceiling area, ($W/m^2 °C$)
  A_R = opaque roof/ceiling area, (m^2)
  $TDeq_R$ = Equivalent Temperature Difference (°C)
  A_S = skylight area, (m^2)
  SC_s = shading coefficient of the skylight
  U_S = the thermal resistance of the skylight, ($W/m^2 °C$)
  ΔT_S = temperature difference between exterior and interior design conditions, (°C)

The code on Envelope Thermal Performance for Buildings, Building and Construction Authority aims to assist architects and professional engineers to comply with the envelope thermal performance standards prescribed in the Building Regulations.

Since 1979, the Building Control Regulations had prescribed an envelope thermal performance standard know as Overall Thermal Transfer Value (OTTV). The OTTV standard applied only to air-conditioned non-residential buildings.

Based on the results of an NUS study commissioned by BCA, the ETTV concept was extended in 2008 to cover residential buildings. As the air-conditioners in residential buildings are usually turned on in the night, the envelope thermal performance standard for residential buildings is given the name Residential Envelope Transmittance Value (RETV) so as to differentiate it from ETTV, which is meant for buildings that operate the air-conditioning system during the day.

1. This Code covers the following Envelope Thermal Performance Standards: Envelope Thermal Transfer Value (ETTV) for air-conditioned non-residential buildings.
2. Roof Thermal Transfer Value (RTTV) for air-conditioned non-residential buildings (with skylight).
3. Residential Envelope Transmittance Value (RETV) for residential buildings.

4. Roof insulation for air-conditioned non-residential buildings (without skylight) and residential buildings.
   - Formula for **ETTV** :
     $ETTV = 12(1 - WWR)\, U_W + 3.4(WWR)\, U_F + 211(WWR)\,(CF)\,(SC)$
   - Formula for **RTTV** :
     $RTTV = 12.5\,(1 - SKR)\, U_R + 4.8\,(SKR)\, U_S + 485\,(SKR)\,(CF)\,(SC)$

     SKR = skylight area/ gross area of roof
   - Formula for **RETV (Residential Envelope Transmittance Value):**
     $RETV = 3.4\,(1 - WWR)\, U_W + 1.3\,(WWR)\, U_F + 58.6\,(WWR)\,(CF)\,(SC)$
   - **Criteria for RETV**:
     $WWR_{Bldg} < 0.3$ and $SC < 0.7$

     Or

     $WWR_{Bldg} < 0.4$ and $SC < 0.5$

     Or

     $WWR_{Bldg} < 0.5$ and $SC < 0.43$

     WWR = Window to Wall Ratio

     SC = Shading coefficient of fenestration = $SC_{glass} \times SC_{Shading\ device}$

     Otherwise detailed RETV is needed to be calculated.

Parameterization Study of the Overall Thermal-Transfer Value Equation for Buildings, W. K. Chow & K. T. Chan, speaks about the concept of the OTTV is applied to study the cooling load of buildings. It is found that the WWR, SC are of great importance. The sensitivities of these parameters will provide guidelines to building designers on the effective means of optimizing the thermal performance of envelope constructions, and possible trade-off among the parameters in meeting with any target envelope heat transfer limit. While the WWR, SC, Uw and Ur values are included in the OTTV eqn, the effect of wall absorptance and heat capacity are not duly reflected. To account for this, some modification in the form of an additional correction factor to the term TDeq in the OTTV equation should be made.

$$OTTV = \frac{\text{Total heat gain through the envelope}}{\text{(Total operating time of air conditioning System x envelope area)}}$$

$$OTTV = f\,(WWR, SC, U_w, H_w, U_f, \alpha\ldots.)$$

- Where, H_w = heat capacity of the opaque wall,
- **The parameters TDeq, ΔT and SF can be calculated as follows:**

$$\frac{TD_{eq}(1 - WWR)U_w}{OTTV} = \frac{\text{Wall heat conduction gain}}{\text{Total heat gain through the envelope}}$$

$$\frac{\Delta T(WWR)U_f}{OTTV} = \frac{\text{Glass heat conduction gain}}{\text{Total heat gain through the envelope}}$$

$$\frac{SF(WWR)SC}{OTTV} = \frac{\text{Solar radiation gain}}{\text{Total heat gain through the envelope}}$$

The concept of Overall Thermal Transfer Value (OTTV) in Design of Building Envelope to Achieve Energy Efficiency, J. Vijayalaxmi, suggests (1) Certain design modifications can be brought in at an early design stage to ensure reduction of OTTV. (2)The OTTV for the time of maximum solar radiation intensity is a good measure for benchmarking. Because this means the building is designed for a minimum solar gain during the worst (hottest condition). But this is relevant only to hot-humid and hot-dry countries which would reduce the load on air conditioners. In cold climates, the benchmark for arriving at OTTV standards must be different as it concerns heating load. (3) Options for varying walling material and glazing type for wall orientation where the OTTV is high must be considered at the early design stage. Such preventive measures would reduce the heat gain and therefore the load on the air conditioner.

$$OTTV_a = \frac{Q_{wc} + Q_{gc} + Q_{sol}}{A_i} \qquad (2)$$

$$= \frac{((A_w) \times U \times \Delta T_s) + (A_g \times U \times \Delta T) + (A_g \times I \times \theta)}{A_i} \qquad \Delta T_s = T_s - T_i = (T_o + I \times a / f_o) - T_i$$

Where,

To = Outside air temperature in deg. C.

I = radiation intensity in W/m2

a = absorbance of the surface.

Fo = Surface conductance outside in W/m2 °C.

Ti = inside air temperature in deg. C

As per, *predetermined overall thermal transfer value coefficients for Composite, Hot-Dry and Warm- Humid climates, Seema Devgan, A.K. Jain, B. Bhattacharjee,* a set of OTTV coefficients have been proposed for 3 types of tropical climates and verified. These coefficients can be used for calculating the OTTV value for 12-h operation, high-rise or midrise air-conditioned office buildings, situated in places with similar tropical climates. Using a similar method as described in this paper, OTTV coefficients can be derived for other building types with different operation schedules. Regulating the OTTV of the building envelope can result in energy efficient design of the building envelope as this study has shown that OTTV correlates well with annual space cooling and heating energy use.

4. Methodology

- Secondary literature was studied to understand the OTTV.
- After gaining the proper insights, a detailed sample calculation to calculate OTTV for an Affordable Housing Project of AUDA was carried out.
- During the process, a CSV based u-value calculator was developed.
- An online tool was developed that helps calculate OTTV for any given project with required inputs.

5. OTTV

As all building typologies have a certain potential for energy conservation, Overall Thermal Transfer Value (OTTV) here plays a significant role as a measure of control, to enhance the energy efficiency of the building. OTTV is a measure of heat gain into the building through the building envelope. It also acts as an index for comparing the thermal performance of buildings. The concept of OTTV is based on the assumption that the envelope of a building is completely enclosed. OTTV comprises two values: Envelope Thermal Transfer Value (ETTV) & Roof Thermal Transfer Value (RTTV). ETTV is a measure of heat transfer through walls or building envelope. RTTV is the measure of heat transfer through the roof of the building.

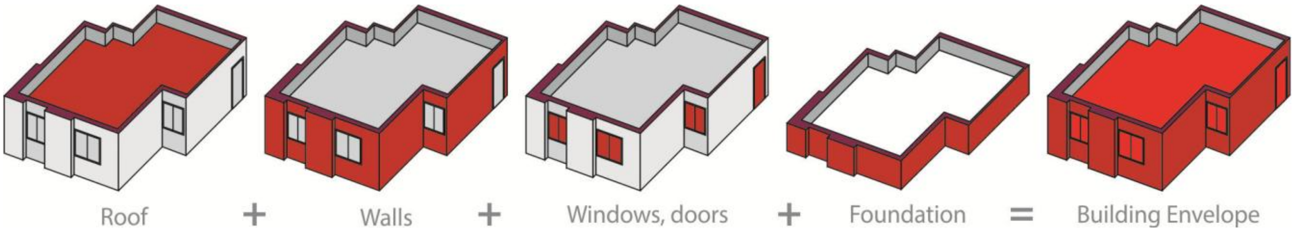

Figure 2 Building Envelope

- **Parameters Affecting OTTV**

Building Design Parameters	Climatic Parameters	Local Parameters
• Building Orientation	• Latitude	• Indoor comfort condition
• Walling Material	• Solar Radiation	
• Roofing Material	• Air Temperature	
• Envelope Color	• Wind Speed	
• Type of Glass	• Humidity	
• Shading of walls	• Precipitation	
• Shading of windows		

Figure 3 Parameters affecting OTTV

Source: Vijayalaxmi, J. "Concept of overall thermal transfer value (OTTV) in design of building envelope to achieve energy efficiency." Int. J. of Thermal & Environmental Engineering 1.2 (2010): 75-80.

5.1 Principles of OTTV

As per the ASHRAE Standard 90-1975, the OTTV is calculated based on three major components:

a. Conduction through the opaque wall, Q_{wc}.
b. Conduction through window glass, Q_{gc}. and
c. Solar radiation through window glass, Q_{gs}.

- The equation is as follows:

$$OTTV_w(ETTV) = \frac{Qwc + Qgc + Qgs}{A}$$

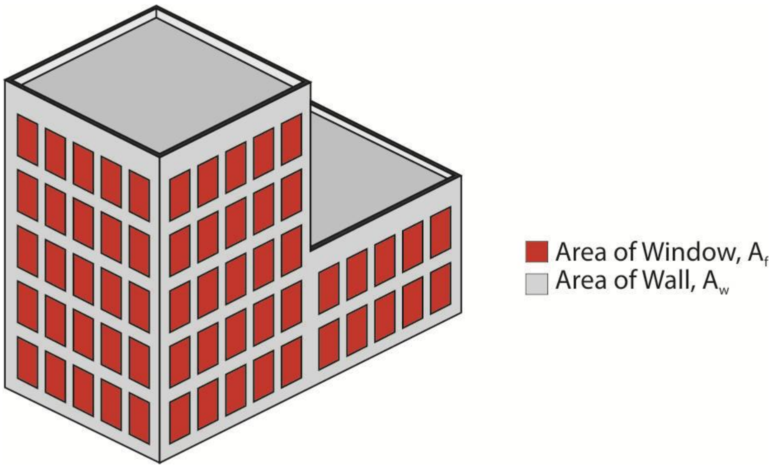

Figure 4 Solar conduction through building envelope

5.2 OTTV Equation

$$OTTV_w = \frac{(A_w . U_w . TD_{eq}) + (A_F . U_f . \Delta T) + (A_F . SC . SF)}{(A_w + A_f)}$$

Where, A_w ,A_f = wall and window area (m^2) ; $A = A_w + A_f$

- U_w, U_f = U – Value of walls and window (W/m^2. K) $W/m^2{}^\circ C$
- TD_{eq} = equivalent Temperature Difference (K)°C
- SC = Shading Coefficient of window glass
- SF = Solar Factor (W/m^2)
- ΔT = Temperature difference between exteriors and interiors design condition (K)°C

This is the standard equation followed as per ASHRAE standard 90 – 1975. This equation was adopted by various countries like Singapore, Malaysia, Thailand etc. and modified further.

Parameters like TD_{eq}, SF and ΔT are location and orientation based. To simply the adversities associated with varying figures for these parameters across the country, standard coefficients were worked out that could be climate specific or region specific or country specific. This made implementation of the equation very easy.

The above parameters are explained in depth below, with the help of a sample calculation.

5.3 Sample Calculation – A Case Study:

A project of Affordable Housing of AUDA was considered to carry out a detailed calculation of OTTV.

The following figure shows the Typical Floor plan for the project. The building consists of G+10 floors.

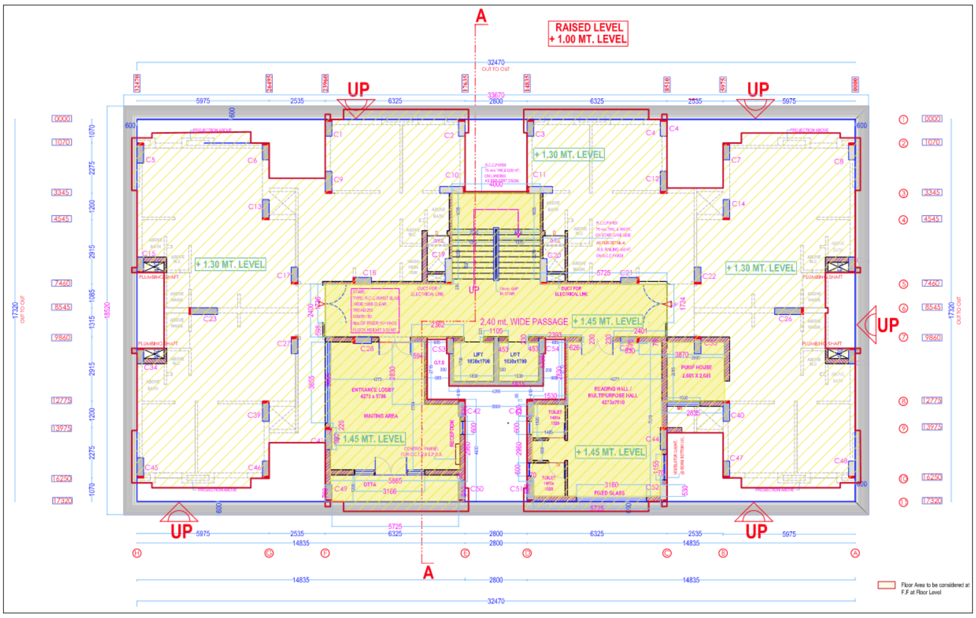

Figure 5 Typical Floor Plan

5.3.1 Step1: Envelope Area Calculation

- Building Envelope refers to the outermost layer of the building that separates the external environment from the internal environment of the building. It includes the roof, the walls and windows of all sides.

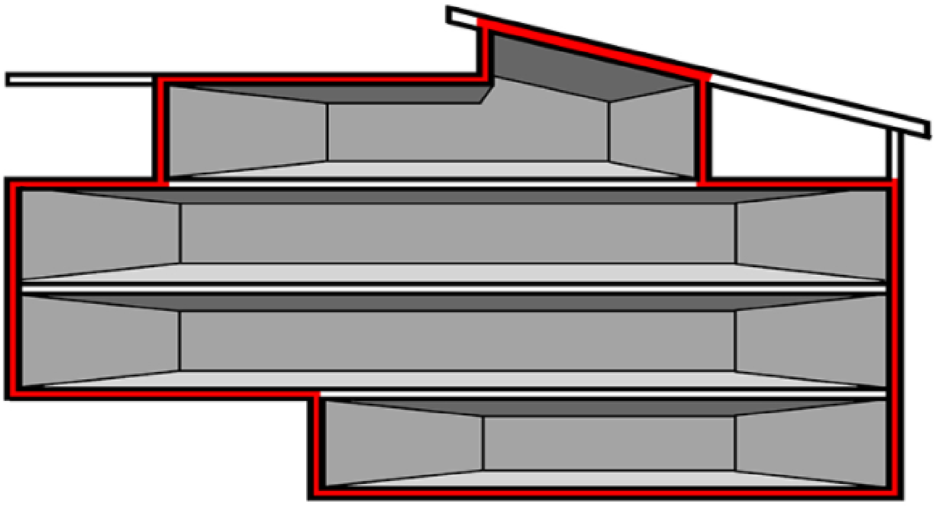

Figure 6 Building Envelope

The following table shows the Envelope Area calculated for the above-mentioned project. The surface area exposed to the outer atmosphere is only considered, as highlighted in the Typical Floor plan shown above.

Table 2 Envelope Area Calculation for the taken Case Study

Envelope Area Calculation												
Floor Level		**Ref. Drg.**	**Floor**		**Walls**			**Window**	**Door**	**Effective wall**	**Roof/Ceiling**	
			Perimeter (m)	**Area (sq.m)**	**Perimeter (m)**	**Height (m)**	**Area (m)**	**Area (Sq.m)**	**Area (Sq.m)**	**Area (Sq.m)**	**Perimeter (m)**	**Area (m)**
Ground Floor	Unit Level	Fig. 1, 2 & 6	-	-	-	-	-	-	-	-	-	-
	Floor Level	Fig. 4 & 6	91.037	160.319	91.037	3.00	273.111	20.400	7.740	244.971	-	-
Second Floor	Unit Level	Fig. 3 & 6	34.187	41.289	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	166.569	310.942	166.569	3.00	499.707	53.580	-	446.127	-	-
Third Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	-	-
Fourth Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	-	-
Fifth Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	-	-
Sixth Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	-	-
Seventh Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	-	-
Eight Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	-	-
Ninth Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	-	-
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	-	-
Tenth Floor	Unit Level	Fig. 5 & 6	-	-	40.521	3.00	121.563	13.395	-	108.168	40.521	87.262
	Floor Level	Fig. 5 & 6	-	-	166.569	3.00	499.707	53.580	-	446.127	166.569	471.262

Note:
Effective area = Total wall area – Door area – Window area

5.3.2 Step 2: U-Value Calculation

The Thermal Transmittance or U-Value of a construction is defined as the quantity of heat flow through a unit area of a building section under steady-state conditions in unit time per unit temperature difference of the air on either side of the section. Expressed in W/m^2K and is given by:

$$U = 1 / R_T$$

- Where, R_T is Total Thermal Resistance and is given by:

$$R_T = R_o + \frac{b_1}{k_1} + \frac{b_2}{k_2} + \ldots + \frac{b_n}{k_n} + R_i$$

- Where, R_o = air film resistance of external surface (m^2K/W)
  - R_i = air film resistance of internal surface (m^2K/W)
  - k1, k2, kn = Thermal conductivity of the basic material (W/m K)

- b1, b2, bn = Thickness of basic material (m)

Here the U-value is calculated using the ***CARBSE Tool: Assembly U-Factor Calculator***

Also, a CSV based U-value calculator was prepared with a u-value library, as shown below.

Table 3 U-Value Calculator

Assembly	Material	Density (kg/m^3)	Specific Heat (kj/kg.K)	Thermal Conductivity (W/m-k)	Thickness (m)	Thermal Resistance, R (=Thickness/ Conductivity)	Surface Film Resistance			Total Thermal Resistance (R_T)	Total Thermal Transmittance (U-Value)
							Location	**Type of Surface**	**Thermal Resistance(m^2 K/W)**		
1	Cement Plaster	1762.00	0.840	0.721	0.01	0.0139	Inside	High Emissivity (Ri-Walls)	0.120	0.3401	2.940
	RCC	2400.00	0.880	1.580	0.23	0.01456	Outside	High Emissivity (Ro-Walls)	0.044		
	Cement Plaster	1762.00	0.840	0.721	0.012	0.0166					
2	Brick Title	1892.00	0.880	0.798	0.02	0.0251	Inside	High Emissivity (Ri-Walls)	0.120	0.3651	2.739
	Cement Plaster	1762.00	0.840	0.721	0.01	0.0139					
	RCC	2400.00	0.880	1.580	0.23	0.01456	Outside	High Emissivity (Ro-Walls)	0.044		
	Cement Plaster	1762.00	0.840	0.721	0.012	0.0166					

5.3.2.1 U-value Library

It was required on the back end for the working of U-value calculator. It contains details of all material generally used in building construction with their properties like density, Specific heat and thermal conductivity. Thermal Resistance, R for all materials of any assembly was calculated using its thickness input and thermal conductivity, as discussed above. The values of Surface Film resistance for different surfaces, for Walls and roofs, are been obtained from ***Singapore Code on Envelope Thermal Performance for Buildings***. The required calculation is done for final U-value for different assembly type for U_W and U_R (as per the formula discussed above).

5.3.2.2 Uf and US

Thermal performance of different glass shading devices is obtained from the ***Bureau of Indian Standards.***

Sl No. (1)	Name of the Shading Device (2)	Transmittance, *U* Value (3)	Shade Factor (4)
i)	Plain glass sheet (3.0 mm thick)	5.23	1.00

Figure 7 Thermal Performance of Different Glass Shading Devices, Bureau of Indian Standards

The user would have to select the glazing type only for the fenestration area of wall and roof skylights, each to obtain their U-values.

5.3.3 Step 4: Solar Factor (SF)

The Solar Factor (SF) is the hourly radiation per square meter for the horizontal and vertical surfaces (W/m^2).

Any sloped or angled walls can be resolved into vertical and horizontal components. The vertical elements are treated as walls and the horizontal components are treated as roof components.

This data for different cities was abstracted from the EWP Weather files in terms of W/m^2, which we have in hourly, daily and monthly basis.

(Note: Considering the fact that data available is along normal direction only and not for all orientations.)

Table 4 Monthly Average Solar Radiation for Ahmedabad for 2016

Month	Solar Factor (SF)		
	$kWh/m^2/day$	**Avg. Sun Hours**	**W/m^2**
Jan	6.47	10.88	**594.669**
Feb	7.27	11.38	**638.840**
March	7.14	12.00	**595.000**
April	6.78	12.68	**534.700**
May	7.28	13.25	**549.434**
June	5.50	13.52	**406.805**
July	2.64	13.38	**197.309**
August	2.51	12.90	**194.574**
September	5.14	12.25	**419.592**
October	6.92	11.60	**596.552**
November	6.35	11.03	**575.703**
December	6.03	10.75	**560.930**

5.3.4 Step 3: Shading Coefficient (SC)

It is the ratio of the solar heat gain through a particular type of glass under a specific set of conditions to the solar heat gain through that of double strength sheet clear glass under the same conditions.

$SC_{max} = 1$

The higher the shading coefficient is, the lower the shading performance of the glass.

Window Type considered – **Single Glazed, clear glass sheet, 3mm thick**

SC for all fenestration type are obtained from the same table of ***Bureau of Indian Standards*** (as of now) as shown in Figure 7

[Note: We intend to factor **ESM, External Shading Multiplier** to SC, which includes the effect of horizontal or vertical or both projections on windows. Which can be done by linking the SHGC tool to the OTTV calculator. ESM for the unshaded window is considered = 1]

5.3.5 Step 5: ΔT, Difference in Temperature

It is the temperature difference between indoors and outdoors environment of the building. Intending to keep the indoor temperature at 26°C, the outdoor temperature is again obtained from the same EWP weather files of SHGC tools on hourly, daily and monthly basis.

Table 5 Average High Temperature of the last 7yrs for Ahmedabad

Month	**Avg. of Last 7 yrs (2016 - 2010)**		
	Outdoor Temperature (Avg. High) (□C)	**Indoor Temperature (°C)**	**ΔT (°C)**
Jan	31	26	**5**
Feb	35	26	**9**
March	41	26	**15**
April	43	26	**17**
May	45	26	**19**
June	44	26	**18**
July	38	26	**12**
August	35	26	**9**
September	38	26	**12**
October	38	26	**12**
November	35	26	**9**
December	34	26	**8**

In this case, we considered Weather Data for Ahmedabad for the last 7 years to calculate ΔT.

5.3.6 Step 6: Equivalent Temperature Difference TDeq

It is the temperature difference which results in total heat flow through a structure as caused by the combined effects of solar radiation and outdoor temperature. It takes into account the types of construction (mass and density), the degree of exposure, time of day, location and orientation of the construction and design condition.

Table 6 Equivalent Temperature Difference

Wall Construction – mass per unit area		**TD_{eq}**	
Lbs/ft²	**Kg/m²**	**F**	**°C**
0 – 25	0 - 125	44	24.5
26 - 40	126 - 195	37	21.0
41 - 70	196 - 345	30	17.0
71 and above	346 and above	23	13.0

Source: ASHRAE Standard 90 – 1975

TDeq for this case was considered as 13°C, as the wall construction mass per unit area, is more than 346 kg/m2, following ASHRAE Standard 90 – 1975.

5.3.7 Step7: OTTV for one Unit

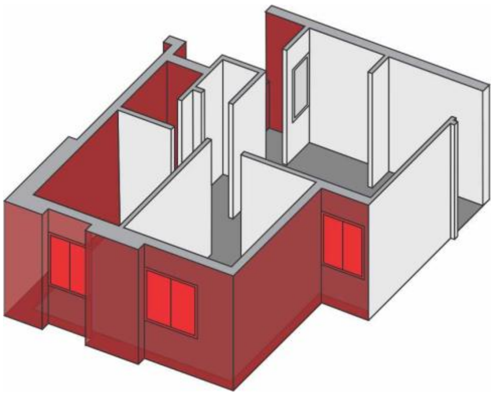

Figure 8 Single Unit

The following table shows the OTTV calculation for one single unit of the building.

OTTV Value for Yearlong Data for one unit									
Month	Aw	Uw (static)	TDeq	Af	Uf	ΔT	SC	SF	OTTV (W/m²)
	(m²)	(w/m²-K)	(C)	(m²)	(w/m²-K)	(C)	-	(W/m²)	$OTTV = \frac{(Aw \times Uw \times TDeq) + (Af \times Uf \times \Delta T) + (Af \times SC \times SF)}{Ao}$
Jan	108.17	2.7	13	13.395	5.23	5	1.00	594.669	99.64
Feb	108.17	2.7	13	13.395	5.23	9	1.00	638.840	106.81
March	108.17	2.7	13	13.395	5.23	15	1.00	595.000	105.44
April	108.17	2.7	13	13.395	5.23	17	1.00	534.700	99.95
May	108.17	2.7	13	13.395	5.23	19	1.00	549.434	102.72
June	108.17	2.7	13	13.395	5.23	18	1.00	406.805	86.43
July	108.17	2.7	13	13.395	5.23	12	1.00	197.309	59.89
August	108.17	2.7	13	13.395	5.23	9	1.00	194.574	57.86
September	108.17	2.7	13	13.395	5.23	12	1.00	419.592	84.38
October	108.17	2.7	13	13.395	5.23	12	1.00	596.552	103.88
November	108.17	2.7	13	13.395	5.23	9	1.00	575.703	99.86
December	108.17	2.7	13	13.395	5.23	8	1.00	560.930	97.65
								Avg.	92.04

Figure 9 OTTV Calculation for a single unit.

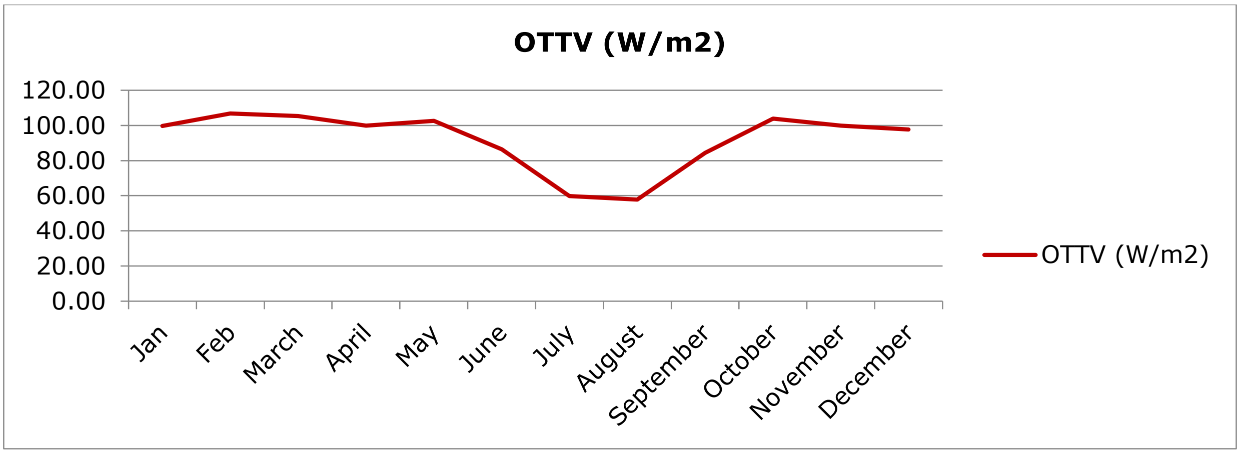

Figure 10 Monthly representation of OTTV for a single unit.

The OTTV ranges from approx. 57 W/m² to 106 W/m². These variations are due to seasonal changes leading to change in intensity of sun i.e. solar radiations in summer, winter and monsoon. The annual avg. of OTTV comes to be around 92 W/m².

5.3.8 Step 8: OTTV for one floor

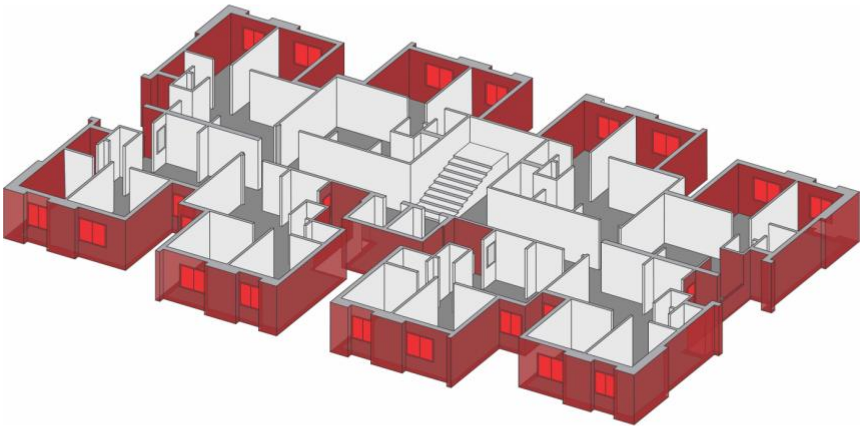

Figure 11Floor plan

OTTV Value for Yearlong Data for one floor									
Month	Aw	Uw (static)	TDeq	Af	Uf	ΔT	SC	SF	OTTV (W/m²)
	(m²)	(w/m²-K)	(C)	(m²)	(w/m²-K)	(C)	-	(W/m²)	$OTTV = \frac{(Aw \times Uw \times TDeq) + (Af \times Uf \times \Delta T) + (Af \times SC \times SF)}{Ao}$
Jan	446.13	2.7	13	53.58	5.23	5	1.00	594.669	97.90
Feb	446.13	2.7	13	53.58	5.23	9	1.00	638.840	104.88
March	446.13	2.7	13	53.58	5.23	15	1.00	595.000	103.55
April	446.13	2.7	13	53.58	5.23	17	1.00	534.700	98.20
May	446.13	2.7	13	53.58	5.23	19	1.00	549.434	100.90
June	446.13	2.7	13	53.58	5.23	18	1.00	406.805	85.05
July	446.13	2.7	13	53.58	5.23	12	1.00	197.309	59.22
August	446.13	2.7	13	53.58	5.23	9	1.00	194.574	57.25
September	446.13	2.7	13	53.58	5.23	12	1.00	419.592	83.06
October	446.13	2.7	13	53.58	5.23	12	1.00	596.552	102.03
November	446.13	2.7	13	53.58	5.23	9	1.00	575.703	98.11
December	446.13	2.7	13	53.58	5.23	8	1.00	560.930	95.97
								Avg.	90.51

Figure 12 OTTV Calculation for one floor

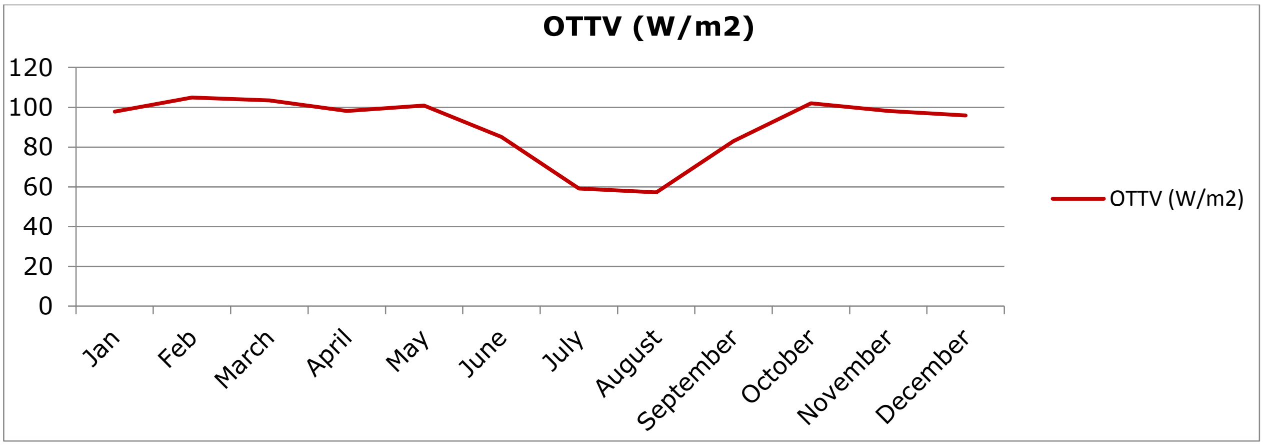

Figure 13Monthly representation of OTTV for one floor.

Here the area of wall and fenestration has been increased in comparison to a single unit, rest all parameters are same. The annual avg. OTTV for one-floor unit approx. 90 W/m². Which is not very different from annual avg. OTTV for single unit, as OTTV is measured per unit area. So increase in the area does not majorly affect the OTTV of a building.

5.3.9 Step 9: OTTV for Building Envelope

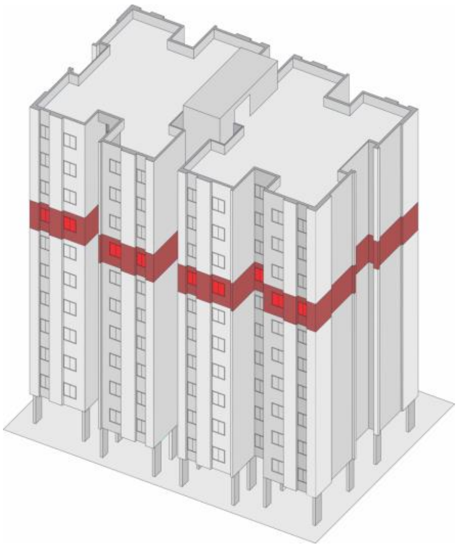

Figure 14 Building Envelope

OTTV Value for Yearlong Data									
Month	Aw	Uw (static)	TDeq	Af	Uf	ΔT	SC	SF	OTTV (W/m^2)
	(m^2)	(w/m^2-K)	(C)	(m^2)	(w/m^2-K)	(C)	-	(W/m^2)	$OTTV = \frac{(Aw \times Uw \times TDeq) + (Af \times Uf \times \Delta T) + (Af \times SC \times SF)}{Ao}$
Jan	4706.24	2.7	13	563.94	5.23	5	1.00	594.669	97.78
Feb	4706.24	2.7	13	563.94	5.23	9	1.00	638.840	104.74
March	4706.24	2.7	13	563.94	5.23	15	1.00	595.000	103.41
April	4706.24	2.7	13	563.94	5.23	17	1.00	534.700	98.07
May	4706.24	2.7	13	563.94	5.23	19	1.00	549.434	100.77
June	4706.24	2.7	13	563.94	5.23	18	1.00	406.805	84.95
July	4706.24	2.7	13	563.94	5.23	12	1.00	197.309	59.17
August	4706.24	2.7	13	563.94	5.23	9	1.00	194.574	57.20
September	4706.24	2.7	13	563.94	5.23	12	1.00	419.592	82.96
October	4706.24	2.7	13	563.94	5.23	12	1.00	596.552	101.89
November	4706.24	2.7	13	563.94	5.23	9	1.00	575.703	97.98
December	4706.24	2.7	13	563.94	5.23	8	1.00	560.930	95.84
								Avg.	90.40

Figure 15 OTTV Calculation for the whole building envelope.

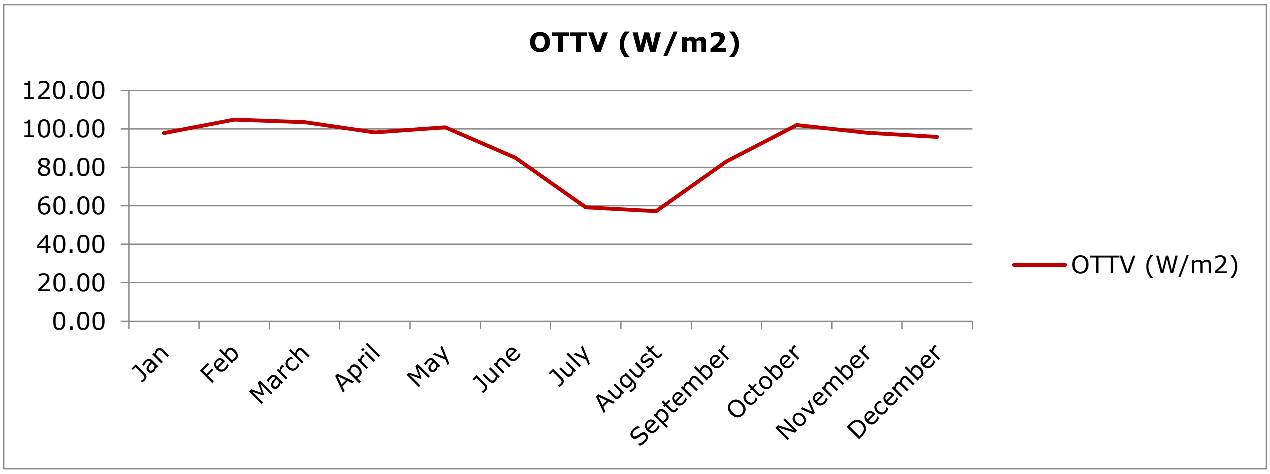

Figure 16Monthly representation of OTTV for whole building envelope.

6. OTTV Tool

From the above understanding, the Centre for Advanced Research in Building Science and Energy (CARBSE) at CEPT University has developed a dynamic OTTV (Overall Thermal Transfer Value) Calculator to measure the heat gain into the building through the building envelope. This tool can also be used as an index for comparing the thermal performance of buildings.

To customize the user's experience, we have incorporated salient features like,

- Choices of equations based on country (India, Singapore, Hong Kong and Malaysia). A detailed explanation is mentioned in the Documentation Tab present on the right panel.
- Step by step procedure to calculate window and wall area using Revit Architecture and corresponding space to enter those values.
- Link to calculate Assembly U-Value of opaque and non-opaque building envelope components based on the user's model building.
- Provision to enter Correction Factor and Solar Absorption coefficient for selected equations.

OTTV Calculator output page shows relevant variables used to calculate OTTV value. Once all the input variables are entered, the user must click "Calculate" and get the corresponding OTTV value.

Care must be taken to enter all input values greater than 0 and SHGC value between 0 and 1.

Equations available for calculation:

1. RETV India (2017): Composite Climate or Hot-dry Climate
(source - Energy Conservation Building Code for Residential Buildings in India - 2017)

2. $RETV = 6.11(1-WWR)U_{opaque} + 1.90(WWR)U_{non\text{-}opaque} + 70.94(WWR)SHGC_{equivalent}$

3. RETV India (2017) : Warm-humid Climate
(source - Energy Conservation Building Code for Residential Buildings in India - 2017)

4. $RETV = 5.19(1-WWR)U_{opaque} + 1.34(WWR)U_{non\text{-}opaque} + 66.70(WWR)SHGC_{equivalent}$

5. RETV India (2017) : Temperate Climate
(source - Energy Conservation Building Code for Residential Buildings in India - 2017)

6. $RETV = 5.27(1-WWR)U_{opaque} + 0.95(WWR)U_{non\text{-}opaque} + 78.92(WWR)SHGC_{equivalent}$

7. ETTV Singapore (2009)
(source - Energy performance of residential buildings in Singapore: K.J. Chua, S.K. Chou - 2009)

8. $ETTV = 3.4(1-WWR)U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC)$

9. ETTV Singapore (code)
(Source - Code on Envelope Thermal Performance for Building: Singapore)

10. $ETTV = 12(1-WWR)U_w + 3.4(WWR)U_f + 211(WWR)(CF)(SC)$

11. RETV Singapore (code)
(Source - Code on Envelope Thermal Performance for Building: Singapore)

12. ETTV = $3.4(1-WWR)U_w + 1.3(WWR)U_f + 58.6(WWR)(CF)(SC)$

13. Hong Kong (1995)
(source - Parameterization Study of the Overall Thermal Transfer Value Equation for Buildings: Hong Kong, 1995)

14. OTTV = $11.4(1-WWR)U_w + 2.6(WWR)U_f + 204.2(WWR)(CF)(SC)$

15. Malaysia (2007)
(source - Malaysia Standards MS1512:2007 Clause 5.2.2)

16. ETTV = $15(alpha)(1-WWR)U_w + 6(WWR)U_f + 194(WWR)(CF)(SC)$

where:
WWR = Window to Wall ratio = $A_{non-opaque}/A_{envelope}$
$A_{non-opaque}$ = Window area (m^2)
$A_{envelope}$ = Facade area (m^2)
U_{opaque} = U-Value for walls (W/m^2-K)
$U_{non-opaque}$ = U-Value for windows (W/m^2-K)
$SHGC_{equivalent}$ = Shading coefficient
U_w = U_{opaque}
U_f = $U_{non-opaque}$
SC = $SHGC_{equivalent}$
CF = Correction factor
alpha = Solar absorption coefficient

7. Conclusion

This study tried to use Overall Thermal Transfer Value (OTTV) as performance criteria other than Energy Performance Index (EPI). As EPI only shows the energy usage index of that building, but it lacks the ability to define which factors in the building are leading to higher energy consumption. Whereas OTTV directly talks about the thermal performance of the building envelope. It provides huge opportunity to play with wall construction and window material, envelope design, WWR, building orientation, etc. to provide the most efficient building envelope with minimal cost.

As part of the outcome of the task, an online tool was developed to calculate Overall Thermal Transfer Value (OTTV) based on various equations followed by different countries.

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9. Appendix

Appendix A: Material Thermal Properties for U-Value Library.

Material	Density (kg/m3)	Specific Heat (kJ/kg-K)	Thermal conductivity (W/m-K)
Burnt Brick	1820.00	0.880	0.811
Mud Brick	1731.00	0.880	0.750
Dense Concrete	2410.00	0.880	1.740
RCC	2400.00	0.880	1.580
Limestone	2420.00	0.840	1.800
Slate	2750.00	0.840	1.720
Brick Tile	1892.00	0.880	0.798
Lime Concrete	1646.00	0.880	0.730
Mud Phuska	1622.00	0.880	0.519
Cement Mortar	1648.00	0.920	0.719
Cement Plaster	1762.00	0.840	0.721
Cinder Concrete	1406.00	0.840	0.686
Foam Slag concrete	1320.00	0.880	0.285
Gypsum Plaster	1120.00	0.960	0.512
Cellular concrete	704.00	1.050	0.188
AC Sheet	1520.00	0.840	0.245
GI Sheet	7520.00	0.500	61.060
Timber	480.00	1.680	0.072
Plywood	640.00	1.760	0.174
Glass	2350.00	0.880	0.814
Sand	2240.00	0.840	1.740
Expanded Polystrene	34.00	1.340	0.035
Foam Glass	160.00	0.750	0.055
Foam Concrete	704.00	0.920	0.149
Rock wool (unbonded)	150.00	0.840	0.043
Mineral wool (unbounded)	73.50	0.920	0.030
Glass Wool (unbounded)	189.00	0.920	0.040
Resin Bounded mineral wool	99.00	1.000	0.036
Resin Bounded glass wool	24.00	1.000	0.036
Asbestos Mill board	1397.00	0.840	0.249
Hard Board	979.00	1.420	0.279
Straw Board	310.00	1.300	0.057
Soft Board	249.00	1.300	0.047
Wall Board	262.00	1.260	0.047
Chip Board	432.00	1.260	0.067
Particle Board	750.00	1.300	0.098
Saw Dust	188.00	1.000	0.051

Rice Husk	120.00	1.000	0.051
Aluminium Composite Panels	150.00	0.902	0.060
Face Bricks	2083.00	1.004	1.300
Ploycarbonate Sheet	1350.00	1.170	0.210
Fly Ash Brick	1570.00	0.800	0.54 - 0.70
Fibre Reinforced Plastic Sheet	1850.00	0.960	0.260
Polyurathane Foam (PUF)	30.00	1.570	0.026
Polyvinyl Chloride Sheet	1350.00	1.255	0.160
Cork Tile	540.00	1.000	0.085
Plastic Tile	1050.00	1.070	0.050
PVC Asvestos Tile	2000.00	1.000	0.850
Gypsum Plasterboard	950.00	0.820	0.160
Acoustic Tile	290.00	1.340	0.058
Ceramic Tile	2700.00	1.140	1.600

Source - Gathered from Multiple Websites

Appendix B: Surface films resistance for walls and roofs.

Type of Surfarce	Thermal Resistance (m^2 K/W)
High Emissivity (Ri-Walls)	0.120
Low Emissivity (Ri-Walls)	0.299
High Emissivity (Ro - Walls)	0.044
High Emissivity Flat Roof (Ri -Roof)	0.162
High Emissivity Sloped Roof 22.5□ (Ri- Roof)	0.148
High Emissivity Sloped Roof 45□ (Ri- Roof)	0.133
Low Emissivity Flat Roof (Ri -Roof)	0.801
Low Emissivity Sloped Roof 22.5□ (Ri- Roof)	0.595
Low Emissivity Sloped Roof 45□ (Ri- Roof)	0.391
High Emissivity (Ro - Roof)	0.055

Source - Code for Envelope Thermal Performance for Buildings

Appendix C: Thermal Performance of different glass shading devices.

Glass Type	Transmittance U Value	Shade Factor (SC)
Plain Glass sheet (3 mm thick)	5.23	1
Plain Glass + Wire Mesh Outside	5.00	0.65
Painted Glass (White Paint)	5.22	0.35
Painted Glass (Yellow Paint)	5.22	0.37
Painted Glass (Green Paint)	5.22	0.4
Heat Absorbing Glass	4.65	0.45
Plain glass Sheet + Light colour venetian blind inside	3.14	0.35
Plain glass Sheet + Dark colour venetian blind inside	3.14	0.4
Plain Glass sheet + 100 percent shaded	5.23	0.14
Plain Glass sheet + 75 percent shaded	5.23	0.34

Plain Glass sheet + 60 percent shaded	5.23	0.56

Source - Bureau of Indian Standards

Appendix D: OTTV Tool