

Thermal Performance of Building Envelope

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Abstract - In the era of raising environmental problems, built structures are considered as one of the main energy consuming entities which are ultimately responsible for environmental degradation. To handle the issue it is important to deal with building's energy demand which is mainly due to extreme weather conditions. Building envelope is the first to encounter with weather thus it plays a major role in deciding building's energy demand. This paper deals with the improvement of thermal performance of Building Envelope according to climate, indices and local solar time of region. This paper also focus on new facades technologies which lower down the building's energy demand with better insulation. To achieve this goal an integrated approach is required which comprise techniques, technologies, architectural innovation all together. These facades also have benefits other than energy saving. Numerous technologies are being developed to generate energy also.

Key words - Solar heat gain, U-value, R-value, Thermal Time Constant, Thermal Damping, Thermal Performance Index, Building Index

INTRODUCTION AND STATEMENT OF THE PROBLEM
Heat transfer from outside to inside takes place through the Building Envelope and the quantities are derived through certain basic principles. The purpose of this paper is to find out the appropriateness of various principles according to the climate and methods to do the climate analysis. The paper will also give the measures for the overall performance of Building Envelope and Building envelope techniques to reduce the energy consumption.

BACKGROUND & CONTEXT

Numerous researches have been done on quantification of various parameters of heat transfer but each parameter will not be giving the same results in each & every climate and for designing, the designers should know the fundamentals of these parameters and which parameter they should focus more on in terms of achieving the required outcome for a specific climate.

The goals of this technical paper are:

- To find out the Impact of Solar time and local clock time on received solar radiation in different directions by giving an example
- To know about the indices of assessing Thermal Performance of Building Envelope
- Actual Meaning of the indices and to figure out whether all the indices are affected by design/orientation, material and the amount of solar exposure.

METHODOLOGY

Extensive studies have been made on several research papers. The performance indices and parameters have been taken from NBC 2016 and ECBC 2017. Manual calculations are being done for the findings and recommendations are given.

DESIGN METHODS ACCORDING TO CLIMATIC CONDITIONS FOR HIGH PERFORMANCE BUILDING ENVELOPE

Building envelope integrates exterior building skin and roofs which comprises opaque components and fenestration systems.

Opaque components – roofs, walls, slabs on grade (in touch with ground), opaque doors & basement walls.

Fenestration Systems – windows, sky-lights, ventilators and doors that are more than half glazed. (ECBC)

High performance building facades are building envelopes that use minimum amount of energy to maintain comfortable indoor environment for occupants as well as improves occupant's health and productivity. High performance facades don't act as barrier between interior and exterior environment rather they participate as active systems in minimizing building energy consumption by responding to external environmental conditions.

As climate plays a vital role in building energy performance all guidelines related to climate must be taken into considerations while designing 'High Performance Building Facades'

Design Strategies for high performance facades in 'Hot & Humid' regions are quite different from those in 'Hot & Arid' regions. Building Facades affects building's energy bills and occupant's health more than any other system.

Heat transfers into buildings through **conduction, convection & radiation**. Heat transfer through conduction depends On conductivity of materials used in exterior facades. Different materials have different conductivity so they offer different resistance to conductive heat. Walls and roofs generally comprise no. of layers composed of different materials so it is very important to know their overall '*thermal resistance and heat transfer coefficient (U-factor)*'. Heat transfer coefficient is also known as '*thermal transmittance*'

DESIGN STRATEGIES OF 'HIGH PERFORMANCE ENVELOPE' ACCORDING TO CLIMATE:

Climate: Cold Climate

Design Strategies:

1. Collection of Solar energy & Passive heating – collection of solar heat through building envelope

2. Daylight – Use of natural light & glazing area of facades can be increased. High performance glass can be used. Light shelves can be used to allow the light into interior spaces.
3. Heat Conservation – through improved insulation heat can be preserved into building.

Climate: Hot Climate

Design Strategies:

1. **Solar Control** – External façade of building can be protected through use of self shading methods (building form) or by using shading devices.
2. **Reduced external heat gains** – Solar heat-gains through infiltration can be protected by use of well insulated opaque façade elements. Also solar heat-gains through conduction can be protected by use of shading devices.
3. **Cooling** – Natural ventilation can be used for cooling of building where environmental characteristics and building's functions allow.
4. **Daylight** – By use of shading devices and lighting shelves natural light can be used for interior spaces with minimum solar heat-gains.

Climate: Mixed Climate

Design Strategies:

1. Solar Control – external facades can be protected from direct solar radiation through shading devices during warm seasons.
2. **Solar collection & passive heating** – Solar energy can be collected in cold seasons
3. **Daylight** – Use of natural light sources and increased glazed façade with use of shading devices.

Some important basic design methodologies of 'High Performance Building Envelope' are as follows-

- Orientation, geometry and massing of building should responds to sun position
- Natural ventilation for enhanced air quality and reduced cooling loads
- Provision of solar shading devices to control cooling loads and to improve thermal comfort
- Optimization of exterior wall insulation and day lighting to minimize energy consumption for artificial lighting and mechanical cooling and heating.

Building Orientation – Building orientation determines its sun exposure. Sun rises in the east & sets in the west only on autumnal & vernal equinoxes. For rest of remaining 363 days it rises and sets differently. As earth is tilted, it causes the sun rise and set slightly south of east & west in the winter and slightly north of east & west in the summer. This slight angle depends on time of the year and distance of observer from equator. So through right orientation solar heat –gain can benefit building in winters and in hot climate building's orientation can avoid director solar radiation into interior spaces.

CLIMATE ANALYSIS

To do the climate analysis, the designer must know two important factors i.e. solstice and equinox and the dates of Summer solstice, Winter solstice and Equinox.

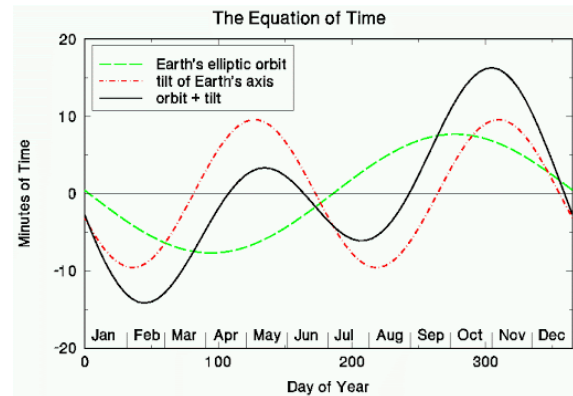
Altitude and Azimuth angles

Local Solar Time:

India's reference longitude is 82.3 degree East longitude.

India has only single time zone irrespective of other countries.

Time Adjustment to be done to find out the local solar time.



Graphic Indicator for Time Correction

Difference in Apparent (Actual) Solar time and Mean Solar time

For Example Mumbai (73 degree East Longitude) : Local solar noon at Mumbai on 26th January will be
 $12:00 - (12:00 - 38 - 13) = 12:00 - (11:09) = 51$ minutes
Every degree of longitude means a time difference of 4minutes. (-13 is taken from the Graphic Indicator for Time Correction)

Therefore, local solar noon at Mumbai occurs 51 minutes later than the Indian Standard Time

IMPACT OF SOLAR TIME & LOCAL CLOCK TIME ON THE RECEIVED SOLAR RADIATION IN DIFFERENT DIRECTIONS

Considering Two examples of different climate :Srinagar (34.1 degree North latitude and 74.8 degree East longitude) and Trivandrum (8.5 degrees North latitude)

In summer solstice, Typically we get sun right above the head, it never crosses towards the Northern side. The sun is slightly tilted towards south, but still, during the morning and evening times, we get sun from the north east and north western side

In Winter solstice December 21st here we have typically the least possible altitude angle. We do not get sun directly on the east or west, it is mostly somewhere close to south-east and south-west and it has a Southern traverse, this is the case of 34 degree north latitude.

Trivandrum : It traverses not directly through south, it is somewhat half the center point, that is it has a slightly Northern traverse during summer solstice. The sun rise happens somewhere close to north-east and sets somewhere close to north-west.

Implication: If you have a Northern wall which has large windows typically during summer especially in latitudes like this say 11 degrees, 10 degrees, you will have solar incidents on your Northern facade and Northern windows during summer months. The lower you go towards equator like typically the case of 8 degrees, 8 and half degrees north latitude, you will have solar incidence on your Northern wall

INDICES OF ASSESSING THE THERMAL PERFORMANCE OF BUILDING ENVELOPE

1. Thermal Transmittance of the Wall (U value)
2. Thermal Damping
3. Thermal Performance Index
4. Thermal Time Constant
5. Building Index¹

Some Definitions:

Thermal Efficiency of Envelop is to be considered at Element level, Component Level and Assembly level

Thermal mass is the capacity of material to absorb, store and release heat.

Heat Capacity is the ability of wall to store heat. Heat capacity is used for quantifying the amount of thermal mass in a wall.

Thermal Lag: When in comparison to the peak time on exterior , time of peak temperature and heat gains on interior is delayed, then this phenomena is called Thermal Lag²

1.Thermal Transmittance :Thermal transmission through the unit area of a building unit divided by temperature difference between the air on either side of the building unit

Requirement of U Value acc. To climate:

U Value is the basic essential quantification measure for every climate but not just the one through which thermal efficiency is obtained.

2.Thermal Damping : Thermal Damping is a characteristic of mass construction that describes the way exterior temperature and heat flow affect the interior of the building. It depends on insulation and heat capacity of construction. Thermal dampers reduces the amplitude of temperature wave.It is dependent on the method of construction,thermal mass, insulation and heat capacity. If there is small fluctuation of temperature inside as compared to high temperature fluctuation outside in summers , that means high thermal damping

$$D = \frac{T_o - T_i}{T_o} \times 100$$

where

To = outside temperature range

Ti = inside temperature range

Thermal Damping varies with orientation, fenestration, compactness of space . Also, varies with Month to Month basis

Requirement of Thermal Damping acc. To climate:

NBC prescribes Minimum Thermal Damping where the Diurnal variation is too high.e.g. Hot Dry climate and Cold climate

Where the Diurnal variation is low,Thermal Damping will not be required. E.g. Moderate climate

3.Thermal Time Constant: TTC is a time required for a thermistor to respond to a change in its ambient temperature. i.e. as a time for thermistor to reach 63.2% of the total difference between its initial and final body temperature. Ratio of Total Heat Gain to Thermal Transmittance of the structure

$$Thermal\ Time\ Constant\ (TTC) = \sum \frac{Q}{U} = \sum \left(\left(\frac{1}{f_o} + \frac{L_n}{2k_n} \right) (L_n \rho_n C_n) \right)$$

where

L_N = thickness of the component

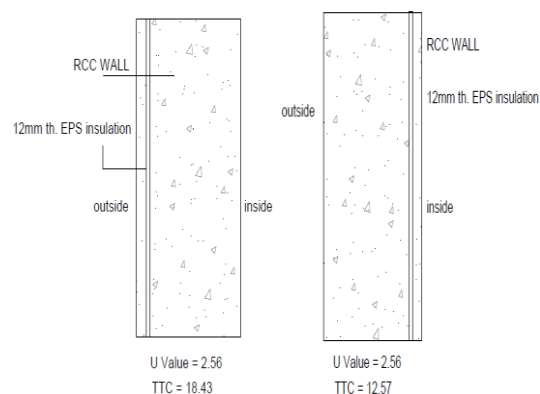
ρ_N = density of the material

C_n = specific heat capacity of the material

Requirement of Thermal Time Constant acc. To climate:

Thermal Time Constant should be calculated for every climate to know about the Thermal efficiency in terms of component level.

For example : If we take two same walls of same thickness i.e. 150mm RCC wall with insulation near to the outer skin and insulation near to interior skin, the U Value will remain the same, but there will be a change in TTC. NBC also prescribes minimum TTC value according to the climate.



¹ NBC Code 2016

² Energy and Buildings Volume24,Issue 1,1996

RCC Wall of 150mm has been taken in both the cases. Case 1: RCC wall with insulation outside and Case II:RCC wall with insulation inside. After manual calculations, Findings: Both will have the same U Value but differs in TTC Value.

4. Thermal Performance Index: Rating of 100 TPI of assembly corresponds to 38 degree Celsius peak inside surface temperature in an unconditioned environment taking base temperature as 30 degree Celsius .³

ASHRAE also defines Radiant temperature discomfort occurs as allowable surface temperature goes up a certain limit as against air temperature

$$\text{Thermal Performance Index} = \frac{(T_{in-peak} - 30)}{8} \times 100$$

The formula is derived from the series of calculation through which 30 degree comes as comfortable temperature in brick wall and if the inside wall surface temperature reaches 38 degree, then it won't be too uncomfortable in an unconditioned building. Corrected TPI is given by

$$\text{Corrected TPI} = (TPI - 50) \times C + 50$$

Correction Factor is different for specific location and absorption of the wall surface.

Requirement of Thermal Performance Index acc. To climate:

Thermal Performance Index is essential in term of assembly level as it takes conductive, resistive, reflective, capacitive insulation parameters into consideration. Also, storage capacity of the whole wall is considered in the formula.

5. BUILDING INDEX: Building Index is overall heat gain through complete system (walls, roofs, fenestrations etc.)

Building Index & Comfort conditions in various situations As per SP:41 (S&T) - 1987

SP : 41 (S&T)-1987

TABLE 17 LIMITS OF BUILDING INDEX CORRESPONDING TO AIR TEMPERATURE AND COMFORT CONDITIONS
(Clause 9.1.1.)

Sl. No.	BUILDING INDEX	INDOOR AIR TEMPERATURE	COMFORT CONDITIONS WITH FAN
		°C	
i)	0-50	32	Comfortable
ii)	51-100	32-36	Slightly warm
iii)	101-150	36-40	Hot

Indices range as per SP: 41(S&T) – 1987

SP : 41 (S&T)-1987

TABLE I THERMAL PERFORMANCE STANDARDS
(Clause 3.1)

Sl. No.	BUILDING COMPONENTS	HOT DRY AND HOT HUMID ZONES				WARM HUMID ZONE			
		U, Max	TPI, Max	T, Min	D, Min	U, Max	TPI, Max	T, Min	D, Min
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
		W/(m²K)		h		W/(m²K)		h	
i)	Roof	2.33	100	20	75	2.33	125	20	75
ii)	Exposed wall	2.56	125	16	60	2.91	175	16	60

FINDINGS

Extent of the Five Indices in the Thermal Performance of Building Envelope

U Value and Thermal Time Constant are just material property i.e. their values won't be affected by orientation, design or zoning and the rest indices will get affected by Design/Zoning or orientation. Whether the indices takes into account the considerations like Property of the material, Design/Zoning and Solar Exposure (Orientation) and upto what extent.

1	2	3	4	5
U Value	Thermal Time Constant	Thermal Damping	Thermal Performance Index	Building Index
Material Property – U value depends on the density of material, surface property and thickness. No weight age for WWR, Orientation	Material Property – The value of TTC takes into account conductivity, density, specific heat and thermal capacity of material	Material Property – The value is affected most by the material of the wall	Solar Exposure- TPI is most affected by the amount of solar exposure	Design/ Zoning – Building Index is most affected by Design / Zoning
		Design /Zoning – After the material, TD Value is then affected by Design and Zoning	Material Property – After Solar Exposure, TPI is affected by the material chosen	Solar Exposure – After Design/Zoning, Building Index is affected by solar exposure
		Solar Exposure- Thermal Damping value will then be affected by the amount of solar exposure	Design/ Zoning – TPI value is then affected by Design and Zoning	Material Property – Building Index is then affected by the property of the material.

³ Definition by www.sciencedirect.com

CONCLUSION

IN TERMS OF DESIGNING BUILDING ENVELOPE, MINIMUM 3-4 INDICES SHOULD BE TAKEN TO QUANTIFY THERMAL EFFICIENCY OF THE ENVELOPE AS ONE MEASURE WILL NOT BE SUFFICIENT .AFTER, THE MICRO CLIMATE ANALYSIS, PRIORTISE THOSE MEASURES ONLY WHICH ARE SUITABLE FOR A PARTICULAR CLIMATE

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