Influence of Thermal Parameters on the Heat Load Calculation of the Building Using HAP Software

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Abstract

The current world we are living in is energy driven and life seems to be almost impossible without it. Hence energy consumption is again another aspect which is closely related to power production process. The two important factors while designing comfortable air conditioning (AC) system is thermal comfort and energy consumption reductionIn this study, HAP software is used to analyse the inside air parameters in order to estimate the best possible condition which indicates minimum power requirement. The parameters on which the best suitable way to reduce heat inside the rooms chosen are as given follows - Walls orientations, windows orientations, climatic season, room level and thermal inertia inside the room. The paper presented is as per the standards provided by Indian standard of refrigeration and air conditioning (ISHRAE) which are in accordance with the climate of India. In particular, buildings require special air condition system and are mostly served by all-air HVAC systems in which control logics are fundamental to guarantee reliability and performance. Apart from this special care has to be taken while designing heating ventilation units in residential buildings. By comparing the output energy requirement of each room in different climatic seasons we can understand the behaviour of properties outside the room in order to minimise the total heat load. Also, it will help in understanding the foremost parameters that are responsible for the performance and functioning of air condition systems. This paper presents some results from operation data analysis of heat load for large residential complex based in Delhi. The main parameters of the energy consumption are shown to be dependent on room orientation and thermal inertia of room which is found to have a significant importance in the energy balance of the system.

1. Introduction

Large residential Structures are found to consume about one-third of the total energy produced in the entire world and this energy consumption is expected to grow at a tremendous rate in the following years to come. The reason behind this substantial increase in energy consumption is the gradual increment in the soaring temperatures which makes life uneasy and derives people to switch on their air conditioners. The greenhouse gases can be understood to be the primary reason of this variation in climatic condition. Among the residential buildings in India, hospital or health related buildings consume the most energy for air-conditioning system compared to shopping complexes, hotels and other residential buildings (1). The primary reason for this being the involvement of life of people which is critical issue. Also, large variations in climatic conditions are required in a hospital which again is hard to maintain and keep constant.

Air conditioning (AC) system is being actively used used in residential and commercial buildings which are primarily responsible for increased power consumption. This brings a competition to all the AC engineers in order to provide best comfort conditions and yet utilise minimum amount of energy.

Energy consumption vastly depends on the performance of the heart of air conditioning unit which is the compressor. If we are able to reduce its overall energy consumption we will be able solve lots of energy consumption problems and also improve the coefficient of performance (COP) of the system (COP), which eventually is related to the velocity of the piston of the compressor. COP value will be comparatively larger at the reduced compressor speed which eventually results in decreased power consumption. Thermal comfort is also an important consideration in evaluating the performance of an air-conditioning system. The main factors that affect thermal comfort are dry bulb temperature, relative humidity and air velocity. Air cleanliness, odour, noise and radiation effect also affect the comfort level of occupants in a conditioned space (2)

The most fundamental problem in high-rise buildings caused by stack effect is the inflow of large amounts of outdoor air into indoor areas. This can cause problems such as excessive heating loads in winter and improper operations of ventilating systems or air conditioning systems due to excessive pressure. However, countermeasures against stack effect made thus far have mainly focused on only solving the problem of low residential performance related to noises and air currents, etc. that can be perceived by occupants (4).

2. Building structure model

In this analysis a building structure was chosen which was approximately 2 storeys, as depicted in figure 1. It had a total surface area of ground floor of Floor Area of 480.0 ft², Avg. Ceiling Height of 12.0 ft and Building Weight of 40.0 lb/ft². And was further divided into a hall, bathroom, dining room home theatre as presented in figure 1. The first floor had similar plan as given above in ground floor. Also separating these two floors is a staircase. The walls are made up concrete brick and insulated properly from the inside with mica material.

Windows were further attached with wooden frames and used triple glazed glass. The roof was flat shaped west side facing. There are approximately 5 windows in each floor. Apart from these two doors in each floor.
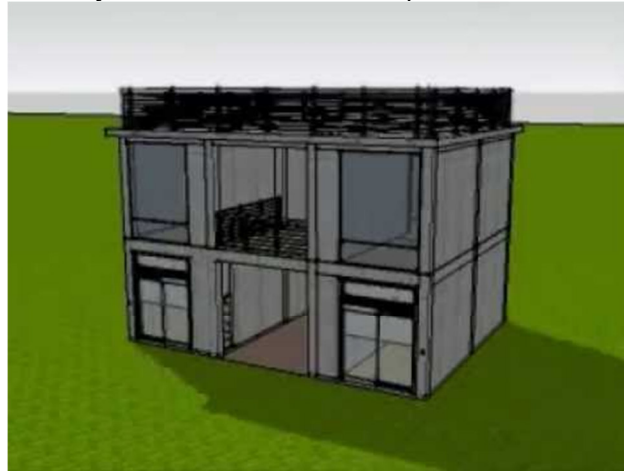

Figure:1 Model of the residential building

3. Mathematical Heat Load Calculation

In this paper the mathematical model is designed with the help of HAP software which uses the sum of external loads and internal loads to calculate the total heat load .the external load comprises of all the building accessories which consist of windows doors roof walls ground etc. similarly the internal load consists of all electrical items such as lights ,bulbs ,television refrigerator, coffee machine ,laptop ,computer etc.in addition to the internal load so consists of hat gain due respiration system and metabolism system of human beings or occupants sitting inside the room.

Basically, there are two types of loads or gains

1. Sensible heat gain
2. Latent heat gain

The sensible cooling load refers to the dry bulb temperature of the building and the latent cooling load refers to the wet bulb temperature of the building. For summer conditions the humidity influence on the selection of the HVAC equipment and the latent load as well as the sensible load must be calculated. The following factors mentioned below are responsible for sensible heat gain or loss

Factors that influence sensible cooling load

- Glass windows or doors
- Sunlight striking windows, skylights, or glass doors and heating the room
- Exterior walls
- Partitions (that separate spaces of different temperatures)
- Ceilings under an attic
- Roofs
- Floors over an open crawl space
- Air infiltration through cracks in the building, doors, and windows
- People in the building
- Equipment and appliances operated in the summer
- Lights

The below grade walls, below grade floors, and floors on concrete slabs do not increase the cooling load on the structure and are therefore ignored.

Factors that influence to the latent cooling load

Moisture is introduced into a structure through:

- People
- Equipment and appliances
- Air infiltration through cracks in the building, doors, and windows

Other latent heat gain is taken care of by the HVAC equipment before the air reaches the rooms (system gain) (3).

A designer, should keep in mind that building occupants constitute the final determining factor on the extent of utilizable of any building system, including thermal mass. Clearly, by changing the use of internal spaces and surfaces one can drastically reduce the effectiveness of thermal storage. Consequently, it is necessary to carefully consider the final use of the space when making calculations of the cooling load and incorporating the possible savings from thermal mass effects (5).

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Following calculations are computed with the help of HAP software which have been made for calculation of air-conditioning cooling

a) Fresh air: 7.5 cfm/per person as per ASHRAE 170 and 62.1.

b) Window glazing: Single/double pane glazed glass

c) Lighting load: 1.1 W/ Sq. ft

d) Occupancy: 20-25 people as per seating plan.

e) Equipment load: 5.6 kW

f) Roof Insulation: The exposed roof of air-conditioned areas shall be insulated.

g) Electrical power supply: 415v/3ph/50Hz, AC power supply

h) Humidity control: Not considered

i) Glass: SHGC- 0.25

U-Value- 0.57 Btu/hr/sq. Ft.

According to thermodynamics heat is considered to be positive when it is entering the whole system and is an indication of increase in overall temperature of the system. Also heat exiting the whole system is considered to be negative and indicates in decrease in overall temperature of the system. The heat amount exchange between the two floors and the environment is noted on every 20 min in order to further analyse the heat load on the building. Thus, all heat gains counting in the cooling load are positive quantities and all heat losses counting in heating load are negative. Standard Delhi environmental conditions are applied for this mathematical model. The terms acquired from met department of India are as provided in the table and further analyses have to be done using this data only.

Table:1 Location Properties for Designing

S.NO.	Properties of location	Values
1	Latitude	28.6139° N
2	Longitude	77.2090° E
3	Elevation	216 m
4	Area	42.7 km²
5	Weather	38°C-46 C in summers
6	Wind E	11 km/h
7	Humidity	40%-50% summers

4. Methodology

4.1 Heat transfer between the walls and atmosphere

This is a sensible heat transfer process. The heat transfer rate through opaque surfaces such as walls, roof, floor, doors etc. is given

$$Q_{opaque} = U.A.CLTD$$

where U is the overall heat transfer coefficient and A is the heat transfer area of the surface on the side of the conditioned space. CLTD is the cooling load temperature difference.

4.2 Heat transfer trough windows

Heat transfer through transparent surface such as a window, includes heat transfer by conduction due to temperature difference across the window and heat transfer due to solar radiation through the window. The heat transfer through the window by convection with CLTD being equal to the temperature difference across the window and A equal to the total area of the window. The heat transfer due to solar radiation through the window is given by,

$$Q_{trans} = A_{unshaded}.SHGF_{max}.SC.CLF$$

where $A_{unshaded}$ is the area exposed to solar radiation, $SHGF_{max}$ and SC are the maximum Solar Heat Gain Factor and Shading Coefficient, respectively, and **CLF** is the Cooling Load Factor. $SHGF_{max}$ and SC are obtained from ASHRAE tables based on the orientation of the window, location, month of the year and the type of glass and internal shading device.

The **Cooling Load Factor (CLF)** accounts for the fact that all the radiant energy that enters the conditioned space at a particular time does not become a part of the cooling load1 instantly. As solar radiation enters the conditioned space, only a negligible portion of it is absorbed by the air particles in the conditioned space instantaneously leading to a minute change in its temperature. Most of the radiation is first absorbed by the internal surfaces, which include ceiling, floor, internal walls, furniture etc. Due to the large but finite thermal capacity of the roof, floor, walls etc., their temperature increases slowly due to absorption of solar radiation. As

the surface temperature increases, heat transfer takes place between these surfaces and the air in the conditioned space. Depending upon the thermal capacity of the wall and the outside temperature, some of the absorbed energy due to solar radiation may be conducted to the outer surface and may be lost to the outdoors. Only that fraction of the solar radiation that is transferred to the air in the conditioned space becomes a load on the building, the heat transferred to the outside is not a part of the cooling load. Thus, it can be seen that the radiation heat transfer introduces a time lag and also a decrement factor depending upon the dynamic characteristics of the surfaces. Due to the time lag, the effect of radiation will be felt even when the source of radiation, in this case the sun is removed. The CLF values for various surfaces have been calculated as functions of solar time and orientation and are available in the form of tables in ASHRAE Handbooks.

In another study it was proposed a simulation tool for generating a probabilistic approach to model the human behaviour related to windows opening and closing. More precisely, the author proposed four models of occupants' interactions with windows and simulated the energy performance for a bedroom and a living room (6).

Table:2 Cooling Load Factor (CLF) for glass with interior shading and located in north latitudes (ASHRAE)

Solar Time, h	Direction the sunlit window is facing								
	N	NE	E	SE	S	SW	W	NW	Horiz.
6	0.73	0.56	0.47	0.30	0.09	0.07	0.06	0.07	0.12
7	0.66	0.76	0.72	0.57	0.16	0.11	0.09	0.11	0.27
8	0.65	0.74	0.80	0.74	0.23	0.14	0.11	0.14	0.44
9	0.73	0.58	0.76	0.81	0.38	0.16	0.13	0.17	0.59
10	0.80	0.37	0.62	0.79	0.58	0.19	0.15	0.19	0.72
11	0.86	0.29	0.41	0.68	0.75	0.22	0.16	0.20	0.81
12	0.89	0.27	0.27	0.49	0.83	0.38	0.17	0.21	0.85
13	0.89	0.26	0.26	0.33	0.80	0.59	0.31	0.22	0.85
14	0.86	0.24	0.24	0.28	0.68	0.75	0.53	0.30	0.81
15	0.82	0.22	0.22	0.25	0.50	0.83	0.72	0.52	0.71
16	0.75	0.20	0.20	0.22	0.35	0.81	0.82	0.73	0.58
17	0.78	0.16	0.16	0.18	0.27	0.69	0.81	0.82	0.42
18	0.91	0.12	0.12	0.13	0.19	0.45	0.61	0.69	0.25

4.3 Heat transfer due to infiltration

Heat transfer due to infiltration consists of both sensible as well as latent components. The sensible heat transfer rate due to infiltration is given by:

$$Q_{s,inf} = \dot{m}_o \, c_{p,m} (T_o - T_i) = \dot{V}_o \, \rho_o c_{p,m} (T_o - T_i)$$

where **mo** is the infiltration rate (in V^3/s), ρ_o and $c_{p,m}$ are the density and specific heat of the moist, infiltrated air, respectively. T_o and T_i are the outdoor and indoor dry bulb temperatures. The latent heat transfer rate due to infiltration is given by:

$$Q_{l,inf} = \dot{m}_o \, h_{fg} (W_o - W_i) = \dot{V}_o \, \rho_o h_{fg} (W_o - W_i)$$

where h_{fg} is the latent heat of vaporization of water, W_o and W_i are the outdoor and indoor humidity ratio, respectively.

The infiltration rate depends upon several factors such as the tightness of the building that includes the walls, windows, doors etc and the prevailing wind speed and direction. As mentioned before, the infiltration rate is obtained by using either the air change method or the crack method.

The infiltration rate by air change method is given by:

$$V_o = (ACH).V / 3600 \quad m^3/s$$

where ACH is the number of air changes per hour and V is the gross volume of the conditioned space in m^3 Normally the ACH value varies from 0.5 ACH for tight and well-sealed buildings to about 2.0 for loose and poorly sealed buildings. For modern buildings the ACH value may be as low as 0.2 ACH. Thus, depending upon

the age and condition of the building an appropriate ACH value has to be chosen, using which the infiltration rate can be calculated.

The infiltration rate by the crack method is given by:

$$\dot{V}_o = A.C.\Delta P^n \quad m^3/s$$

where **A is the effective leakage area of the cracks, C is a flow coefficient** which depends on the type of the crack and the nature of the flow in the crack, ΔP **is the difference between outside and inside pressure ($P_o - P_i$)** and **n is an exponent** whose value depends on the nature of the flow in the crack.

4.4 Calculation of internal loads

The internal loads consist of load due to occupants, due to lighting, due to equipment and appliances and due to products stored or processes being performed in the conditioned space.

a) **Load due to occupants:** The internal cooling load due to occupants consists of both sensible and latent heat components. The rate at which the sensible and latent heat transfer take place depends mainly on the population and activity level of the occupants. Since a portion of the heat transferred by the occupants is in the form of radiation, a Cooling Load Factor (CLF) should be used similar to that used for radiation heat transfer through fenestration. Thus, the sensible heat transfer to the conditioned space due to the occupants is given by the equation:

$$Q_{s,\ occupants} = (No.\ of\ people).(Sensible\ heat\ gain/person).CLF$$

The sensible heat gain fraction as a function of activity in an air-conditioned space. However, it should be noted that the fraction of the total heat gain that is sensible depends on the conditions of the indoor environment. If the conditioned space temperature is higher, then the fraction of total heat gain that is sensible decreases and the latent heat gain increases, and vice versa.

Table 3: Total heat gain from the occupants

Activity	Total heat gain, W	Sensible heat gain fraction
Sleeping	70	0.75
Seated, quiet	100	0.60
Standing	150	0.50
Walking @ 3.5 kmph	305	0.35
Office work	150	0.55
Teaching	175	0.50
Industrial work	300 to 600	0.35

The value of Cooling Load Factor (CLF) for occupants depends on the hours after the entry of the occupants into the conditioned space, the total hours spent in the conditioned space and type of the building. Values of CLF have been obtained for different types of buildings and have been tabulated in ASHRAE handbooks. Since the latent heat gain from the occupants is instantaneous the CLF for latent heat gain is 1.0, thus the latent heat gain due to occupants is given by

$$Q_{l,occupants} = (No.\ of\ people).(Latent\ heat\ gain/person)$$

b) **Load due to lighting**: Lighting adds sensible heat to the conditioned space. Since the heat transferred from the lighting system consists of both radiation and convection, a Cooling Load Factor is used to account for the time lag. Thus, the cooling load due to lighting system is given by

$$Q_{s,lighting} = (Installed\ wattage)(Usage\ Factor)(Ballast\ factor)CLF$$

The usage factor accounts for any lamps that are installed but are not switched on at the time at which load calculations are performed. The ballast factor takes into account the load imposed by ballasts used in fluorescent lights. A typical ballast factor value of 1.25 is taken for fluorescent lights, while it is equal to 1.0 for incandescent lamps. The values of CLF as a function of the number of hours after the lights are turned on, type of lighting fixtures and the hours of operation of the lights are available in the form of tables in ASHRAE handbooks.

C) Internal loads due to equipment and appliances: The equipment and appliances used in the conditioned space may add both sensible as well as latent loads to the conditioned space. Again, the sensible load may be in the form of radiation and/or convection. Thus, the internal sensible load due to equipment and appliances is given by:

$$Q_{s,appliances} = (Installed\ wattage).(Usage\ Factor).CLF$$

The installed wattage and usage factor depend on the type of the appliance or equipment. The CLF values are available in the form of tables in ASHARE handbooks.

The latent load due to appliances is given by:

$$Q_{l,appliance} = (Installed\ wattage).(Latent\ heat\ fraction)$$

Table 4: climatic difference's and humidity ratio for building

Climatic conditions	DB	WB	RH
	°F	°F	%
Summer >	110	78	24.09
Monsoon>	87	82	81.06
Winter >	54	44	43.43
Inside (Summer& Monson) >	75	-	55
Inside (Winter) >	68	-	55
Temp. Diff.(Summer)>	35	-	-
Temp. Diff.(Monsoon)>	12	-	-
Temp. Diff.(Winter)>	14	-	-

5. Results and discussions

Basically, the temperature chosen for further analysis is approximately45 C and the month chosen for analysis is June and December. The building studied for external and internal heat loads which add on to the total heat load.

Influence of exterior walls

The external loads are calculated using HAP software for each room and are depicted in the graph given below for the months June and December. It can be clearly understood that during the month of June the overall heat transfers are positive for the structure and thereby has to be added in the total cooling load of the building. Another reason of this gain can also be predicted that rooms oriented towards the east west or south have maximum heat gain as they are directly exposed to the sun rays throughout the day. Hence positive care has to be taken while designing the rooms mainly towards the north side for minimum heat gains.

In the month of December, the heat load is mostly negative, which contribute to a decrease in the overall building cooling demand.

It can be also understood that, during a few hours in the entire day period in which the sun is on zenith, the external load becomes positive, depending on which side is the room situated and total of exterior walls facing that orientation. As revealed by figure 3 (b), the one dining room, stairs and bathroom at the ground-floor and upper ground-floor have high load requirement throughout the day; these rooms have one exterior walls each and the highest surface is east oriented facing towards the sun rays.

On the other hand, the ground-floor kitchen, has three exterior walls, and has the highest number of exterior walls. These walls are facing towards the north and are much cooler than other rooms. Also, the kitchen is required to be cooler than other rooms in order to make feasible for the cook inside. The rest of positive loads in January characterize rooms having only one exterior wall.

Table 5: exterior wall gains through different orientations

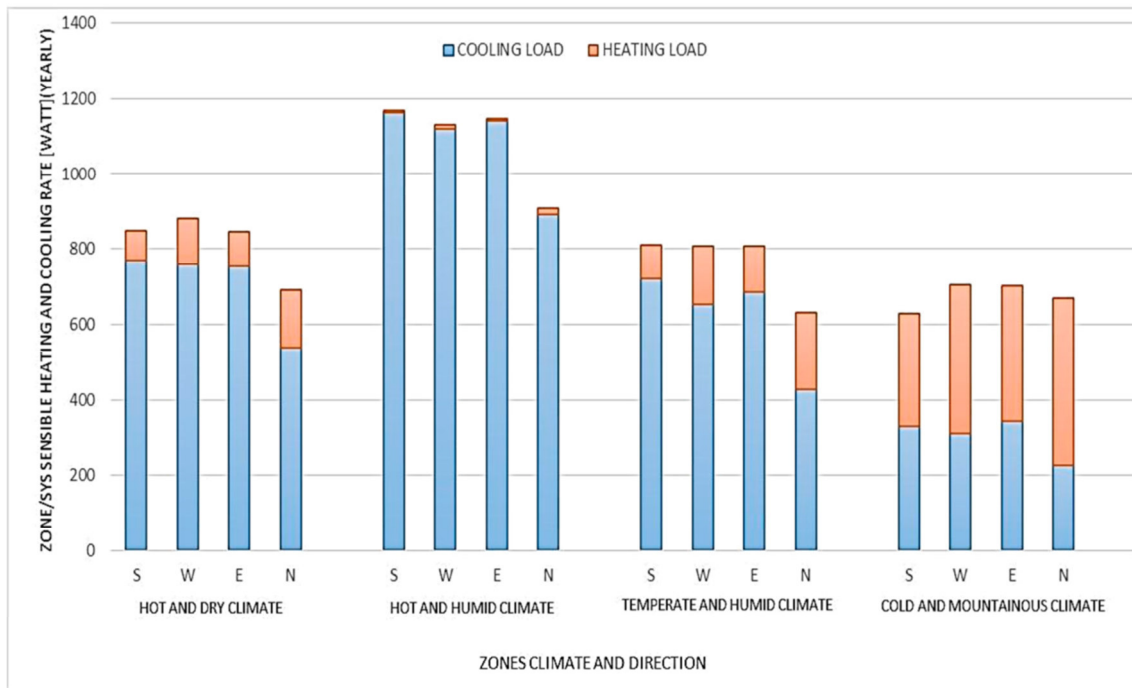| orientations	Summer	Monsoon	Winter	U-Value
	TD	TD	TD	
East	34	11	14	0.36
West	33	5	14	0.36
South	32	9	14	0.36
North	20	-3	14	0.36
S.East	34	11	14	0.36
S.'West	30	7	14	0.36
NE	26	3	14	0.36
NW	22	5	14	0.36
Roof sun	48	25	14	0.12
Roof sun	14	0.48		

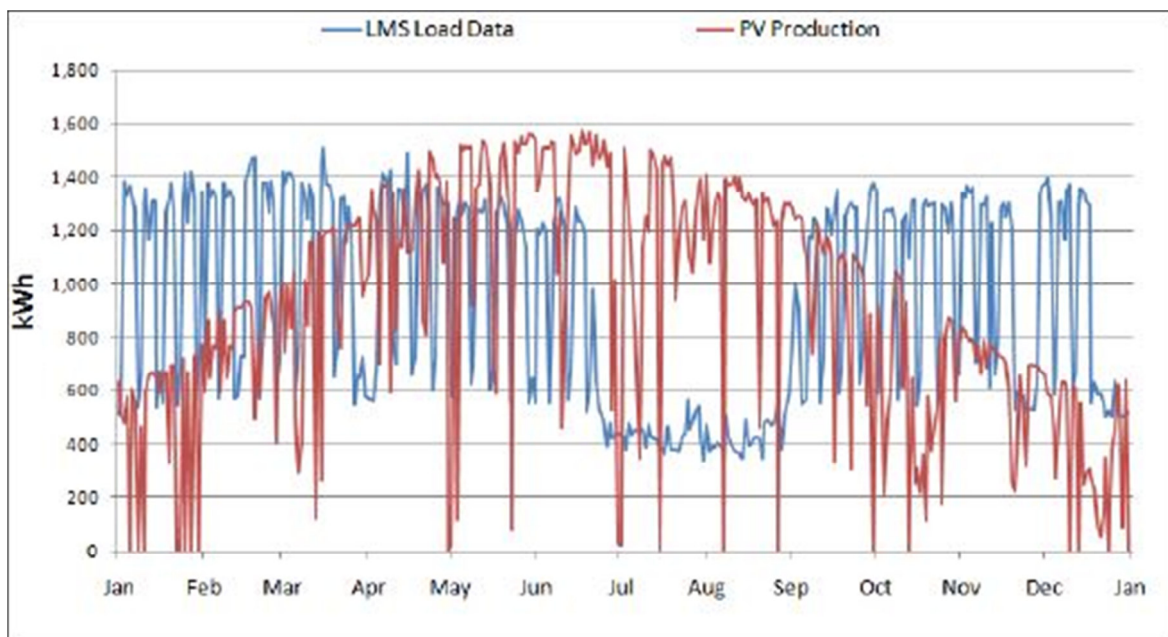Figure 2: heat gains through different orientations by the exterior wall

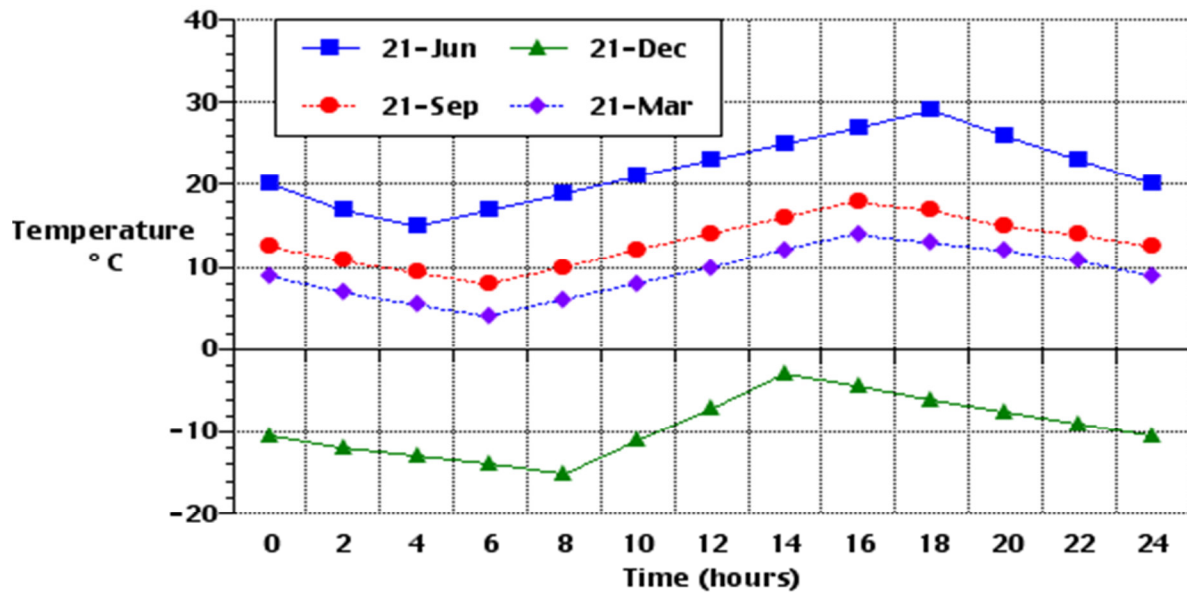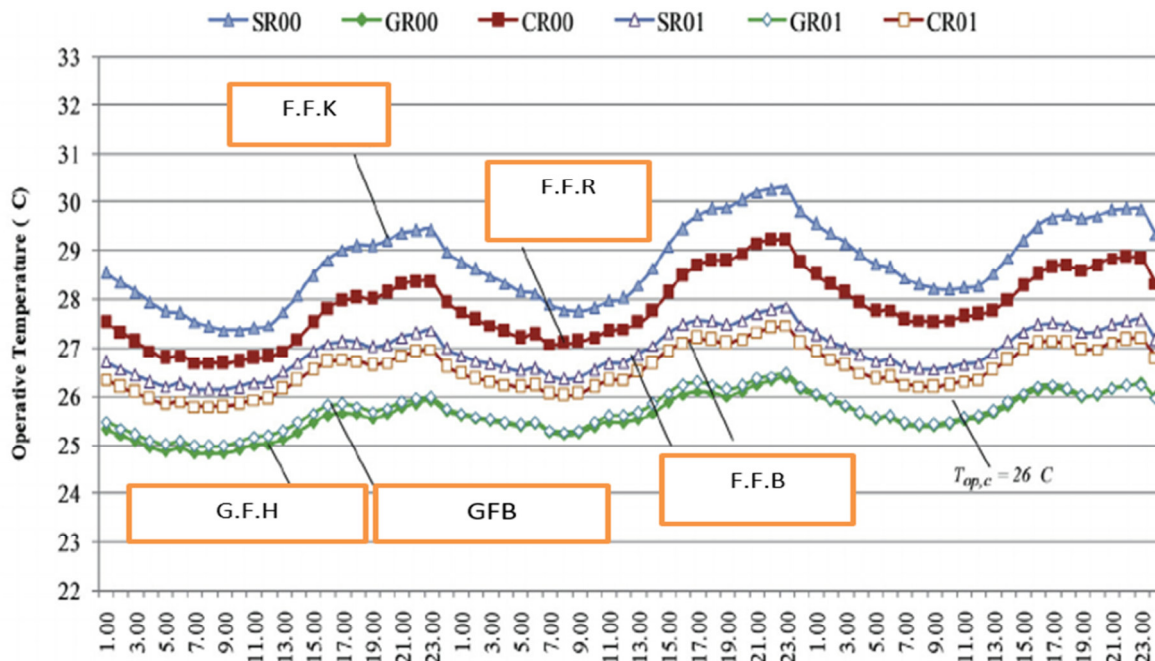Figure 3: heat gains in different month of year by exterior walls

Figure 4: Heat gains through different time of day by the exterior walls

Figure 5: temperature difference observed throughout the day for different rooms

Influence of room orientation

The influence of room orientation plays a vital role in the total heat load calculation of the building. Maximum heat gains were registered for those walls which ere oriented towards the east side, as the sun rises from the east peak gains were registered in this orientation. These orientated walls were found to add on the total heat load till noon 1:00, after which the sun started to shift on to the west side walls.

On the other hand, the West side oriented exterior walls rooms have the zenith heat load after noon, as Sun moves from east west and finally goes down in the West. The exterior walled rooms with South side-oriented walls encounter the peak exactly at noon, as the azimuth angle is zero.

The zenith value of heat gains is obviously lower in winter (December, figure 3 (bin comparison to summer season (June, figure 3(a)) and it also seems to be closer to noon in cold climates and further from noon in hot climates. This is due to a shorter path of the Sun in the sky during winter, respectively late sunrise hours and early sunset hours, as comparing to summer longer path, earlier sunrise hours and later sunset hours.

Influence of room level

In this section we will be considering the effects of previous dimensions and previous orientations of the rooms which are placed at ground floor and first floor i.e. rooms 2 and 3, bathroom and kitchen. It can be easily observed that in the month of June the upper ground floor rooms have higher net heat transfer that is positive heat transfers. This can be again understood by the fact that ground floor rooms are placed near to the floor and are constantly rejecting heat to the ground, thereby keeping it colder in respect to the upper ground which is comparatively warmer due to the reason that it is constantly absorbing heat from the lower rooms and the ceiling which may be directly exposed to the sun making it hotter than previously. But this case becomes completely different in case of December where the ground floor rooms exhibit better thermal behaviour in comparison to first floor rooms as it needs lower heating equipment. External load losses are lower in absolute value for ground-floor rooms, while external load gains during the daylight are higher. But in case of upper ground floor rooms which are oriented towards the East we have to make an exception as it has better heat gains in winter climate time and has higher heat gains for few hours, due to direct Sunlight during morning.

TABLE 5: Temperature difference and heat loads for each room in building

Room name	Floor	Temperature difference(C)
Ground floor hall (G.F.H)	Ground	25.9
Ground floor bath (G.F.B)	Ground	26.3
First floor bath (F.F.B)	Upper ground	27.1
First floor room (F.F.R)	Upper ground	29.5
First floor kitchen (F.F.K)	Upper ground	31.5

Influence of building elements

In addition to the above loads there is another load which contributes to the total heat again which is through windows present in each room and also its orientations in each respective room. In this analysis we have to also observe the thermal inertia present in each room which is major contributor in heat gains. Elements without thermal inertia (e.g. windows) present heat gains as long as they are directly heated by Sun. The East oriented window of the upper ground floor kitchen) represents heat inputs from sunrise to afternoon, which are directly exposed to sun rays. A completely differed behaviour is observed when the thermal inertia is associated to walls exposed to east side orientation which is directly towards sun. The East oriented wall of the previous room begins rejecting heat inside at about 3 PM, attaining the peak around 7 PM, although it was subjected to direct sun rays for the same duration as the earlier exposed window. This can be interpreted by understanding that walls have a tendency to absorb a part of radiation imposed by the sun rays and eventually stores inside it. Later it is released into the room throughout the evening which is again due to the fact of phase shift of the wall or when cooler air blows on to it. The phase-shift for the considered exterior wall structure is about 10 hours (more precisely, 11 hours but one hour is left as safety factor as the climate as its own changes). This can be understood by a simple calculation of time analysis, that heat absorbed around 10 AM by the wall is rejected inside the room at 6 PM. A particular aspect is emphasized by the North oriented wall. The two zeniths are studied in respect to the both very tiny durations in which this wall facing the radiations directed by the Sun. during the hotter seasons, Sun rises and sets in the East-West line, hence we can conclude that there are two periods with direct sunlight on a North oriented surface, in clear sky conditions. Another characteristic which has to be observed closely is the total amount of heat gained during this span by each element. In comparison, the windows   are larger contributors of total heat supply as compared tom the exterior faced walls. The overall heat gained through the window of surface 2.22 m^2 is much higher than that through the 9.15 m^2 wall on which it is mounted although being comparatively less in area also. While assuming to 1 m2 of element, the zenith heat absorbed through an outer window surface is about 405 W/m^2, whereas the outer wall absorbs only 8.5 W/m^2.

These outcomes are quite handy while designing and implication of a house for lowest heat load consumption, keeping in mind the aspects of the thermal behaviour building elements.
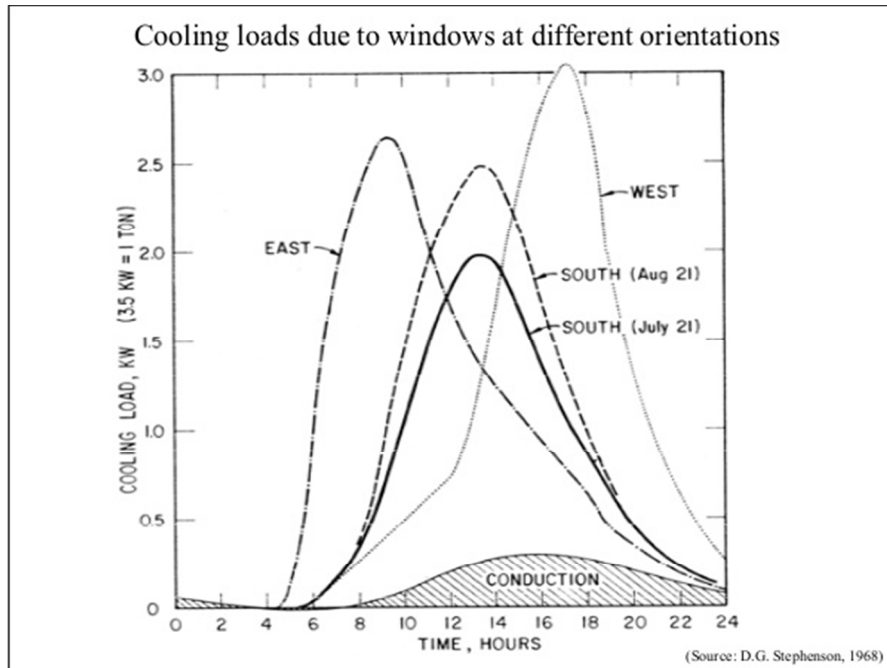
Figure 6: heat gain through windows for different time of the day

Table 4 window heat gains through different orientations

Orientation	Area	Sun Gain			U-Value
	feet	Summer	Monsoon	Heat gain	
		TD	TD	W/m2	
East		12	11	1.2	0.28
West		163	165	21.12	0.28
South		12	11	1.2	0.28
North		23	11	2.2	0.28
S.East		12	11	1.1	0.28
S.'West		85	113	20.1	0.28
NE		12	11	0.9	0.28
NW		138	118	24.12	0.28
Skylight(Hor.)		118	107	15.12	0.28

6. Conclusion

The thermal properties of a two-level residential building designed in Delhi (28.25 N latitude) was analysed in clear no cloud condition sky. Results showed that the foremost contributor to the building thermal loss is the window, contributing to a heat gain during summer of about 653 Wm-2, while the exterior wall contributes with only 20.23 Wm-2 phase-shifted, for East orientated surfaces. Also, the number of exterior walls and their orientation with respect to East-West axis influence the contribution to the external load of the building.

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