HEAT AND LIGHT

Heat gain and heat loss phenomenon in buildings. Thermal performance parameters. Role of building enclosures, openings and materials in thermal environment. Basic principles of light and daylight. Energy efficient light design of buildings. Daylight design of buildings.

INTRODUCTION

The energy conscious design approach helps designers and building owners to economically reduce building operating costs, while improving comfort for the building's occupants. The energy consumed by a building depends on its use (whether residential, commercial or industrial), the type of building (air-conditioned or otherwise), the interaction of spaces, and the climate.

Building envelopes not only provide the thermal divide between the indoor and outdoor environment, but also play an important role in determining how effectively the building can utilise natural lighting, ventilation, and heating and cooling resources. Thus, intelligent configuration and moulding of the built form and its surroundings can considerably minimise the level of discomfort inside a building, and reduce the consumption of energy required to maintain comfortable conditions.

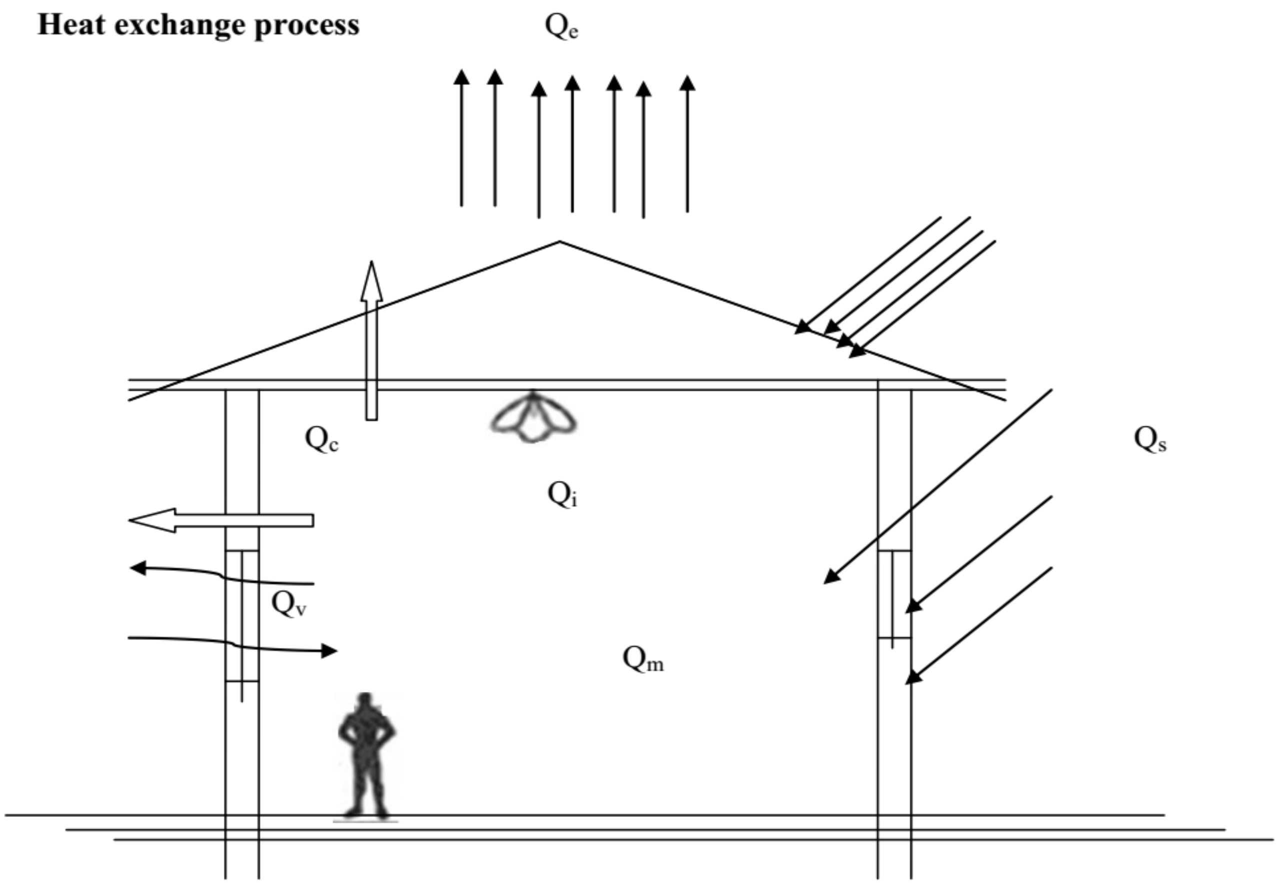
Yet, in extreme climate s, comfortable indoor conditions cannot be completely achieved by limiting oneself to simple techniques. For example, in a city like Ahmadabad where the ambient temperatures can reach up to 42 ^{0}C in summer, simple techniques such as orientation, shading, colour of external surfaces and insulation may help to bring down the temperature to around 36^{0}C.

TRANSFER OF HEAT

- ✓ Heat exchange of building:
- ✓ Heat exchange process
- ✓ Conduction
- ✓ Convection
- ✓ Radiation through windows
- ✓ Internal heat gain
- ✓ Heating and cooling

- ✓ Evaporation
- ✓ Heat loss calculation
- ✓ Heat gain calculation
- ✓ Cooling by air
- ✓ Heating by air
- ✓ Transmittance of composite walls
- ✓ Thermal gradient
- ✓ Condensation
- ✓ Thermal design

Heat exchange process



$$Q_i + Q_s \pm Q_c \pm Q_v \pm Q_m - Q_e = 0$$

Q_i - Internal heat gain

Q_s - Solar heat gain

Q_c - Conduction

Q_v - Ventilation

Q_m - Heat flow rate and mechanical controls

Q_e - Evaporation

Internal heat gain: may result from the heat output of human bodies, lamps, motors and appliances.

Solar heat gain: Solar radiation on opaque surfaces can be included in the above by using Sol – air temperature concept but through transparent surfaces (windows) the solar heat gain must be considered separately.

Conduction of heat: may occur through the walls either inwards or outwards.

Ventilation: heat exchange in either direction may take place with movement of air.

Heat flow rate: removal of heat using some form of outside energy supply. The heat Flow rate of such mechanical controls may denoted (Q_m)

Evaporation: take place on the surface of the building (e.g. a roof pool (or) within the building, human sweat (or) water in a fountain) and the vapours are remove, this will produce a cool effect.

Conduction

Conduction heat flow rate through a wall of a given area can be described by equation.

$$Q_C = A \times U \times \Delta T$$

Where Q_c = Conduction of heat flow rate in W

A = surface are in m^2

U = Transmittance value in $W/m^2\ °C$

ΔT = Temperature difference

Convection

Depends rate of ventilation (i.e. air change)

$$Q_v = 1300 \times V \times \Delta T$$

Where Qv = Ventilation heat flow rate in W

1300 = volumetric specific heat of air, J/m^3

V= Ventilation rate in m^3/sec

T = temperature difference ° C

V = (N x room volume) /3600

(3600 – No. of seconds in an hour)

Radiation through windows

$$Qs = A \times I \times Q$$

Where A = area of window in m^2

I = radiation heat flow density in W/m^2

Q = Solar gain factor of window glass

Internal heat gain

Heat output from a body (inside the building) is a heat gain for the building.

* Total rate of energy emission of electric lamps can be taken as internal heat gain.

Heat and cooling

Mechanical controls -- deliberately controllable

Evaporation

"rate of cooling by evaporation can only be calculated if the rate of evaporation itself is known"

Evaporation rate expressed in Kg / h

$$Q_e = 666 \times Kg / h$$

Depends – Available moisture
– Humidity of the air
– Temperature of the moisture
– Temperature of air movement

Evaporation cooling will be utilized to reduce air temperature as far as possible

Heat loss calculation

Purpose – designing of a heating installation

No solar radiation and no evaporation loss are considered the thermal balance equations.

$$Q_i - Q_c - Q_v + Q_m = 0$$

Heat gain calculation

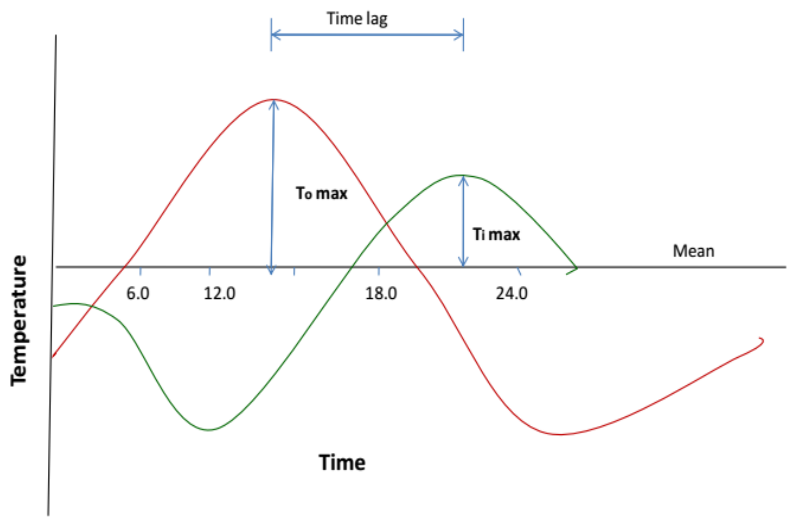
Calculated for the purpose of air conditioning design

Air conditioning system must be capable of removing heat at this rate (or) rounded upto 5 KW

PERIODIC HEAT FLOW IN BUILDING ELEMENTS

- Variation of climate conditions produces a non-steady state
- 24 hour cycle – temperature increasing and temperature decreasing
- In hot period – heat flows from the environment into the building, when some of it is stored.
- At night during cool period the heat flow is reversed. (From building to the environment)

INTRODUCTION TO TIME-LAG AND DECREMENT FACTOR



To max – Maximum outer surface temperature

Ti max – Maximum Inner surface temperature

$$\text{Decrement factor:} \quad \mu = \frac{\text{Ti max}}{\text{To max}}$$

- Above figure shows dual variation of external and internal temperatures in periodically changing thermal regime.
- In the morning the outer temperature increases, heat starts entering the outer surface of the wall.
- Each particle in the wall will absorb a certain amount of heat for every degree of rise in temperature, depending on the specific heat of the wall material.
- Heat to the next particle will only be transmitted after the temperature of the first particle has increased.
- Thus the corresponding increase of the internal surface temperature will be delayed as show by the green line.
- The outer temperature will have reached its peak and started decreasing, before the inner surface temperature has reached the same level.
- From this moment the heat stored in the wall will be dissipated partly to the outside and only partly to the inside.
- As the out-door air cools, an increasing proportion of this stored heat flows outwards, and when the wall temperature falls below the indoor temperature the direction of the heat flow is completely reversed.
- The two quantities characterizing this periodic change are the time-lag (or phase shift, denoted Φ) and the decrement factor (or amplitude attenuation, denoted μ) The latter is the ratio of the maximum outer and inner surface temperature amplitudes taken from the daily mean.

The artificial is lighting load on a building can be significantly reduced if its design allows for effective daylighting. Additionally, building materials also play an important role in energy conscious architecture. This also describes daylighting as a passive solar technique, and concludes with a discussion on alternative building materials .

BUILDING ENVELOPE

A building interacts with the environment through its external façades such as walls, windows, projections, and roofs, referred to as the building envelope. The envelope acts as a thermal shell, which if thoughtlessly constructed, would result in energy leaks through every component. Hence, each component needs to be properly chosen to ensure an energy efficient building. The choice depends on the site and the primary objective is, therefore, to examine the site conditions. Besides, an ideal orientation of the building at a site and proper building configuration play a significant role in the building's performance.

Site

Of the various factors influencing the building design, site conditions occupy an important position. The environmental conditions experienced on the site are due to the macroclimate as well as the microclimate .Site-specific conditions such as land form, vegetation, water bodies, open spaces, etc**.** play an important role in building design. Proper analysis of these conditions can enable one to choose a site and make suitable design plans. This would help save energy and also provide a fairly satisfactory indoor environment throughout the year.

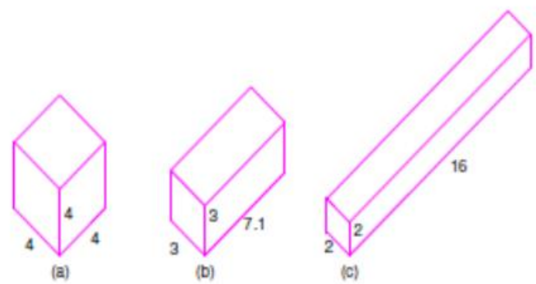
Building configuration

Heat exchange between a building and its surroundings occurs primarily through the 'skin' of the building. Configuring the geometry of the building appropriate to the climate and usage can control the magnitude of the heat flow. For example, in an extremely cold climate, one needs to minimise heat loss from the building to the environment. This can be achieved by:

a) using buffer spaces, e.g., sunspaces and balconies act as sitouts in favourable weather;
b) locating infrequently used spaces such as store rooms and toilets in the direction that face prevailing cold winds
c) maximising exposure to solar radiation, e.g., major living rooms may be arranged facing the sun to gain heat;
d) locating habitable spaces appropriately, e.g., the most habitable spaces may be kept on leeward side to avoid cold winds. They may be clustered together to reduce exposure to cold.

The heat flow due to radiation and air movement can be controlled by varying the following aspects of the building configuration:

- **Surface area to volume ratio (S/V ratio):** The ratio of the surface area to the volume of the building (S/V ratio) determines the magnitude of the heat transfer in and out of the building. The larger the S/V ratio, the greater the heat gain or loss for a given volume of space. Conversely, a smaller S/V ratio will result in the reduction of heat gain/loss. For example, in cold climates it is preferable to have compact house forms with minimum S/V ratio. Figure. 3.3 shows the surface to volume ratios for various building shapes.



SOLID SHAPE	SURFACE AREA 'S'	VOLUME 'V'	SURFACE AREA/ VOLUME RATIO 'S/V'
a	96	64	1.5
b	103.2	64	1.61
c	136	64	2.13

Fig. 3.3 Surface area to volume ratio (S/V ratio) for a few building shapes

- **Shape of the building:** Wind when obstructed by a building creates pressure differences, that is, positive pressure on the windward side and negative pressure on the leeward side. Consequently, a new airflow pattern is established around the building. Thus, wind pattern across a building can be modified by shaping it appropriately.
- **Buffer spaces:** Buffer spaces such as courtyards, atria, balconies and verandahs provide shading and catch wind.
- **Arrangement of openings:** Appropriate openings connecting high and low pressure areas provide effective ventilation. Solid and glazed surfaces need to be suitably arranged and oriented for receiving or rejecting solar radiation.

Building components

The nature of a building envelope determines the amount of radiation and wind that will enter the building. It consists of the following elements:

(A) Roof

(B) Walls

(C) Ground-based floor

(D) Fenestrations

(E) External colour and texture

The heat flow through these elements is characterised by their resistance, thermal capacity, absorption, transmission and emission. The materials for these components have to be chosen carefully depending on specific requirements. The thermophysical parameters of materials that must be considered are specific heat, density and thermal conductivity. While the product of the first two determines the energy storage capacity of a material, the third characterises the energy-flow behaviour. These three parameters together define the time lag (or phase shift) and decrement factor. The former refers to the time delay of heat flow whereas the latter signifies the reduction in the amplitude of heat waves. Thus, depending on the climatic requirements, one would look for materials that would provide the desired thermal storage, time delay and amplitude decrement.

Colour and texture define surface characteristics such as emissivity, reflectivity, absorptivity and roughness. These are vital for heat flow and light distribution. For example, if the roof of a building is painted white, then the transmission of heat can be reduced by upto 80% as compared to a dark colour.

Generally, the building components can be categorised into opaque and transparent elements. For example, a brick wall is an opaque element whereas a glazed window is a transparent element. Transparent elements allow direct solar radiation into the living spaces. Furthermore, an element may also be openable (e.g. skylight, window, door, etc), thereby allowing for air exchanges between the building and its surroundings.

Heat loss or gain from various building components may be reduced by insulating them appropriately. Walls, floors and roofs can be insulated by materials such as polyurethane foam

(PUF), or thermocol, either externally or internally. Another mode of insulation is by incorporating an air cavity in the external building envelope. In cavity walls, the air gap inhibits the transmission of the heat into or out of the building as air acts as a bad conductor of heat. Variations can be achieved by using different insulation materials, adjusting their thickness, and using them in different locations (internal or external). In cavity walls, the property of the air gap can be varied by opting for a ventilated or unventilated air cavity, and adjusting its thickness. It may be noted that water absorption adversely affects the performance of insulation materials.

The heat gain through each element can be varied by:

- area of the element
- orientation and tilt of the element
- material properties (U-value, time lag, decrement factor, transmissivity, emmissivity, etc)
- finishes
- control of incoming solar radiation

(A) Roof

The roof of a building receives a significant amount of solar radiation. Thus, its design and construction play an important role in modifying the heat flow, daylighting and ventilation. As per Indian Standard I.S. code 3792 – 1978 [4], the maximum value of overall thermal transmittance (U-value) of a roof should not exceed 2.33 W/m^2-K in hot-dry, and warm and humid climates. The code recommends that the heat gain through roofs may be reduced by the following methods:

- Insulating materials may be applied externally or internally to the roofs. In case of external application, the insulating material needs to be protected by waterproofing treatments. For internal application, the insulating material may be fixed by adhesive or by other means on the underside of the roofs. A false ceiling of insulation material may be provided below the roofs with air gaps in between. Shining and reflecting material (e.g. glazed china mosaic) may be laid on top of the roof.
- Roofs may be flooded with water in the form of sprays or in other ways. Loss due to evaporation may be compensated by make-up arrangement.
- Movable covers of suitable heat insulating material, if practicable, may be considered.
- White washing of the roof can be done before the onset of each summer.

The second and fourth recommendations would be fully effective if the surfaces are kept clean, without accumulation of dust. The recommended thickness of some insulating materials for roofs is given in Table 3.3. Figure 3.7 [6] shows the reduction of ceiling surface temperature due to some of the above techniques for a flat roof in a hot and dry climate on two consecutive summer days. It is seen that the ceiling surface temperature can be reduced by about 10^0C.

A massive roof composed of material such as reinforced cement concrete (RCC) tends to delay the transmission of heat into the interior when compared to lighter roofs such as asbestos cement sheet roofing. Sometimes, the roof is also covered by inverted earthen pots with a layer of earth over them. The earth and the air inside the pots provide good insulation for resisting heat gain. A doubly pitched or curved roof provides a larger surface area for heat loss compared to a flat roof. Thus, both the shape as well as the material have an effect on the performance of the roof.

(B) Walls

Walls constitute a major part of the building envelope and receive a large amount of direct radiation. Depending on whether the need is for heating or cooling, the thickness and material of the wall can be varied to control heat gain. The resistance to heat flow through the exposed walls may be increased in the following ways:

- The thickness of the wall may be increased
- Cavity wall construction may be adopted.
- The wall maybe constructed out of suitable heat insulating material, provided structural requirements are met.
- Heat insulating material may be fixed on the inside or outside of the exposed wall. In the case of external application, overall water proofing is essential.
- Light coloured whitewash or distemper may be applied on the exposed side of the wall.

The performance indicators, such as U-values (thermal transmittance), thermal damping, thermal performance index and thermal time constant of some typical wall constructions have been discussed in SP:41 (S&T):1987 [5]. The I.S. code 3972-1978 [4] specifies that the U-values of exposed walls should not exceed 2.56 W/m^2-K in hot and dry, and hot and humid regions. In warm and humid regions, they should not exceed 2.91 W/m^2-K.

(C) Ground-based Floors

Heat is transferred by conduction from the building to the ground through the floor which is in contact with the ground. The transfer of heat between the building and the ground occurs primarily via the perimeter of the building, and to a lesser extent through the central portion of the floor. In warmer climates, this heat loss is desirable from the point of view of comfort. On the other hand, in cold climates, heat loss through the ground needs to be minimised and hence insulation may be provided. The effectiveness of insulation under a floor will depend on factors such as the moisture content and temperatures of the ground. If the moisture content is high or the temperature is low, the tendency for heat to be lost through the floor to the ground will increase. In these instances, insulation (typically of U-value = 0.09 W/m^2-K) of thickness of 50mm and depth of 600mm should be provided along the entire perimeter of the slab. To improve performance, the entire slab should be insulated. Foundation insulation using foam board on the inside face of the foundation wall may also be provided. This protects both during construction and during the life of the building.

(D) Fenestration (openings)

Fenestration is provided for the purposes of heat gain, daylighting and ventilation. Their pattern and configuration form an important aspect of building design. Appropriate design of openings and shading devices help to keep out sun and wind or allow them into the building. Ventilation lets in the fresh air and exhausts hot room air, resulting in cooling.

While planning the position of a window, it must be remembered that the tendency of hot air is to rise. Openings at higher levels would naturally aid in venting the hot air out. The size, shape and orientation of the opening affect the speed and flow of air inside the building.

For reducing solar gain during summer, the window size should be kept minimum in the hot and dry regions. For example, in a city like Ahmadabad, the number of uncomfortable hours in a year can be reduced by as much as 35% if glazing is taken as 10 % of the floor area instead of, say, 20%. Thus, though natural light is introduced into the building through glazed openings, skylights, lightshelves, the amount of light and glare that enters needs to be controlled. This can be achieved by providing openable shutters and movable covers like curtains or venetian blinds Besides, tinted glazing or glazing with surface coatings can be used to control solar transmission, absorption and reflection. For example, the direct transmission of solar radiation through a 6mm thick absorbing glass can be reduced by about 45%. Reflective glass is usually made by coating the glass with a layer of reflective material or low emittance layer