

Heat gain and heat loss phenomenon in buildings. Thermal performance parameters

Heat and light

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 climates, comfortable indoor conditions cannot be completely achieved by limiting oneself to simple techniques.

Transfer of heat mediums

- ✓ 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

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 sit outs 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.
- **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 verandas 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 up to 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, emissivity, 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.

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 may be 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.

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.

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.

Smart windows

Smart windows are characterised by their ability to vary the visible light as well as solar radiation. This is achieved by incorporating a chromogenic material in the window. Generally, this is done in the form of a thin film having photochromic, thermochromic or electrochromic properties. As the terms suggest, these devices are activated by light, heat and electricity respectively.

Electrochromic windows

An electrochromic window is a thin, multi-layer assembly sandwiched between traditional pieces of glass. The outer two layers of the assembly are transparent electronic conductors. The next one is a counter-electrode layer and an electrochromic layer, with an ion conductor layer in between. When a low voltage is applied across the conductors, the ions move from the counter-electrode to the electrochromic layer. This causes the assembly to change colour. When the voltage is reversed, the ions move from the electrochromic layer back to the counter electrode layer; this restores the device to its previous clear state. The glass may be programmed to absorb only part of the light spectrum.

Thermochromic windows

Thermochromic windows alter their properties due to heat. In response to changes in the ambient temperature, clear thermochromic glazing become diffused. Among the thermochromic technologies, gel-based coatings seem to be the most promising. In addition to automatically changing from clear to diffuse in response to heat, the glazing also turn white and reflective, thereby reducing the transmission of solar heat. This property can reduce air conditioning costs significantly when the outside is quite hot. As one cannot see through the window once it loses its transparency, this glazing is probably better suited for skylights rather than view windows.

Photochromic windows

Photochromic windows respond to changes in light, much like sunglasses that darken when one moves from a dim light to a bright one. They work well to reduce glare, but don't control heat gain. This is because the amount of light that strikes a window does not necessarily correspond to the amount of solar heat a window absorbs.

Photochromic windows are still in the development stage and are yet to be tested successfully on a large-scale and commercial level. Smart windows hold the promise for reducing energy demands and cutting air conditioning and heating loads in the future. They offer the next major step in windows that are increasingly sophisticated and energy efficient.

e. External colour and texture

The nature of the external surface finish determines the amount of heat absorbed or reflected by it. A smooth and light-coloured surface reflects more heat and light; a rough textured surface causes self-shading and increases the area for re-radiation. White or lighter shades have higher solar reflectivity and therefore are ideally used for reducing heat gain in warmer climates. Moreover, a heavy texture on these light-coloured surfaces helps to reduce the glare. Dark colours absorb more radiation, which increases heat gain through the surface, and can thus be used in cooler regions.

PASSIVE HEATING

Direct Gain.

Direct gain is a passive heating technique that is generally used in cold climates. It is the simplest approach and is therefore widely used. In this technique, sunlight is admitted into the living spaces directly through openings or glazed windows. The sunlight heats the walls and floors, which then store and transmit the heat to the

indoor environment. The main requirements of a direct gain system are large glazed windows to receive maximum solar radiation and thermal storage mass.

During the day, the affected part of the house tends to get very hot, and hence, thermal storage mass is provided in the form of bare massive walls or floors to absorb and store heat. This also prevents overheating of the room. The stored heat is released at night when it is needed most for space heating. Carpets and curtains should not be used to cover floors and walls used as storage mass because they impede the heat flow rate. Suitable overhangs for shading and openable windows for ventilation must be provided to avoid overheating in the summer. Thus, a direct gain system has the following components:

- (a) glazing – to transmit and trap the incoming solar radiation,
- (b) thermal mass – to store heat for night-time use,
- (c) insulation – to reduce losses at night,
- (d) ventilation – for summer time cooling, and
- (e) shading – to reduce overheating in summer.

Direct gain is the most common, simple, cheap and effective heating approach.

However, overheating, glare and degradation of building materials due to ultraviolet radiation are some of its disadvantages.

f. Thermal Storage Mass

In direct gain systems, solar energy can be stored in the floor, walls, ceiling, and/or furnishings of the living space if these components have sufficient capacity to absorb and store heat for use at night. Materials such as concrete, brick and water have this capability and can be used effectively in direct gain applications. Also used, are phase change materials (PCM) such as salt or wax that store thermal energy when they melt and release heat when they solidify. Care should be taken to ensure a balanced distribution of mass throughout the living space. In general, a thin material spread over a larger area will perform better than thick material concentrated in one part of the space. Generally, for every square metre of south-facing glazing area, 30 percent of storage area should be provided to receive direct sunlight.

Indirect Gain

Thermal storage wall

Thermal storage wall systems are designed primarily for space heating purposes. In this approach, a wall is placed between the living space and the glazing such that it receives maximum solar radiation (generally the southern face of the building in the northern hemisphere). This prevents solar radiation from directly entering the living space; instead, the collection, absorption, storage and control of solar energy occur outside it. The glazing reduces heat loss to the ambient. Windows can also be integrated into the thermal storage wall to provide light, view and some direct gain heating. Movable insulation can be applied outside the glazing façades or in the airspace between the glazing and the storage wall to reduce heat loss at night. Shading and reflecting devices are typically placed on the exterior. Different types of storage walls are briefly below.

(a) Trombe wall

A Trombe wall is a thermal storage wall made of materials having high heat storage capacity such as concrete, bricks or composites of bricks, block and sand.

Thermal Storage Mass

The effect of a thermal storage wall is largely determined by the wall's thickness, type of material and the colour of the external surface. Materials with high thermal capacity (concrete, brick, and water) and phase change materials (PCM) can be used effectively in Trombe walls.

(b) Water wall

Water walls are based on the same principle as that of the Trombe wall, except that they employ water as the thermal storage material. Water walls can store more heat than concrete walls because of the higher specific heat. A water wall is a thermal storage wall made up of drums of water stacked up behind glazing. It is painted black externally to increase the absorption of radiation. The internal surface can be painted with any other colour and can be in contact with the interior space directly, or separated by a thin concrete wall or insulating layer. A large storage volume provides longer and greater storage capacity, while smaller units enable faster distribution. In order to fix the quantity of water, the thumb rule is usually taken as 150 litres of water per square metre of south oriented water wall. A variety of containers like tin cans, bottles, tubes, bins, barrels, drums, etc., provide different heat-exchange surfaces to the storage mass ratio. Care should be taken to ensure that steel and metal containers are lined with corrosion resistant materials. Also, the water should be treated with algae retardant chemicals. Troughs should be provided as a precaution against leakage of water from containers or from condensation.

(c) Trans wall.

Trans wall is a thermal storage wall that is semi-transparent in nature. It partly absorbs and partly transmits the solar radiation. The transmitted radiation causes direct heating and illumination of the living space. The absorbed heat is transferred to the living space at a later time. Heat loss through the glazing is low, as much of the heat is deposited at the centre of the trans wall ensuring that its exterior surface does not become too hot. Thus, the system combines the attractive features of both direct gain and Trombe wall systems.

A trans wall has three main components:

- Container made of parallel glass walls set in metal frame.
- Thermal storage liquid, which is generally water.
- A partially absorbing plate set at the centre of the trans wall, parallel to the glass walls.

PASSIVE COOLING

The cooling of buildings by using passive methods has evoked great interest. The underlying principle of passive cooling is to prevent heat from (or at least reduce heat flux) entering the building, or remove heat once it has entered. In this section, we discuss the principles governing each of the concepts used for passive cooling of buildings. The various concepts discussed are ventilation cooling, evaporative cooling, nocturnal radiation cooling, desiccant cooling and earth coupling. The

applicability of these concepts depends greatly upon the climatic conditions prevailing in a particular place.

Ventilation Cooling

Ventilation is generally defined as the replacement of stale air by fresh air. It also provides cooling by air movement. Hence, it would be appropriate to define the term ventilation as the supply of outside air to the interior for air motion and replacement of vitiated air. A faulty design resulting in inadequate ventilation will result in higher energy consumption in the building for creating comfortable indoor conditions.

Therefore, the ventilation requirements of different seasons, for different types of occupancies should be determined first. A ventilation system should then be suitably designed to meet the required performance standards. There are many ways in which ventilation can improve comfort. For example, opening the windows to let the wind in, and thus providing a higher indoor air speed, makes people inside a building feel cooler. This approach is termed as comfort ventilation. In hot environments, evaporation is the most important process of heat loss from the human body for achieving thermal comfort. As the air around the body becomes nearly saturated due to humidity, it becomes more difficult to evaporate perspiration and a sense of discomfort is felt. A combination of high humidity and high temperature proves very oppressive. In such circumstances, even a slight movement of air near the body gives relief. It would, therefore, be desirable to consider a rate of ventilation which may produce necessary air movement. If natural ventilation is insufficient, the air movement may be augmented by rotating fans inside the building.

The air movement indoors is mainly due to stack effect (stratification of temperature) and wind pressure. Manipulating these two effects can considerably improve the ventilation. For example, a solar chimney works mainly on the stack effect. The solar chimney is used to exhaust hot air from the building at a quick rate, thus improving the cooling potential of incoming air from other openings. Similarly, wind towers use wind pressure for cooling. The wind is captured at the top of the terrace and is diverted to the indoors using wind towers. Windows can also be arranged to take advantage of stack effect and wind pressure.

An indirect way of cooling is to ventilate the building only at night to cool the interior mass of the building. During the following day, the cooled mass reduces the rate of indoor temperature rise and thus provides a cooling effect. This strategy is termed as nocturnal ventilative cooling.

Cross ventilation

Requirements for air motion in the early summer and late post-monsoon periods are usually small. These can be easily met by providing adequate cross ventilation through rooms. When a building is cross ventilated during the day, the temperature of the indoor air and surfaces closely follow the ambient temperature. Therefore, ventilation in daytime should be considered only when indoor comfort can be experienced at the outdoor air temperature (with acceptable indoor speed).

Wind tower

Wind tower is generally used in hot and dry climates for cooling purposes. The tower is meant to “catch” the wind at higher elevations and direct it into the living space.

The air flow passages in the tower may have equal or different areas. The tower may have only one opening facing the wind, if wind is predominantly in one direction, or may have openings in all directions in locations with variable wind directions.

Working: Night

The tower area is so designed that the top part provides large heat storage capacity, and also has a large surface area for heat transfer. The tower walls and the internal walls of the air-flow passages absorb heat during the day and release it at night, warming the cool night air in the tower. Warm air moves up creating an upward draft and is exhausted through the openings. The pressure difference thus created pulls the cool night air through the doors and windows into the building. In the absence of wind, the tower acts as a chimney. The nocturnal radiation through the roof and the external walls brings about further cooling. In the presence of wind, the cool night air enters the tower and forces itself down into the structure. Though it is warmed slightly during the process, sufficient cooling can be achieved due to forced circulation. Again, cooling due to nocturnal radiation adds to this process.

Wind towers can easily be incorporated in low-rise buildings. It may be noted that wind towers may need to be shut off when cooling is not required, and hence, such provisions may be included in the design. Due consideration must also be given to prevent the entry of dust, birds and insects.

Evaporative cooling

Evaporative cooling is a passive cooling technique in which outdoor air is cooled by evaporating water before it is introduced in the building. Its physical principle lies in the fact that the sensible heat of air is used to evaporate water, thus cooling the air, which in turn cools the living space in the building. Evaporation occurs at the water-air interface. An increase in the proportion of the contact area between water and air enhances the rate of evaporation and thereby the potential for cooling. The presence of a waterbody such as a pond, lake or sea near the building, or a fountain in the courtyard can provide a cooling effect. Cisterns or wetted surfaces can also be placed in the incoming ventilation stream. Such direct systems typically use little or no auxiliary power, are simple and can avoid the need for large surfaces of water and movement of large volumes of air. They are, therefore, particularly suited to hot and dry regions. The airflow in these systems can be induced mechanically or passively – for example, evaporative cooling towers that humidify the ambient air can be used. This is direct evaporative cooling. The main disadvantage of direct systems is in the increased moisture content of the ventilation air supplied to the indoor spaces. High evaporation may result in discomfort due to high humidity. However, passive evaporative cooling can also be indirect - the roof can be cooled with a pond, wetted pads or spray, and the ceiling transformed into a cooling element that cools the space below by convection and radiation without raising the indoor humidity.

The efficiency of the evaporation process depends on the temperatures of the air and water, the vapour content of the air, and the rate of airflow past the water surface. The provision of shading and the supply of cool, dry air will enhance evaporation.

High-efficiency heating, ventilation, and cooling equipment: Heating ventilating air conditioning (HVAC) systems extremely influence energy consumption in buildings. The relationship between building specifications and HVAC systems are highly efficient building envelopes reduce the need for heating and cooling systems. Good and intelligent designed buildings can reduce the need for HVAC systems. Efficiency improvements in HVAC systems can lead to substantial savings. If, for instance, energy efficiency is improved in a heating boiler or an air-conditioner, total savings will depend on the total need for heating or cooling in the building. In a well-insulated building envelope, the energy needs of the HVAC system are reduced. The building can be separated into thermal zones at suitable dimensions, reducing the need for heating, cooling and ventilation with careful building planning.

Energy-efficient methods in post building phase

The post building phase is the phase when the usage phase is completed. This phase includes the demolition of building, recycling, and destruction of it. In this phase, it is important to recycle the building materials and compositions used in the buildings and reuse buildings. After the functional uses of buildings have been completed, reutilization of them in other functions instead of demolishing them protects such resources as raw material, water, and energy. It should be enabled to reuse the building compositions of the buildings, for which demolition decision has been taken, such as the roof truss, woodworks. Following the saving of appropriate building compositions, recyclable building materials are needed to be separated. In this way, raw material protection is provided for the building material to be reproduced, and thus it is saved from the energy to be consumed while processing raw material. It is necessary to use machines and equipment as few as possible while demolishing buildings and select equipment procuring energy saving for demolition.

Conclusion

Buildings have a huge potential for energy efficiency. To obtain this large potential, there is a need to take some regulations and initiatives to improve the efficiency in buildings. Energy consumption in buildings occurs in every phase of building life cycle. However, the important phase is the usage and maintenance process of buildings where energy is consumed most within the scope of life cycle. During the building life cycle, the highest energy consumption occurs during the usage stage. This is because this period is much longer in duration compared to the other stages and the comfort levels necessary for human health and working efficiency need to be provided at this stage. Therefore, in energy-efficient building designs, especially the usage stage should be taken into consideration. In order to reduce energy consumption in the usage process of building, renewable energy sources instead of fossil-based energy sources should be preferred. Importance to the use of renewable energy sources should be given. In particular, the use of active and passive systems should be noted. Energy simulation programs in building design should be used. Within the scope of this study, energy-efficient strategies described under the titles of the choice of settlement in the prebuilding phase, planning settlement, building form, building organization and planning, building envelope, choice of building material, landscape design, and utilization of renewable

energy sources are directed to using less energy or cleaner energy in the usage process of buildings. Examining these strategies, it is clear that cooperation of very different disciplines (architecture, mechanical engineering, civil engineering, landscape architecture, urban and regional planning and interior architecture) is required. For this reason, designing an energy-efficient building is possible with a multidisciplinary study which begins from the emergence of the idea of constructing a building and lasts until the demolition of the building at the end of usage period.

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