Chapter 11
Thermal Insulation of Building Envelope for Ecological Conservation

Mir Firasath Ali and M. M. Vijayalakshmi Natarajan

Abstract Sustainability has been a rising concern for facility projects since the early 1990s. It is conscious that in terms of carbon emissions, energy usage, water use, utilisation of raw materials, waste production and many other factors, construction and operation of buildings have enormous direct and indirect environmental consequences. Increased economy and population will create more and more challenges for the design, construction and operational community to fulfil the new requirements for infrastructure that are affordable, safe, resilient and sustainable while reducing their environmental impact. The building envelope's key feature is to offer shelter, safety, solar and thermal control, control of moisture, control of indoor air quality, access to sunshine, and outdoor views, fire resistance, acoustics, cost-effectiveness, and aesthetics. This study seeks to promote awareness on the energy friendly design strategies which economically minimize operational expenditure, while enhancing comfort of the occupants in the building. This work would allow architects, engineers and builders to choose the most efficient or climate-reactive envelope alternative in order to improve thermal environment efficiency of the construction design being proposed.

Keywords Building envelope · Environmental friendly · Reactive envelope · Sustainable · Thermal comfort

11.1 Introduction

Buildings built and used today, due to exorbitant energy use, and other natural resources, lead to severe environmental problems. The strong relationship between energy usage in buildings and environmental damage comes from a significant depletion of essential environmental resources as energy intensive solutions are pursued to create a building and satisfy its heating, cooling and ventilation & lighting requirements (Owusu and Asumadu-Sarkodie 2016). Sustainability is now a main consideration for prominent stakeholders in the construction industry, given the rising demand

---

M. F. Ali (✉) · M. M. V. Natarajan
Department of Civil Engineering, Sathyabama Institute of Science and Technology, Chennai, India

J. A. Malik and S. Marathe (eds.), *Ecological and Health Effects of Building Materials*,
https://doi.org/10.1007/978-3-030-76073-1_11

from customers for ecologically sustainable building products and materials (Akadiri et al. 2012). Insulating resources used in residential or commercial buildings are an integral part in the energy efficiency, with a major environmental problem raised by the processing and disposal of a large quantity of insulating materials. In this context, this study proposes to analyse the metrics of alternative insulation used in buildings in a sustainable design process (DOE 2015). One of the most significant criteria for buildings is to provide thermal comfort without unnecessary space conditioning costs. Thermal management in almost any building is therefore an essential feature. In order to assess a building's sustainable energy conscious nature, understanding of heat exchange mechanism, periodic heat-flow in building elements and building envelope is essential (Yüksek and Karadayi 2017).

11.1.1 Heat Exchange Process

Like the human body, the buildings could be treated as a fixed entity and their mechanisms of heat exchange can be studied in the outdoor environment. Different heat exchange mechanisms between a building and the outside world are possible. Heat flows through different building elements like walls, roof, door, windows etc. Heat transmission often occurs by convection and radiation from various surfaces (Ling et al. 2016). Internal heat gain (Qi) heat outputs of human bodies, lamps, motors and appliances can lead to internal heat gain. Solar heat gain (Qs) involves solar radiation on opaque surfaces, but the solar heat gain must be considered separately on the basis of a solar temperature concept via transparent surfaces (Windows). Conduction (Qc) can happen inside or outside through the walls. Ventilation (Qv) heat exchange will take place with air movement in either direction. Heat flow rate and mechanical (Qm) heat removal with any external energy supply. Evaporation (Qe) takes place on the building surface (e.g. a roof pool (or) inside a building, human sweats (or) water from a fountain), and the vapours are removed and a cool effect is caused. The thermal equilibrium condition prevails when $Qi + Qs \pm Qc \pm Qv – Qe = 0$. Building tends to cool down if the sum of this equation is lower than zero and the temperature in the building increases when more than zero (Auliciems and Szokolay 1997).

11.1.2 Periodic Heat Flow in Building Elements

- Climate change creates unbalanced conditions,
- 24 h period—rise in temperature and decrease in temperature,
- During hot times—heat flows from the atmosphere into the building, as some of it is stored,
- The heat flow is reversed at night during the cool time i.e. from building to environment.

$$\text{Decrement factor}(\mu) = (T_{i\text{-max}})/(T_{o\text{-max}})$$

where,

$T_{o\text{-max}}$ is maximum outer surface temperature.

$T_{i\text{-max}}$ is maximum Inner surface temperature.

There are the two variations in external and internal temperatures in thermal regimes (Koenigsberger et al. 2010).

- Outdoor temperature rises in the morning; heat tends to penetrate the wall's outer surface.
- Each wall partition absorbs, in accordance to the specific heat of the wall material, a certain amount of heat for each degree of temperature increase.
- The heat will not be passed on to the next particle until the first particle temperature has risen.
- As shown by the green line, the corresponding rise of the inner surface temperature is thus delayed.
- Before the interior surface temperature is equal, the outside temperature reaches its peak and begins to fall.
- After that, the heat contained in the wall would be partially dissipated outside and only partially inside.
- As the outside air cools, a growing share of this stored heat fluctuates outwards, and the direction of the heat flow reverses fully when the wall temperature falls below the inner temperature.
- Time lag (or phase transition, denoted as Φ) and the decrement factor (or amplitude mitigation, denoted as μ) are the two quantities defined by this periodic change. The second is the ratio between the peak external and internal surface temperature amplitudes derived in accordance with every day average.

If the design allows for efficient daytime lighting, artificial lighting demand of a building can be minimised. In energy-conscious architecture, building materials play a major role too. Day lighting is also a passive solar technology and concludes with a debate on other construction materials (Koenigsberger et al. 2010; Vijayalakshmi et al. 2006).

11.1.3 Building Envelope

The exterior façades of a building like walls, windows, screenings and towers known as the building envelope communicate with the surroundings. The building envelope is mainly known as the building skin. It plays a key part in ensuring that indoor areas are safe, friendly and contributes to the reputation and character of the building within the public sphere. The building envelope needs to balance the need for ventilation and daylight while ensuring thermal safety that suits the site's climate conditions.

The estimation of the operational energy usage and the cost of lifetime of a building is an important factor. The success of the building envelope depends on the choice and combination of the necessary materials and components (Sozer 2010).

11.2 Role of Building Enclosures, Openings and Materials in Thermal Environment

The building envelope functions as a thermal shell that would contribute to energy leakage across all components if built thoughtlessly. Each part must therefore be selected correctly to achieve an effective building. The preference relies upon the location and thus the main goal is to look at the terms of the site. The perfect orientation of the building on a site and the right design layout often play an important part in the efficiency of the building (Gan et al. 2019).

11.2.1 Building Configuration

The heat exchange takes place mainly through the skin of the building between a building and its environment. The heat flow can be regulated by setting the configuration associated with the building that is worthy of climate and use. For instance, in an extremely cold climate, loss of heat from the premises of building to the atmosphere must be reduced (Givoni 1998).

This can be done through (Koch-Nielsen 2013);

a. Use of buffer spaces, for example in favourable weather, sun spaces and balconies can act as sit-outs.
b. The positioning, in the direction of cold winds, of seldom used areas such as storerooms or toilets.
c. Optimise solar radiation exposure, for example, arrangements for large living rooms facing the sun to heat.
d. Proper location of living room, i.e. leeward to escape cold winds, most of the habitable spaces may be held. They can be combined to minimise cold exposure.

The radiation and air movement due to heat flow may be governed by differing the following features of a structure:

11.2.1.1 Surface Area to Volume Ratio (S/V Ratio)

This specifies the degree of heat flow in and out of the building. Higher the S/V ratio, higher the heat gain or heat loss over a certain volume space. On the other hand, it will minimise heat gain/loss by a smaller S/V ratio. For instance, compact building shapes with a minimum S/V ratio can be preferable in cold climates (Kohlhepp and Hagenmeyer 2017).

11.2.1.2 Building Shape

Winds produce pressure differences i.e. positive windward pressures and negative leeward pressures when interrupted by a building. Therefore, the building is surrounded by a modern airflow pattern. Thus, a building's wind pattern may be changed by properly shaping it (Bauman 1988).

11.2.1.3 Buffer Spaces

Shading and catching wind within buffer-spaces in particular balconies, courtyards, atrias and verandahs.

11.2.1.4 Arrangement of Openings

Suitable openings which provide effective ventilation, link high- and low-pressure areas. For receiving or rejecting solar radiation, solid and glazed surfaces must be arranged and orientated (Gulati and Paul 2013).

11.2.2 Building Components

Presence of a structural envelope determines the extent of radiation and wind entering the building. This consisted of elements (A) Roof (B) Walls (C) Floor (D) Exterior colour and texture (E) Fenestration.

Heat flow by means of said elements is marked through resistance, thermal capacity, absorption, transmission and emission of each of these elements. Depending on specific criteria, the resource materials for these elements must be specifically chosen. The heat, density and thermal conductivity are the thermophysical parameters of materials that need to be considered. Whereas the product between the first two defines the material's energy storage capability, and the third specifies the performance of energy flow. Taken together, these three criteria depict time lag (phase shift) and decrement factor. The first is a heat flow delay, while the second is a reduction in heat wave amplitude. According to climate requirements, materials which contribute the intended thermal stock, time delay and amplitude decrease were to be looked for. Surface qualities such as emissivity, reflectivity, absorption and roughness are characterised in colour and texture. These are important for the distribution of light and heat flow. In the case of a painted white ceiling, for instance, the heat transfer in contrast to a dark colour can be decreased by up to 80% (Arnold 2009).

Building components may usually be categorised as opaque (brick wall) and transparent (glazed window). Transparent members permit sunlight in living spaces. An element may also be opened to allow air exchange between the building and its vicinity (such as skylight). Materials like polyurethane foam (PUF) may insulate the walls, floors window, door, etc. By properly insulating them, heat loss or gain from different components of buildings can be minimised and roofs (externally or internally). The introduction of an air cavity on the exterior building envelope is another form of insulation. In cavity walls the air gap prevents heat from being transferred in or out of the building because the air behaves as an inappropriate heat conductor. Variations can be accomplished by the utilisation, modification and usage of various isolation materials in different locations (internal or external). The property of the air gap can be varied in cavity walls by changing its thickness and selecting a ventilated or unventilated air cavity. The efficiency of insulation materials can be adversely affected by water absorption (Mirrahimi et al. 2016).

The heat gain can be varied by the following:

- Component orientation and inclination
- Component Area
- Finishes
- Material characteristics (U-value, lag time, factor of decrement, emissivity, etc.)
- Incoming solar radiation control.

11.3 Sustainable and Energy Efficient Thermal Comfort Techniques

11.3.1 Passive Heating

11.3.1.1 Direct Gain

Direct gain is the most widely used, passive heating technology in cold climatic conditions. It turns out to be a modest and thus commonly used solution. According to said method, direct sunlight through openings or glazed windows is admitted in the living spaces. The sunlight warms up walls and floors that will accumulate the heat within the indoor atmosphere and transmit it. Maximal solar radiation as well as thermal storage mass is the key criteria of a direct gain system. The impacted area of the house has a tendency to get very hot through the day, so the thermal storage mass is made available as uncovered vast walls or floors for the absorption and storage of heat. This particular inhibits the room from being overheated. If it is more and more necessary for space heating, the stored heat is released in the night. The floors and walls used as storage mass should not be covered with carpets and curtains because they hinder the heat flow rate. To be able to inhibit overheating in the summer, sufficient overhangs for shade and open ventilation windows have to be provided (Chiras 2002). A direct gain system therefore comprises the following parts (Johnson 1981):

1. **Glazing**—for transmission and trapping of solar radiation (incoming);
2. **Thermal mass**—towards stocking heat with regard to night usage;
3. **Insulation**—to attenuate losses during evening time;
4. **Ventilation**—Pertaining to cooling during the summer months;
5. **Shading**—to reduce heating up too much during summer.

Reflectors can also be installed outside windows to make the direct benefit system more effective. Heat gain can also be enhanced from Clerestories and skylights. The most popular, simple and efficient approach to heating is direct gain. Some of its drawbacks, however, are overheating, glare as well as deterioration of construction materials due to UV radiation (Tiwari 2002).

Solar energy can be stored in direct recovery systems in the living room floor, walls, ceiling or furnishings if these sections have adequate capacity for night absorption and storage of heat. This capacity is provided by materials (concrete, brick and water) and can be used in direct heat gain use effectively. PCMs, such as salt or wax, are often used to store thermal energy when melting and release heat when solidified. A balanced distribution of mass over the entire living area should be maintained. A thin material extending through a wider area will usually carry out higher than a thick material focused in one section of the room (Yüksek and Karadayi 2017).

Generally, 30% of the storage area must be made available to receive direct sunlight in accordance with per square metre of south-facing glazing area. The storage material requires a thickness of 50–150 mm, and walls should have a thickness of 50–100 mm. With full mortar bedding, the used masonry units should be solid. For the sake of more heat absorption, the storage mass vulnerable to direct sunlight must be dark in colour. Providing thicker rather than thinner storage mass is typically more thermally effective considering optimal thickness. For instance, the storage effect increases with the increase in the thickness of the floor as the storage mass. Increase in the storage effect is insignificant for 100 mm and above thickness. In practice, for thicknesses over 200 mm the performance decreases (Block and Bokalders 2010).

11.3.1.2 Indirect Gain

Thermal wall systems are specifically designed for use in space heating. Actually a wall is situated involving the living area and also the glazing to gain full solar radiation in this way by orienting the southern part of the face associated with the building into the northern hemisphere. Doing this hinders the direct entry of solar radiation to the living spaces, where solar energy is captured, absorbed, stored in, and controlled. The glazing decreases the ambient heat loss. Additionally it is possible to incorporate windows within thermal storage walls to offer illumination, vision plus some direct heating gain. Portable insulation exterior to the glazing façade or in between glazing and the storage wall may be added to minimise heat loss during night times. Usually, shading and reflecting devices are mounted on the external wall (Nayak and Prajapati 2006). In this section, different types of storage walls are discussed.

Trombe Wall

A particular trombe wall is a thermal storage wall manufactured from material, for example concrete, bricks or brick composites, blocks and sand that have high storage capacity. To maximise its absorption, the exterior surface associated with the wall happens to be painted black and is positioned immediately at the rear of the glazing along with some sort of air gap in the middle. The blackened surface absorbs solar radiation and is stored in the wall as sensible heat. The stored heat slowly migrates into the interior of an unvented wall, the place wherein it heats the living space that is adjacent. This wall will offer the living space with sufficient heat during the night if properly built (Mazria 1979).

The heat produced in the air between the glazing and the storage wall is lost through the glass to the outside. Hotter the air, greater is the heat loss in the airspace. This loss of heat can be minimised by venting the top and bottom of the storage wall. These units are referred to as “vented trombe walls.” The air between the glazing and the wall is warmed and enters through the upper vent into the living room. Via lower vents, cool room air takes its place, thus creating a natural circulation pattern (thermo-circulation) that involves no mechanical means to move the air.

The impact associated with a thermal storage wall is dependent mostly on the dimensions, kind of material and colour of the outside area of the wall. In Trombe’s walls, materials (concrete, brick, and water) with good thermal ability and PCM-phase change materials can be utilized potentially. To absorb solar radiation, the storage mass confronted with direct sunlight needs to have a dark colour. Particular coatings are often added to the exposed surface of storage walls to enhance performance. The coatings have high solar absorptivity and low re-radiation emissivity. The wall inner surface might perhaps be painted or else kept unprocessed. The thermo-circulation part concerning vents ought to be around 2% associated with the wall area, split equally amongst the upper as well as lower vents (Zhang and Li 2019).

Water Wall

Water walls, with the exception that they use water because the thermal storage material, are derived from exactly the same principle as compared to the Trombe wall. The higher specific heat allows water walls for storage of a lot more heat when compared with concrete walls. Actually a water wall can claim to be a thermal storage wall composed of water drums piled in the back of a window. They are externally painted black to make radiation more absorbent. The inner surface could be coated in almost any different colour and may instantly enter into exposure with or insulate the interior space. The heat storage from the water wall is a convective mass, which is very quick compared to a wall of masonry (Wujek and Dagostino 2011).

A large volume of storage offers extended and much more storage capacity, whilst smaller sized products allow for faster distribution. The thumb rule is generally considered as 150 L/m^2 of this water wall facing south to fix the volume of water. The storage mass ratio has a number of heat exchange surfaces including tins, cans, bottles and tubes, bins and drums. Care should be taken to ensure the corrosion-resistant lining of steel and metal containers. Water can also be treated with chemicals that avoid algae. Troughs must be made in the form of safeguard towards container or condensation leakage of water.

The flow of heat through a wall of water is significantly quicker rather than a trunk wall. A check of the heat circulation is required in case heat isn't needed for the building immediately. Through the use of a thin concrete layer or insulating layer, or by supplying air ventilation through vents, this can be accomplished. The rapid heat transfer in the water walls benefits buildings such as schools or government offices working during the day. The water wall glazing is normally filled with insulation at night to minimise heat losses. Using movable overhangs will avoid overheating during the summer (Noseck 2013).

Transwall

Transwall is a semi-transparent thermal storage wall. The solar radiation is partially absorbed and distributed. Direct heating and lighting of living space is caused by the transmitted radiation. The absorbed heat is subsequently transferred to the living room. The heat loss due to the glass is very minimal, since much of the heat is contained in the centre and does not get too hot on the outside of the wall. The system therefore incorporates the desirable characteristics of the trombe wall and direct gain system. There are three main elements in a Standard Transwall segment (Fuchs and McClelland 1979):

- Container made of metal frame parallel glass walls,
- Liquid for thermal storage, typically water,
- A partly absorbent plate mounted parallel to the glass walls on the middle of the transwall.

It is situated directly behind double glazing on the south side of the building (in the north hemisphere). A kind of suppressing agent could possibly be applied to prevent the growth of microorganisms in the storage.

11.3.2 Passive Cooling

The cooling of buildings has created great interest through the use of passive methods. Passive cooling is based on the prevention and/or elimination of heat from entering (or, at least, reducing heat flux) the house. This section addresses the concepts that govern each concept used to cool buildings passively. Ventilation cooling, evaporative cooling are the terms discussed. The applicability of these principles is highly dependent on the climatic conditions in that specific location (Kamal 2012).

11.3.2.1 Ventilation Cooling

The substitution of stagnant air by using fresh air is commonly termed ventilation. Moreover it offers cooling by air movement. The term ventilation should therefore be specified as the external air supply towards inside with regards to air motion and vitiated air replacement. When it comes to hot and humid regions where in fact the outside maximum air temperature will not exceed 28–32 °C, an internal air velocity of one and half to two meter per sec could result in comfort (O'Connor et al. 2016). In the design process of buildings, ensuring adequate ventilation in buildings needs due consideration. In order to create comfortable indoor conditions, a flawed design that results in insufficient ventilation would lead in much higher energy expenditure in the building. Therefore, for various types of occupancy, the ventilation criteria for different seasons should be calculated first. In order to meet the appropriate performance requirements, a ventilation system needs to be then appropriately designed. Ventilation can enhance comfort in a variety of ways. For example, it helps to make people feel cooler in a building by opening up the windows to allow the wind inside and therefore give greater indoor air speed. This technique is called ventilation comfort. Evaporation is the most significant process of the human body's heat loss to maintain thermal comfort in hot environments. As the air around the body is almost filled with moisture, transpiration is harder to evaporate and a feeling of un-comfortableness could be experienced. Extreme humidity and higher temperature combinations are highly oppressive (Nayak and Prajapati 2006).

Perhaps a little air flow close to the body provides easing in these circumstances. A rate of ventilation which must induce required air movement will therefore be desirable. In case of inadequate natural ventilation, running fans inside the building will increase the airflow. Indoor air movement is primarily because of stacking effect (temperature stratification) in addition to wind pressure level. The management of both of these effects will enhance ventilation substantially. The main feature of solar chemistry is the stack effect, for example. The solar powered chimney is employed to rapidly evacuate hot air through the house, thus increasing the cooling down ability associated with the air from all the other open positions (Kleiven 2003).

Wind towers also use wind pressure for cooling. On the top of the terrace, winds are collected and transferred to the interior by wind towers. In addition, Windows may be positioned to make use of the wind pressure and stack effect. In order to cool down the inside mass associated with the building; an indirect type of cooling would be to ventilate the building components exclusively during the night. The cooled mass decreases the rate of indoor temperature rise during the following day and thus offers a cooling effect. This is called night ventilation cooling (Walker 2016).

11.3.2.2 Cross Ventilation

Air movement requirements are typically low during the beginning of summer and later part of the post-monsoon cycles. By providing sufficient cross ventilation through spaces, these can be easily met. The temperature of this interior air and areas accurately matches the surrounding temperature when a building is cross-ventilated during the day. Daytime ventilation also needs to be viewed provided when interior comfort and ease could certainly be enjoyed at the temperature of the outside air (with acceptable indoor speed) (Aman 2017).

11.3.2.3 Wind Tower

For cooling purposes, wind towers are commonly utilized in warm and dried up climates. The particular tower can be intended at higher elevations to "catch" the wind and guide it inside the living space. There may be equal or distinct areas in the air flow passages in the tower. If the wind is mainly in one direction, the tower might perhaps posse's sole opening facing the wind, or could possibly possess openings each of them directions at places with different wind directions. For decades, these technologies have been used for natural ventilation and passive cooling in Western Asian countries (Konya 2013).

A condition for using a wind tower is that winds with a considerably good and constant velocity should be encountered on the location. Depending on the time duration related to day as well as the existence or shortage of wind, a wind tower works in different ways. Altering the temperature and then the denseness regarding the air close to the tower is the main principle of its operation. The density difference produces a draft, dragging air upwards or may be down wards throughout the tower (Malone 2012).

Working at Night The tower area is built to provide high heat storage capacity for the top portion, and also has a large heat transfer surface area. During the day, the tower walls and the internal walls of the air-flow passages collect heat and release it at night, thus warming the tower's cool night air. Warm air rises up to create an upward draft and is exhausted by the openings. The difference in pressure thus created pulls the cool night air into the building through the doors and windows. The tower serves as a chimney in the absence of wind. Further cooling is brought on by night time radiation by using the roof in addition to exterior walls. The cool night air reaches the tower in the presence of wind and drives itself down into the structure. While it is warmed slightly during the process, due to forced circulation, adequate cooling can be achieved. Again, cooling contributes to this process due to nocturnal radiation. Low-rise buildings can easily add wind towers. It must be noted that when cooling is not needed, wind towers may need to be shut down and, thus, such requirements must be included in the design. In order to prevent dust, birds and insects from entering, due consideration must also be given (Sarbu and Sebarchievici 2018).

11.3.2.4 Evaporative Cooling

Evaporative cooling is a passive cooling method in which ambient air is cooled until it is released into the building by evaporating water. The physical theory lies in the use of sensible air heat to evaporate water, thus cooling the air, which in turn cools the living space of the building. At the water–air interface, evaporation occurs. A rise in the proportion of the contact area between water and air increases the evaporation rate and hence the cooling capacity. A cooling effect may be created by the presence of a water source such as a pond, lake or sea near the house, or a fountain in the courtyard. It is also possible to position cisterns or wetted surfaces in the incoming ventilation stream. Usually, such direct systems use little to no auxiliary power, are easy, and can eliminate the need for large water surfaces and significant amounts of air movement. They are, therefore, ideal for hot and dry regions in particular. In these systems, the airflow may be induced mechanically or passively, such as.

It is possible to use evaporative cooling towers that humidify the ambient air. This is direct evaporative cooling. The key drawback of direct systems is that the humidity content of the ventilation air supplied to the interior spaces is increased. Owing to high humidity, high evaporation can result in discomfort (Maheshwari 2001; Amer 2006).

Passive evaporative cooling, however, can also be indirect, the roof can be cooled with a pond, wetted pads or spray, and the ceiling converted into a cooling feature that cools the space below without increasing the indoor humidity through convection and radiation. The evaporation process' efficiency is based on the air and water temperatures, air vapour content and air flow rate over the surface of the water. Evaporation would be improved by the provision of shade and the availability of cool, dry air. Bansal et al. have published a detailed discussion on evaporation. The desert cooler consisting of water, evaporative pads, a fan and a pump is the only evaporative cooling system in North India. It is a direct evaporative cooling system with a hybrid form. The guidelines for use of evaporative cooling have been suggested by Watt (2012);

- The average saturation efficiency of direct evaporative coolers should be 70 percent or more, and cooled air must reach the indoor room without any extra warm-up.
- The cooled air induced indoor air speed must be 1 m/s.
- Before cool air is discharged from room, the room temperature should be reduced to at least 3 °C.
- The cool down area temperature ought to be around four degree centigrade beneath the outside temperature of the dry bulb. The incoming radiant heat must be counteracted.

11.3.2.5 Roof Surface Evaporative Cooling (RSEC)

The solar radiation incident on roofs is very high in a tropical country like India in summer, leading to overheating of rooms below them. By spraying water over sufficient water-retentive materials (e.g., gunny bags) scattered over the roof surface, roof surfaces can be cooled easily and cheaply. It draws much of the necessary latent heat from the surface as the water evaporates, thereby lowering its temperature and reducing heat gain. Besides, the air above the roof is also cooled by evaporation. Via penetration and ventilation, the cool air slides down and reach the living space, providing extra cooling. This is a specific case of the technique of indirect passive evaporative cooling. The sustained wetness of the roof surface is a crucial factor deciding the efficiency of the RSEC system. It is possible to spray the surfaces intermittently, as it is only important to keep them moist (Nayak and Prajapati 2006).

To minimise the cooling load in the summer, the evaporation of water from a roof pond (a large mass of water accumulated on the roof) can also be used. However, the roof needs to be made structurally stable and waterproof to use this cooling technique. Cooling by sprinkling water is more beneficial in contrast, as it gives a greater evaporation surface area without the need for any storage (Bhamare et al. 2019). The following points need to be taken care of in order to implement a roof surface evaporative cooling system (Yannas et al. 2006):

1. Adequate roof waterproofing treatment should be performed.
2. Water-absorbing and water retentive materials must cover the roof. These materials, because of their porosity, serve as a free water surface for evaporation when wet. The durability of such materials is reasonably good, but for fire protection they must be handled.
3. The amount of water required during peak summer is approximately 10 kg/day/m^2 of roof area.
4. Using a water sprayer, the roof must be kept damp during the day. An automatic moisture-sensing system can run or control the sprayer manually. Usually, the sprayer operates at a low water pressure, which can be accomplished by either a water head on the roof of the storage tank or a small water head.

11.4 Sustainable Building Materials

There are several energy efficiency improvement strategies in buildings, and it is the duty of the inhabitants to run them in an energy-conserving manner. However, inhabitants can only run it within the framework of the designers of the building. Finally, it is the designers' duty to provide the owners and tenants with the most energy efficient building. This service is not only economically feasible, but also prevents the building from being unsustainable as a result of high energy costs. In energy-conscious architecture, building materials play an important role. The heat flow rate through different components of a building, it's time lag and amplitude decrement, as well as the building's energy storage capacity are all controlled by the materials used. Therefore, from the perspective of the building's thermal efficiency, the choice of materials is essential. Besides, the materials provide the building with the requisite structural strength. Although traditional building materials are well known to architects, building scientists and consumers, in order to minimise costs and energy usage, it is important to concentrate on alternative materials. It should be remembered that for the production of building materials from their basic raw ingredients a certain amount of energy is consumed. This is known as the materials' embodied energy. The selection of construction materials depends on this aspect (DOE 2015).

11.4.1 Embodied Energy of Building Materials

The energy utilized in the building construction practice needs to be reduced collectively, particularly in the building materials used. The cost of construction is influenced by resources used in the purchasing, manufacturing, and process and recycling of building materials. The energy assessment process consists of three phases: (i) the energy consumption in raw material processing, (ii) the energy consumption in manufacture of finished products, and (iii) the energy used in the manufacturing process for machinery and equipment (Akadiri et al. 2012). The sum of the three is referred to as the intensity of energy. Building materials, based on their energy strength, have been divided into three groups. High-energy materials include products such as aluminium, steel, plastics, glass and cement and are such with energy levels surpassing around 5 GJ/tonne of processed materials. Materials in the medium energy category include those requiring energy inputs of between 0.5 and 5 GJ per tonne of material, including concrete, lime plaster and most types of cement-based, lime-based, fly ash-based and fireclay-based bricks and tiles. The materials of the low energy category include fine and coarse building aggregates, pozzolana soil forms and stabilised soil (Gutowski et al. 2013).

Promoting low-cost, low-energy and medium-energy materials for energy efficiency in building construction is important. These products, however, should be durable as well, need less maintenance and should be recyclable. It should be noted that, while highly energy intensive, materials such as aluminium and steel possibly recycled pretty inexpensively because of energy (Martin et al. 2000). Development Alternatives, New Delhi, has conducted a thorough analysis of the embodied energy of different building materials. The document provides information on various building materials and components at different levels, namely production, processing and manufacturing. Data on material description, technology and resources, environmental effects, statistics of the development and world status of energy data are accessible to designers. The study also provides data on the energy consumed when raw materials, intermediate materials and finished products are mined, manufactured and transported.

11.4.2 Alternative Building Materials

Summary of different sustainable building materials and technologies built to reduce both energy usage and costs.

11.4.2.1 Autoclaved Aerated Concrete (AAC)

In different parts of the world, AAC is acknowledged by different brands as Siporex, Trustone and Environcrete. It is a lightweight precast concrete manufactured by the factory that is obtainable in various sizes and shapes. Thin layer of adhesive can be bonded to AAC blocks, so no mortar is required. Mixtures of OPC, fly-ash or silica sand, lime, water and powder or paste of aluminium are used to make AAC bricks. Millions of very small bubbles of hydrogen extend the mixture to about 5 times its original volume when combined. AAC can be improved by means of traditional carpentry equipment and can be quickly cut. It is a very stable, pollution free, thermally and acoustically insulating, and durable material that resists fire. It needs to be plastered for rain safety, however.

11.4.2.2 Fly Ash

In thermal power plants, fly-ash is a by-product of coal. It consists of non-burnt organic and inorganic matter which could be reused in manufacturing a wide range of construction materials. The characteristics of fly ash find application in manufacturing of stains, solid and hollow bricks, partial cement replacement, and cellular concrete as well as can be used in the manufacturing of paint, distempers etc. A variety of benefits can be accomplished by using fly ash in construction materials.

11.4.2.3 Compressed Earth Blocks

For centuries manual processing of earth blocks has been performed by compacting them in tiny moulds. The method is now automated or industrialized. The earth is made of a mixture of pebbles, sand, silt and clay for blocks. To stabilise earth blocks, approximately 5 percent cement is used. The goods range from solid, cellular and hollow bricks with precise shapes to flooring and paving components. The sun is dry and need not be burned in the compact earth bricks. They are also cost-effective, strong, economical, and easy to produce. A hollow and interlocking soil stabilised block does provide higher thermal isolation than bricks. Fal-G stabilised mud blocks are much stronger than concrete stabilised blocks and absorb less water. Extensive study on this material has been conducted by Development Alternatives, New Delhi and Auroville, Pondicherry. A number of buildings were constructed on compressed blocks of earth at Auroville, Pondicherry.

11.4.2.4 Clay Red Mud Burnt Bricks

These are formed by industrial wastes of aluminium plants in combination with clay, are made of red alumina mud or bauxite. The brick has all the physical characteristics of typical clay bricks. Moreover, the waste management and environmental pollution problems are also solved. Moreover, due to their pleasant colours, they have a strong architectural value as bricks.

11.4.2.5 Lato Blocks

Lato blocks are laterite soil bricks of lime or cement. They are moulded to create solid and better quality blocks which use very less energy when compared to traditional bricks, making them cheaper.

11.4.2.6 Precast Hollow Concrete Blocks

Blocks are constructed from lean cement concrete mixes, extruded by egg laying or static block making machines. They require less amount of cement mortar and thus easy to build in comparison with brick masonry. The thermal safety is enhanced by the cavity in the blocks. Moreover, external or internal plastering may not be needed for the blocks. These can be used as walling or inverted precast t beams as roofing blocks.

11.4.2.7 Bamboo/Timber Mat Based Walls

Such walls consist of a bamboo mat between vertical and horizontal wood/bamboo frames. On both sides, the plastering is achieved with mud or cement. These are simple to build, less costly and common in hilly areas because they can be assembled. However, they do not hold load and need a support system. This improved conventional technology is a key alternative to mitigate damage in case of collapse from the perspective of earthquakes.

11.4.2.8 Rat Trap Bond

The rat trap bond for both English and Flemish Bond is another brick bonding system. It is cost-effective, strong and attractive. The quantity of bricks can be saved by about 25%, while the cost of a wall is about 40%. The rat trap bond is easy to build and has better insulation properties.

11.4.2.9 Composite Ferrocement System

The technique is simple to create and consists of ferrocement (rich mortar reinforced with chicken mesh and welded wire mesh). This reduces the thickness of the wall and makes a greater carpet area. The RCC columns are integrated with precast ferrocement units in trough shape. Units of ferrocement act as a permanent unit for the skin and as an inter-column diagonal stripe. Within coverings it is possible to render mud blocks or any material locally available. This is suitable for seismic conditions.

11.4.2.10 Coconut Fibre and Wood Chips Roofing Sheets

Coconut fibre and wood chips or fibre are submerged in water for two hours and the water is then washed away. They are then mixed with cement, placed on a corrugated mould and held under pressure for 8–10 h. After demoulding before use, the sheets must be cured as well as dried in sunlight.

11.4.2.11 Cement Bonded Fiber Roofing Sheets

This particular is developed in combination with cement as a binder for the manufacture of corrugated or plain roofing sheets of coir waste, coconut pith, wood wool or sisal fibre. These sheets are 50% cheaper than sheets from AC/CGI and use less cement than sheets from AC. They are also lightweight, fire-proof, water-proof and are ideal for sloping roof choices.

11.4.2.12 Micro Concrete Roofing Tiles

Micro cement tiles are composed of a graduated layer of cement mortar built over the inclined roof mould. It is used in roofing pitch systems and is less expensive than ACC/CGI sheets. These tiles are suitable where there are no fired clay tiles and the skeletal system supported by wood is more expensive. When micro concrete roofing tiles are used, the rafter and purlin system cost less. By using ferrocement rafters and purlins, further cost reduction can be carried out.

11.4.2.13 Stone Patti Roofing

Stone Patti roofing is a flat sandstone slab roof system (patties) that rests on steel or sleek RCC beams. The slabs are overlaid for insulation with terracing. This type of roofing is more economical than RCC roofing when (sand) stone sheets are available. The beams are not necessary in locations where large granite stone patties are available, as the Pattis can rest on walls.

11.4.2.14 Precast Brick Arch Panel System

In this method, 50 cm × 50 cm precast brick arches are cast on a base. Side by side, the arches are located above the partly precast joist. Cement concrete covers the haunches between the arches to have a level surface on the top. 30% more such roofs/floors are economical when compared to traditional RCC.

11.4.2.15 Filler Slabs

RCC slabs whereupon filler materials are substituted by bottom half (tension) concrete portions. Filler materials (bricks, cellular concrete blocks, tiles, etc.) are positioned so that structural integrity is not compromised. These are healthy, sound and give ceilings with an aesthetically pleasing pattern. An additional benefit of slabs of filler is that they do not require plastering.

11.4.2.16 Particle Boards

These are made from and bonded by resin from wood waste, cotton stalk and bagasse. They can be used as inserts and they can be used with veneering in panelling, partitioning, false ceiling and furniture as an alternative to timber.

11.5 Conclusion and Recommendation

At minimum 2.35% of the world's energy generation can be able to save by effective passive solar design techniques. Passive design technology includes approaches to collect, reserve, disperse and manage thermal energy by means of different conceptual and physical thermodynamics principles suitable to building materials. These concepts can be converted into attributes inherent in the building design and operation technique through a number of vocabulary frameworks. It creates a structure that is more integrated with its practical environment and gives design opportunity to the architecture and construction profession. The direct gain for heating (office) during sunshine hours is a more convenient passive heating technique whereas the other passive heating principles are used in residential buildings. Dual-glazed systems result in a 9% reduction in heat gain and a 28% decrease in losses compared to single-glazed systems. Double-glazing of the exposed walls should be mandatory to preserve solar radiation within the room with minimal U-value. The combination of evaporative cooling and wind tower is very productive for passive cooling and that can lessen temperature in the range of 12–17 °C. One of most economical methods for cooling a building is evaporative cooling.

Combining Trombe wall, cool roof and thermal isolation as a passive heating/cooling technique will save about 46 and 80% of energy cost respectively in winter and summer. The vast space requirements for thermal energy storage are a major concern in passive design. The building structure can hold approximately 0.23 kWh/°C/ton of its mass. Consequently, the mass of the structure will partially solve the storage issue. The building mass should be focussed within the building's interior to achieve efficient heat storage, e.g. in the inner partition and floors, while the outer walls should be highly isolated. The heat storage inside the building structure, therefore, involves a specific approach to building design.

References

Akadiri PO, Chinyio EA, Olomolaiye PO (2012) Design of a sustainable building: a conceptual framework for implementing sustainability in the building sector. Buildings 2(2):126–152

Aman J (2017) Impact of windows for daylighting on thermal comfort in architecture design studios in Dhaka

Amer EH (2006) Passive options for solar cooling of buildings in arid areas. Energy 31(8–9):1332–1344

Arnold C (2009) Building envelope design guide–introduction. Whole building design guide

Auliciems A, Szokolay SV (1997) Thermal comfort. SL: PLEA

Bauman F, Ernest D, Arens EA (1988) The effects of surrounding buildings on wind pressure distributions and natural ventilation in long building rows. Ashrae Transactions 94

Bhamare DK, Rathod MK, Banerjee J (2019) Passive cooling techniques for building and their applicability in different climatic zones—the state of art. Energy Build 198:467–490

Block M, Bokalders V (2010) The whole building handbook: how to design healthy. Routledge, Efficient and Sustainable Buildings

Chiras DD (2002) The solar house: passive heating and cooling. Chelsea Green Publishing

DOE U (2015) An assessment of energy technologies and research opportunities. Quadrennial Technology Review. United States Department of Energy

Fuchs R, McClelland JF (1979) Passive solar heating of buildings using a transwall structure. Sol Energy 23(2):123–128

Gan W, Cao Y, Jiang W, Li L, Li X (2019) Energy-saving design of building envelope based on multiparameter optimization. Mathematical Problems in Engineering

Givoni B (1998) Climate considerations in building and urban design. Wiley & Sons

Gulati M, Paul A (2013) Principles of energy conscious design

Gutowski TG, Sahni S, Allwood JM, Ashby MF, Worrell E (2013) The energy required to produce materials: constraints on energy-intensity improvements, parameters of demand. Philos Trans Royal Soc Math Phys Eng Sci 371(1986):20120003

Johnson TE (1981) Solar architecture: the direct gain approach. NP, United States

Kamal MA (2012) An overview of passive cooling techniques in buildings: design concepts and architectural interventions. Acta Technica Napocensis: Civil Eng Arch 55(1):84–97

Kleiven T (2003) Natural ventilation in buildings: architectural concepts, consequences and possibilities. Institutt for byggekunst, historie og teknologi

Koch-Nielsen H (2013) Stay cool: a design guide for the built environment in hot climates. Routledge

Koenigsberger OH, Ingersoll TG, Mayhew A, Szokolay SV (2010) Manual of tropical housing and building. Hyderabad

Kohlhepp P, Hagenmeyer V (2017) Technical potential of buildings in Germany as flexible power-to-heat storage for smart-grid operation. Energ Technol 5(7):1084–1104

Konya A (2013) Design primer for hot climates. Elsevier

Ling SJ, Sanny J, Moebs W, Friedman G, Druger SD, Kolakowska A, Anderson D, Bowman D, Demaree D, Ginsberg E, Gasparov L (2016) University physics, vol2

Maheshwari GP, Al-Ragom F, Suri RK (2001) Energy-saving potential of an indirect evaporative cooler. Appl Energy 69(1):69–76

Malone A (2012) The Windcatcher house. Architectural record: building for social change. McGraw-Hill

Martin N, Worrell E, Ruth M, Price L, Elliott RN, Shipley AM, Thorne J (2000) Emerging energy-efficient industrial technologies. Mazria, Edward. Passive solar energy book (1979)

Mirrahimi S, Mohamed MF, Haw LC, Ibrahim NLN, Yusoff WFM, Aflaki A (2016) The effect of building envelope on the thermal comfort and energy saving for high-rise buildings in hot–humid climate. Renew Sustain Energy Rev 53:1508–1519

Mazria E (1979) Passive solar energy book. Rodale Press, Pennsylvania, United States

Nayak JK, Prajapati JA (2006) Handbook on energy conscious buildings. Prepared under the Interactive R & D Project 03(04):03

Noseck RR (2013) The water wall: a passive solar collection and thermal storage device for supplementary radiant heating

O'Connor D, Calautit JKS, Hughes BR (2016) A review of heat recovery technology for passive ventilation applications. Renew Sustain Energy Rev 54:1481–1493

Owusu PA, Asumadu-Sarkodie S (2016) A review of renewable energy sources, sustainability issues and climate change mitigation. Cogent Eng 3(1):1167990

Sarbu I, Sebarchievici C (2018) A comprehensive review of thermal energy storage. Sustainability 10(1):191

Sozer H (2010) Improving energy efficiency through the design of the building envelope. Build Environ 45(12):2581–2593

Szokolay SV, Koenigsberger O (1973) Manual of tropical housing and building. Orient Langman, Bombay

Tiwari GN (2002) Solar energy: fundamentals, design, modelling and applications. Alpha Science Int'l Ltd

Vijayalakshmi MM, Natarajan E, Shanmugasundaram V (2006) Thermal behaviour of building wall elements. J Appl Sci 6(15):3128–3133

Walker A (2016) Natural ventilation: whole building design guide. National Renewable Energy Laboratory, USA

Watt J (2012) Evaporative air conditioning handbook. Springer Science & Business Media

Wujek JB, Dagostino FR (2011) Mechanical and electrical systems in architecture, engineering and construction. Pearson Higher Ed

Yannas S, Erell E, Molina JL (2006) Roof cooling techniques: a design handbook. Earthscan

Yüksek I, Karadayi TT (2017) Energy-efficient building design in the context of building life cycle. Energy Efficient Buildings 93–123

Zhang Z, Li Z (2019) Heat transfer performance of the Trombe wall implanted with heat pipes during daytime in winter. Sci Technol Built Environ 25(7):935–944