A Review on Passive Cooling Methods for Green Energy Buildings

Muthusamy Ponmurugan, M. Ravikumar, and Athimoolam Sundaramahalingam

Abstract Due to the population growth, the energy demand for thermal comfort for human increases. The global warming also rises the temperature of the universe. The residential demands for electricity are electric lighting, air-conditioning, and household appliances. Fifty percentage of the power supply is consumed by the building sector in economically developing countries. The natural cooling methods are not supportive to meet the requirement. Heat dissipation, heat reduction, and thermal management are passive cooling techniques. For these, storage of energy is needed and its role is vital in power generation management. The suitable technology is to be selected, and it depends on so many factors. Many investigations have been done to reduce the cooling load of a building through reflective and radiative roofs. It is not easy to adopt a particular technology universally. This review reveals the reducing, modifying heat gains as well as the removing internal heat by considering the factors involved in these. It paves the way to select the appropriate technology that plays a dominant role for the particular requirement.

Keywords Passive cooling · Phase change materials · Coating on ceilings · Cool roof · Thermal storage

1 Introduction

"Buildings are a key driver of energy demand, and developments within the sector such as the growing uptake of air conditioners are having a big impact on energy and environmental trends at the global level," said Dr. Fatih Birol [1], Executive Director of the International Energy Agency (IEA). "If we do not make buildings more efficient, their rising energy use will impact us all, whether it be through access to affordable energy services, poor air quality, or higher energy bills." The building sector includes both residential and commercial. The building sector takes in around

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34% of the total energy consumption probably in most countries. The residential demands for electricity are electric lighting, air-conditioning, and household appliances. Fifty percentage of the power supply is consumed by the building sector in economically developing countries. In developed countries, the economic growth leads to the increase of residential demand for electricity. They transform the living standards to a higher level. Cooling technologies for buildings are broadly classified into two types, namely active cooling and passive cooling. Electricity is needed to produce the cooling effect in active cooling method. Natural processes and passive technologies are used in passive cooling method. The advantages of the later method are the absence of power source and low-grade energy usage. Of many alternative energy sources methods, passive cooling method is the best among the existing methods.

2 Classification of Passive Cooling Methods for Green Energy Buildings

There are three ways of cooling the buildings, viz. protecting the entry of solar heat into the building, modulating the heat inside the building, and dissipating the heat from the building. The classification of passive cooling methods for buildings is shown below.

1. Reducing heat gains
    - (i) Microclimate—Vegetation, landscaping, water surfaces
    - (ii) Solar control—Aperture, glazing, shading
2. Modifying heat gains
    - (i) Thermal mass without energy storage
    - (ii) Thermal mass with energy storage by PCM enhanced ventilation/walls/wallboard/roof/
    - (iii) Night ventilation
3. Removing internal heat (heat dissipation technique)
    - (i) Free cooling with thermal energy storage
    - (ii) Natural cooling without thermal energy storage
        - (a) Evaporative cooling
        - (b) Radiative cooling via paints, movable insulation, flat plate air cooler
    - (iii) Natural ventilation without thermal energy storage
        - (a) Single-sided ventilation
        - (b) Wind-driven cross-ceiling
        - (c) Buoyancy-driven stock ventilation through Trombe wall/solar chimney.

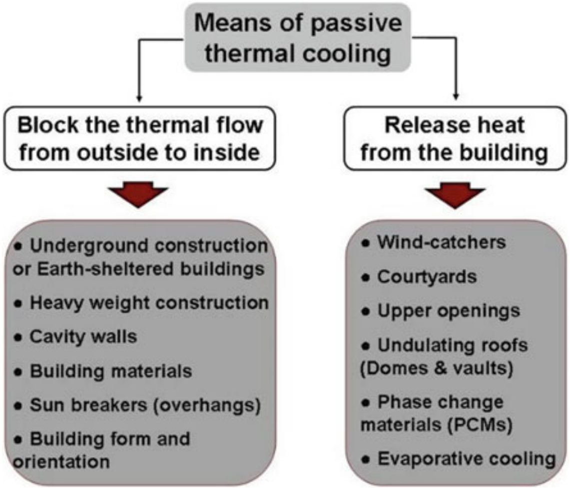

Fig. 1 Means of passive cooling

Heat can be released from buildings through wind-catchers, courtyards, undulating roofs, or by using phase change materials, evaporative cooling. Thermal flow can be blocked to the buildings by some techniques. These are illustrated in Fig. 1. Heat dissipation, heat reduction, and thermal management are passive cooling techniques. For these, storage of energy is needed and its role is vital in power generation management. Energy can be stored either for a short period or for a long period. "Short-term energy storage" is meant for storing the energy for hours, whereas "long-term energy storage" is meant storing the energy for days. But, many energy sources are intermittent in nature. Solar energy is available only during the daytime, and it has to be stored by efficient thermal energy storage to utilize during the night. Many researchers have attempted to utilize the passive cooling technologies in global warming affected countries. But the challenges for achieving this are more [2], and the sustainability is very less in those countries. This work aims at reviewing the various passive cooling methods for the green energy buildings and the challenges to utilize the technologies in hot countries.

3 Passive Cooling Techniques

The passive cooling techniques for heat prevention mainly focus on the reduction of air temperature. This can be approached by radiation loss, conductive loss, reducing the thermal mass, providing microclimate and ground cooling. The buildings are directly in contact with the atmospheric air and the ground (earth). The buildings act as a direct contact earth–air heat exchanger. The vegetation, landscaping, and providing water surfaces are the techniques to provide microclimate. Shading, night sky radiation, aperture, glazing are the other passive cooling techniques. Different phase change materials are employed in the ceilings, wallboards, roof, and this is one of the effective techniques to reduce the heat gain [3].

3.1 Reducing Heat Gains

Combustion of fuels results in high pollution as the electricity demand has been increasing due to population growth. Maintaining internal air quality (IAQ) standards for air-conditioning engineers has become a challenge in the recent past. The technologies have changed their gears to move to cool materials for roofs as well as walls of the buildings. The materials which have high reflecting and emitting characteristics are needed for this. Synnefa et al. [4] found that the maximum difference between the solar reflectance of a conventional color coating and cool color coating is 0.22 with a corresponding surface temperature difference of 10.28 °C. In ancient days, the solar reflectance was in the range of 0.05–0.25. Nowadays, it has improved a lot around 0.30–0.45 reported by Santamouris and Asimakopoulos DN in their book [5]. Shen et al. [6] studied the impact of reflective coatings on thermal comfort, energy consumption, air temperature, globe temperature, and building surface temperatures experimentally. Packett [7] concluded that by applying two coats, i.e., an appropriate primer and a gloss white acrylic paint, over it will be the most effective solution. Suehrcke et al. [8] suggested using a light or reflective roof color to achieve the efficient heat reduction in the roof. He emphasized that an R-value can be assigned to the reflectivity of a roof surface. Hosseinia et al. [9] found that for the largest energy demand in the world cool roof coating with less insulating material is recommended. They concluded that higher energy saving can be obtained in real life by an application of cool roof in the long term. Gupta et al. [10] conducted experiments on the sites the two office rooms located in the central workshop premises near Katra town in Reasi District of the Indian state of Jammu and Kashmir Katra is located at 32.98 °N, 74.95 °E and has an average elevation of 754 m (2474 ft). They analyzed the heat reduction by cool roof pavements and found that the maximum percentage of heat reduction was 80%. The impact of using cool roof technologies on the thermal comfort of the office buildings were discussed in a report of cool roof kit [11]. Suriya Pradap Singh et al. [12] compared the green roof and white roof and concluded that white roofs are three times more effective than green roofs in cooling down the neighborhood. Cement-based materials in wall and roof ceilings are useful in tropical weathers as they are extremely resistant to hot and cold temperature.

3.2 Modifying Heat Gains

Heat gains can be modified either by free cooling or changing the thermal mass. Phase change materials are incorporated for both methods. Analysis of natural cooling of building with phase change materials by conducting experiments was done by Srinivasan and Ravikumar [13], Madhumathi and Sundarraja [14], Heier et al. [15] combined the different thermal energy storage techniques for buildings and presented. A study [16] shows that by adopting cool roofs, the consumption of electricity can be decreased by 25%. The methods of modifying heat gains are illustrated in Fig. 2. Pasupathi and Velraj [17] explained the various effects of phase change material in building roof for year round thermal management and applied in residential and commercial establishments [18].

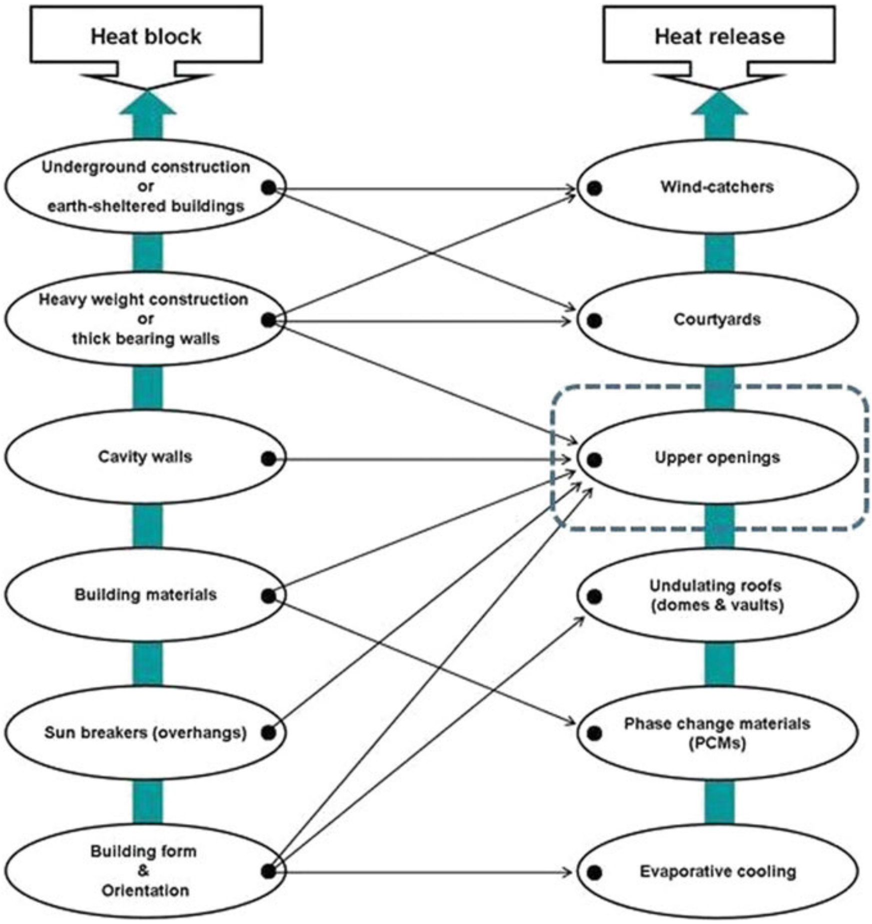

Fig. 2 Ways of modifying heat gains

3.3 Heat Dissipation Technique (Remove Internal Heat)

Radiation means the release of heat in the form of electromagnetic waves. The photons having energy of $E = h\nu$ are released continuously, and there is no zero radiating materials in practice according to third law of thermodynamics. This radiation heat release stops when the system (buildings) and the atmosphere are in equilibrium condition. Heat dissipation techniques are summarized as follows in a line diagram (Fig. 3).

One of the techniques used to reduce heat through roof is nocturnal cooling. Nocturnal cooling systems for space cooling and its challenges are reviewed by Nwaigwe et al. [19], Watson and Chapman [20], emphasized that air is cooled by radiant cooling in two-storeyed buildings using light color coatings with high reflection. Chung et al. [21] analyzed the loads handled, characteristics of load, air systems in different zones and control strategies used in (Fig. 4) thermally activated building systems (TABS).

The envelope's insulation, solar protection, and surface properties are the factors to increase the cooling effect. Givoni [22] concluded that protecting the roof from heat during the daytime is completely different from other approaches such as flat

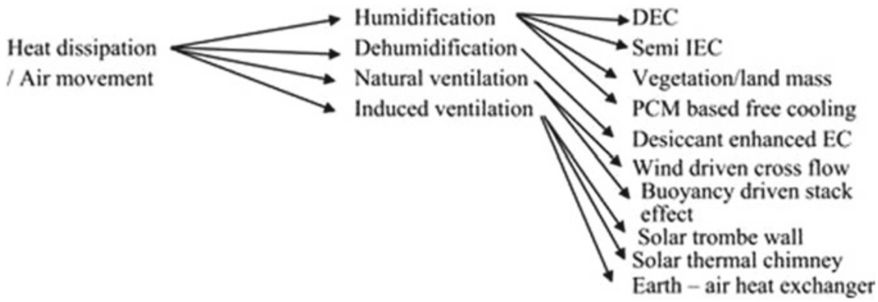

Fig. 3 Heat dissipation techniques

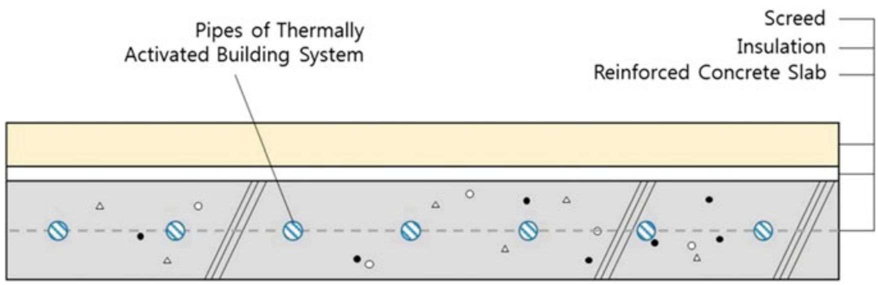

Fig. 4 Section view of the thermally activated building system (TABS)

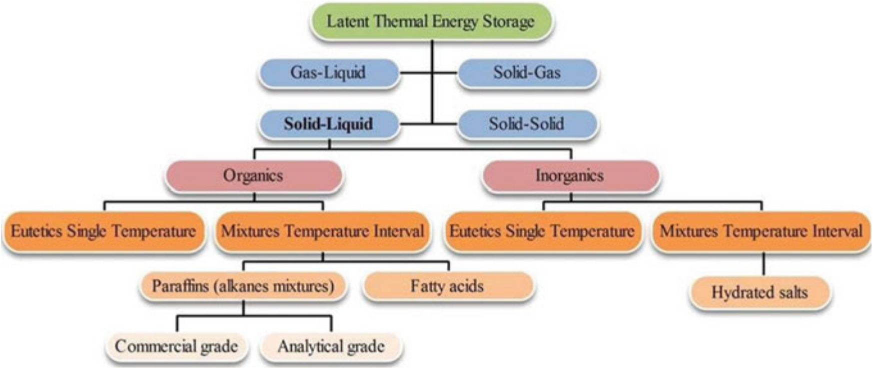

Fig. 5 Classification of latent thermal energy storage

plate air cooler and reflective insulation system. This method provided a cooling effect of 0.266 kWh/m^2 per day [23].

Muscio [24] insisted that when photons from radiation hit a surface of dense material, these photons are neither reflected nor absorbed and found that solar reflectance is associated with the use of flat surface and polish of the surface. Radiative cooling using solar plate collector [25] can be done effectively. Energy can be stored and retrieved for passive cooling. Figure 5 shows the various possible ways of latent heat energy storage systems in practice. Solar control glazing on energy savings is analyzed by Bakker and Visser [26].

4 Conclusion

In this paper, a review of various passive cooling technologies has been done instinct. Due to the population growth, the energy demand for thermal comfort for human increases. The global warming also rises the temperature of the universe. The natural cooling methods are not supportive to meet the requirement. Hence, the appropriate modern passive cooling technology has to be employed for buildings. The various studies show that the suitable technology is to be selected and it depends on so many factors [27–29]. Many investigations [30–32] have been done to reduce the cooling load [33, 34] of a building through reflective and radiative roofs. It is not easy to adopt a particular technology universally. However, the cool roof technology with reflective coating and radiant cooling through with latent heat thermal energy storage materials play a dominant role among these technologies.

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