Effect of Passive Solar Cooling Systems Performance on Indoor Air Quality in Buildings[I]

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Abstract

Passive cooling systems are designed to reduce or eliminate electrical and mechanical cooling equipment, mainly in areas where building cooling is an important issue in the summer season. Therefore, cooling as well as air conditioning is one of the main and most expensive problems of today's advanced buildings in many regions, especially in temperate and humid regions. This article looks into the effect of passive solar cooling systems on indoor air quality (IAQ) in buildings. Passive solar cooling, a sustainable design method, saves energy by relying on natural processes to regulate temperature. The study compares the effects of several passive cooling approaches, such as shade, natural ventilation, and thermal mass, on IAQ parameters like temperature, humidity, and pollutant levels. According to the research, almost 40% of the total energy production in developed societies is spent in the building sector, most of which is related to air conditioners. This article, using the descriptive-library method, examines the types of passive solar cooling systems in the optimal performance of energy in the building, and in this regard, tries to express the use of different types of energy saving in buildings passive solar cooling systems will be discussed.

Keywords: Passive solar cooling, Indoor air quality, Building, Renewable energy.

Introduction

Energy has always played a vital part in human life and is one of the driving forces behind economic progress. A substantial portion of human energy consumption is derived from fossil fuel sources such as oil, coal, and natural gas; however, because millions of years are required to replace these fuel sources, it is expected that these resources will be depleted in the not-too distant future (Sadegh Sabery et al., 2018). Because of the gravity of the situation, several countries are attempting to invest in new technologies that employ renewable energy sources such as solar energy, wind energy, water energy, and even geothermal energy, which is less damaging than fossil fuels. It leaves less environment for them to consume as resources to provide their necessary energy (Fetros, 2012).
Saving energy is a practical approach to minimize global fuel and energy consumption (Jalilian et al., 2017). In this regard, the building sector is particularly important, accounting for 40% of the overall consumption of energy, with 50-60% going toward heating and cooling the structures' residential spaces. This is despite research indicating that 30 to 40% of the fuel

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consumption in the building can be easily conserved. Some of the recommended solutions include reducing fuel usage in buildings through the use of insulation and alternative energy sources (Taghavi, 2014). Optimizing demand and energy consumption in buildings necessitates a comprehensive approach that encompasses how to preserve human comfort and the performance of multiple building components (Keshtkar et al., 2014).

Passive Solar Cooling Systems

Natural cooling techniques keep the house cool in the summer without requiring any energy. Shade is a useful and vital feature in passive solar homes because the same structure absorbs sunlight in the winter. Thermal mass and building components are effective for both cooling and heating. They store heat in the winter and use it to cool the house in the summer. Another passive cooling method is to utilize windows that cast a shadow and transmit less heat into the house during the summer.

1. Thermal mass

The thermal mass functions by accumulating and releasing heat. This practice is beneficial during hot seasons since it causes The indoor air temperature does not rise quickly, which improves thermal comfort. Instead, heat is kept within the building's structure. This stored heat permeates the building during night, when the inside air temperature is low. In this manner, the body of the structure is cooled and ready to store heat again the next day (Nielsen, 2009).

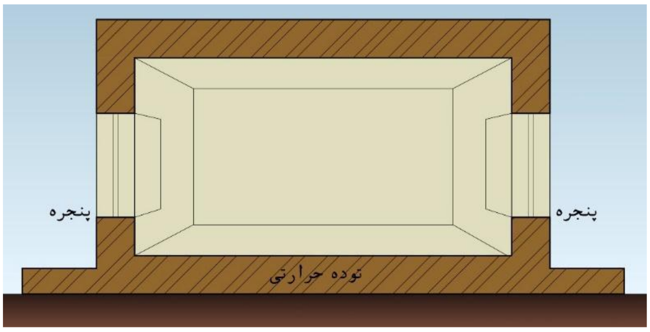

Figure. 1. Cooling through thermal mass (Nasrollahi, 2009)

2. Natural ventilation

The purpose of ventilation is to remove used and undesired indoor air and replace it with cold, fresh outdoor air. Natural ventilation is the process of preparing and extracting air using natural forces such as wind or buoyancy. Natural ventilation is achieved by utilizing the natural pressure difference surrounding the building created by the wind and the action of the chimney. Natural ventilation relies on three meteorological phenomena: wind speed, wind direction, and temperature difference (Kasmaei, 1989). Natural ventilation is achieved through a variety of architectural components that connect the indoor and outdoor environments. These elements include windows, windshields, apertures, vents, and so on. Ventilation involves three things:

- Preserving indoor air quality by replacing it with clean outdoor air.
- Improving thermal comfort by promoting heat dissipation from the body.
- Preventing discomfort from wet skin.

- Cooling the building construction when the indoor temperature exceeds the outdoor. Natural ventilation performs a different cooling effect.
- Replace indoor heated air with outdoor cool air.
- Reducing humidity and air pollution, which enhances evaporation from the skin's surface and generates a cooling sensation.
- Increasing evaporation, which cools the space (Givoni, 1969).

The efficiency of natural ventilation is determined by the orientation of the opening in relation to the wind direction, the type and dimensions of the entrance and exit openings, wind speed, wind temperature, space depth, and other factors. There are four different types of natural ventilation:

- One-way ventilation.
- Cross ventilation.
- Chimney ventilation.
- Ventilation-Shaft (Nielsen, 2009).

3. Evaporative cooling

3.1. Water

Water absorbs latent heat when evaporating. This heat is removed from the surrounding environment, causing cooling. The same feature of water is used for cooling. The rate of evaporation, and thus the rate of cooling, increases with the increase in water surface area, the movement of air or water particles, and the decrease in air humidity (and pressure). The relative humidity has an inverse connection with the rate of evaporation and the temperature differential between the dry bubble and the cooler bubble (Nielsen, 2009).

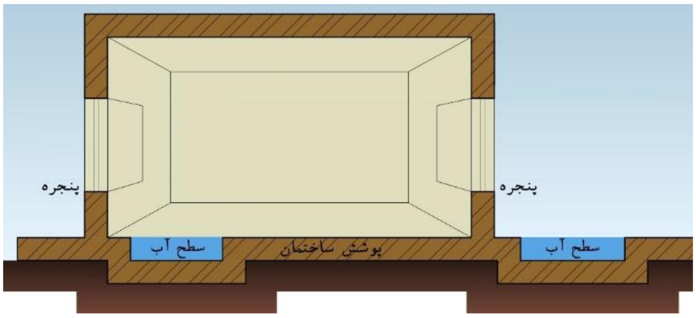

Figure. 2. Evaporative cooling through water surfaces (Nasrollahi, 2009)

3.2. Vegetation

Plants evaporate the water received by their roots via the leaves, and the latent heat required for this process is extracted from the environment. As a result, vegetation, particularly water-loving and leafy plants, perform better under evaporative cooling. Pools and water basins, trees, and plants can be used in the open space of a building's courtyard to create a cool sub-climate that affects the internal environment. The utilization of these elements within the building can also be implemented with suitable design (Karimpour, 2015).

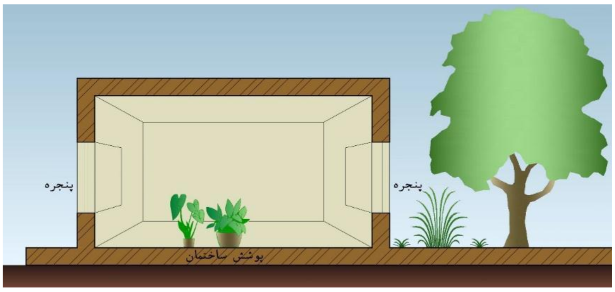

Figure. 3. Evaporative cooling through vegetation (Nasrollahi, 2009)

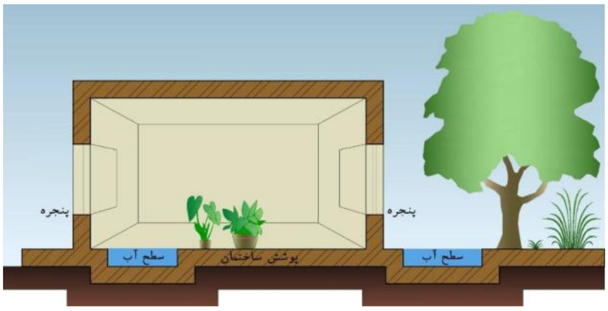

Figure. 4. Evaporative cooling through water pool and vegetation (Nasrollahi, 2009)

4. Evaporative cooling and natural ventilation

4.1. Natural ventilation through water ponds and vegetation

Increasing air movement accelerates evaporation and cooling. Therefore, natural ventilation and evaporative cooling through water ponds and vegetation, together, can aid to boost cooling efficiency (Nielsen, 2009). Natural ventilation can also be employed to transport cool air from evaporation into indoor spaces. As a result, the above method of evaporative cooling can be employed in open spaces as well as in front of windows, cooling towers, and vents (Ghiabaklou, 2000).

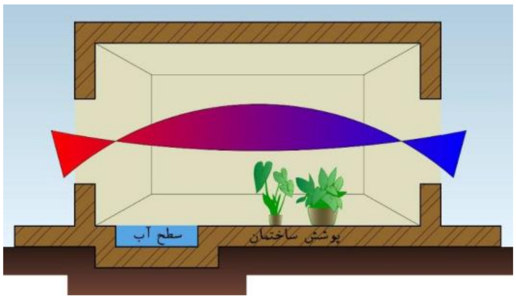

Figure. 5. Evaporative cooling through water pool and vegetation (Nasrollahi, 2009)

4.2. Ventilation-Shaft and water pond

Ventilation-shaft are used to direct wind from an upper level to the inner sections of a building. When a pool of water is placed under a ventilation-shaft, not only does evaporative cooling occur to improve the efficiency of natural ventilation, but the flow of air also doubles the rate of evaporation from the water surface, resulting in greater cooling.

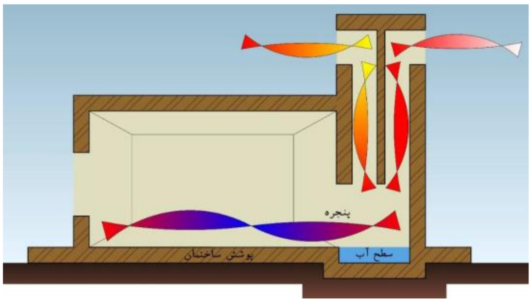

Figure. 6. Ventilation-shaft and water pond (Nasrollahi, 2009)

5. Ground cooling and natural ventilation

During the summer, the ground temperature is lower than the ambient temperature. As a result, the air that naturally enters the building through underground vents or pipes (due to buoyancy and chimney effect) has a significant cooling effect (Muehleisen, 2011).

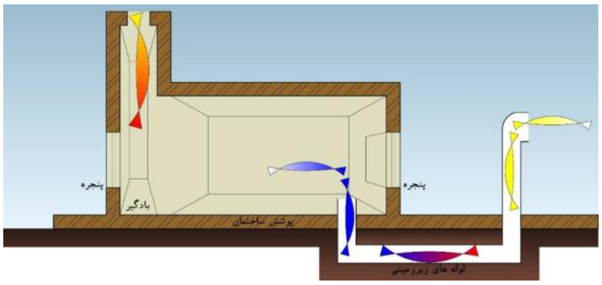

Figure. 7. Ground cooling and natural ventilation (Nasrollahi, 2009)

6. Ground cooling, natural ventilation, and evaporative cooling

The air transfer mechanism, which uses subsurface vents and natural ventilation, is highly efficient concerning of cooling. The reason for this is that natural ventilation, the earth, and evaporation all improve cooling performance.

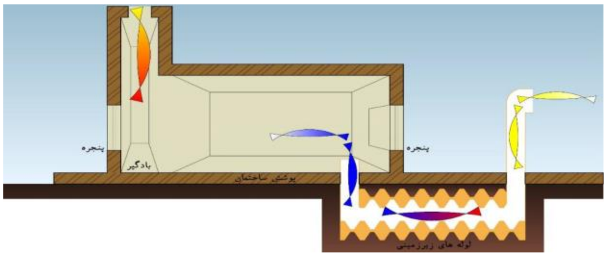

Figure. 8. Ground cooling, natural ventilation, and evaporative cooling (Nasrollahi, 2009)

7. Green roof

Green roofs help to reduce the environment by collecting and evaporating solar heat. They lower the daily and night temperature difference of the roof surface and act as insulation.

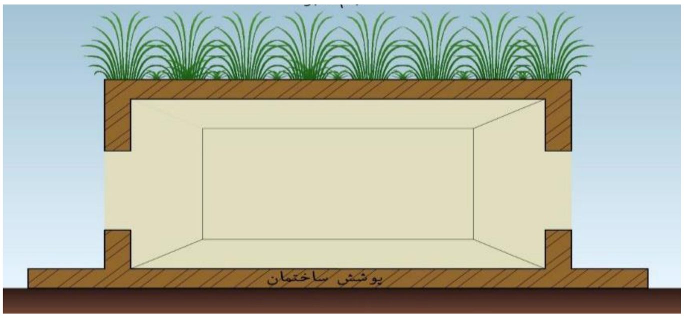

Figure. 9. Green roof (Nasrollahi, 2009)

8. Night cooling

8.1. Night cooling of the building (through thermal mass)

Increasing The temperature of the night air is lower than the daily temperature, especially in hot climates. By using building elements that cool the thermal mass during the night, passive cooling can be achieved the next day (Karimpour, 2015).

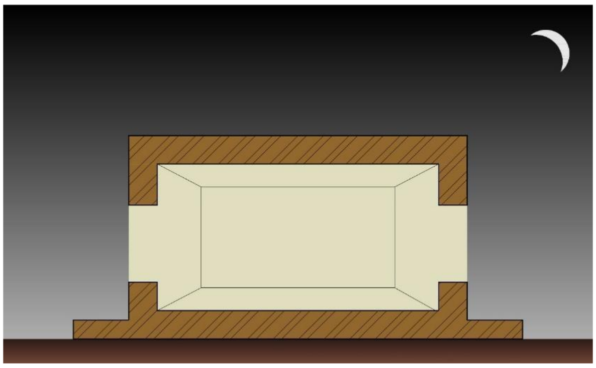

Figure. 10. Night cooling through massive thermal mass (Nasrollahi, 2009)

8.2. Night summer cooling

During the cold hours of the night, when the sky temperature drops, heat can be transferred to the sky from the warmer space via the surface of the glasses, causing the inside space to cool down. Movable and adjustable sunshades should not be utilized in night radiation cooling to avoid blocking the passage of high wavelength rays. If radiant cooling is designed for nighttime use, it is preferable to open the windows, as the glass reflects high wavelength radiation, reducing cooling efficiency (Ghiabaklou, 2016).

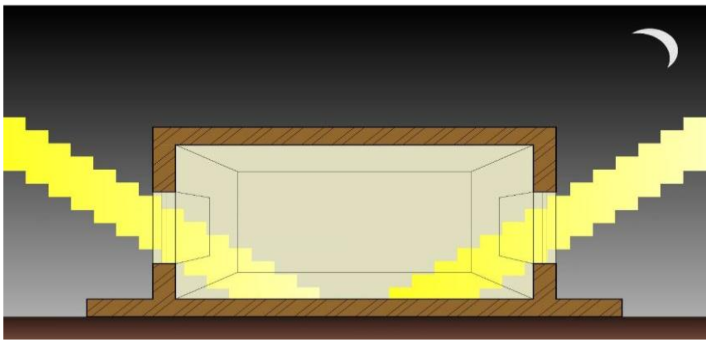

Figure. 11. Night summor cooling (Nasrollahi, 2009)

9. Green roof, evaporative cooling, and natural ventilation

Vents facing the wind on green roofs are extremely successful in achieving cooling aims through evaporative cooling (using water and vegetation), green roofs, and natural ventilation. The advantage of this system is the high evaporation rate, less energy demand for conveying cool air to indoor spaces (thanks to the fluid property), and higher space efficiency (Thom & Bosen, 1959).

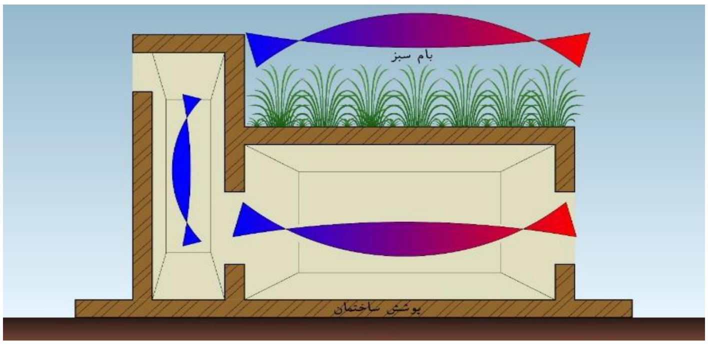

Figure. 12. Green roof, evaporative cooling, and natural ventilation (Nasrollahi, 2009)

10. Natural ventilation and evaporative cooling (ventilation-shafts, windows and vents along with wet surfaces)

Building a water-saturated filter, such as a damp cloth, in front of a window, draft, or ventilation-shaft, or laying water-saturated materials, such as brick or wet soil around the draft or vents, boosts the cooling efficacy of natural ventilation through evaporation of the air in the circulation.

11. Combined cooling

11.1. Underground heat exchange systems (ground cooling)

During the summer, mechanical cooling of the ground (with the help of a fan) is utilized in conjunction with other cooling methods. When air in subterranean pipes passes over the surface of water or wet materials, or passes through open vents and strikes the surface of wet mud walls, evaporative cooling effectiveness improves.

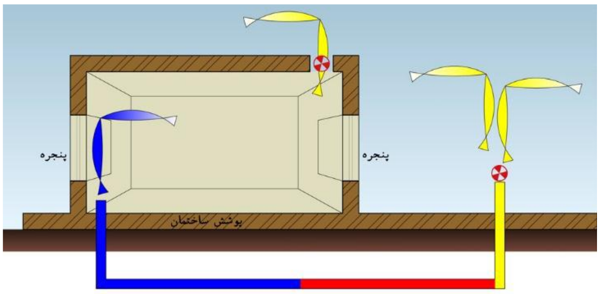

Figure. 13. Underground heat exchange systems (Nasrollahi, 2009)

11.2. Night cooling (through storing cooled water at night)

A water tank outside the building that is shaded during the day can store cooled water overnight for use the following day. If the tank is situated on the roof, water circulation requires less energy. This is due to pressure and buoyancy, which cause cold water to easily fall from above into the internal areas while hot water rises towards the tank. During the day, cool water is transferred to indoor spaces via an automated pump and then returned to the tank after absorbing heat from the air.

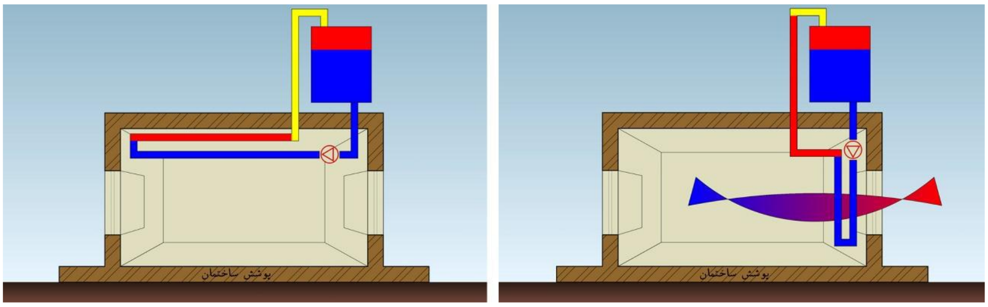

Figure. 14. Cooling by storing cooled water at night (Nasrollahi, 2009)

11.3. Green roof and evaporative cooling

Evaporation from the surface of plant and damp soil on the green roof, as well as vegetation-induced shading, lowers the temperature of moist soil. It can be used to chill the structure by circulating cold water inside and out.

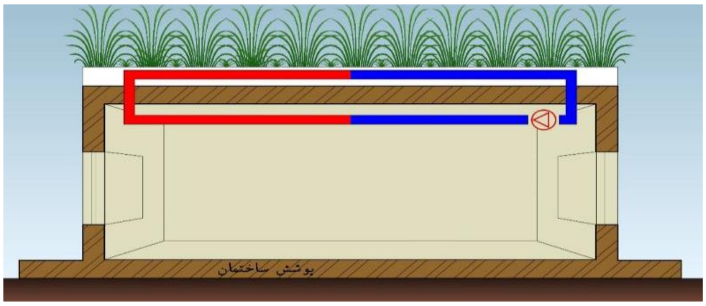

Figure. 15. Combined cooling with green roof and evaporative cooling (Nasrollahi, 2009)

11.4. Night cooling and evaporative cooling

If the green roof is paired with rooftop water tanks for night cooling, the vegetation and humid areas around the tank will cool the water inside the tank more (both during the day and at night). This combination has the benefits of both methods, resulting in excellent efficiency. A pump can be used to convey cooled water from the storage area to the indoor as needed.

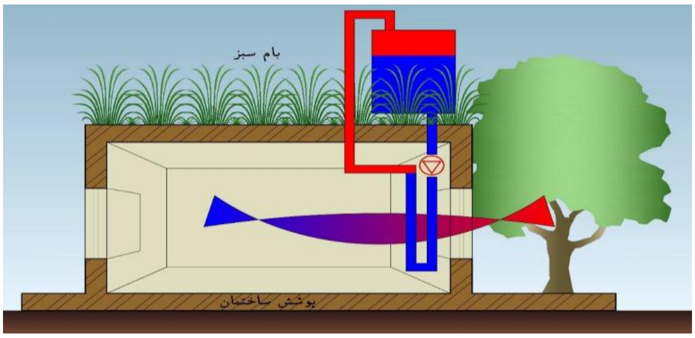

Figure. 16. Night cooling and evaporative cooling (Nasrollahi, 2009)

The water in the yard's ponds cools due to the low air temperature at night and evaporation during the day and night (Karimpour, 2015). If a water circulation pipe is routed from within the tank to the interior spaces, the cooling capacity will be doubled. When the water temperature is lower than the indoor air temperature, pumps automatically circulate it.

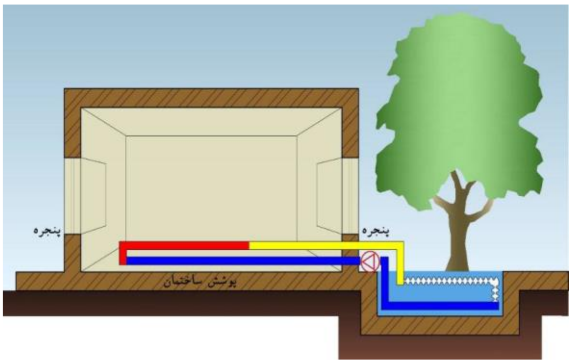

Figure. 17. Night cooling and evaporative cooling (Nasrollahi, 2009)

12. Solar control

To prevent excessive heat gain through solar radiation during hot seasons and to lower the building's cooling energy consumption, glass shells should be insulated against unwanted radiation of heat throughout the structure (Feist, 2008). This is achieved by darkening the sun's rays before they reach the structure (Goulding et al., 1993). To attain the indoor comfort temperature, certain factors such as sun control, external absorption, indoor absorption, ventilation, and natural cooling should be discussed. The average height and orientation of windows to the south in passive residential buildings (or any energy efficient building) may result in overheating throughout the summer. Therefore, architectural opportunities especially in sunny areas, should be coupled with appropriate shade systems.

Conclusion

In recent years, most countries' attention has been drawn to the development of renewable energy access technologies due to concerns about non-renewable energy consumption and depletion, as well as pollution caused by the consumption of these resources. As a result, intensive research into renewable energy sources has resulted in an increase in production of these clean energies in both developed and developing countries. The aim of the article is to give ideas for achieving renewable energy sources using passive solar cooling. A climate-compatible design can improve the temperature conditions of the occupied area; nevertheless, in some cases, we cannot fully establish a comfort zone by depending solely on the potential of the environment and must use mechanical facilities. Solar systems are always effective at reducing energy use. This feature decreases the volume required for mechanical facilities while also lowering the building's fuel and energy supply costs.

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