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Investigation of Various Types of Passive Solar Cooling Systems in the Optimal Energy Performance in the Building

Mehdi Mehrabi[1], Mehrdad Hajian Zeidy[2,*], Razieh Ghadarjani[3], Mohamad Mehdi Vatandoost[4], Sajad Jalilian[5].

1- Ph.D of Architecture, Islamic Azad University, Kish, Iran.
mehrabi602@gmail.com
2- Master of Architecture, Sariyan Higher Education Institute, Sari, Iran.
mehrdad_hajian_zeidy@yahoo.com
3- Lecturer of Islamic Azad University, Ahwaz, Iran.
razieh.ghadarjani@yahoo.com
4- Faculty of ArchitectureAllameh Amini Higher Education Institute, Bahnamir, Babolsar, Iran.
mohamadmehdi.vatandoost@yahoo.com
5- Master of Environmental Sciences, Tehran University, Tehran, Iran.
sajadjalilian@ut.ac.ir
* Corresponding Author: Mehrdad Hajian Zeidy
Email: mehrdad_hajian_zeidy@yahoo.com

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 summer. Therefore, cooling and air conditioning is one of the main and most expensive problems of modern advanced buildings in many areas, especially temperate and humid areas. According to research, approximately 40% of all energy production in developed societies is spent on the construction sector, most of which is related to air conditioners. This article uses a descriptive-library method to investigate the types of passive solar cooling systems in the optimal energy performance in the building and in this regard, in order to save energy in buildings, the use of passive solar cooling systems is discussed.

Keywords: Passive solar cooling, energy, building, renewable energy.

1. Introduction

In the present day, the dwelling and habitat are invariably linked to making buildings as comfortable and convenient possible all over the world. The building sector is growing at a rapid pace by investing 30–40% of total global basic resources. The present day buildings have become the third largest consumer of fossil energy after industry and agriculture. The Asia-Link program is an initiative by the European Commission to promote and spread the knowledge on sustainable built environment with nearly zero energy approach. In this sustainable built environment program, there is promotion toward the integration of proven renewable energy technologies with the building for various applications such as water heating, heating/cooling and electricity production. The operational energy use in the building is of growing importance all over the world [1].

The building labels have been introduced in European countries, such as 'Passive House' in Germany and 'Min energy' in Switzerland to certify standardized low energy buildings [2]. Sources place the amount of energy expended in the building sector in Europe to about 40–45% of total energy consumption [3]; about two-thirds of this amount is used in private buildings. Other sources claim, that in industrialized countries, energy usage in buildings is responsible for approximately 50% of carbon dioxide emissions [4,5].

Hence, sustainability assessment of buildings is becoming necessary for sustainable development especially in the building sector all over the world. The main goals of sustainable design were to reduce depletion of critical resources such as energy, water, and raw materials; prevent environmental degradation caused by facilities and infrastructure throughout their life cycle; and create built environments that are safe, productive and effective utility of the water and solar energy. The tool for building environmental assessment system (BEAS) has been proposed by Burdova and Vilcekova and carried out at Slovakia given in Table 1 [6] for all resource conservations.

Hence, there exists a tremendous potential to conserve energy in buildings. Energy conservation measures are developed for newly constructed buildings and for buildings under refurbishment. However, to achieve a significant reduction in energy consumption in the building apart from the standard energy-efficiency methods, proven renewable energy technologies should be implemented and integrated with the passive building [7]. In the European Union, from year 2020 all new buildings are going to implement all the aspects to achieve the nearly zero energy building for the operational energy conservation. The four main aspects for energy efficiency in a building are discussed in this paper for sustainable development in the building sector all over the world [1].

The first aspects are related to the utility of solar daylight, passive heating/cooling designs and provision for rain water harvestation to be integrated with passive building based on the prevailing climatic conditions of the site in the world. In the cold countries, the passive heating designs are integral part of passive buildings e.g. sunspace, Trombe wall, air handling unit with air-air heat exchangers and the air tightness with the required air change per hour. In the hot and dry climatic zones, passive cooling designs include the heavy design of wall and roof cooling using water evaporation, roof texture designs, the earth-water heat exchangers, passive downdraft space cooling, solar refrigeration, etc. Secondly, the aspect regarding usage of the low energy building materials (such as fly ash bricks; fiber reinforced bricks; wood and stabilized adobe blocks) is becoming popular especially in India, Middle East, Europe, USA and UK. The

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embodied energy of the building should be low so as to achieve building a low energy houses for sustainable habitat development. The third aspect deals with the operational energy conservation using energy efficient equipments such as LED lighting, five star rated fans, refrigeration and air-conditioning equipments in India. Lastly, the aspect of using integrated renewable systems such as solar water heater for the hot water utility, small wind turbine or solar photovoltaic electricity generation at the roof top of building are discussed in this paper with their economic analysis and environmental emissions [1].

Table 1 The building environmental assessment system (BEAS) at Slovakia [6].

3. Site Selection and project planning	A1. Site Selection	Use of land with high ecological sensitivity value; Land vulnerable to flooding; Land close to water endangered contamination; Distance to commercial and cultural facilities; Distance to public green space, etc.
	A2. Site Development	Development of density; Possibility of change of building purpose; Impact of the design on the existing streets scapes, etc.
B. Building Construction	B1. Materials	Use of materials that are locally available, Re-use and recycling, etc.
	B2. Life cycle analysis	Embodied energy of building materials; Global warming potential of material for construction, etc.
C. Indoor Environment		Thermal comfort; Humidity, Acoustic; Day lighting; Indoor air quality; Total volatile organic compound, PM 10, etc.
D. Energy Performance	D1. Operational Energy	Heating energy consumption; Energy consumption for domestic hot water; Energy for Air handling unit; Energy for cooling, energy for lighting, energy for appliances, etc.
	D2. Active systems using renewable energy sources	Solar water heaters; Heat pump; Photovoltaic technology; Heat recuperation, etc.
	D3. Energy Management	Operation and management; Control of lighting systems; occupant sensors and technical control of appliances, etc.
E. Water Management		Reduction and regulation of water flow; surface water run-off, drinking water supply; filtration 'gray water', etc.
F. Waste Management		Measures to minimize waste resulting from building operation; Measures to minimize emission

		from building construction, operation and demolition; Handling risk of hazardous waste resulting from facility operation, etc.

2. Energy conservation in building

There are four broad ways to reduce the energy consumption of building which ultimately results in mitigating emissions of CO2 emissions through energy conservation. These aspects are described as follows:

a. Comfort passive building design and its orientation for harnessing solar energy.

b. Low embodied energy materials for building construction.

c. Energy efficient domestic appliance to conserve the building operational energy.

d. Building integrated renewable energy technologies [33].

2.1. Passive building design

The most sustainable energy technique is to conserve energy as much as possible. Passive solar building design can aid energy conservation efforts because building design is directly related to energy use. Buildings with passive solar building designs naturally use the sun's energy for free of charge heating, cooling and daylighting. This reduces the need to consume energy from other sources and provides a comfortable environment inside. The principles of passive solar design are compatible with diverse architectural styles and can be renovated with existing building for net zero energy use [8].

2.1.1. Passive solar design principles

Passive solar design integrates a combination of building features to reduce or even eliminate the need for mechanical cooling and heating and daytime artificial lighting. Designers and builders pay particular attention to the sun to minimize heating and cooling needs. The design does not need to be complex, but it should involve knowledge of solar geometry, window technology, and local climate. Given the proper building site, virtually any type of architecture can integrate passive solar design [8].

The basic natural processes that are used in passive solar energy are the thermal energy flows associated with radiation, conduction, and natural convection. When sunlight strikes a building, the building materials can reflect, transmit, or absorb the solar radiation. Additionally, the heat produced by the sun causes air movement that can be predictable in designed spaces. These basic responses to solar heat lead to design elements, material choices and placements that can provide heating and cooling effects in a home. Passive solar energy means that mechanical means are not employed to utilize solar energy. There are some rules of thumb which must be considered for effective solar energy utilization through passive solar systems [9,10]. The building energy management can be achieved smartly using the nearly zero energy building concept [10].

2.1.2. Passive solar heating

The goal of all passive solar heating systems was to capture the sun's heat within the building's elements and release that heat during periods when the sun is not shining [34]. At the same time that the building's elements (or materials) are absorbing heat for later use, solar heat is available for keeping the space comfortable (not overheated). Two primary elements of passive solar heating required are as follows:

- South facing glass for northern region and vice versa.
- Thermal mass to absorb, store, and distribute heat.

There are three approaches to passive solar heating systems: direct gain, indirect gain, and isolated gain [1].

2.1.3. Passive solar cooling

A combination of proper insulation, energy-efficient windows and doors, daylighting, shading, and ventilation will usually keep homes cool with a low amount of energy use [11]. The approaches include use of operable windows, wing walls and thermal chimney. Natural ventilation can be created by providing vents in the upper level of a building to allow warm air to rise by convection and escape to the outside. At the same time cooler air can be drawn in through vents at the lower level. This lower vent is provided where there are trees planted besides the building to provide shade for cooler outside air [12].

2.1.3.1. Passive cooling of buildings

Buildings, although static in space, are dynamically related to time. In addition to offering a shelter and fulfilling aesthetic criteria, they should ensure means of comfort (thermal, visual, acoustic) for their inhabitants [13].

The thermal behavior of buildings is affected by various parameters. These include the climatological ones, which are environmental variables and are not subject to human control. The other type of parameters is the design variables, which are under control at the design stage. Insufficient attention to the aspect of a building's thermal behavior at the first stages of its design can lead to an inhospitable internal environment. During summer, especially in climates with hot weather, buildings are exposed to high intensities of solar radiation and high temperatures. This may result in overheating conditions that exceed the threshold of thermal comfort in the interior of buildings. Under these conditions, cooling of buildings is of great importance [13].

Traditional architecture can show examples of harmonization with local climate. In hot and dry climates the buildings were of massive construction with few and small openings and light colours on the external surface. Fountains, pools, water streams and vegetation accomplished the cooling effect through evaporation. In hot and humid climates, where ventilation is desirable, we find lightweight structures with large openings and large overhangs. Modern buildings, in many cases, fail to follow the examples set by tradition. Part of the blame for the failure, from the climatic point of view, has been attributed to the so called 'international style', that brought science and technology to its design, adapting design ideas and features regardless of different climatic regions. This was connected with the separation of the envelope's design, which was the task of the architect, and the interior operation, which was entirely left to service engineers. This approach led to a total dependence on mechanical equipment to support the energy needs of buildings. With the present state of the art of air conditioning, the cooling needs of any building can be met, but at the cost of using unnecessary amounts of energy [13].

2.1.3.1. Benefits of passive cooling

The energy required for heating and cooling of buildings is approximately 6.7% of the total world energy consumption. By proper environmental design, at least 2.35% of the world energy output can be saved [14]. In hot climate countries, energy needs for cooling can amount to two or three times those for heating, on an annual basis [15]. Utilization of the basic principles of heat transfer, coupled to the local climate, and exploitation of the physical properties of the construction materials, could make possible the control of the comfort conditions in the interior of buildings. Even in areas with average maximum ambient temperature around 31.7°C, comfortable conditions inside buildings can be achieved by means of proper building design [16] that frequently makes the use of air-conditioning units in dwellings unjustified. It is estimated [17] that an increase of 9 mtoe (million tons of oil equivalent) per annum in the total technical potential solar contribution (all potential solar usage is exploited) is possible in all the EU countries by the year 2010, compared to 1990, if passive cooling is applied in dwellings [13].

Passive cooling strategies in the design of buildings should be considered, since the extensive use of air-conditioning units is associated with the following problems:

1- Environmental

- Wide use of air-conditioning units has caused a shift in electrical energy consumption to the summer season and an increased peak electricity demand. Peak electric loads impose an additional strain on national grids, which can only be covered by development of extra new power plants. It is estimated [18] that in the USA the total electric peak load induced by air conditioning units is about 38% of the non-coincident peak load. In addition to environmental implications, increased electrical peak loads result in an increase of the average cost of electricity to cover the construction of new power stations.

- Increased electrical energy production contributes to exploitation of the finite fossil fuels, to atmospheric pollution and to climatological changes. During the production process (fuel conversion), CO2, which is one of the main causes of the greenhouse effect, is released. Coal-fired power plants burn and emit approximately 0.5 kg of carbon in the

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form of CO_2 for each kWh generated [19]. From the pre-industrial period to 1987, the ever increasing use of fossil fuel and deforestation together have raised atmospheric CO_2 concentration to some 24% [20].

- Heat rejection during the production process (for electrical energy and air conditioning units) and from the operation of air-conditioning units themselves increases the phenomenon of the 'urban heat island' (the climate modification due to urban development, which produces generally warmer air in cities than the surrounding countryside). Studies [21] show that summer heat islands are of average daily intensity of 3-5°C, resulting in discomfort and increased air-conditioning loads. It is estimated [22] that 5 to 10% of the urban American electrical demand is for additional air conditioning to compensate for heat islands.

- Ozone-layer depletion can be caused by CFCs and HFCs (the most common refrigerants of currently used air-conditioning units) from possible leakage during manufacture, system maintenance or unit failure. It has been estimated [23] that in the UK the average annual rate of refrigerant leakage from building air-conditioning units is 20% of the total machine charge and that around 75% of CFC consumption in 1991 by the refrigeration systems for building air conditioning was for servicing existing systems. Although long-term alternatives to CFCs and HFCs will have zero ozone-layer depletion potential (ODP), most of them will still be strong greenhouse gases.

2- Indoor air quality

- Increased indices of illness symptoms (lethargy, headache, blocked or runny nose, dry or sore eyes, dry throat and sometimes dry skin and asthma), known as 'sick building syndrome' [24] are reported in people working in air-conditioned buildings [25, 26].

- Occupants' dissatisfaction with indoor comfort conditions.

3- Economic

- Economic and political dependence of countries with limited natural resources on other countries, richer in natural resources.

- Installation of air-conditioning units presents an extra cost in the construction of a building, followed by an additional operation and maintenance cost. In EU countries 3.1 million ECU were spent on air-conditioning units in 1991, with Germany the largest contributor (22% of total) [27].

- Expenses for importation of ALC units. Countries with hot climates exhibit an increased rate of sales of air-conditioning units. In Greece, sales of packaged air conditioning have increased ~y 900 per cent over recent years [28], with 80% of them delivered to the residential sector [27].

Passive cooling systems have the same basic components as passive heating systems, but work in a different manner. Whereas the purpose of passive heating systems is to draw heat into the building, the purpose of a passive cooling strategy is to remove or reject heat from the building, and thereby cool it. Because the mechanisms that drive passive cooling strategies are not fully understood, many cooling concepts are difficult to fully evaluate during the comprehensive planning process [29]. Therefore, the number of cooling concepts advocated in this article is limited.

2.1.3.2. Peak Cooling

Passive cooling benefits are achieved by avoidance of the cooling load in the building. In many commercial-type buildings, the *peak cooling* requirement is directly associated with solar gains. By avoiding solar gains, a portion of the cooling load is avoided. This can be accomplished by shading the apertures of the building [29].

2.1.3.3. Types

(I) Ventilation and Operable Windows

- Place operable windows on the south exposure.
- Casement windows offer the best airflow. Awning (or hopper) windows should be fully opened or air will be directed to ceiling. Awning windows offer the best rain protection and perform better than double hung windows.
- If a room can have windows on only one side, use two widely spaced windows instead of one window [30].

(II) Wing Walls

Wing walls are vertical solid panels placed alongside windows perpendicular to the wall on the windward side of the house. Wing walls will accelerate the natural wind speed due to pressure differences created by the wing wall as shown in Fig. 1 [30].

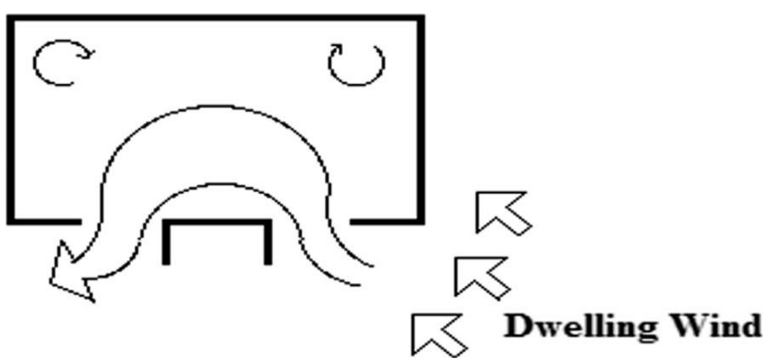

Figure 1 Top view of wing walls airflow pattern [30].

(III) Thermal Chimney

A thermal chimney employs convective currents to draw air out of a building. By creating a warm or hot zone with an exterior exhaust outlet, air can be drawn into the house ventilating the structure. Thermal chimneys can be constructed in a narrow configuration (like a chimney) with an easily heated black metal absorber on the inside behind a glazed front that can reach high temperatures and be insulated from the house. The chimney must terminate above the roof level. A rotating metal scoop at the top which opens opposite the wind will allow heated air to exhaust without being overcome by the prevailing wind. Thermal chimney effects can be integrated into the house with open stairwells and atria as shown in Figs. 2 and 3. This approach can add into the aesthetic of the home [1].

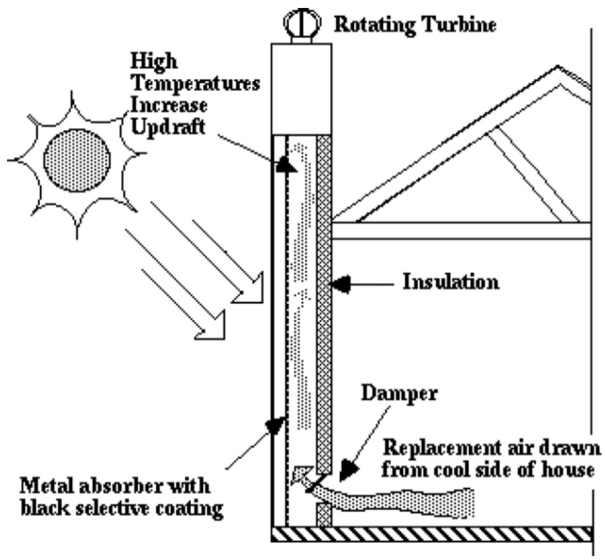

Figure 2 Thermal chimney [30].

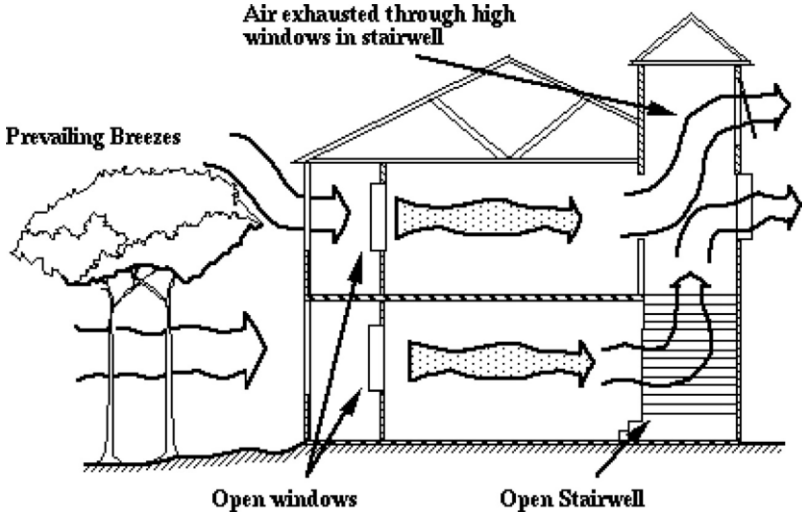

Figure 3 Thermal chimney effect built into home [30].

(IV) Other Ventilation Strategies

- Make the outlet openings slightly larger than the inlet openings.
- Place the inlets at low to medium heights to provide airflow at occupant levels in the room.

Passive solar building cooling design is used to (1) slow the rate of heat transfer into a building in the summer, and (2) remove unwanted heat from a building. The principles of physics are holistically integrated into the exterior envelope. This is much easier to do in new construction. It involves a good understanding of the mechanisms of heat transfer: heat conduction, convective heat transfer, and thermal radiation (primarily from the sun) [31].

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Table 2 Passive Cooling System [32]

Passive Cooling System											
Green Roof, Evaporative Cooling and natural Ventilation	Night Nooling	Green Roof	Basement Ventilation	Evaporative Cooling and Natural Ventilation	Evaporative Cooling	Natural Ventilation				Heat Storage Mass	Solar Control
						Chimney	Windbreaker	Two-Way Ventilation	One-Way Ventilation		

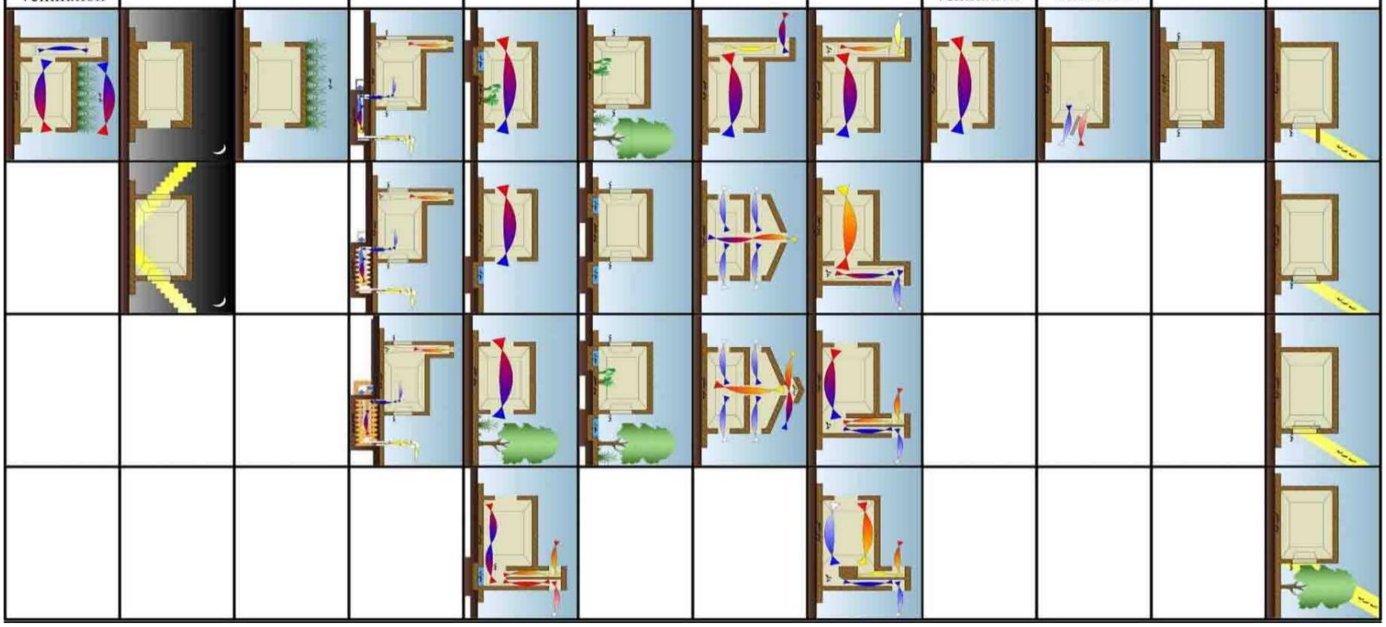
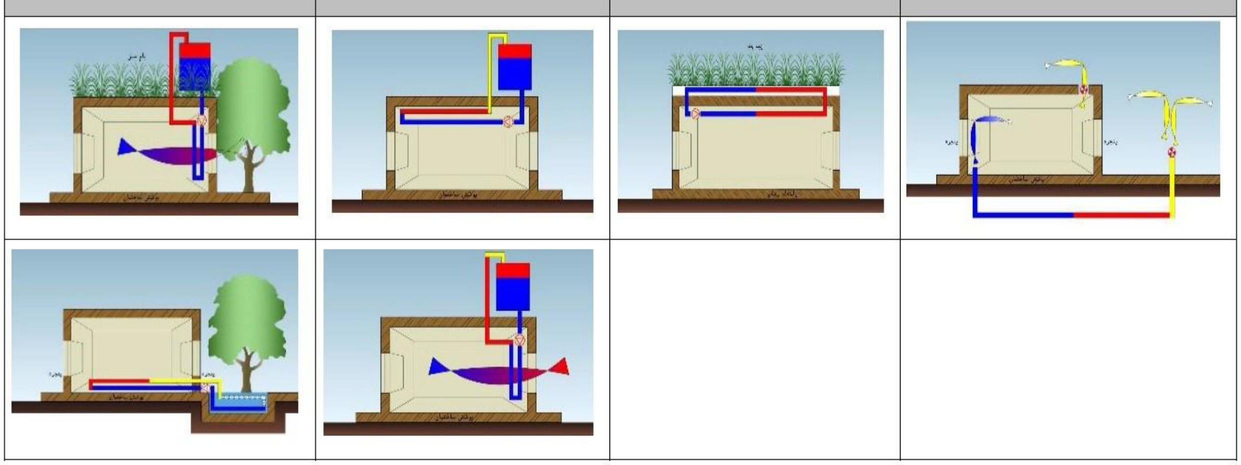


Table 3 Different Methods of Combined Cooling [32]

Combined Cooling			
Night Cooling and Evaporative Cooling	Night Cooling	Green Roof and Evaporative Cooling	Underground Heat Exchanger



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Conclusion

In recent years, concerns about the excessive use of renewable energy and the debate over its depletion, as well as pollution from the use of this type of resource, have led most countries to develop the use of renewable energy technologies. Therefore, extensive studies have been conducted on the availability of renewable energy and has led to an increase in the production of this clean energy in developed and developing countries. In this article, we have tried to provide solutions for using the passive solar cooling method to achieve clean energy. A climate design can improve the thermal conditions of the space used, but in certain conditions, relying on the potentials of the environment alone, the comfort zone can not be fully created and we need to use mechanical facilities. The use of solar systems always has a great impact on reducing energy consumption. This performance reduces the volume of need for mechanical installations and reduces the cost of fuel supply and energy supply in the building.

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