Sustainability through Natural Cooling: Bioclimatic Design and Traditional Architecture

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Abstract

There has been a grave energy crisis in developing countries especially during summer season primarily due to cooling energy consumption in buildings. Increasing consumption of energy has led to environmental pollution and thus global warming and ozone layer depletion. Hence reducing the emission of greenhouse gases, caused by fossil fuels to power the cooling requirement of the buildings has stimulated the interest towards adoption of passive cooling techniques for buildings. Natural and passive systems using non-mechanical methods to maintain a comfortable indoor temperature are a key factor in mitigating the impact of buildings on the environment. This paper focuses on ways to reduce cooling energy consumption because it is the highest usage in any building. Also, the paper shows a comparison between traditional and bioclimatic techniques by explaining the methods with applications that prove their benefits. The reason behind this comparison is to confirm that traditional methods use less energy, however, their development is needed to achieve better thermal comfort.

Keywords

Natural Cooling; Sustainability; Bioclimatic Design; Traditional Architecture

Introduction

There has been a heavier reliance on energy-consuming technology in cooling and ventilation system to achieve thermal comfort in buildings (Kamal, 2012). According to recent statics such US Energy Information Administration (EIA, 2011) and world meter website, the energy usage in buildings has increased in the last three decades and has continued to rise. It is true that these solutions have led to the discovery of new technologies such as solar panels, new materials and wind turbines; however, it is mostly applied in commercial buildings. Some researchers have proposed that traditional architecture has the solution to lower cooling energy consumption and minimize the dependence on mechanical devices in order to achieve thermal comfort. Traditional techniques such as wind towers and chimneys have sustained the life of people for so many years. Serghides suggested that combining the two technologies, bioclimatic and traditional would result in better energy efficiency buildings. The present research discusses a comparison between traditional and bioclimatic techniques which may reveal a new perspective that could open new topics: researchers, architects and engineers for further researchers.

Noble, in his research has focused on traditional ways of cooling techniques around the world. The natural technologies have sustained people life for thousands of years and were purely for heating or cooling in some areas but a combination of both in other areas. Cooling techniques were used in vernacular buildings in hot dry and humid climate; and ventilation tunnel was used in US Midwest. In Middle East countries, other larger strategies are used to cool the house. Mashrabiyas were used in humid areas for privacy and ventilation through water element while in hot dry areas wind tower and courtyard are used to do the same function. The above techniques show how to deal with climate variations for the two extreme hot and cold climate (Noble, 2007).

Kipnis research is similar to the previous entry but focuses on natural cooling strategies. One of them is using solar chimney which was used to let air flows from a high level opening that faces toward the favorable wind. This way the house will be naturally ventilated and controlled. Another way is to use shading devices which can reduce the sun heating in summer but allow it in winter. The use of appropriate thermal mass; materials such as adobe and masonry brick are better to prevent external heat. In addition, electric fans and evaporative cooling systems could speed the air movement and reduce the heat from air. These simple techniques may reduce the cost and save energy (Kipnis, 2011).

Serghides shows a study on traditional technologies that have been previously explained. The gist of the research is the use of traditional thermal techniques and how it can result in the required standard of thermal comfort. Furthermore, the relationship between Cyprus climate and vernacular architecture is illustrated by using an archetype consists of a single room, small rectangular patio and courtyard. It was found that all building elements contribute in the comfort of living. For more clarification, the author used the optimization studies which show that the use of courtyard and overhang of solarium create a thermal comfort of the house. In comparison with today's approach, modern villas depend on machines over the natural techniques which have led to an increase in heating and cooling energy consumption and cost. Despite all the negative impacts of modern technology, the author suggested that it should not be neglected but with traditional approach would result in better energy efficiency (Serghides, 2010). One limitation of this article is the choice of Cyprus as an example because it may not work in different climate zones such as cold climates

In a research done by Tucci, proves that benefits of using traditional methods is an examination of the design strategies applied in housing complex redevelopment in Salve, Italy. The criteria of the analysis were by bioclimatic comfort, energy saving and carbon dioxide. The reason behind similar experimentations is to create a good example of bioclimatic design. The author first illustrates the air mass usage steps and the types of systems which are used to ventilate the housing complex. Some examples of air mass systems are air scoops, earth pipes, ventilation chimneys and air ducts. Then by using Energy Plus simulation system, the results indicated that there was 84% reduction on discomfort hours and around 65% in total energy saving. Also, Tucci predicted that if these strategies are used in a wide scale, it could achieve almost 64% decrease in CO_2 emission (Tucci, 2010).

An experiment by Bagneid shows the thermal benefits of using courtyard in house design by using: computer thermal simulation models, scale physical thermal models and field measurements. The author had relied more in the last method because of the accuracy of the results. Two students' apartment buildings at Arizona University which have different types of courtyards: a concrete floor courtyard and a natural courtyard with a tree and grass flooring are the platform for the testing. Also, the effect of water element in the courtyard was tested. The researcher found out that courtyards create a more comfortable outdoor area during hot summer. Despite the fact that openings were closed during the experiment, there was a slight air movement in high wind seasons. In addition, it was discovered that the rooms in the second courtyard with grass flooring were cooler in the day time and warmer at night (Bagneid, 1992).

Methodology

In this paper, qualitative method is used. A qualitative analysis of traditional architectural systems and bioclimatic techniques with reference to cooling has been done. Environmental problems associated with air conditioning and the need for environmental sustainability has also been studied. A comparison of traditional techniques with bioclimatic and modern design has been done. The comparison was done by used books such as Traditional buildings and biophilic and bioclimatic architecture. However, it was mostly from journals like Renewable Energy, Modern Earth News, The Open Construction and Building Technology and Journal of Sustainable Development.

Environmental Sustainability in Architecture

Architectural sustainability is linked to the much quoted Brundtland commission report definition through an emphasis on limits to the carrying capacity of the planet, and they pointed to the UK's Building Services Research and Information Association (BSRIA) definition of sustainable construction as 'the creation and management of healthy buildings based upon resource efficient and ecological principle' (Edwards and Hyett, 2001). In principle, sustainable buildings relate to the notion of climate-responsive design, which places emphasis upon natural energy sources with the aim of achieving building comfort through the interaction with the dynamic conditions of the building environment (Hyde, 2000). Sustainable architecture aims at creating environment friendly and energy efficient buildings. It is evident that the total energy consumption of buildings for cooling purposes varies as a function of the quality of design and climatic conditions. In hot climates, commercial buildings with appropriate heat and solar protection and careful management of internal loads may reduce their cooling load down to 5 kWh/m^2/year, while buildings of low quality environmental design may present loads up to 450 kWh/m^2/year (Santamouris and Daskalaki, 1998).

An Overview of Traditional Architecture

Traditional buildings were designed according to the microclimate of the specific region because heat and cold control the thermal comfort in the houses and this different from one place to another. The natural technologies applied in these buildings have sustained human life for many decades and are purely for heating or cooling purpose. Examples of these techniques are fire chimneys, courtyards, wind towers and mashrabiya (Noble, 2007). In hot-dry and warm humid zones such as Middle East and North Africa where cooling is more important than heating, ventilation tunnel, wind tower, wind catcher, wind sail, maziara and courtyard are used to achieve thermal comfort (Noble, 2007). The tower height is almost double the house in order to catch most preferred wind. Since the wind temperature is high because of the hot climate, wind tower catches through vertical openings. Then, air passes through cold pods and wet clothes in order to cool down before it reaches the rooms (Almusaed, 2011). Fig. 1 shows a wind tower (badgir) in traditional architecture of Iran.

FIG. 1 WIND TOWER (BADGIR) IN TRADITIONAL ARCHITECTURE OF IRAN

FIG. 2 MASHRABIYAS IN TRADITIONAL ARCHITECTURE OF JEDDAH

In high humid zones, Mashrabiyas were used instead of wind towers because houses are in similar height and to minimize moisture by reducing interaction with water surfaces (Noble, 2007). Ventilation towers are widespread and can be seen in many countries with different names: Malqaf and wind scoops in Egypt, Bating in Syria, Badgeer in Iran and Gulf countries (Abro, 1994). Fig. 2 shows Mashrabiyas in traditional houses in hot humid climate of Jeddah.

Analysis of Traditional Architecture

Many researchers have evaluated and analyzed buildings which represent an application of traditional techniques. A road in Ghadams, Libya shows a good comparison between old and modern buildings; 600 years old houses are facing young houses. It was found that in summer when the temperature is around 44 C, the degree inside the old ones is 26° C and 38° C in the new houses (Abro, 1994). This is one example of the negative impacts of the industrial revolution in the middle of the last century. Humans have became more dependent on mechanical devices such as air conditioning to achieve thermal comfort and this caused high energy consumption (Serghides, 2010). In accordance with USEIA, US energy consumption has increased by 28% in the last 30 years and around 40% of energy is used by residential sector. In this sector 52% of the energy goes to heating and cooling the building. This percentage varies between different climates where one aspect heating or cooling is important.

These statistics proves that modern architecture have created unbalanced indoor environment whereas traditional architecture elements had worked together for thousands of years. Serghides examined the linking between Cyprus traditional architecture with its climate and modern villas that have traditional elements. A house with cluster of rooms, a patio, a courtyard and a light well was evaluated by using optimization studies and simulation software

(Serghides, 2010). It was discovered that all traditional elements work together cool the house in summer and create a warm environment in winter. As a result, thermal comfort for living is achieved. Courtyards are also an essential traditional element in thermal control (Fig. 3). Bagneid in an investigation on almost two identical courtyards of student's dormitory at Arizona University; concrete and grass flooring, it was found that courtyards generate cooling feelings for outdoor seating. Also, they react as a barrier during wind seasons while allowing little air to circulate inside. The experiment revealed that the rooms in the second courtyard with grass flooring were cooler at day time and warmer at night, resulted in thermal comfort. (Bagneid, 1992).

FIG. 3 COURTYARD IN TRADITIONAL ARCHITECTURE

The two applications of traditional architecture in Cyprus and Arizona State University provide benefits in traditional elements. However, the dependence of natural wind speed can create improper ventilation. Wind speed varies in different climate zones and countries. To avoid this reliance on unpredictable wind pattern, more human control has to be involved in these techniques (Almusaed, 2011). Traditional methods have to be developed to suit modern time but with taking the energy consumption in consideration.

Bioclimatic Architecture

Bioclimatic Architecture is any design that takes climate in its process in order to achieve thermal comfort. It can be noticed that it follows traditional Architecture principle (Williams, 2009). So, the bioclimatic techniques could offer the control needed to the development of traditional architecture methods.

Bioclimatic Techniques

A technique called energy recovery system is a vertical element that provides air to the building. It consists of two outlets: one for catching fresh air and the other to ejecting. Air is directed through inlet ducts to building rooms. These ducts contain filters to eliminate bacteria and moisture. Also, the use of vent fans is useful for air circulation. In this method, fresh air outlet is placed in a low height and the exhaust outlet near the celling. When the air temperature rises, its level increases (Almusaed, 2011). This technology is similar to wind catcher but without water surface included for cooling the air. The use of water element is important for cooling the incoming air. A technique called rock bed is similar to a bucket of water constructed below the house and connected to wind tower or air duct. The hot air enters the ducts during the day and moves above the cold water before it exhausts from rooms vent. Also, this way offers reusing the air by cooling it again. Because the rock bed is underground, it is protected from the sun heat. A modern version of wind towers created by University of Arizona is called "reverse chimney" (Almusaed, 2011). There are two types: roof one and tower style. The one placed above the roof contains cellulose vessels which lower the passing air temperature. The other type is exactly the wind towers but with addition of a device that consist of water tank and air pumper, as shown in Fig. 4. The device works as a cooler by water drops and air accelerator. It was found out that the new cooling towers lowered the temperature to around 23° C (Almusaed, 2011). So, this technology is an example on the development of traditional architecture.

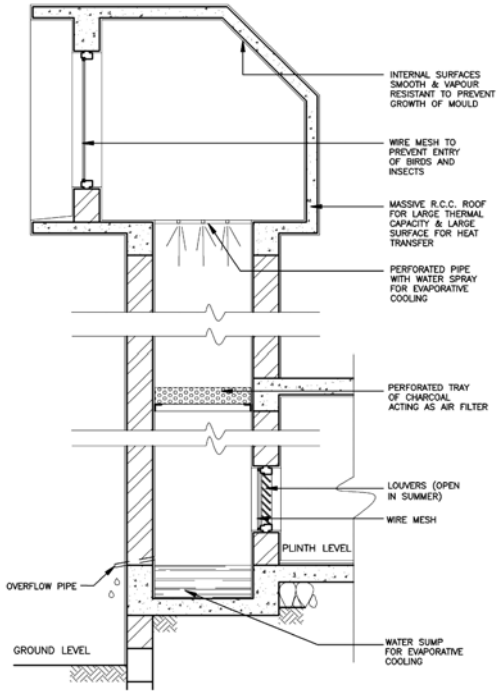

FIG. 4 BIOCLIMATIC DESIGN DETAILS OF A WIND TOWER

It was found that underneath the ground level is colder than above it; deeper is much colder. Therefore, Earth temperature offers three technologies to achieve thermal comfort. First method named thermal inertia system is a space underneath the building used to store air coming from wind tunnel, as shown in Fig. 5. It is important to filter the air before it enters the space. For more beneficial use of the space, it is suggested to be kept isolated only from its ceiling and to be connected with small ducts.

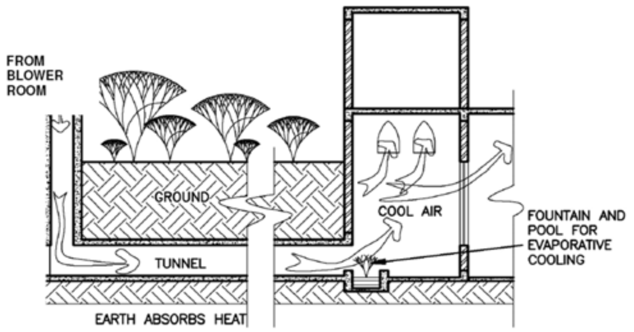

FIG. 5 WORKING PRONCIPLE OF AN EARTH AIR TUNNEL

Another way to exploit the earth is bedrock which is an improved rock bed. It allows air to pass through rocks and force it to move in a maze way by placing vertical walls. The third earth technique is burying tubes which are 15 to 45 cm in diameter buried vertical or horizontal and open or closed ended. Open ended tube means that one end is above ground level in order to collect air. In this kind, air filters and protection from unwanted animals to enter the building. The closed tube recycles the indoor air by cooling it again (Almusaed, 2011). From these three technologies, the earth has a great potential to be a medium to create thermal comfort for people above it.

Analysis of Bioclimatic Architecture Applications

A redeveloped housing complex located in Slave, Italy is a representative of bioclimatic architecture because of the use of three technologies: air scoops, earth pipes and ventilation chimneys. Tucci evaluated the housing complex in three aspects: bioclimatic comfort, energy saving and carbon dioxide emission. By using Energy Plus simulation software, it was found out that these technologies result in 16% better thermal comfort and 65% energy saving. In addition, it is predicted that if these methods applied widely, there could be around 64% decrease in carbon dioxide emission (Tucci, 2010). The housing complex proves that the use of bioclimatic techniques achieves thermal comfort with consuming less energy.

Comparison between Traditional and Bio-climatic Architecture

The previous mentioned technologies: energy recovery system, rock bed, reverse chimney, underground space, water wall, roof pond and thermosyphon collector used air or water as a medium to cool the building. Similarly, traditional techniques use the same medium. Serghides suggested that developing traditional architecture helps achieve modern human thermal comfort. This comparison showed that the bioclimatic techniques offer the human control that traditional ones lack (Serghides 2011).

Conclusion

The paper concludes that bioclimatic techniques are the modern version of traditional technologies. They offer the human control that traditional techniques are missing. Even though developing the traditional methods would help create thermal comfort using less energy, more applications are needed in other bioclimatic technologies. Generally, concern for energy consumption is only marginal in the majority of architectural-design practices, even in the developed countries. Passive solar energy-efficient building design using traditional systems and bioclimatic techniques should be the priority of any building designer, because, in most cases, it is a relatively low-cost exercise that will lead to savings in the capital and operating costs of the air-conditioning plant. Incorporation of traditional and bioclimatic techniques will certainly reduce our dependency on fossil fuel and minimize the environmental problems due to excessive consumption of energy and other natural resources and hence will evolving a built form, which will be more climate responsive, more sustainable and more environmental friendly.

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