THE POTENTIAL OF PASSIVE COOLING STRATEGIES FOR IMPROVING AMBIENT COMFORT CONDITIONS AND ACHIEVING ENERGY SAVINGS IN A TYPICAL HOT/ARID CLIMATE

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ABSTRACT Passive cooling strategies can offer significant opportunities for improving the occupants' ambient comfort conditions whilst reducing the energy consumption in hot climates. This is particularly applicable for buildings located in hot/arid regions with large cooling loads due to the use of mechanical systems for space climatization. This research examines the potential of passive cooling strategies in a commercial building located in a typical hot/arid climate of Mexico. The main objective of this work is to achieve maximum human comfort and air quality at minimum capital and operational energy costs, whilst preserving the external environment. The results of this work can contribute to achieve a favorable multiple effect in the country for other buildings with similar conditions and this approach can be useful to provide an authentic sustainable development aimed at improving the natural environment and the quality of life.

1 Introduction

Historically, buildings were built to satisfy basic human needs to achieve appropriate shelter conditions. Under this approach, traditional architecture emerged by transferring knowledge and practical experience from generation to generation. The main premise of a traditional building was to offer a dynamic and effective "response" to surrounding factors of climate and other living forces. The "response" of a building to the climatic conditions of a given site was determined from the particular characteristics of the typology and design criteria of the architectural project as well as from the building materials used.

Nowadays, most modern buildings incorporate architectural styles and materials that ignore the local climatic conditions as well as its culture and traditions. This is the case of many contemporary buildings located in hot/arid climate regions of Mexico (the hot/arid area covers more than two-thirds of the country). As a result, such buildings are highly dependent on mechanical and electrical systems to control the indoor environment. This situation causes the consumption of large quantities of energy and thus high running costs for both artificial lighting and air-conditioning, associated with problems of occupants' discomfort, both thermal and visual. Therefore, people who live in air-conditioning buildings have to pay huge energy bills and have also to confront serious maintenance and economic problems, mainly from early Spring to early Fall. For those who can not afford air-conditioning, their building interiors become unbearable and their health is severely affected. The lack of ambient comfort conditions is also a burden for efficiency, productivity and competitiveness in these regions, where these matters are crucial for promoting an encouraging economic development.

The psycho-physiological function of occupants as well as their efficiency and productivity are strongly related to the comfort conditions available in a building space. The "desirable" comfort conditions within a building interior can be achieved "naturally" by means of the application of *passive cooling systems*. This is a suitable alternative to air-conditioning as it has a potential for reducing both capital and energy running costs, and for improving indoor comfort conditions of people as well as for supplying air quality in their indoor spaces, whilst providing the basis for preserving the environment.

2 Bioclimatic design and passive systems

Passive systems, for both cooling and heating, are the essential strategies for the implementation of *Bioclimatic Design, which implies the utilization of the building itself to "dynamically" select those components of the local external environment which can contribute to the users' natural comfort conditions in the indoor environment*. Therefore passive cooling and heating systems are aimed at achieving maximum human comfort and air quality, at minimum energy cost, whilst preserving the external environment. Passive cooling systems have been investigated and their potential for reducing energy consumption and providing comfort conditions in hot climates demonstrated (Givoni 1979, 1981, 1994; Alvarez 1990, 1992, 1993; Antinucci et al. 1990, 1992; Santamouris 1990, 1993, 1996).

2.1 Passive cooling techniques applied in hot/arid climates of Mexico: Advantages and benefits

The implementation of passive cooling systems in buildings with high thermal cooling loads, mainly those located in hot/arid regions of Mexico, is a promising alternative to contribute to solve problems of occupants related to energy use, economy impact, lack of comfort, health conditions and environmental damage (Garcia-Chávez 1994). Passive cooling strategies offer real opportunities for improving the occupants ambient comfort conditions in buildings located in hot/arid climates of Mexico, whilst reducing the energy consumption due to the use of mechanical systems for space climatization. The implementation of this approach can lead to an increase in efficiency, productivity and competitiveness and this can also contribute to achieve a practical *sustainable development* process.

3 Research work objectives

The objective of this research is to examine the potential of passive cooling strategies in a commercial building located in a typical hot/arid climate of Mexico. The main objective of this work is to achieve maximum human comfort conditions and air quality at minimum capital and operational energy costs, whilst preserving the external environment. The passive cooling strategies investigated in this research are focussed on the "prevention of overheating" and on the "provision of cooling". It is expected that the results of this work can contribute to achieve a favorable multiple effect in the country for other buildings with similar conditions, and this approach can be useful to provide a real sustainable development aimed at improving the natural environment and the quality of life.

3.1 Passive cooling strategies: prevention of overheating, provision of cooling

The *prevention of overheating*, that is the minimizing of heat gains from solar radiation and from internal sources, is the starting point for achieving comfort conditions in a building during the *overheated season*. When the climatic conditions and the building use demand internal conditions to be cooler than the outdoors, or when internal heat gains are very high, then the *provision of cooling* applies. Conventional mechanical refrigeration, active and passive cooling methods can also be used as supplemental equipment for the provision of cooling to achieve comfort conditions for the occupants of a building.

4 Building situation in Mexico: energy, environment, health implications

In Mexico, most modern commercial buildings consume large quantities of energy, in the form of fossil fuels, to provide heating, cooling, ventilation, lighting and to heat water. This situation has provoked a number of health, environmental, economic, social and cultural problems in the country (Moncada 1990; Tijerena 1990). All of those requirements can be satisfied to some extent by the application of *Bioclimatic Architecture*, and the use of the diverse natural renewable energy resources, widely available throughout the country, thus reducing the dependence on energy consumptive services, and the emission of pollutants to the atmosphere. Furthermore, these contemporary buildings do not respond to the local traditional, cultural and climatic conditions. Instead, they seem to follow "international pattern styles" produced for unjustified reasons such as "social status" and "fashion in vogue".

5 The case study building: architectural description and characteristics

The case study selected for investigation of the potential of passive cooling strategies is a commercial building located in the city of Torreón, North Mexico, a typical and representative hot/arid region. The land surface is 630 m^2 and total constructed area is 450 m^2, in three stories. The ground floor of the building has the following spaces (Fig.1): reception, lobby, vestibules, library, offices, auditorium, surveillance control room, services room, restrooms and a staircase. External spaces of this level include regulator patio, lawns, exhibition area for solar technology and ecological equipment, botanical garden, greenhouse, technical services and parking area. The second floor consists of: reception, lobby, open terrace, vestibules, staircase, restrooms, coordinators offices, president and vice president executive offices, bathroom, storage room and meeting room. The third floor has an exhibition area for solar technology and ecological equipment and a staircase. The design principle that was handled in this building is to come up with a representative example of an architectural typology that responds to regional climate, tradition and cultural patters. The building is clearly seen from the main avenue and occupies a relevant urban image. The internal and external spaces are organized so that all functions and activities can be carried out dynamically and harmoniously. The facades provide a vivid and evident character that expresses a compatible relationship with local patterns (Fig.2).

5.1 Bioclimatic features of the building

The bioclimatic methodology applied in this project has shown that orientation and solar control and shading devices are essential strategies to achieve indoor comfort conditions for the occupants for the ***Prevention of Overheating***. The shading devices designed and evaluated for this building respond to this requirement. Eggcrates in the form of projecting frames, tilted depending on the solar access analysis to prevent the indoor spaces from getting overheating conditions, are integrated in the East facade (Fig.2). Whereas horizontal shading devices are located on North and South facades to control solar access (Fig.2). Regional landscaping is used in external zones to promote evaporative cooling, shading and a favorable microclimate for achieving ambient comfort conditions to the building users. Thermal mass is provided in the building envelope using concrete blocks in walls (200 mm thick) and 150 mm concrete slab roofs. Thermal insulation consists of an average of 50 mm of polyurethane foam on the outside, having a k-value of 0.03 W/m·K. As to color on external surfaces, on walls and roofs, ninety percent of these are clear matte white, with a mean reflectance value of seventy five percent. Argon filled double low-e insulating glazing is used in the fenestration of the building. This glazing is made with fully tempered and heat strengthened float glass. Energy efficient equipment in all lighting fixtures is integrated with conscious daylighting utilization in all building spaces. An appropriate internal layout was designed to minimizing thermal loads. All above-mentioned strategies will be oriented to prevent overheating in the building and to promote ambient comfort conditions for the occupants.

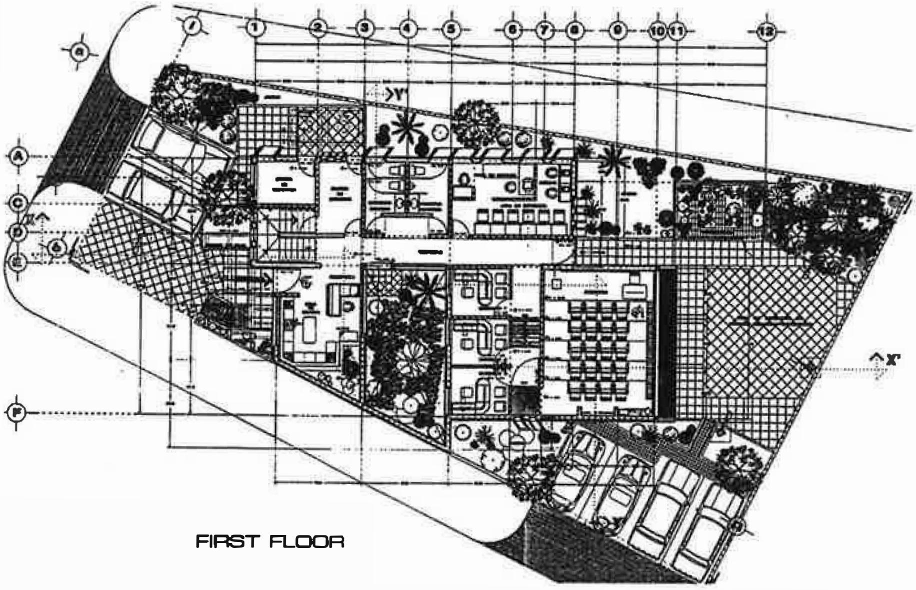

Fig. 1 First floor of case study building

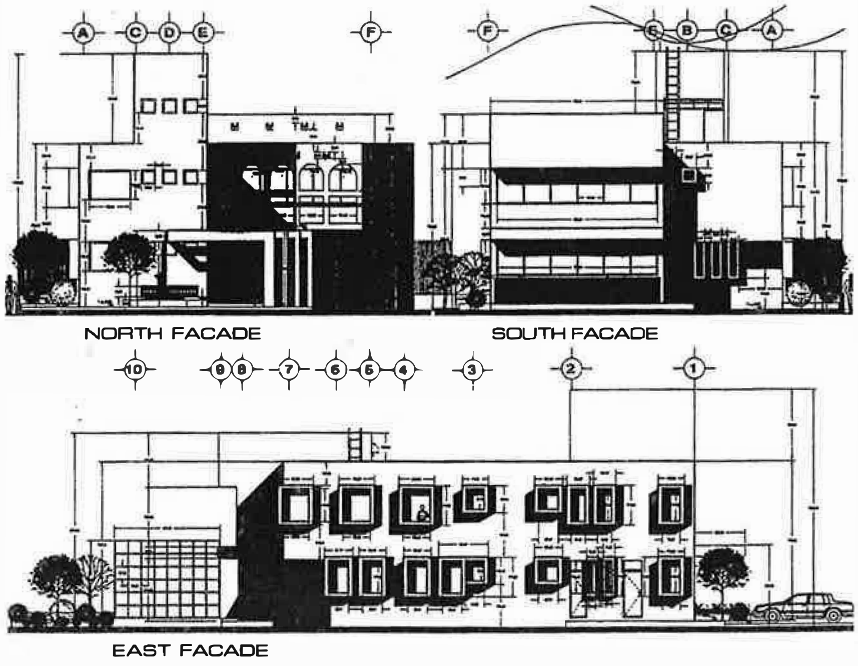

Fig. 2 North, South and East facades of the case study building

The ***Provision of Cooling*** in the building includes the use of earth-to-air-heat exchangers (*earth pipes)* for **Ground Cooling**, based on the heat-loss dissipation from a building to the ground (this latter remains practically constant below a given depth, generally below 1 meter). During the cooling period, the ground has a temperature lower than the ambient, and higher in winter during the heating period. The heat exchangers can be in an *opened-loop circuit* (inlet is outside and outlet is inside the building), or a *closed-looped circuit* (both inlet and outlet are inside the building). This passive cooling strategy takes place in the auditorium, located in the ground floor. It consists of injecting air into this space, that has been previously circulated underground by means of the earth-to-air-heat exchangers. The temperature decrease of the air depends on: a) inlet air temperature, b) the ground temperature at the depth of the exchanger, c) the thermal conductivity of the pipes and the d) thermal diffusivity of the soil as well as the e) air velocity, and f) pipe dimensions. Thermal diffusivity (α) is the ratio of thermal conductivity to density and specific heat of the soil, and is expressed by the following equation:

$$\alpha = \lambda/\rho c$$

Where λ is the thermal conductivity (often denoted as k-value), ρ the density, and c the specific heat of the soil. Thermal diffusivity determines the thermal behavior of the soil. Some of the considerations for the earth-to-air-heat exchangers integrated in the building are as follows: a) the length of the exchanger is 15 meters, the material of the pipe ducts is PVC and their diameter is 20 cm, buried at 1.5 meters depth. The air velocity will be handled by an automatic control silent ventilator at 6 m/s (Alvarez 1993), located in the outlet of the exchanger, next to the south side of the auditorium floor. The air temperature at the outlet (Tout) of the pipe was calculated using a model proposed in recent studies (Santamouris and Asimakopoulus 1996):

$$\text{Tout} = \text{Tg} + \text{Ucord} \times (\text{Tin}-\text{Tg})$$

Where Tg is the ground temperature at the depth of the exchanger in °C; Ucord is the corrected U value; and Tin, the inlet air temperature of the worst climatic condition during the cooling period. For this case study, Tin is 32 °C in the specific location, where there is also a pre cooling effect by vegetation shading and evaporative cooling. The Tout calculated for the specific climatic and earth-to-air-heat exchanger dimensions and characteristics was 27 °C, which, according to the bioclimatic analysis conducted for this particular case study, is in the upper limit of the comfort zone.

Radiative Cooling. This is based on the heat loss by long-wave radiation emission from a body (the building) towards another body of lower temperature that plays the role of the heat sink (the sky). The sky temperature is lower than the temperature of most objects on earth. This strategy is combined with *Indirect Evaporative Cooling* and will take place in the meeting room located on the second floor. The mass of the white painted roof is exposed to the night sky and is integrated with a pond over its surface with floating insulation, made of extruded polystyrene. This is an impermeable material to water. During the day, water is insulated from the sun and the warmer ambient air by a tightly assembled floating insulation. At night, water circulates over the floating insulation and thus is cooled by a combination of convection, evaporation (indirect) and long wave radiation.

Natural Ventilation. There are two ways in which natural ventilation is used in the building to improve comfort. One is by means of *Comfort Ventilation*, to provide a *direct physiological cooling effect* through the openings. This strategy will be applicable only when the indoor comfort can be experienced at the outdoor air temperature, with acceptable indoor air speeds. The other is by means of *Nocturnal Ventilative Cooling*. This is an indirect technique used to ventilate spaces only at night; then during the following day the cooled mass reduces the rate of indoor temperature rise and thus serves effectively as a heat sink. The *regulator patio* of the building plays an important role in applying this passive cooling strategy. It is located in a central position within the building. Cooled ambient outdoor air at night will flow downwards towards the *patio*, which is surrounded by windows left open during the night during the cooling season. Then, ambient air, at lower temperatures than the building structural mass and the neutral temperature, will cool its interior elements (walls, roofs, partitions and floors), acting as a heat sink the following day, and providing a favorable cooling effect for the occupants.

6 Conclusions and further work

The passive cooling techniques proposed for investigation in this building can provide energy savings with a satisfactory payback period, an improvement of the ambient comfort conditions of the occupants and air quality at minimum capital and operational energy costs, whilst preserving the external environment. Providing ambient comfort conditions is also an important factor directly related with efficiency, productivity and competitiveness of work activities in buildings located in these regions, and these matters are crucial for promoting an encouraging economic development, which is essential for the country advancement. These techniques will be monitored during one year and the results can contribute to achieve a favorable multiple effect in the country meant to be applicable for other buildings under similar conditions. This approach can also be useful to provide a true sustainable development aimed at improving the natural environment and the quality of life, which can be followed as a new paradigm in the evolution of the built environment of the coming generations in the next millennium.

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