USING PASSIVE HEATING AND COOLING STRATEGIES TO IMPROVE THERMAL COMFORT AND REDUCE ENERGY CONSUMPTION IN HOT ARID REGIONS

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ABSTRACT

Hot arid climates are characterized by prevailing high temperatures and high solar radiation, with large diurnal temperature differential, often larger than 20 K. In Mexico, hot arid regions cover more than seventy-five percent of the country, with severe climate conditions in winter and summer. Most buildings located in these climates present large energy consumption patterns due to their high dependence on air conditioning systems (AC) for providing comfort to occupants, which in turns provokes the emission of huge amounts of greenhouse gasses (GHG), severely affecting the environment. For those people who cannot afford AC in their buildings, the situation is even worse, as it severely affects their health. This research deals with the investigation of several passive cooling and heating strategies in experimental modules aimed at achieving hygrothermal comfort whilst reducing energy consumption. The cooling techniques involved the four environmental heat sinks, and included: Ground cooling, solar control, natural ventilation, direct evaporative cooling, night sky infrared radiation and thermal insulation. During the underheating season, direct and indirect heat gain techniques along with infiltration control and thermal insulation were also implemented and investigated. The systems were built in the modules and their performance monitored during the prevailing overheating and underheating periods. The results showed that the combined effect of the strategies provided better results than their single influence. During the underheating period, the minimum temperature was 15°C, and the maximum during the overheating season was 25°C. As a result of this research, it is suggested to implement the combined action of the passive cooling and heating techniques in buildings located in prevailing hot arid regions, to improve hygrothermal comfort and to reduce the energy consumption for AC and this would eventually reduce also the emission of pollutants to the atmosphere and promote a favorable sustainable approach.

Keywords: Passive cooling and heating; thermal comfort; hot arid regions; health; energy consumption.

INTRODUCTION

The main characteristics of hot arid regions are the high summer daytime temperatures, large diurnal temperature range, and high solar radiation. Direct solar radiation is as intense as the radiation reflected from the light-coloured and bare ground. The sky is clear most of the year, with high heat loss patterns by long infrared radiation during the nights and mostly during winter season, requiring heating. Horizontal global radiation can approach 1000 W/m^2 and continuous net long-wave radiation loss can be about 100W/m^2. The result is a large diurnal temperature that reach in extreme cases up to 50°C although in many hot-arid regions the typical maximum dry bulb temperature is about 35°C-45°C. Minimum temperatures in summer are about 25°C to 30°C. The round surface temperature in summer may reach up to 70° C. Sunlight reflection for the bare, often light-coloured ground may produce intense glare which, together with reflection from building's walls and external surface obstructions, may cause visual discomfort and significant radiant heat load for buildings through the envelope mainly from windows and walls [Figure 1]. Certainly, in hot-dry regions the summer is the more demanding season. Therefore the design of buildings and exteriors should aim mainly to minimise indoor stress and maximise hygrothermal comfort during the overheating period, whilst minimizing the heat gains from the external heat sources and maximizing the dissipation of heat gains load from interior spaces. However, these regions, which are hot in summer, may also experience uncomfortable winters due to low temperatures that in some cases maybe well below freezing and the lower limit of the comfort range for buildings occupants. On the other hand, cold winds and dust/sandstorms prevail in winter. The air humidity is low. Therefore, in such regions, winter performance should also be considered carefully in the design of buildings and external urban spaces, consequently, the buildings in these climate regions should be carefully designed to consider both overheating and underheating periods.

Figure 1. Typical Building Typology in Hot Arid Regions

RESEARCH OBJECTIVES

The objective of this work focused on investigating the hygrothermal performance of several passive cooling and heating strategies implemented in experimental modules aimed at achieving hygrothermal comfort for building occupants. Pervious research has identified the favorable performance and potential these systems [1, 2, 3, and 4]. The passive cooling techniques involved the four environmental heat sinks, and included these strategies which were implemented in the experimental modules: Ground cooling, solar control, natural ventilation, direct evaporative cooling, night sky infrared radiation and thermal insulation.

The premise of passive cooling focuses on heat gain control from external heat sources (heat gain prevention) and heat dissipation of internal heat gains load (removing heat). It is aimed at improving and maximizing the indoor hygrothermal comfort with the minimal energy consumption. Therefore, this approach works either by preventing heat from entering the interior (heat gain prevention) or by removing heat from the building (passive or hybrid cooling). Natural cooling utilizes on-site energy, that is, heat sinks, which are energy ambient storage components, available from the natural environment, combined with the architectural design of building components of the envelope, rather than using mechanical systems to dissipate heat. Therefore, natural cooling depends not only on the architectural design of the building but how it uses the local site natural resources as heat sinks: earth, water, air and sky (Figure 2). The research was conducted using experimental modules located in Mexico City Metropolitan Area (MCMA) (Figure 3), built with lightweight polystyrene panels with the dimensions: 2.44 meters length, 1.22 meters width, and 0.051meters thickness, on a slab of reinforced concrete foundation (Figure 4). One of the modules served as a control or reference unit and the other modules were where the bioclimatic strategies were implemented and investigated. Results will be extrapolated and applied in typical hot arid regions of the country. A solar shading analysis was conducted to orient the experimental modules towards true south and to select the most suitable location to prevent self-shading among them and to make sure that any external obstruction could not block solar irradiation on the modules (Figure 3).

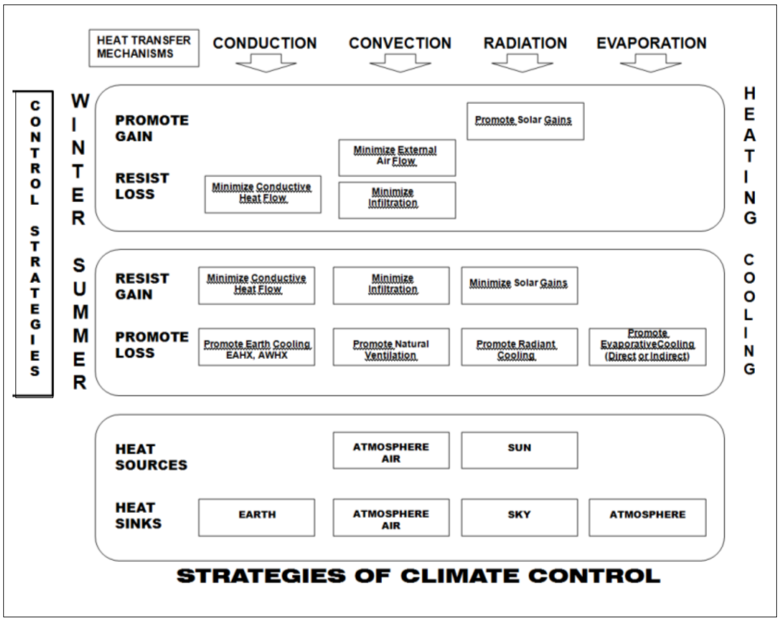

Figure 2. Strategies of Climate Control. Heat Sinks

CLIMATE CONDITIONS

The climate conditions on the experimental site indicate that the average annual temperature is 16.8°C; the maximum annual average is 24.8°C and the minimum 8.8 °C. During the overheating period, maximum average temperatures occur in March, April, May and June, of 27.0° C, 27.9°C, 27.7°C, and 25.9°C, respectively. During overheating period the lower temperatures occur in November, December, January, February and March, of: 6.8°C, 4.9°C, 4.1°C, 5.3°C and 7.5°C, respectively. Annual temperature differential is 16.0 K. Annual rainfall is 608.2 mm. Prevailing wind direction most of the year, comes from the NE with an average annual rate of 1.9 meters/second and a maximum of 2.4 meters/second The average annual solar radiation is 18.01 MJ/m^2, which is equivalent to 5.0 kWh/m^2 [5].

METHODOLOGY OF THE RESEARCH

Monitoring of the test and control modules took place during representative underheating and overheating periods, using data loggers to measure the temperatures in the middle of the experimental modules, as well as on surface temperatures of the interiors, on the plafond, and walls. External temperatures and relative humidities were concurrently registered using a weather station, located sixty meters from the experimental site. To calibrate the experimental arrangement, and to make sure all the modules have the same conditions and configuration, the internal temperatures and relative humidity of all the modules were monitored during fifteen consecutive days. Results were similar, indicating the validation of the experimental procedure.

Figure 3. Experimental modules investigated. Site Plan

Figure 4. Experimental Modules. Construction process and arrangement

RESULTS. ANALYSIS AND INTERPRETATION

From all the strategies investigated, the most promising was the Earth-to-Air-Heat Exchanger (EAHX), for both heating and cooling. This strategy consisted of earth tubes implemented in the test module and the results were compared with those of the control module, without any strategy applied. The experimental arrangement consisted of 100 mm polyvinyl chloride (PVC) underground pipes, located in a depth of 1.60 meters and 24 meters length. The tubes enter the test module for the lower northern side and are linked with a low energy fan to move and transfer in the air passing through. Data loggers were located in the experimental module to measure dry bulb temperature (DBT) and relative humidity (RH). The monitoring period covered the typical underheating and overheating seasons of the location and was conducted during ten representative days and are summarized in Table 1. The EAHX module showed an increase of 3.32 K maximum DBT; 2.84 K minimum DBT; and 3.10 K average DBT, relative to the control module. The temperature difference between the outside DBT and the EAHX module were: 6.76 K maximum DBT; 13.32 K minimum DBT; and 3.7 K average DBT. These results demonstrated the effectiveness of using the earth tubes for reducing the temperature differential between the external temperatures and those registered inside the EAHX module during the typical underheating period and to increase the indoor temperature to get closer to the lower limit of the comfort zone for this location.

During the overheating period (February 26.March 7), the EAHX showed a decrease of 7.13 K maximum DBT; 1.14 K minimum DBT; and 3.12 K average DBT, relative to the control module. The temperature difference between the outside DBT and the EAHX module were: 5.3 K maximum DBT; 6.01 K minimum DBT; and 1.22 K average BDT. These results demonstrated the effectiveness of using the earth tubes for reducing the temperature differential between the external temperatures and those registered inside the EAHX module during the typical overheating period and to reduce the indoor temperature to get into the comfort zone for this location.

Other strategy evaluated was the conductive thermal insulation located on West wall and the roof of the test module, evaluated during the typical overheating period for 10 days, from May 4th to May 13th. The results of the temperature inside the control module and experimental test module had a slightly lower variation relative to the previous system, with a temperature differential of about one degree at the maximum DBT temperature and slightly half a degree above the minimum DBT. Throughout the monitoring period the DBT of the test module temperature presented a lower temperature differential relative to the control module (Table 1). The results of the monitoring process showed that the thermal insulation applied in the test module provided an important reduction of maximum DBT of 31.77º C to 24.29 ºC, that is, a 7. 48 K temperature differential. This strategy was more effective during the overheating period.

Other strategy evaluated was direct evaporative cooling, consisted of a geotextile material forming a wet curtain positioned on the west opening of the test module. The monitoring period of this system run for 12 consecutive days, from May 16-27. However, on May 21 and 22, the evaporative cooling process was not applied and then data from these days were excluded, During the monitoring process, one liter of water was added daily to the geotextile, by means of a sprinkler every 1.30 hours at which time the volume of water evaporated completely. The DBT inside the experimental modules varied little, but remained within the comfort range. The results of this system are summarized in Table 1.

BIOCLIMATIC STRATEGIES INVESTIGATED SUMMARY					
Testing Period	Temperatures (°C)				
			Exterior	Control Module	Test Module
Underheating Period December 4-13	EAHX	Maximum DBT	24.58	14.50	17.82
		Minimum DBT	-2.98	7.50	10.34
		Average DBT	10.88	11.48	14.58
Overheating Period March 10-23	EAHX	Maximum DBT	29.17	31.00	23.87
		Minimum DBT	3.35	10.50	9.36
		Average DBT	16.90	21.24	18.12
Overheating Period February 26 to March 7	Tower Collector for Natural Ventilation	Maximum DBT	29.41	21.00	22.01
		Minimum DBT	17.26	17.73	17.62
		Average DBT	3.46	14.00	12.24
Overheating Period May 4-13	Thermal Insulation West Wall and Roof	Maximum DBT	31.77	25.00	24.90
		Minimum DBT	7.70	15.50	16.08
		Average DBT	20.87	21.02	20.99
Overheating Period May 16-27	Direct Evaporative Cooling	Maximum DBT	34.68	27.00	27.16
		Minimum DBT	11.71	19.00	18.79
		Average DBT	22.58	22.86	22.75

Table 1. Summary of Experimental Results of Investigated Passive Cooling and Heating Strategies

CONCLUSIONS

The results of this research work indicate that the bioclimatic systems evaluated are a promising alternative to reduce energy consumption whilst providing hygrothermal comfort conditions for the building occupants. The subsequent work of this research is aimed at transferring and extrapolating the results to be applied in buildings located in hot arid regions, where due to the severe climate conditions; the results can be even more improved. Additionally, the results of this research can be even improved with the integration in a synergic action of all the bioclimatic systems, evaluated individually in this work, aimed at being implemented in both new and existing buildings. The application of this approach can eventually reduce the emission of GHG and improve the environment, which hopefully promote a more sustainable attitude in the application of bioclimatic architecture at regional and global levels for the wellbeing of people.

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