Potential of Indirect Evaporative Passive Cooling with Embedded Tubes in a Humid Tropical Climate

Applications in a typical hot humid climate

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ABSTRACT: The prevailing high temperatures and excessive air humidity are conditions that represent an opportunity for exploring the potential of indirect evaporative cooling systems in hot humid regions. This paper investigates the performance of embedded tubes in a typical tropical humid location in the city of Veracruz, Mexico, which has hot humid conditions during most of the year, causing high energy consumption in air conditioned buildings and high thermal stress for the occupants in un-conditioned buildings, affecting their health, productivity and efficiency. The experimental facility of this case study is located at the Gulf Meteorological Prevision Centre in Veracruz, Mexico, and consisted of two identical insulated experimental cells, one serving as the control and the other one as the test unit, where the technique of embedded tubes in the roof was implemented and investigated during a typical overheating season. Results showed that this indirect evaporative cooling system can be an effective strategy to reduce indoor temperatures without increasing the indoor humidity in buildings located in hot humid climates. The indoor maximum temperature was lowered by 2.72 K in the experimental test cell relative to the control unit. Furthermore, the resulting reduction of radiant temperatures in the test unit can also have an additional comfort influence for the occupants of buildings located in prevailing hot humid climates. It is expected that the implementation of this passive cooling technique can provide a multiple effect in similar climates and that this can eventually contribute to reduce the energy consumption and the use of air-conditioning systems in buildings as well as to prevent the emission of greenhouse gases to the atmosphere.

Keywords: Passive cooling, embedded tubes, humid climate, comfort

INTRODUCTION. APPLICATION OF PASSIVE COOLING STRATEGIES IN BUILDINGS

The application of passive cooling techniques in buildings can offer beneficial comfort conditions for the occupants as well as the potential to reduce energy consumption [1, 2, 5, 7, 9]. Passive cooling strategies applied in buildings are mainly focussed on the "prevention of overheating" and on the "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 action for achieving comfort conditions in a building during the overheated season. The use of conventional mechanical refrigeration, as well as active and passive cooling methods can also be applied as supplemental equipment for the "provision of cooling" to achieve ambient comfort conditions for the occupants of a building.

For the "prevention of overheating" some strategies can be used, particularly implementing measures at the building envelope, such as the use of solar control and shading devices, vegetation materials, thermal insulation, thermal mass, high reflectance external buildings surfaces, selective smart glazing, high energy efficient equipment, conscious integration of daylighting and electric lighting, as well as appropriate internal layout, among others. When the climatic conditions and the building use demand that internal conditions are significantly cooler than the outdoor ambient, or when internal heat gains are very high, then the "provision of cooling" applies.

For the "provision of cooling" in buildings, the passive techniques to reduce indoor air temperatures imply the use of the four natural ambient heat sinks (i.e. earth, sky, water and air). Depending on the climatic conditions, the strategies under this category include: Ground cooling, radiative cooling, direct and indirect evaporative cooling and natural ventilation. These strategies can offer significant opportunities for improving the occupants ambient comfort conditions furthermore while reducing the energy consumption under prevailing overheating conditions. This implies to achieve maximum human comfort conditions and air quality at minimum capital and operational energy costs, while preserving the external environment and is particularly applicable for buildings located in hot climatic regions, with large cooling loads due to the use of mechanical systems for space climatization (Air-Conditioning, AC).

The evaporation of water implies a phase change from liquid to gas (vapour), and is driven by the absorption of heat from the surrounding air. Then, the air in contact with this process loses heat and cools but gains moisture, becoming more humid. This process is known as *Direct Evaporative Cooling* and results in the conversion of sensible heat to latent heat at a constant wet bulb temperature. This is a useful cooling strategy as the evaporation of one litre of water could cool approximately 200 m^3 of air by 10 ºC, since the amount of energy required to evaporate water at a temperate of 25ºC under standard atmospheric pressure conditions of 100kP is about 2.45 MJ/kg. On the other hand, the *Indirect Evaporative Cooling* process reduces the dry bulb temperature without increasing its moisture content. Direct Evaporative Cooling is a passive cooling technique more suitable for hot dry climates.

In prevailing hot humid climates, the application of *indirect evaporative cooling* is a useful strategy for providing hygrothermal comfort conditions to the building's occupants, and it can be achieved in a building by circulating cooled water within some elements of the building's structure, such as roof, walls and floors, for example, in pipes embedded within the respective building elements [4, 8]. Thus, these cooled elements provide and transfer radiant and convective cooling to the interior spaces, without raising the indoor humidity. Therefore, the pipes can act as cool air emitters to the interior space of buildings. As a result, indoor temperatures can be lowered and the hygrothermal comfort of the occupants is improved. Previous studies [1, 2, 3, 6] using *indirect evaporative cooling* have shown that indirect evaporative cooling techniques can significantly reduce the indoor dry bulb temperature without elevating the water content of the ambient air. Therefore, this strategy is highly recommended in locations with high air moisture content. When combined with cooling by convection and radiation to the sky, the performance of this system in terms of comfort perception can be better from the viewpoint the occupant's.

THE CASE STUDY. CLIMATE CONDITIONS

The case study of this research was located in the city of Veracruz, a typical hot humid climate in Mexico, which is characterized by annual average dry bulb temperatures of 25.3 ºC and annual average wet bulb temperature of: 22.6 ºC and a vapour pressure of 25.9 hPa. These conditions provoke high energy consumption in air conditioned buildings and high thermal stress for the occupants in un-conditioned buildings, affecting their health, productivity and efficiency. This is a representative hot humid climate of most hot humid locations in Mexico.

EXPERIMENTAL ARRANGEMENT

An experimental arrangement consisted of two identical cells was built and implemented with several passive cooling techniques to be investigated in a long term project.

Some of the implemented passive cooling techniques included: Roof pond with floating insulation [1], roof pond with soil and gravel, water pipes embedded into the roof with insulation over the roof, convective cooling, night ventilation, radiant cooling, and earth cooling, among others. Two identical test cells were built, and tested, with the following dimensions: 1.2 m width x 1.2 m length x1.35 m height each (Fig. 1).

Figure 1: Experimental arrangement showing the test and control cells

The walls of the cells were built of concrete bricks, 10 cm thick, with sand-cement mortar, 2.5 cm thick plastered on both surfaces, to a total thickness of 15 cm. The roof was built of concrete, 10 cm thick, with a waterproofing layer. The floor was also of concrete, 10 cm thick. The insulation was 5 cm of polystyrene. These experimental models were built with walls and roof using common materials for low cost houses in this region.

During a preliminary stage of the program, the calibration of the two modules was conducted concurrently, by comparing the results of indoor dry bulb temperatures and relative humidity values under identical building configurations and design details. The resulting indoor temperatures and relative humidities in both modules were very similar.

The experimental set up was built in the facilities of the *Gulf Meteorological Prevision Centre in Veracruz, Mexico* (Figure 2), and this condition was very convenient to collect climate data directly and concurrently during the monitoring period. One of the cells served as the control, without any cooling system implemented, and the other one served as the test unit, with the copper embedded tubes and with floating insulation over the roof implemented and tested for the particular passive cooling technique presented and investigated in this stage of the program.

Fig. 2: Experimental set up at Gulf Meteorological Prevision Centre in Veracruz, Mexico

APPLICATION OF EMBEDDED TUBES

The experiments on embedded tubes as an indirect evaporative passive cooling technique were conducted during a typical overheating period of the location (Fig. 3).

MONITORING PROCESS

The experiments with the embedded tubes in the roof were monitored for 10 consecutive days during a typical overheating season in the location. HOBO´s data loggers were used for the monitoring process. The location of the data loggers is shown in figures 4 and 5)

The Control Cell: **Logger 1 (DL-1)** with four channels used to measure DBT and RH indoors, located in the middle of the space. Also, surface temperature on the ceiling was recorded concurrently using a HOBO´s probe. **Logger 2 (DL-2)** with two channels was used to record DBT on the floor and solar radiation on top of the roof. **Logger 3 (DL-3)** with two channels was used to measure DBT and RH at floor level.

Figure 3: Text Cell

The Test Cell: Inside the test cell, **Logger 1 (DL-1)** with four channels was used to record dry bulb temperature (DBT) and relative humidity (RH) in the middle of the experimental space. Also, surface temperature on the ceiling was recorded concurrently using a HOBO´s probe. **Logger 2 (DL-2)** with two channels was used to measure DBT on the floor with a probe, and water temperature, with a probe in contact with the water in the cistern underneath the experimental test cell.

Logger 3 (DL-3) with four channels was used to measure DBT and RH at floor level, and surface temperature on the ceiling recorded concurrently using a HOBO´s probe, as well as water temperature, with a probe in contact with the water in the cistern underneath the experimental test cell. **Logger 4 (DL-4)** with two channels was used to measure relative humidity at floor level and outside water temperature underneath the polystyrene insulation.

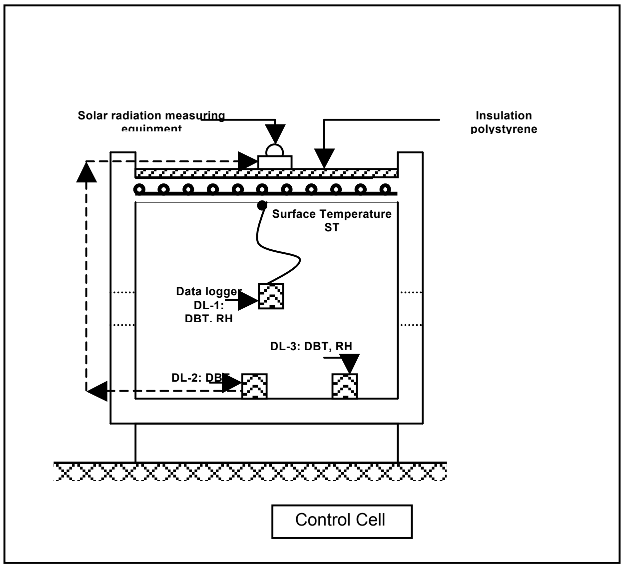

Figure 4: Experimental Arrangement. Control Cell with data loggers location for the embedded tubes experiment

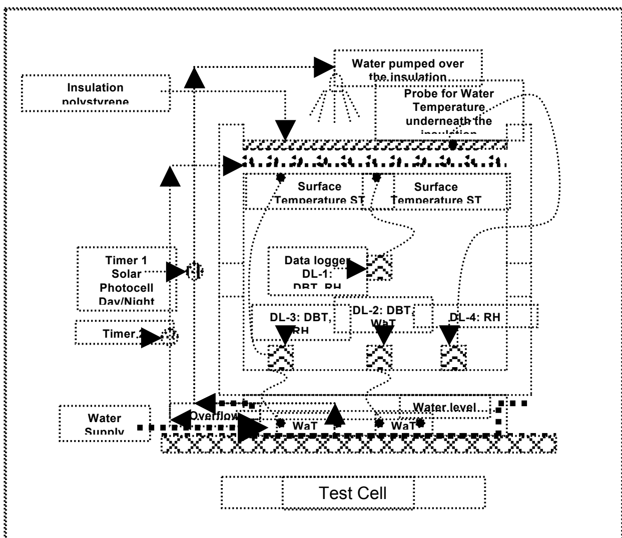

Figure 5: Experimental Arrangement. Test Cell with data loggers location for the embedded tubes experiment

Table 1 summarizes the data logger's arrangement and their location in the control and test cells.

Table 1: Data loggers measuring parameters and location

CONTROL CELL	Measuring parameters	Location
DL-1 4 Channels	DBT, RH indoors Surface Temperature	Middle of cell Center of ceiling
DL-2 2 Channels	DBT Solar Radiation	Floor of cell Center of roof
DL-3 2 Channels	DBT, RH indoors	Floor of cell

TEST CELL	Measuring parameters	Location
DL-1 4 Channels	DBT, RH indoors Surface Temperature	Middle of cell Center of ceiling
DL-2 2 Channels	DBT Water temperature	Floor of cell Inside cistern
DL-3 4 Channels	DBT, RH indoors Water temperature	Floor of cell Inside cistern
DL-4 2 Channels	RH indoors Water temperature	Floor of cell Roof underneath insulation

TIMING OF WATER HANDLING FOR THE EMBEDDED TUBES IN THE TEST CELL

To complement the experimental arrangement, two pumps were connected to the equipment in the test cell.

Timer Pump 1 + Photocell (with a Day-Night performance).

Starting time: about 8 pm. Then water from the cistern underneath the cell circulates over the insulation on the roof using a typical shower (Fig. 5). Ending time: 6 am. Therefore, water from the cistern circulates over the insulation from 8 pm until 6 pm.

Digital Timer-2 Pump 2. This configuration was set up and programmed to start operating from 8 am, from then, water circulates through the embedded tubes, and this mode ended up at 6 pm. During this period water circulates through the embedded tubes.

DBT an RH values in the Test and Control cells were recorded every 15 minutes. Climatological data from the local Meteorological Centre on site was recorded concurrently during the experimental period.

RESULTS OF COOLING PERFORMANCE. DATA ANALYSIS AND INTERPRETATION

Figure 6 shows the time patterns of the outdoor dry bulb temperature and the indoor temperatures of the test and the control cells and of the water in the cistern.

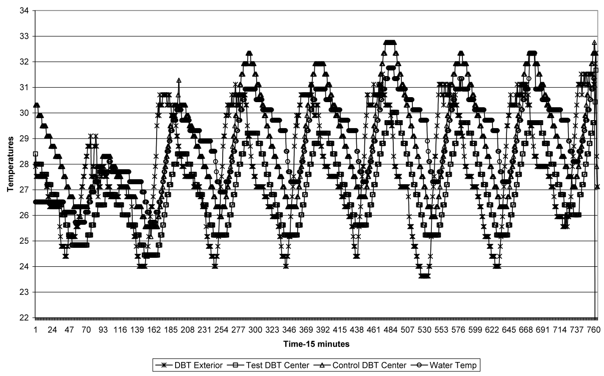

Figure 6: Time patterns of the dry bulb outdoor temperature and the indoor temperatures of the cell and the control cells and of the water in the cistern.

From the experimental results it can be inferred that the *quantitative cooling performance (dT)* of the embedded tubes in the roof can be defined as the difference in indoor temperatures between the test cell and the control cell and expressed as follows:

$$dT = T_{control} - T_{cooled}$$

The water in this type of passive cooling technique, which is cooled during the night by radiation and evaporation and pumped down to the underneath cistern, serve as the cooling source for the test cell. Therefore, the *relative cooling performance* of the cooled test cell, *dTrel*, is the ratio between *dT* and the difference between the outdoor temperature and the water temperature in the cistern. This formula is expressed as follows:

$$dTrel = dT/(T_{outdoor} - T_{Water})$$

Therefore, analysis of the cooling performance of this technique is with respect to the *average, maximum and minimum temperatures, respectively*.

CONCLUSIONS

The results of the experimental work showed that the indoor maximum temperature of the test cell was lower by 2.72 K than the control's maximum. The indoor average temperature of the test cell was 1.8 K lower than that of the control cell. The temperature differential can be larger if the walls of the test cell are insulated as the daily heat gain through the un-insulated thin walls was affecting the cooling effect of the embedded tubes system. The minimum of the test cell was 1.5 K below the control's minimum but 1.2 K above the outdoor minimum. The application of night ventilation is another alternative to further improve the performance of the embedded tubes as it would improve significantly the night comfort conditions in prevailing hot humid climates. It would also lower the indoor average and might also lower the indoor maximum in buildings.

Therefore, results showed that the passive cooling system with embedded tubes in the roof can be an effective strategy to reduce indoor temperatures without increasing the indoor humidity in buildings located in hot humid climates.

It is expected that the results of this research can be applied in buildings located in hot humid regions of Mexico aimed at providing comfort as well as energy savings and to improve both the environment and the life quality of local people.

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