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PASSIVE COOLING TECHNIQUES IN LIGHT-WEIGHT STRUCTURES: THE PALENQUE AT EXPO'92

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ABSTRACT. This paper presents the climatic conditioning strategy designed for a light-weight structure located on the site of the Seville Universal Exhibition (EXPO'92). The Palenque constitues the geometric centre of the EXPO'92 site and covers an area in excess of 8000 m^2. The purpose of the space is to serve as a theatre with capacity for 1500 people, surrounded by lateral staying zones and resting and refreshment areas. The design is based on natural cooling techniques together with a conventional support system to complement the former at peak times. The analysis of specific isocomfort graphs leads to the establishment of the values of the parameters which govern comfort and allow us to decide the basic criteria for the thermal design. We present the features of the irrigation system for the covering and its control strategy. Also described are the air handling units and the combinations thereof which lead to the maximum usage of soft techniques (ponds and humidification) and minimum usage of conventional techniques.

1. Description

The Palenque is an open building located at the geometric centre of the EXPO'92 site and covers an area in excess of 8000 m^2. Functionally, it is divided into two zones (see figure 1). The central zone constitutes an area of 5.000 m^2 for shows with seating capacity for 1500 people. The stage is separated from the spectators by two ponds situated at different levels and connected by a cascade. These two ponds have fountains which are not only decorative but also a key element in the conditioning strategy which has been designed. Transition between central area and lateral ones has been carried out by means of trees and ponds. The north and south lateral zones contain kiosks, restaurants and shops. The central zone is separated from the lateral zones by a barrier of trees and fountains. The entire Palenque is in turn separated from the exterior space by a virtually continuous peripheral barrier of similar characteristics to the former.

The entire area is covered with white PVC (see figure 2), forming a structure made up of 50 cone-shaped elements. Covering has been designed to protect people from solar radiation and eventually rain without closing the space.

The architectural design is the work of J. M. de Prada and the climatic conditioning was carried out by the authors of this paper.

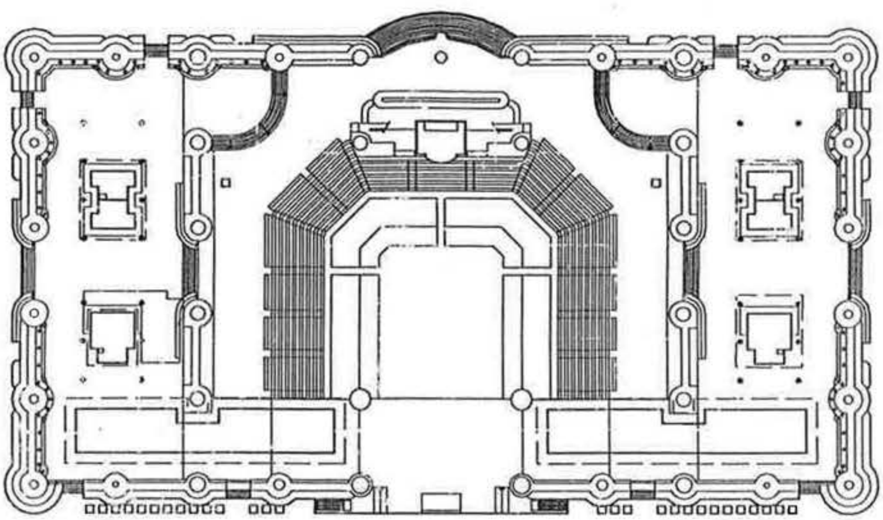

Figure 1: Floor plant.

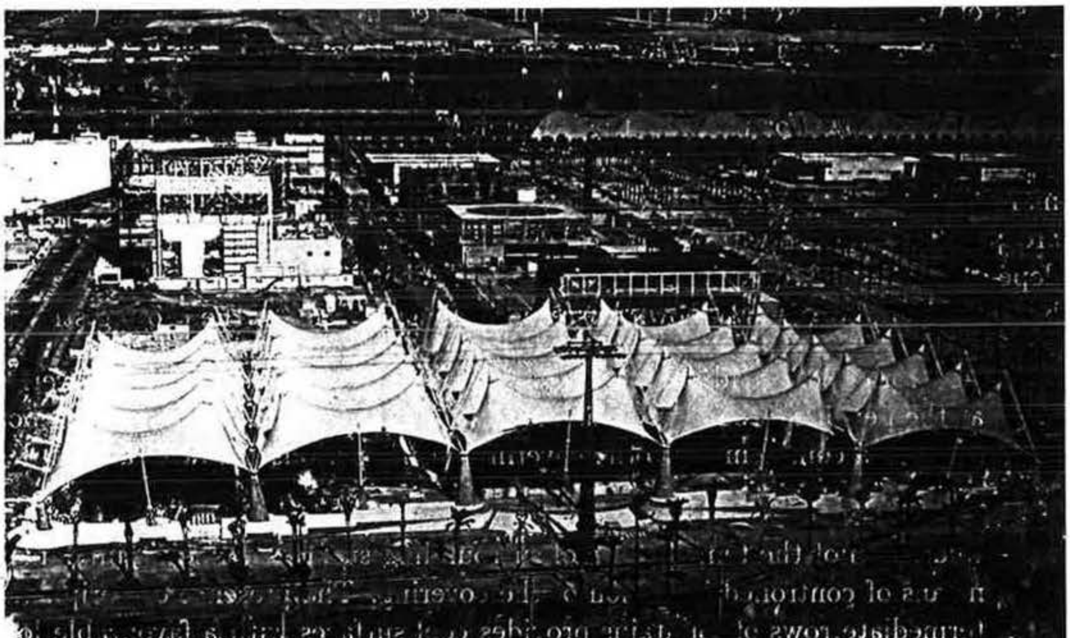

Figure 2: General view of the Palenque.

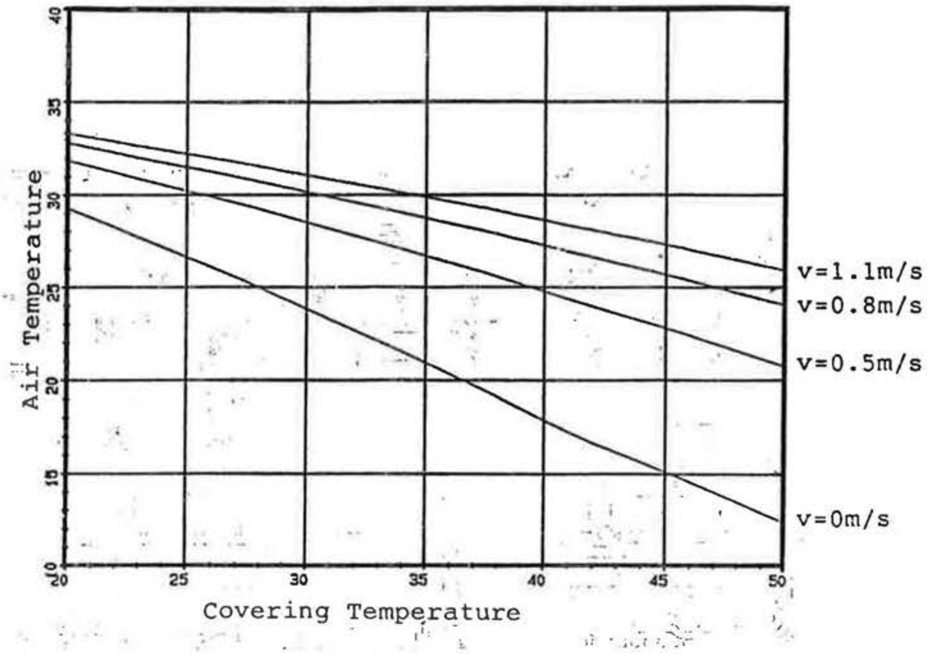

Figure 3: Isocomfort Graph of the Palenque; Central zone; $E_{sw} = 30g/h$

2. Cooling strategies

The determination of the best combinations of values for the different variables which lead to a given level of comfort has been done with the aid of isocomfort graphs, the basis of which is described in [1], assuming a required level of comfort (E_{sw}) of 30 g/h in the central zone and 60 g/h in the lateral rest areas.

Figure 3 shows for instance the isocomfort graph for the central zone, in which the covering temperature, air temperature and air velocity appear as the variables to be manipulated. Ground temperature, temperatures of sorrounding surfaces and humidity are parameters that we suppose to be known. It can be seen that air temperature depends very much on covering temperature. That is why design of the covering must be very carefully studied. Down we resume the guidelines of the cooling strategies:

- Control of solar radiation by means of a continuous white PVC covering. Trees at the peripheral barrier act as blocking elements for the reflected component and serve as a complement to the covering during periods of low solar elevation.

- Reduction of the temperature of surrounding surfaces, achieved fundamentally by means of controlled irrigation of the covering. The presence of peripheral and intermediate rows of fountains provides cool surfaces with a favourable local effect, negligible in any case on an overall scale. Other possibilities, such as cooling the ground, were discarded due to its low efficiency and difficulties of implementation and control.

- Reduction of the air temperature, achieved by the use of 6 air handling units (AHU). The efficiency of this action depends to a great extent upon the confinement of the zones to be treated which is accomplished by sinking the space in the

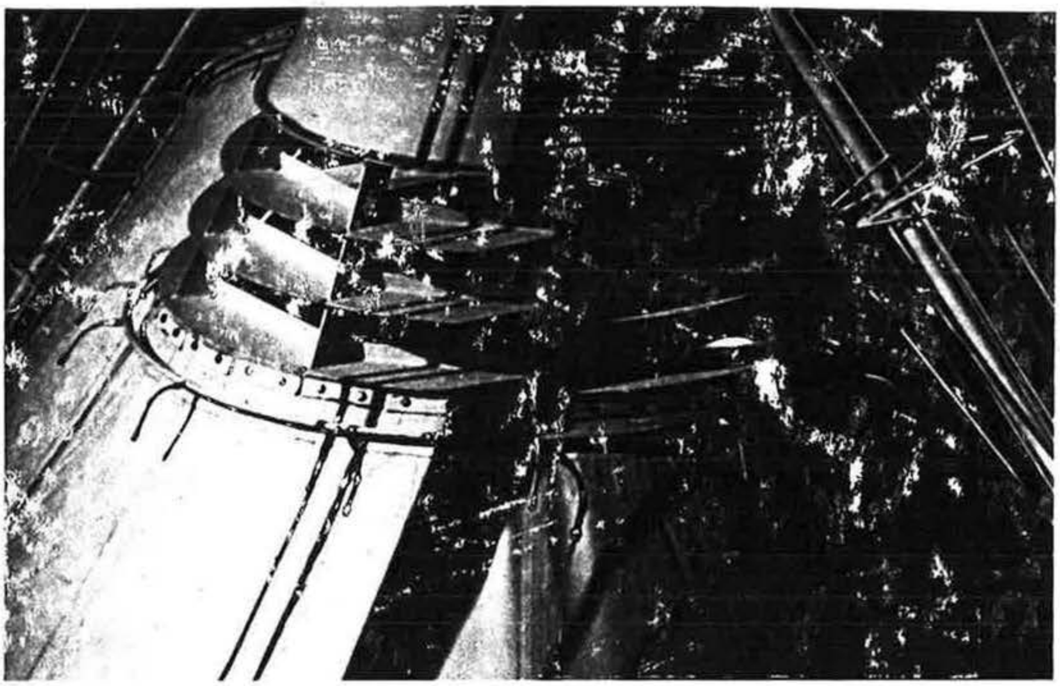

Figure 4: Opening at the top of the covering.

seating area and by means of barriers of vegetation and fountains for the remaining zones.

Additionally, the installation of micronizers incorporated into the peripheral fountains prevents the wind from neutralizing the reduction of the air temperature in the lateral rest zones.

3. Covering

A continuous white PVC covering, trees and the peripheral barrier assure control of solar radiation. Openings were left at the top to favour elimination of the hot air (see figure 4).

When clean, the covering has the following properties: transmissivity 13%, absortivity 10% and reflectivity 77%. Because of dirt these proterties change, specially the absortivity which reach a value of 32%. Using former data theoretical models revealed that the surface temperature of the covering would surpass 45 °C . Under such conditions, it is clear from the isocomfort graphs (figure 3) that, in order to obtain the desired comfort levels, the air temperature required would have to be very low (23 °C with v=0.5 m/s) and the subsequent implementation cost would be too high. For this reason, several methods of cooling the covering were examined, including different possibilities with water films and irrigation.

The solution selected consists of controlled irrigation that maintains an average surface temperature below 30 °C during peak outdoor conditions. The maximum water flow rate required for such a reduction is 10 m^3/h. In order to properly size the irrigation system, experiments carried out in the bioclimatic rotunda have been used [2]. It should be clarified that cooling is not due to the water temperature (convection) but to its evaporation. The monitoring system guarantees that the covering is permanently wet and ensures that the maximum surface temperature (there are three differently orientated

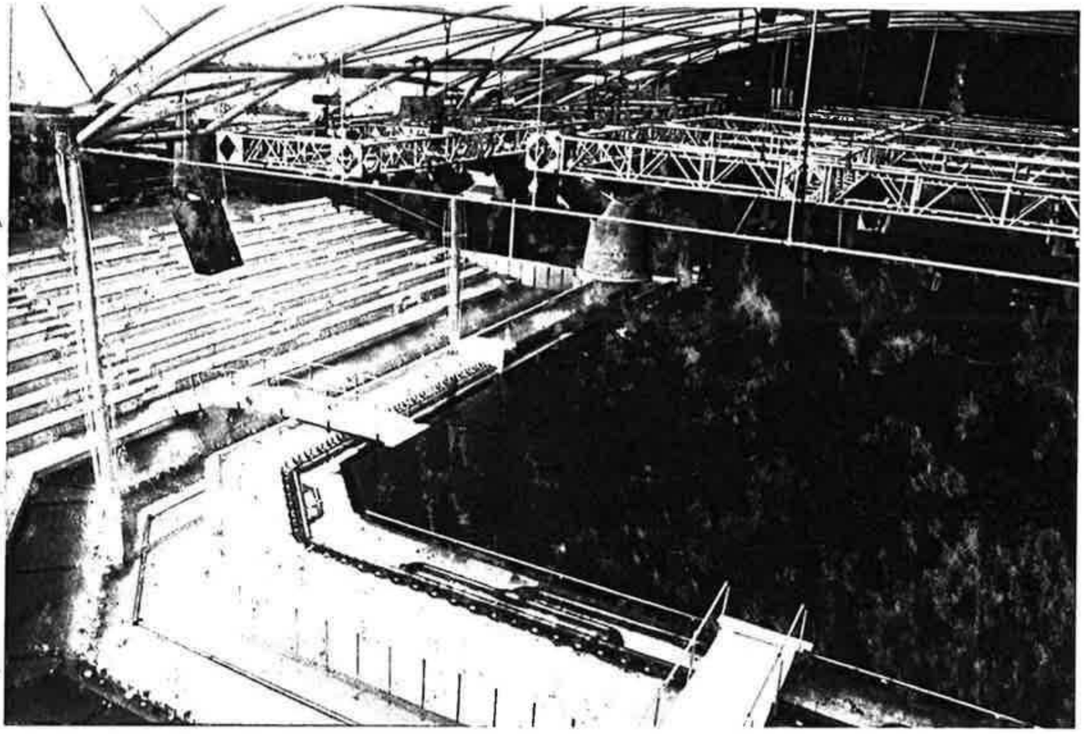

Figure 5: View of the stage and spectator area.

sensors) never exceeds a value 7 °C below the outdoor air temperature. An additional advantage of the irrigation is the fact that the covering is kept clean and a lower absorption of solar radiation is obtained. Irrigation system can be observed in figure 4.

4. Systems in stage and spectator areas.

Figure 5 shows a partial view of the stage and the spectator area. In order to obtain the required comfort levels, and once the covering temperature has been controlled, the air temperature of every zone is a function of the estimated air velocity. The diffusion of air to the central zone gives rise to an air velocity of 0.5 m/s which implies a temperature of 27 °C . We assume exterior conditions of 38 °C -30% HR.

The simulations carried out revealed that, under peak conditions, 70.000 m^3/h of air at 20 °C were needed to mantain the prescribed comfort level. Cooling of the air is achieved by means of 2 AHU's, all outside air, each with a capacity of 35.000 m^3/h. Each AHU is composed of three cooling sections, as shown schematically in figure 6.

The output conditions of the treated air are 19 °C and 90% relative humidity. The first section precools the outside air by means of a coil which is supplied with water from the pond which surrounds the stage.

If the dry-bulb temperature of the air on exit from the precooling coil is above 19 °C the evaporative section comes into operation. For peak load periods (maximum occupancy and extreme exterior conditions), the temperature on exit from the evaporative section may be above 19 °C . Under these conditions, the evaporative section pump is halted and the cooling coil, supplied with cool water from one auxiliary chilling plant, comes into operation.

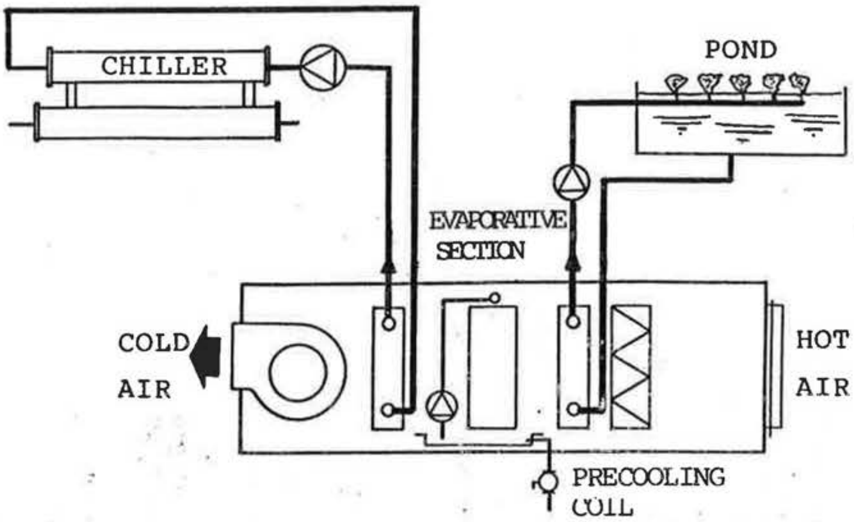

Figure 6: Basic elements of cooling system.

One of the fundamental aspects of the air-cooling strategy described is the design and sizing of the ponds and fountains which provide the cool water to the first section of the AHU's. In the stage pond, which has a capacity of 200 m^3, cooling is accomplished by having the fountains operate during the night and during the intervals between shows. Selection of the different design variables, such as the capacity of the ponds, the water flow rate to be sprayed by the fountains, the droplet size (type of nozzle), etc., was effected by means of the model described in [3].

Under design conditions, natural air-cooling techniques provide 60% of the cooling load. During the time the Exposition is to be held (April to October) the auxiliary chiller plant will provide only 25% of the total cooling requirements of the Palenque. Finally, the currently instaled capacity is only a 40% of the requiered capacity if only conventional chilling plants would be instaled.

5. Systems in lateral zones.

For the lateral zones (figure 7) cooled is achieved by means of 4 AHU's. Taking into account the dominant direction of the wind and similar design and operation conditions as for the central zone, cool air si distributed as follows:

- South lateral zone: 2 AHU with a total capacity of 20.000 m^3/h
- North lateral zone: 2 AHU with a total capacity of 15.000 m^3/h

In the intermediate ponds, the water is cooled by sprayers which operate permanently the whole time the Palenque is occupied (10 a.m. to 2 a.m.).

6. Some results.

Preliminary results are shown in figure 8. Data have been taken on may the 12 th. While exterior temperature reaches 35 °C , temperature in the spectator area is manteined at

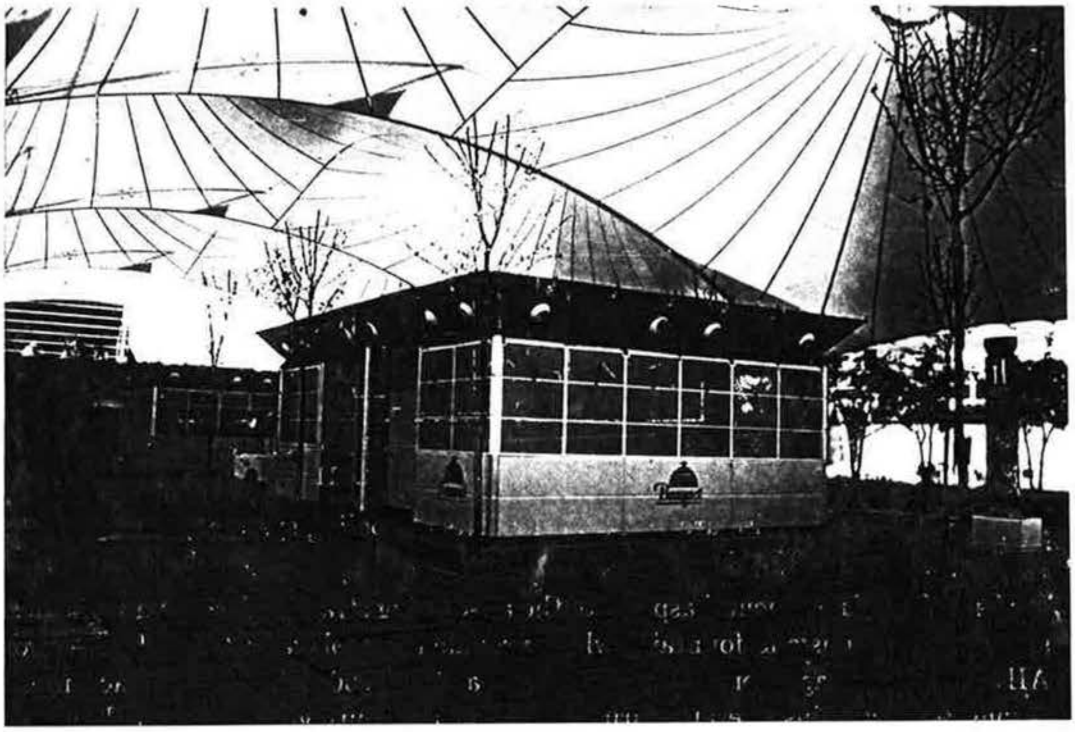

Figure 7: View of the north lateral zone.

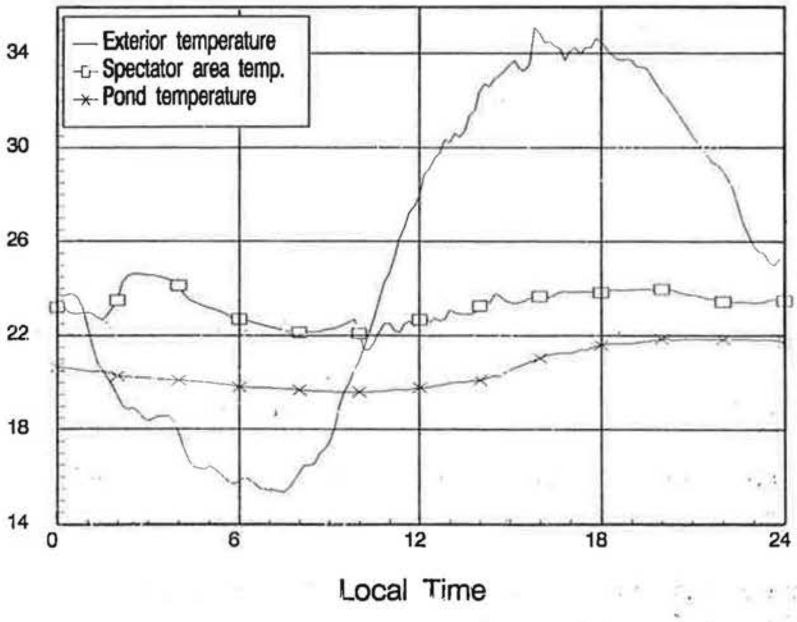

Figure 8: Evolution of temperatures.

24 °C just by means of the precooling coil and evaporative section of AHU's. Relative humidity does not reach 60%.

Acknowledgements

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