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CLIMATIC CONDITIONING OF OPEN AREAS. THE CHALLENGE OF THE EXPO'92 UNIVERSAL EXPOSITION

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A five years research and development project has been carried out by the Department of Energy Engineering and Fluidomechanics of the University of Seville with the aim of improving the comfort in the outdoor spaces of the EXPO'92 Universal Exposition, making feasible the set of activities intended to be donne on them. Present paper describes general aspects of the project and emphasizes the work performed on innovative natural air cooling techniques, including modelling, experimental and validation activities. Different cost-effective and energy efficient ways to cool the air are presented and discussed. The paper includes preliminary evaluations data recorded during the current summer.

INTRODUCTION

Conventional conditioning techniques have concerned themselves almost exclusively with the environmental treatment of the enclosed spaces which make up buildings. Changes in certain social behavioural patterns, the endless search for an improved quality of life and the ever-increasing desire for closer contact with our surroundings, have all contributed to a more important role being played by the outdoor spaces in which urban buildings are located. The ability of these outdoor spaces to satisfy the foregoing requirements are closely linked to achievement of acceptable levels of comfort in such spaces. This requirement must be fulfilled, because of the demands of the conditions to be met, by means of soft techniques which are compatible with the architectural and urban design.

THE PHYSICAL SETTING OF EXPO'92

The Seville Universal Exposition takes place between April 20th and October 12th 1992. The 215 hectares it occupy are located on what is known as the Cartuja Island, a lowland surrounded by the two branches which form the natural and artificial courses of the Guadalquivir River (Figure 1).

Five large avenues measuring 300×80 metres make up the area reserved for the pavillions of the international participants. Perpendicular to these avenues there is a wide pedestrian way some 2 kilometers in length, along which are strung the various theme pavilions. An 16 hectares artificial lake, semicircular in shape is bordered by the pavilions which represent the different autonomous regions of Spain.

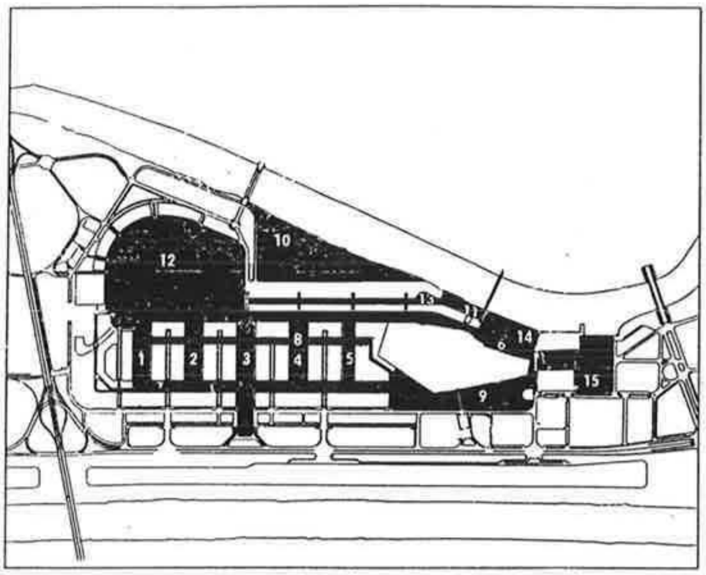


Figure 1: General Plan of the EXPO'92 Site

In all, the built-up area comprises some 600,000 m^2 scattered throughout 170 hectares of open spaces in which restaurants, cafeterias, shops, bars, kiosks and small show areas abound. Over 100,000 trees, 35 kilometres of hedges and 500,000 m^2 of parks and gardens alternate with avenues, promenades and rest areas, forming in a certain sense one immense park.

Unlike other occassions in which public areas remainded as residual spaces always dependent on the exhibition pavilions, EXPO'92 has treated therm as designs with a personality of their own. this is greately due to the wish to highlight the Sevillian tradition in particular and Mediterranean in general of living out-of-doors.

Forecasts of attendance calculate some 18 million visitors to the Expo, who will generate some 40 million visits to the site.

THE CLIMATE OF SEVILLE

Table 1 shows the most representative meteorological variables of the city's climate for the time of year during which the Exposition will take place.

The hottest period covers the months of June to September, with a maximum ab solute temperature of 45 °C recorded. 1% of the hours in this period (29 hours) give temperatures in excess of 37,8 °C ; 2,5% of the hours exceed 36,4 °C ; and in the 5% percentile (144 hours) the levels are around 35 °C .

GENERAL CONDITIONING CRITERIA

The comfort model described in [1] provides the starting point for determining the actions to be carried out. In synthesis, in order to improve the level of comfort it is necessary to reduce the contribution of the various unfavourable heat flows (gains), eliminating them whenever possible or even transforming them into favourable flows (losses) if they admit sign inversion.

Table 2 summarizes this strategy and allows a rough evaluation of the degree of

Table 1: The Climate of Sevilla

	Maximum Mean Temperature (°C)	Minimum Mean Temperature (°C)	Mean Relative Humidity* (%)	Mean Absolute Humidity (g/kg)	Maximum Mean Radiation** (W/m^2)
April	22,9	9,9	45	8,1	772
May	26,0	12,1	47	9,8	825
June	31,2	15,6	39	11,1	840
July	35,3	17,3	34	12,3	863
August	35,1	17,7	35	12,3	827
September	31,4	16,0	43	12,3	725

* At the peak temperature time ** Upon horizontal surface

effectiveness achievable with each action. It is clear that there are numerous combinations of actions which give rise to the same level of comfort. In each case, the number of variables which may be operated upon and the intensity of manipulation depends on a series of factors including:

- The characteristics of the space to be treated (geometric dimensions, orientation, degree of confinement).
- Activity of the occupants and foreseen length of stay in the area.
- Effectiveness and cost of the possible techniques to be used.
- Possibility of integration of these techniques into the area without distortion of its aesthetic content.

OBJECTIVES AND SCOPE OF THE PROJECT

The climatic data above clearly show that during the middle hours of the day, the thermal conditions do not favour the use of outdoor spaces unless in parts thereof something is done to attenuate these conditions. This was the origin and goal of the research work discussed in this paper.

From a scientific viewpoint, a set of intermediate objectives exist:

- To understand and to evaluate the heat and mass transfer processes taking place in outdoor areas.
- To develop elements and systems able to modify the climate conditions of an outdoor space.
- To prepare guidelines which allow planners, architects and landscape designers a rational predesign of the outdoor spaces from a comfort viewpoint.
- To develop calculation tools to optimize the sizing and control of the different elements and systems.

Table 2: General Criteria of Conditioning

Measures	Generic Actions	Tipical reductions of gains (W)	Specific techniques
Reduction of the solar radiation	Blocking of the direct and diffuse	40 to 70	- Coverings
	Blocking of the reflected radiation	25 to 50	- Confinement - Treatment of adjacent surfaces
Reduction or inversion of the long wave radiant exchange	Reduction of the temperatures of the surrounding surfaces	20 to 50	- Ground: cool pavements water films - Covering: irrigation water films - Vert. surfaces: cascades water curtains
Reduction or inversion of the convective exchange	Reduction of the air temperature	15 to 50	- Confinements - Sensible cooling - Latent cooling
	Movement of cooled air		- Chanelling of breezes - Jets of water

- To develop a working methodology which allows the interaction with the designers and the taking decission process during the different stages of the design.

In relation with the scope of the project, the climatic treatment concentrates in those spaces with a high density of visitors. To be precise, we have studied in detail the five avenues that shape the international pavilions area and the Palenque, which means about 120.000 m^2.

Finally, it should be clarified that, it is not proposed in the open spaces to achieve thermo-hygrometric conditions comparable to those occurring in the air-conditioned interior spaces. Firstly, it is not necessary for the comfort and secondly, it is virtually impossible from the technical point of view and economically unfeasible.

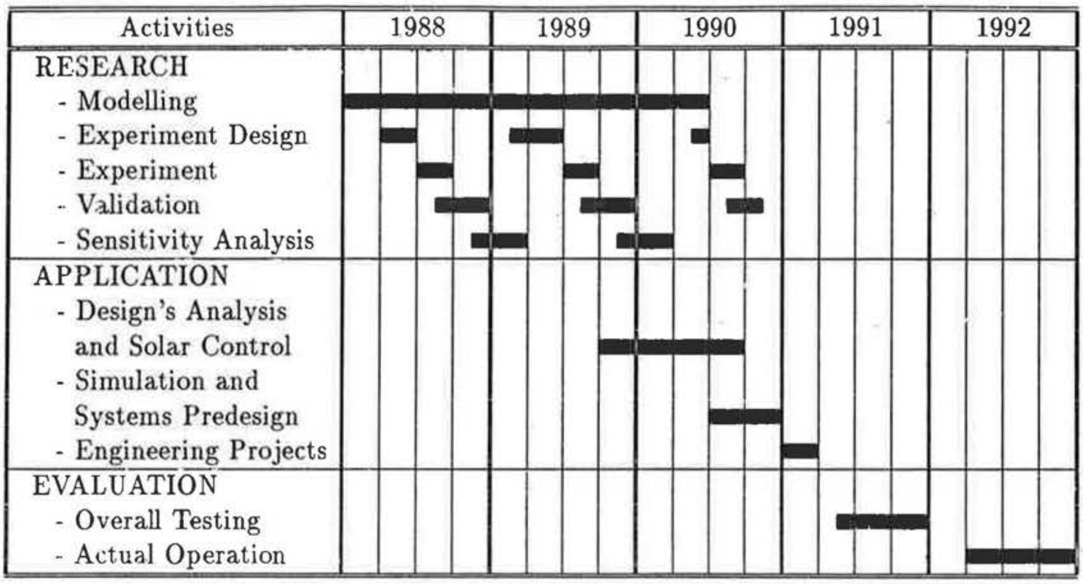
Consequently, when we speak of climatic conditioning of the outdoor spaces at EXPO'92, it is more appropiate to speak in terms of softening, tempering or improving, even though, due to the generalized use of the expression, we use the term "thermal comfort".

METHODOLOGY

The innovative nature of the project implied a serious lack of experiences and scientific literature on the subject. Consequently it has been necessary the building up of the theoretical corpus contrasted with the experiments in order to give it validity and make it generalizable (see table 3).

For this previous research, the basic stages where:

Table 3: Workschedule



Modelling. Consisting in the development of mathematical models based on the physical principles which sustain each of specific techniques.

The diferent models were carried out during 1.988, 1.989 and 1.990 and the following are worthy of mention:

- Thermal comfort in outdoor spaces.
- Thermal behaviour of coverings.
- Calculation of shadows cast by coverings.
- Thermal performance of the ground, conventional pavements and cool pavements.
- Cooling of air by underground ducts.
- Ponds and water films with and without sprayers or jets.
- Evaporative cooling of the air using water droplets in natural convection (micronizers in trees or under pergolas).
- Evaporative cooling of the air using water droplets in forced convection (wet barriers and cool towers).
- Interzonal air movements.

Experiments. Oriented, on the one hand, to evaluating qualitatively and quantitatively the behaviour of the various techniques tested, with particular emphasis on the air cooling techniques and on the other, to supplying data for validating the theoretical models.

A full scale experimental setup was established containing the most significant elements which were to form part of the outdoor spaces. This setup of about 10.000 m^2 includes walkway of various sizes with different coverings, a pond with jets and fountains of various types and a 900 m^2 rest area known as the bioclimatic rotunda.

The experiments were performed during the summers of 1.988, 1.989 and 1.990.

Validation. The results forecast for each model were contrasted with the actual results as measured in the multiple full-scale experiment, adjusting the model when required.

Sensitivity analyses. Once the models had been validated, the next step was to run the models with sistematic variations of the design variables and the climatic conditions. In such a way, information is obtained which allow us to know:

- The relevant and secondary design variables of each technique.
- The optimum range of variation of the relevant design variables.
- The cost /benefit ratio of each technique.

This set of information was the starting point of the design guidelines which assured an efficient interaction between the architectural design and the climatic control.

The calculation tool. Since any treatment is made up of the inclusion of various components, it was necessary to have available a tool capable of establishing the couplings between them and predicting their joint behaviour. This task was entrusted to the S3PAS computer code [2], which allow the final sizing of any subsystem used in an specific zone.

After the research, further steps included the practical application of the strategies for climatic control to the different outdoor spaces in which an intensive interaction process with the designers took place and a preliminary evaluation of the systems during the summer of 1.991.

Presently, we are involved in the follow up of the actual results in terms of comfort conditions, achieved, thermal behaviour of any subsystem, energy and water consumption etc. For that end, a data acquisition system with 186 sensors provides a complete information about the evolution of the different variables in every place of interest. The data acquistion system has been financed by the General Directorate for Industry, Energy and Mines of the Andalusian Goverment and the CIEMAT-IER in order to ensuring the future expploitation of the work both to outddor spaces and to the design and use of natural cooling techniques in buildings.

USE OF NATURAL COOLING TECHNIQUES

When the basic criteria for conditioning: (Solar control and lowering the temperature of the nearby surfaces) have been fulfilled and the comfort level is not the required, it is necessary to reduce the air temperature of the zone considered.

In open areas the major problem to get this reduction is the big amount of cool air which must be supplied in order to compensate the intense mixing action (even without wind) between the air of the treated zone and the surrounding hotter air. This effect can be partially reduced with a previous strategy of confinement (sunken the space or using natural barriers such as hedges) oriented to increase the stability of the volume of air.

Lowering the air temperature of a confined open area would result, in any case, in an unacceptable cost if conventional cooling systems were used. Additionaly, these systems are difficult to integrate if the aesthetic appearance of the urban design must be preserved. Consequently, the reduction of the air temperature has been based on the use of natural cooling techniques.

Two major groups can be distinguished: sensible cooling when the air temperature is reduced without increasing its humidity and evaporative cooling when the reduction of the air temperature is obtained via an adiabatic humidification process. Next sections describe briefly the most significant techniques proposed or applied in the EXPO'92 projects.

Sensible cooling: Underground ducts.

The modelling research performed revealed [3] and the experiments confirmed that the efficiency of a standard buried duct decreares with the time due to the progressive heat saturation that takes place in the soil around the duct, whenever the air flow required is significant.

To avoid that, we seek different solutions:

a) To increase the thermal conductivity of the soil (for example by irrigation).

b) To bury the tube near a treated (cooled) surface in order to have an advantageous boundary condition.

c) To assure a suitable temperature in the massive material surrounding the duct, cooling it during the night taking advantage of the low temperature of the environmental air at this time.

In the EXPO'92, underground ducts have not been formally used because of problems of adjustment to the important infrastructure work which had to be concluded prior to commencement of the outdoor spaces conditioning project.

However, two 30 m. long galleries in the PALENQUE [4] act as high efficiency buried ducts. The galleries are permanently wet and serve to precool the air blown to the Kiosk's peripheral areas. Figure 2 shows some results of the inlet and outlet air temperature of the ducts.

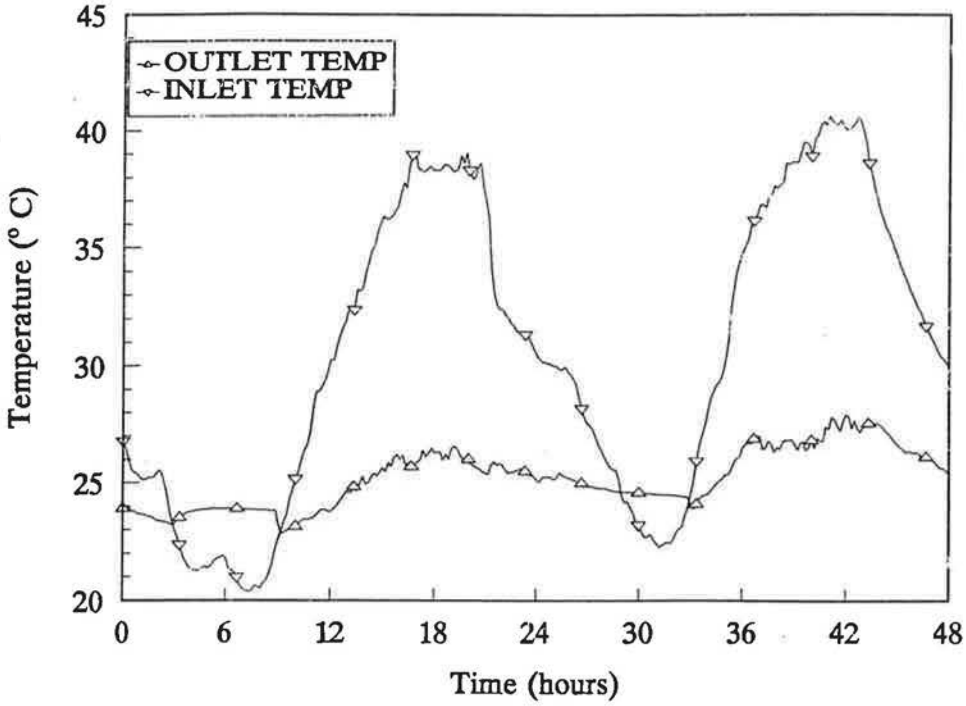


Figure 2: Performance of an Underground Gallery.

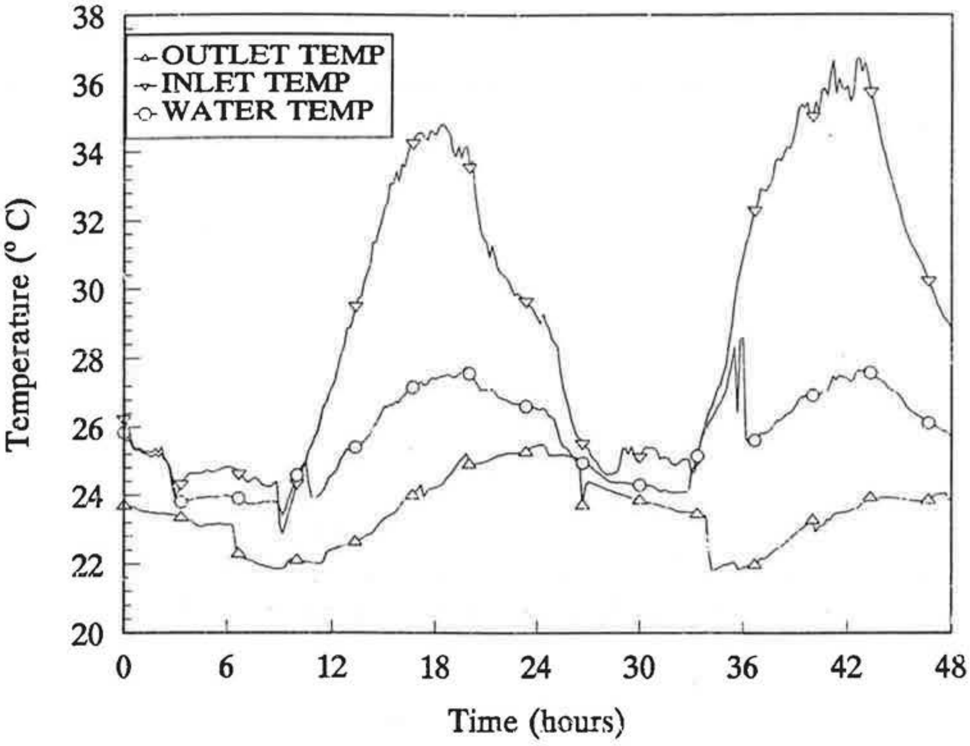


Figure 3: Performance of a Cooling Section feeded with water of a pond.

Sensible cooling: Ponds as a cooling source

An indirect sensible cooling of the air can be achieved by using cool-water contained in a pond as an intermediate source. To assure the low temperature of the water, the pond must be provided with sprays or fountains and preferably shaded.

The relevant design parameters are:

- Spray system water flow rate (in pond volume circulations per hour).
- Nozzle type (droplet diameter and height of the spray).
- Depth of the pond.
- Bottom reflectivity.
- Air velocity about the pond.
- Covering type (transmissivity).
- Working schedule of the spray system.

The heat transfer between the hot air and the cool water takes place in a crossflow heat exchanger which constitutes on of the actions of a Air Handling Unit.

This strategy have been used in 6 zones of the EXPO'92 site.

As a matter of example, figure 3 represents results of the inlet and outlet air temperature in one of the heat exchanger mentioned, as well as the water temperature of the central pond of the the Palenque, which constitutes the cooling source.

Evaporative cooling

Must of the natural cooling techniques developed within the frame of the present project are based on the transfer phenomena that take place when water drops and air are put into contact. The water drops evaporate taking the necessary energy from the surrounding air which becomes cooler.

The physical equations governing the heat and mass transfer phenomena can be seen in [5] [6] and [7].

The major design objective is to assure total evaporation of the water droplets, so that the air cooling capacity is maximized while preventing people from getting wet. From the models developed, it was concluded that for a lifetime of between 2 and 5 seconds a drop with less than 50 μm diameter will evaporate totally in almost all applications.

The device chosen for drops generation was a impaction type nozzle (micronizer) in which the water exits from the orifice as a cylindrical jet and then spreads into an expanding hollow come after striking the impact pin. The cone breaks into small drops (Volume Mean Diametre of 17μm) at a given distance of the orifice.

The practical implementation of the micronizers admits many configuration although the more relevants are micronizers in tress or pergolas and cool towers.

* Micronizers in trees or pergolas.

Micronizers placed in the foliage of trees or on the lower part of vegetation pergolas create an artificial fog. Droplets evaporate in contact with the surrounding hot air which becomes cooler, and, consequently heavier. A continious descending flow of cool air is obtained.

Trees and vegetation pergolas are element that are pleantiful in the landscape of EXPO'92 and so, they have been profusely used to integrate micronizers.

Modelling revealed that the chosen micronizers produce droplets small enough for evaporating before striking the floor whenever they are released higher than 4 metres. For lower heights the descending cool air flow induced is not sufficient to evaporate the plume. The solution for these cases consists of an intermittent working of the nozzles following short ON/OFF periods. The ON time span must be shorter than the airborne time of a drop so as to break the plume.

Figure 4 shows results of the air temperature obtained in two zones which incorporate respectively micronizers in tress and micronizers under pergolas. The higher efficiency observed in the zone with micronizers in trees is due to the better degree of confinement of such a zone in relation to the other

* Cool Towers.

The idea of providing cool air by wind or gravity flow within a tower has precedents in the oldern Middle Eastern wind towers as described by Bahadori [8] and especially in the natural downdraft evaporative cool towers cited in [9] or [10].

The major difference between the above application and the design proposed in this paper is that the former operate by air passing through evaporative cooler pads where as the towers of the Avenue of Europe use micronizers as cooling element.

The use of atomizers is due to two main reasons:

- The need to minimize the air pressure losses in order to obtain a good efficiency under boths still air and wind conditions.
- The need of having a fine regulation capability so that, independently of the outdoor climatic conditions (air temperature and humidity, wind velocity and direction), the cooling capacity can be maximized while preventing people from getting wet because of non-evaporated water droplets.

There are a total of twelve towers, distributed in two parallel rows. Each tower is 30m high in all, 5m of which are the mast and the remaining 25m the trunk covered with a white plastic material. The diameter of the trunk decreases from 8m at the bottom to 3m at the top (Figure 5).

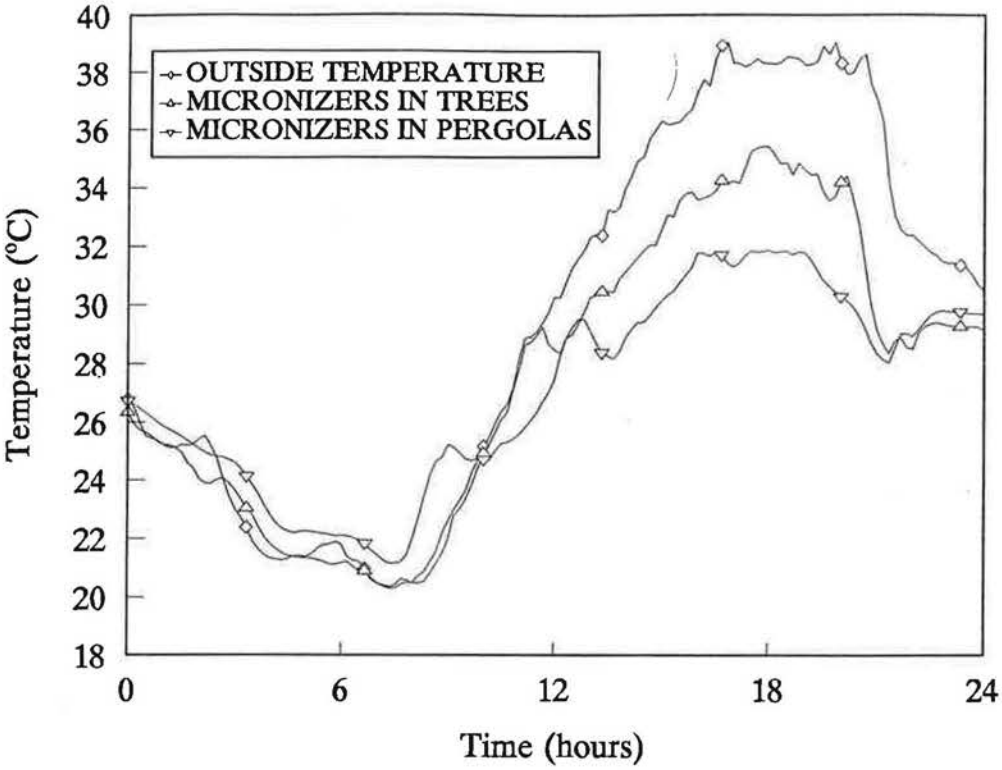


Figure 4: Resultant temperatures in two zones with micronizers.

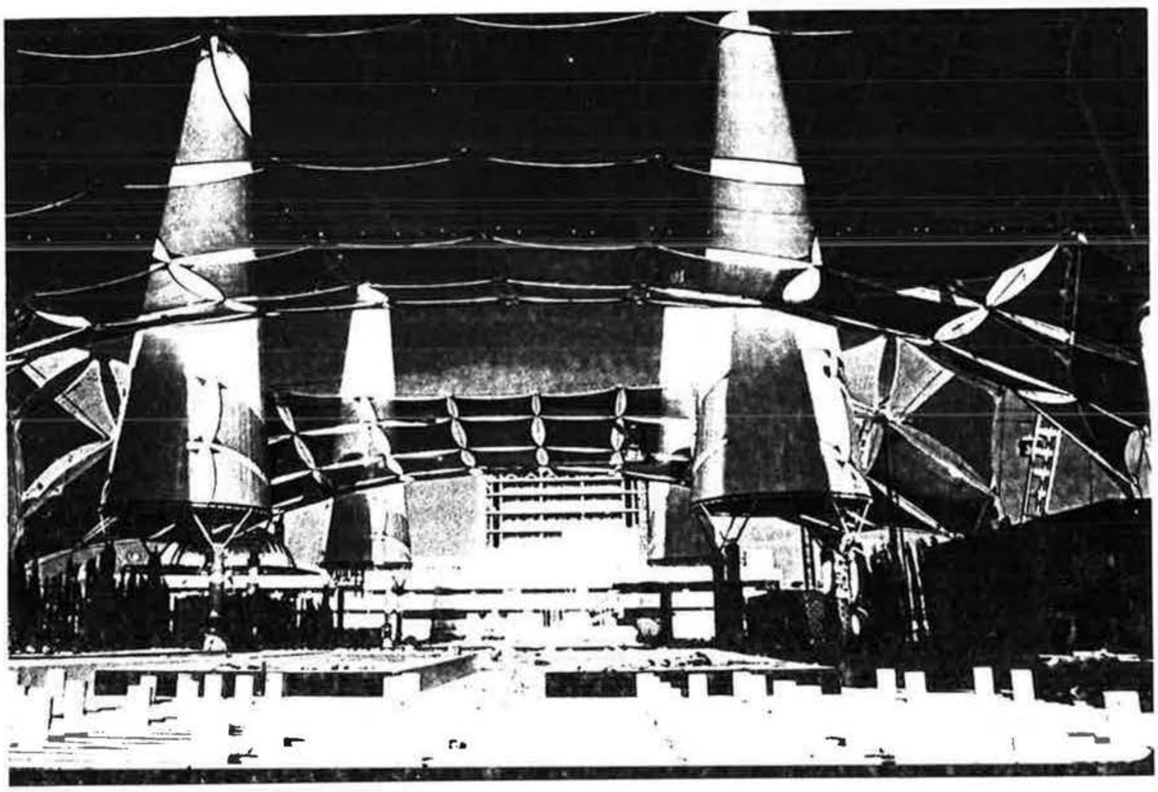


Figure 5: Cool Towers of the Avenue of Europe.

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