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INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR/400- 5

WORKSHOP INTERACTION BETWEEN PHYSICS AND
ARCHITECTURE IN ENVIRONMENT CONSCIOUS DESIGN
25 - 29 September 1989

"Outdoor Comfort Control:
Simulation Monitoring and Evaluation of a
Recent Experience: The EXPO '92 Project in Seville"

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OUTDOOR COMFORT CONTROL

SIMULATION MONITORING AND EVALUATION OF A RECENT EXPERIENCE: THE EXPO'92 PROJECT IN SEVILLE

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1. GENERAL FRAMEWORK

1.1. EXPO'92: THE BASIC FACTS

HOST CITY:Seville(Spain)

CATEGORY:Universal(class one),accorded by the B.I.E.(International Exhibitions Bureau).

THEME:The Age of Discovery.

SURFACE-AREA OF SITE:215 hectares (2,150.000 m^2).

BUILT-UP AREA: 40 hectares(400.000 m^2).

PARKING SPACES:over 30,000.

PAVILIONS:over 100,between the participating countries and international bodies,the Autonomous Comunities of Spain, and the single-theme pavilions in the charge of the organizers.

PARTICIPANTS:over 80 countries,almost 20 international bodies, the 17 Autonomous Comunities of Spain and up to 15 private firms.

OPENING-DATE: April 20th, 1.992 (Easter Monday)

CLOSING-DATE: October 12th, 1.992 (Aniversary of the Discovery of America).

DURATION: 6 months(176 days).

NUMBER OF VISITORS: 18 million(55% from Spain, 45% from abroad).

NUMBER OF VISITS:36 million.

RATE OF REVISITING PER PERSON: 2.01.

PREDICTED NUMBER OF VISITORS ON AVERAGE DAY: 250,000.

AFFORESTATION:350,000 trees and plants (over 500 different species),50 Kms.of hedging,500,000 m^2 of parks and gardens.

ON-SITE ROAD NETWORK:40 Kms.

ENTRANCE POINTS: 6.

ACCESS ROUTES: 7-road traffic 4
-pedestrian 2
-rail 1

NEW BRIDGES OVER THE GUADALQUIVIR: 7.

BUILDINGS FOR ENTERTAINMENTS: 13.

RESTAURANTS: 105.

BARS AND CAFETERIAS. 38.

SHOPS: 105.

STATIONS FOR PANORAMIC RAILWAY: 3.

TELECABIN STATIONS: 3.

LANDING STAGES: 10.

MEANS OF DIRECT ACCESS TO SITE:car,bus, train,boat,helicopter,horse-drawn carriage,pedestrian access.

INVESTMENT IN INFRASTRUCTURE, SURROUNDING AREA: 600,000 million pesetas.

INVESTMENT IN EXPO SITE. 75,000 million pesetas.

(Data represent latest estimates) April, 1.989.

1.2. THE OUTDOOR SPACES IN EXPO'92.

A significant percentage of the EXPO'92 surface are open spaces.

The EXPO'92 organizers want the life in the open-spaces to be during the Exhibition period, a reflection of the way of life of the sevillian people. So, the outdoor spaces will be the place of many social activities and not merely, a physical connection between pavilions. Most of the waiting, resting shoping and restaurant areas are located in open spaces.

For methodological reasons, the outdoor-spaces have been divided into three groups, which differ each other as it is shown below:

	Pedestrian	Rest	Adjacent
Characteristic length (L)	3m <L< 8m	L>20m	-
Residence time (t)	t< 15'	15'<t<90'	-
Activity degree	Light	Sedentary	-
Conditioning intensity	Medium	High	Low

The adjacent spaces have been included because, even being "unoccupied" during the hot hours, the fraction which surrounds the walkways contributes significantly to their conditioning and so, this fraction has to be treated.

In Figure 1, the shaded area represents the open spaces which will be intensively use by visitors.

In Figure 2 shows one hypothetical distribution of spaces in one the 5 existing avenues (300m × 80m).

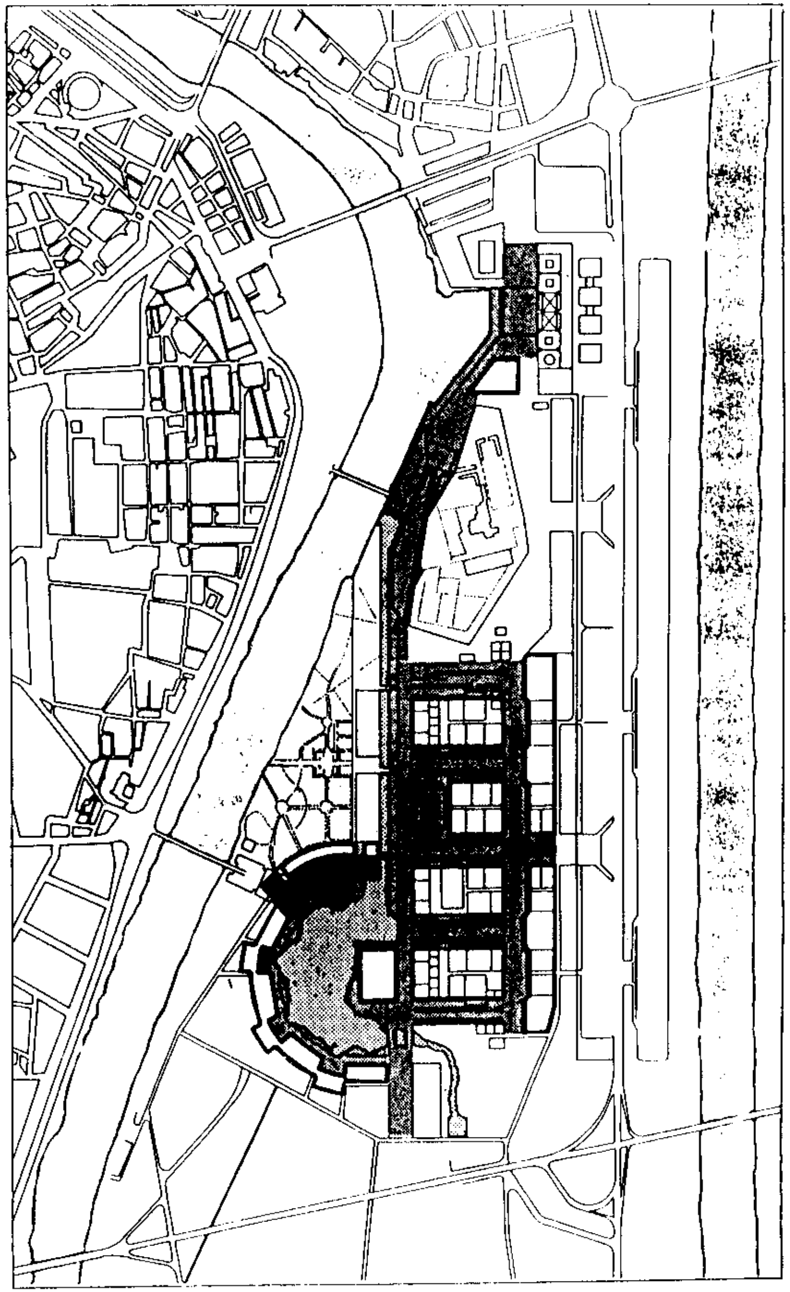


Figure 1

CLASSIFICATION OF THE OPEN SPACES.

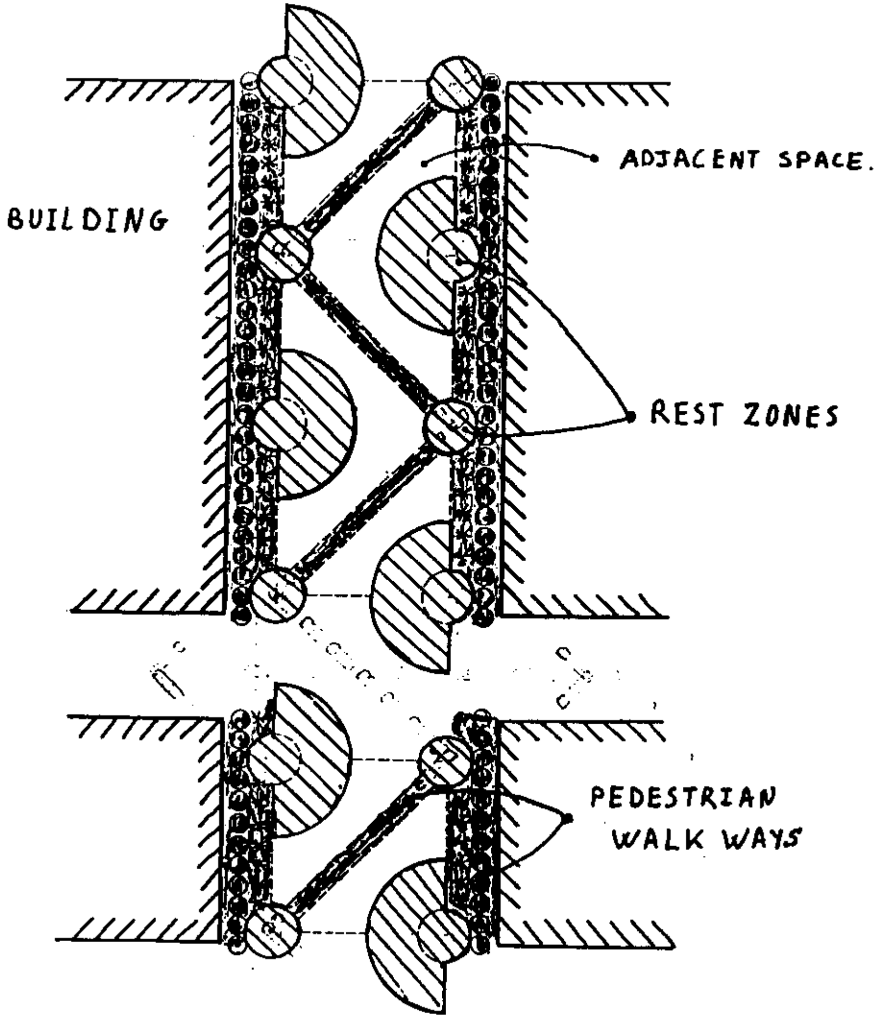


Figure 2

1.3 THE CLIMATE OF SEVILLE.

In many days of the months from June to September, the climatic conditions of Seville are very hard. In a standard summer, the 1% of the hours has a temperature above 38° C.

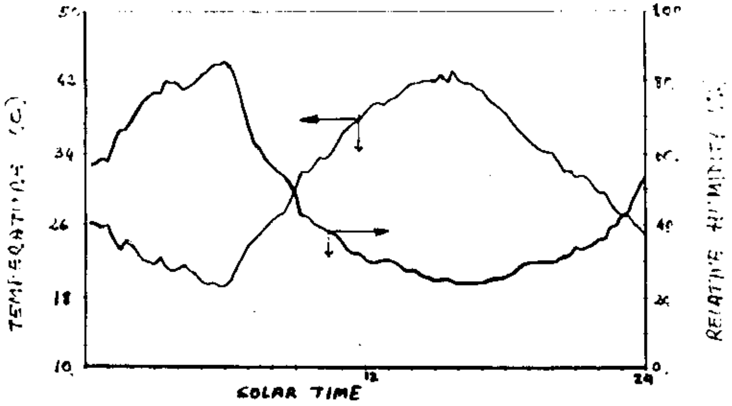
To be more specific, during the summer of 1.989, 18 days had a maximun temperature above 40° C.

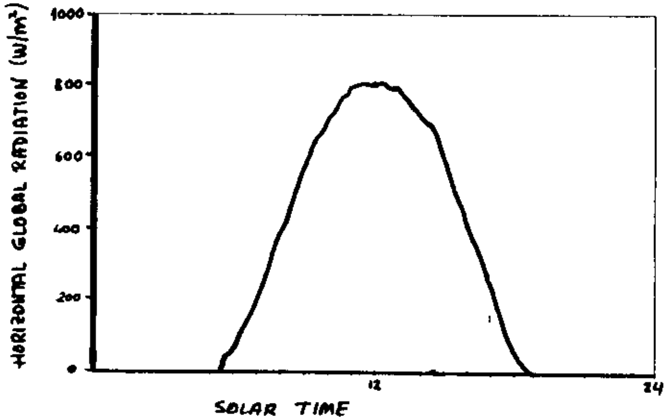
These values of temperature, together with a high solar radiation make unlivable the open spaces during the central hours of the day.

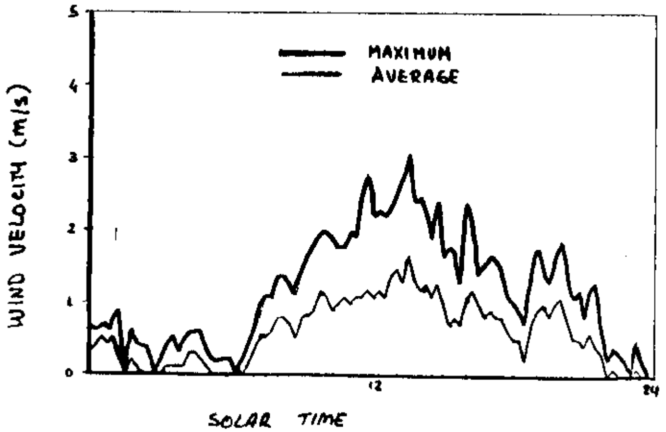
Figure 3 shows the values of dry temperature, relative humidity, horizontal global solar radiation, wind velocity and direction for an actual day (August the 20th, 1.987). The data has been taken at the EXPO'92 site.

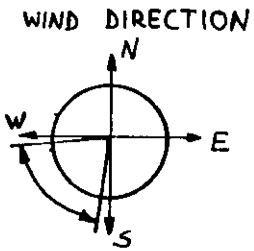
Concerning the wind velocity and direction, it is important to know that most of the summer days exhibit a behaviour very close to that in the figure.

* OUTSIDE CLIMATIC CONDITIONS : 20-08-87

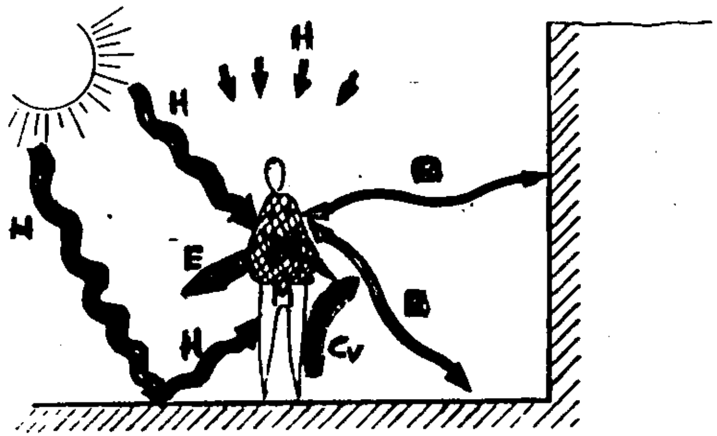






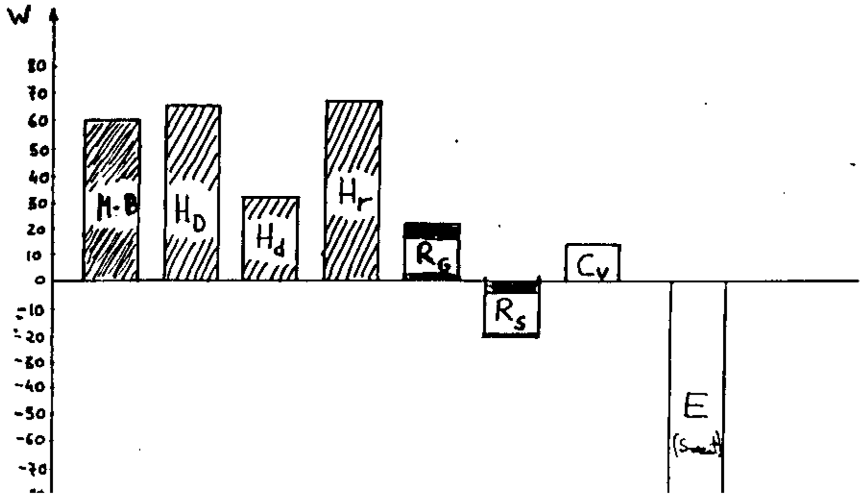


Thermal Equilibrium of the Human Body.



$$M \pm C_V + H \pm R - E = S$$

Typical Heat Flows In An Exposed Situation.



1.4 THE COMFORT IN OUTDOOR SPACES.

As pointed-out in the paper "cooling of outdoor spaces" by Baruch Givoni, basic *differences exist between the enviromental factors affecting human comfort in outdoor and in indoor spaces.*

The conceptual starting point of the work on climatic control of the outdoor spaces in EXPO'92 has been the development of a comprehensive model about the thermal equilibrium of the human body.

Figure 4 shows typical heat flows in an exposed non-covered and non-treated situation.

This kind of model allows us to identify the dominant heat flows and, from these, what measurements had to be taken and in which order.

The resulting main criteria for conditioning are:

1.- Blocking the solar radiation (direct, diffuse and reflected).
2.- Lowering the temperature of the surrounding surfaces.
3.- Lowering the air temperature.
4.- Increasing the air velocity.

Taking into account that the outdoor comfort conditions are not clearly defined so far, we have developed a working methodology which allows us to compare very accurately (in terms of comfort) different solutions. This method uses the "Sensation temperature" concept and to be more precise the "Increase of sensation temperature" concept which will be clarified below with an example.

2. AIMS AND METHODOLOGY.

Comparing what the EXPO'92 organizers want and what the clima of Seville permits, it is obvious that open-spaces have to be conditioned, in order to make feasible the set of activities intended to be done on them.

Starting from the conditioning criteria described in section 1.4, the aim of the work is to find how those criteria can be efficiently carried out preserving a set of aesthetic, economic and funtional constraints.

The project includes the following items:

- To identify, understand and evaluate the heat transfer phenomena occurring in open spaces.
- To provide basic rules for the comfort-oriented design of the different zones.
- To develop design tools to optimize the sizing of elements and air-treatment systems.

For each individual system or element, the methodology includes:

Theoretical modelling.
Experiments.
Validation.
Sensitivity analysis.
Studies about comfort.

The different individual models have been coupled by using the informatic structure S3PAS.

3.BASIC ACTION FOR CONDITIONING: SHADING.

3.1.INTRODUCTION.

The first criterium for outdoor comfort control is to protect the occupied space from the sun.
The requirements of a good covering are:

a) To guarantee the whole obstruction of the solar radiation over the occupied space (geometric factor).

b) To assure a low level of solar transmissivity (quality of the shadow).

c) To avoid the overheating of the covering's underside.

As we will see later, the appropiate design of a covering is not a straigthforward activity, due to the large number of variables involved and to the very different behaviour showed by different coverings.

Three kind of coverings have been analyzed (Figure 5)

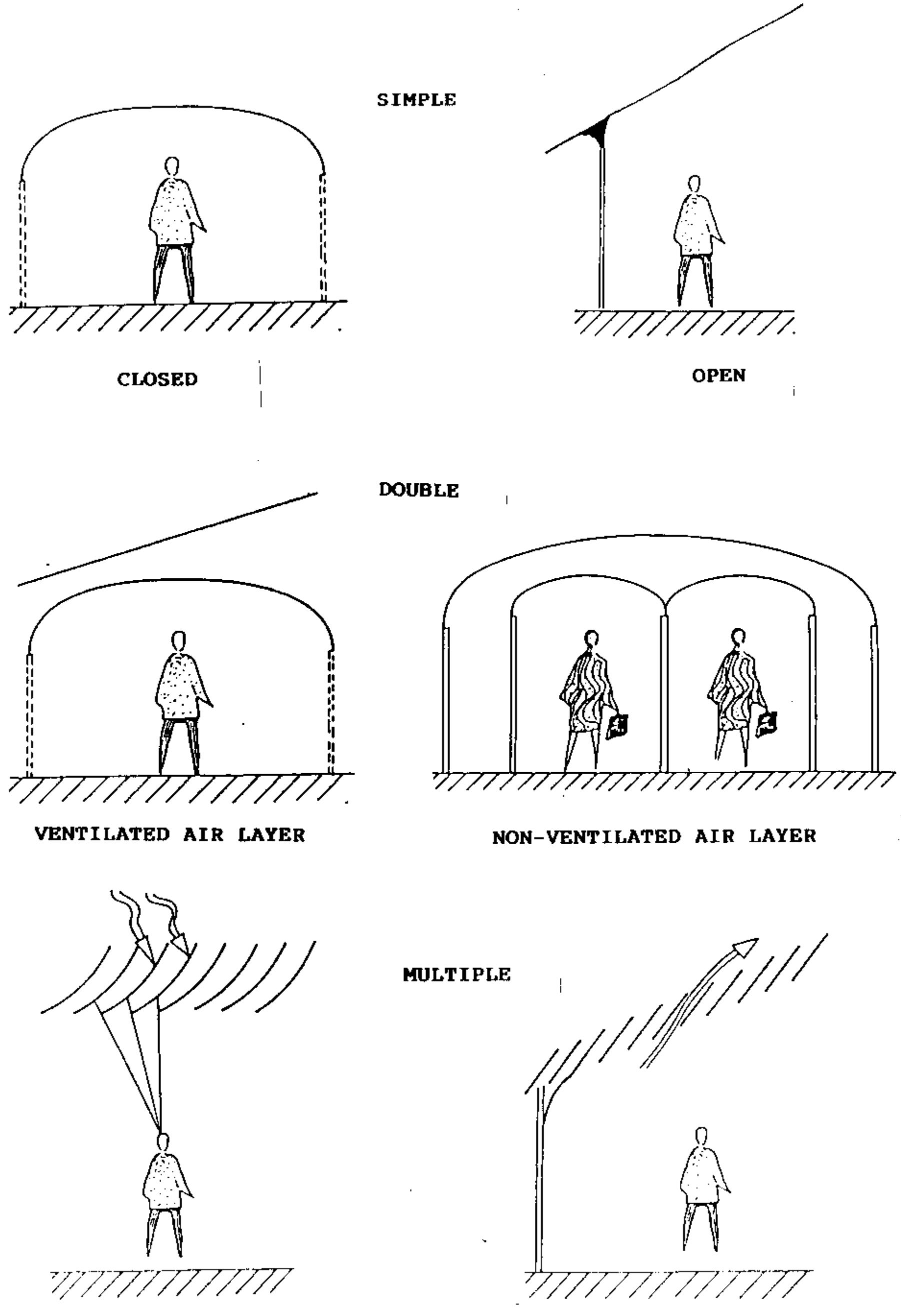


Figure 5

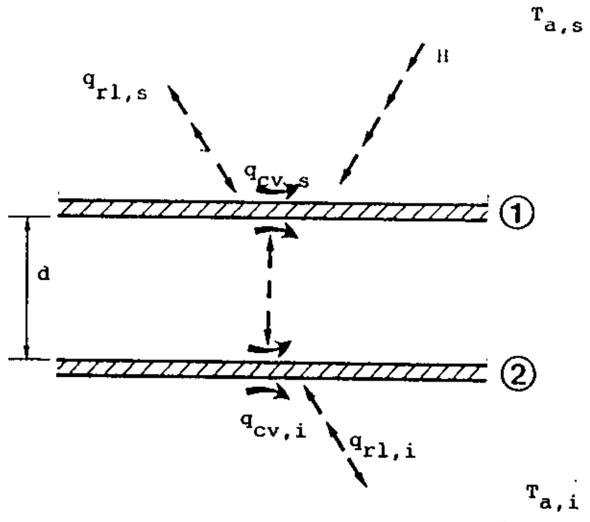
3.2. MODELLING.

As a matter of example, Figure 6 shows the governing heat transfer equations for a double covering (non ventilated).

The same level of detail have been used for the modelling of simple and multiple coverings.

In all cases, the major incertitudes of this formulation are the short-wave radiant properties of the materials and the film coefficients.

To evaluate these variables, it has been necessary the setting-up of two kind of experiments which will be described in the next section.



Shortwave radiant properties

$$\begin{cases} \tau_{eq} = \dfrac{\tau_1 \cdot \tau_2}{1 - \rho_1 \rho_2} \\ \alpha_{eq1} = \alpha_1 \left[1 + \tau_1 \rho_2 \dfrac{1}{1 - \rho_1 \rho_2} \right] \\ \alpha_{eq2} = \alpha_2 \tau_1 \left[\dfrac{1}{1 - \rho_1 \rho_2} \right] \end{cases}$$

Equation Cover 1 $\alpha_{eq,1} \cdot R = h_e (T_1 - T_{a,e}) + \epsilon_{1,e} \sum_{j=1}^{n_1} F_{1-j} (T_1^4 - T_j^4) + h_r (T_1 - T_2) + h_c (T_1 - T_2$

Equation Cover 2 $\alpha_{eq,2} \cdot R = h_i (T_2 - T_{a,i}) + \epsilon_{2,i} \sum_{j=1}^{n_1} F_{2-j} (T_2^4 - T_j^4) + h_r (T_2 - T_1) + h_c (T_2 - T_1$

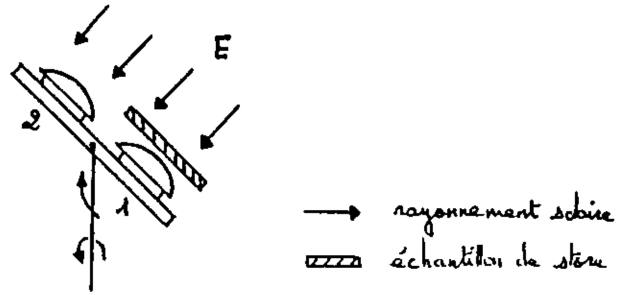
$$h_r = \frac{4 \sigma T_m^3}{\dfrac{1}{\epsilon_1} + \dfrac{1}{\epsilon_2} - 1}$$

3.3. EXPERIMENTS.

- Specific experiment to calculate the short-wave radiant properties (absortivity and transmissivity) of semitransparent materials (Figure 7).

- Full-scale experiment oriented to validate the model (Figure 8).

MEASUREMENT OF TRANSMISSIVITY



MEASUREMENT OF REFLECTIVITY

3

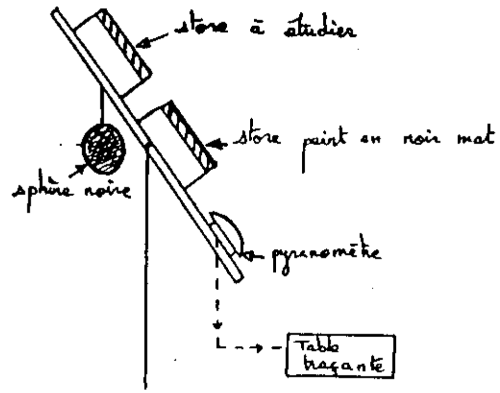


Figure 7

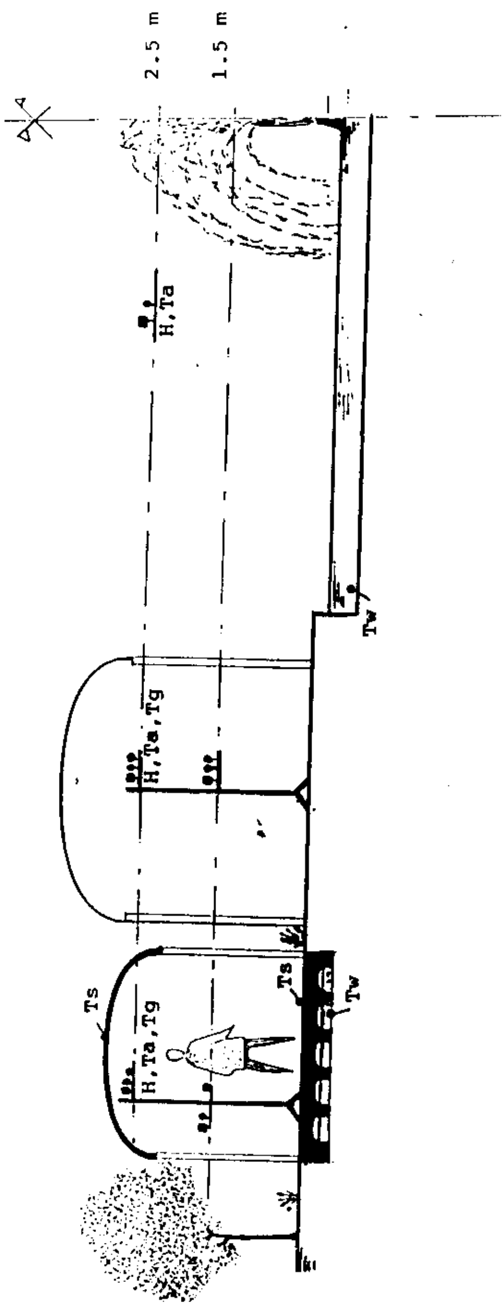


Figure 8

3.4. VALIDATION.

Figures 9 and 10 show the comparisons between the calculated and the measured values of the covering surface temperature. As it can be seen, there is a considerable agreement between them. The disagreement observed during the central hours of the day (Figure 10) are due to shadows projected by trees over the sensor.

The validation revealed that the dust gave rise to an increase of the covering absortivity from 0.25 to 0.36.

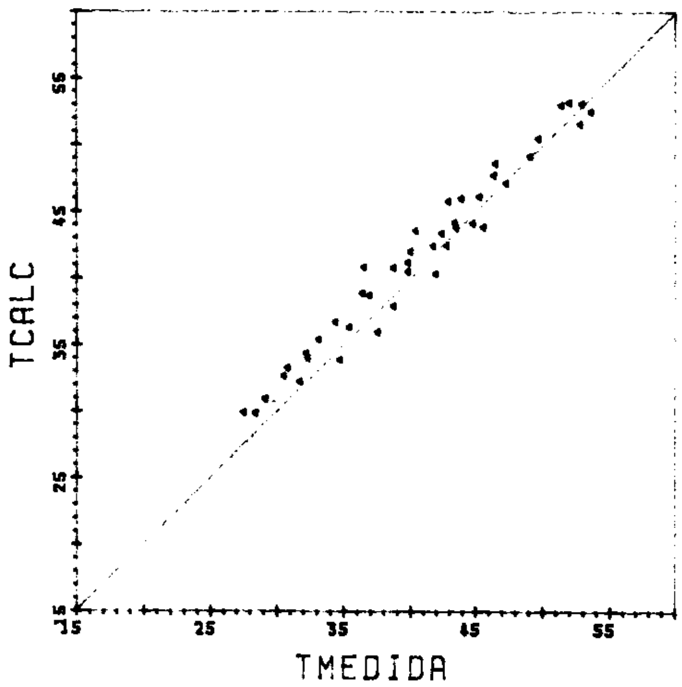
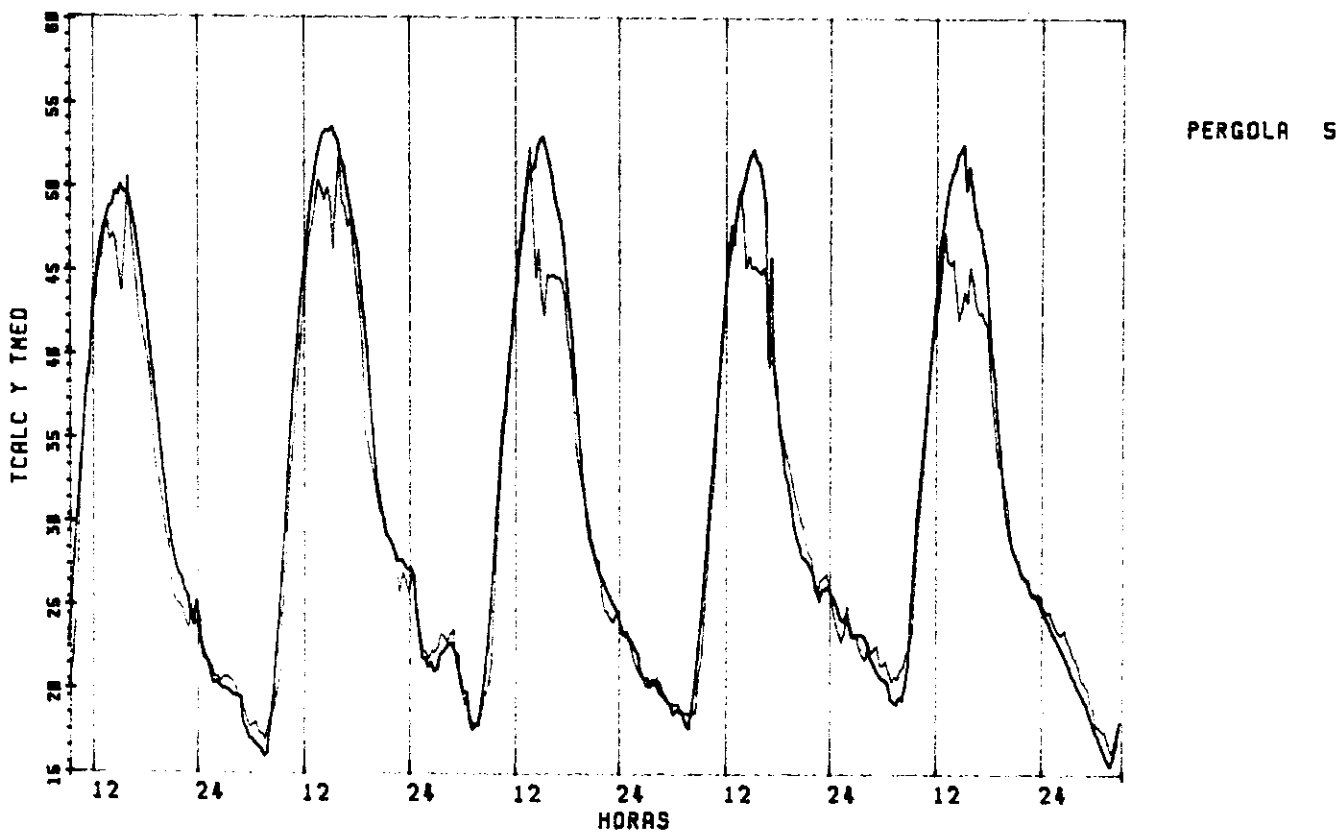


Figure 9

Figure 10



3.5. SENSIVITY ANALISIS.

A large set of sensitivity analisis was carried out over the three kind of coverings.

In all cases we want to know how changes in design variables affect the transmissivity and the overheating of the covering.

As a matter of example, Figure 11 shows the influence of the transmissivity of the upper cover on the overheating of a ventilated double covering.

Figure 12 shows the influence of the shape on the transmissivity for a multiple covering.

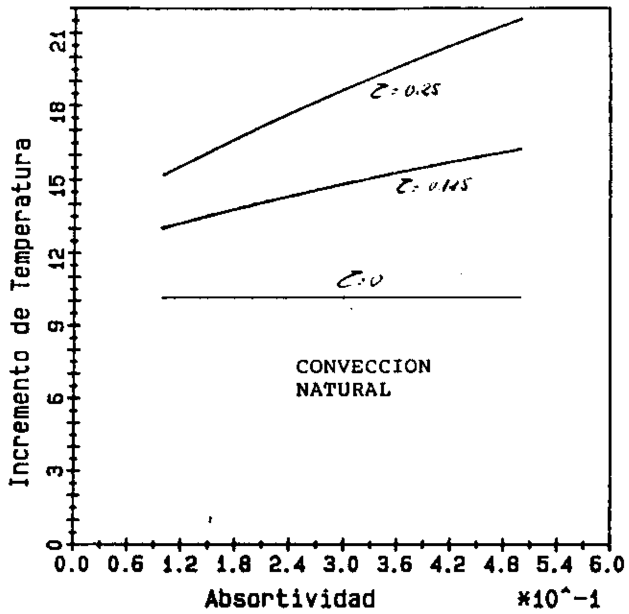


Figure 11

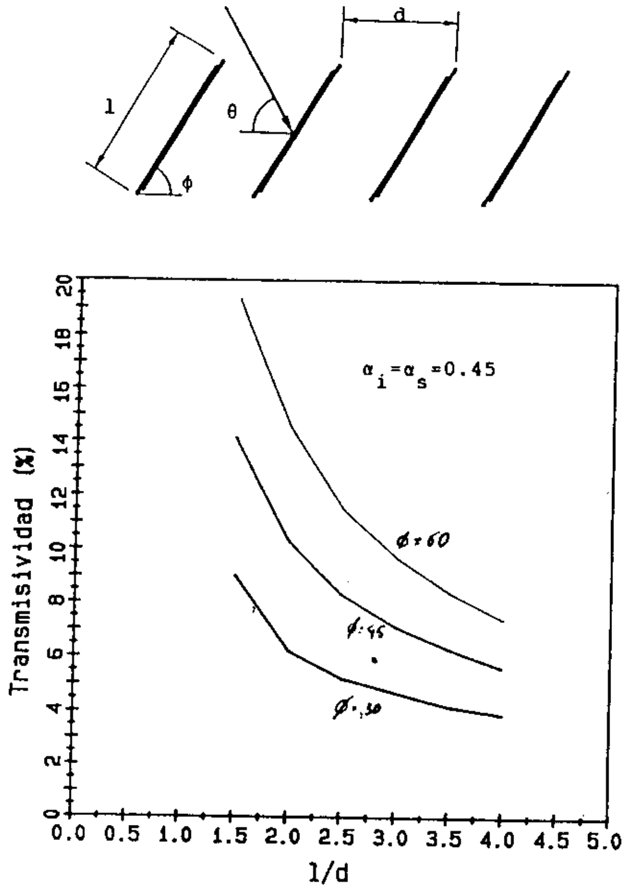


Figure 12

3.6. EFFECT ON THE COMFORT CONDITIONS (INCREASE OF THE SENSATION TEMPERATURE).

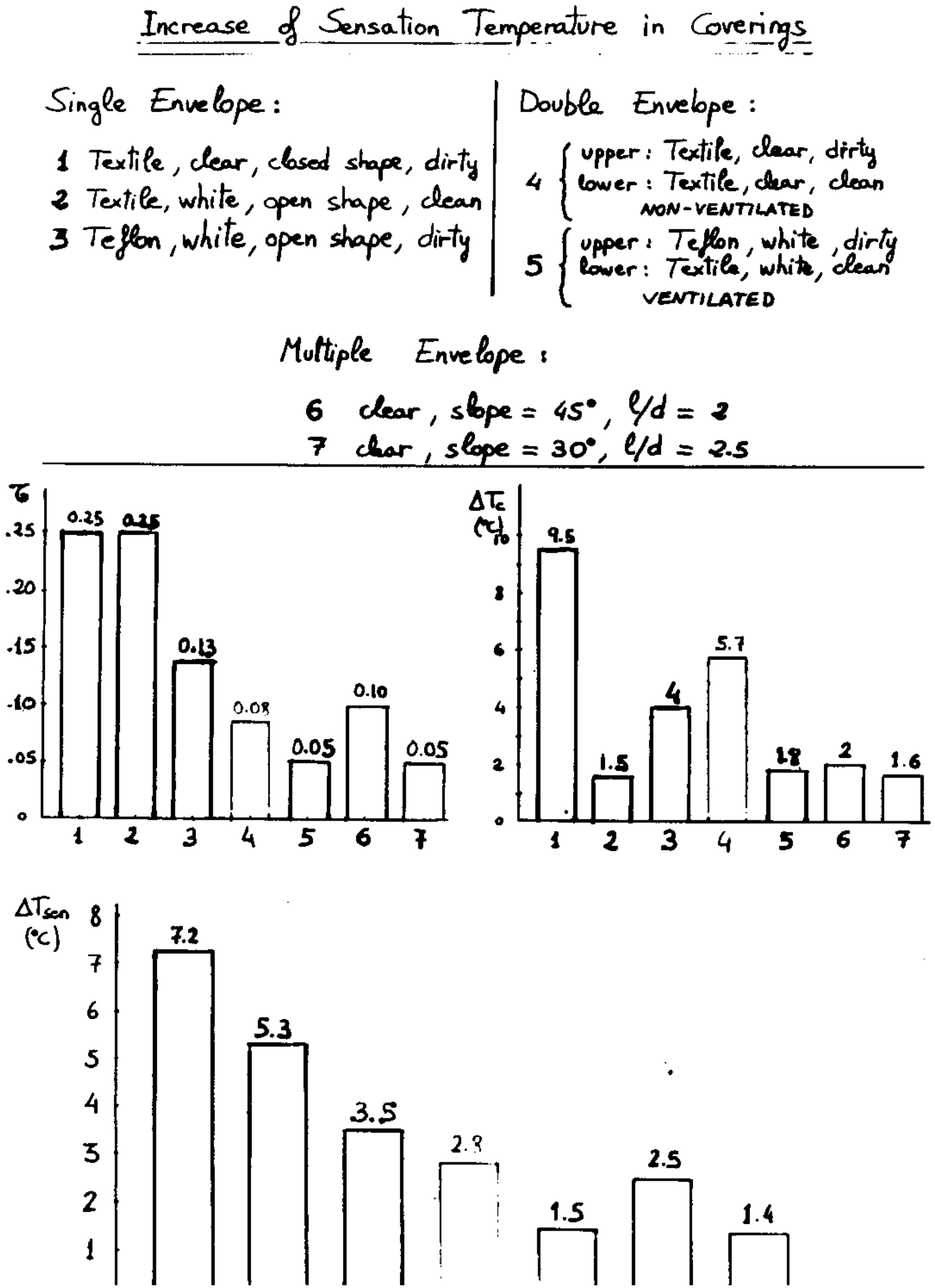
To take a decision about the covering best suited to a certain application, it is necessary to compare, in terms of comfort, the effect of the differents possibilities.

The major problem to evaluate the interest of each possibility is that very often, the lower the transmissivity of a certain covering, the higher its absortivity and hence, the higher the overheating. As a consequence, both effects have to be characterized by a single variable.

Starting from a reference situation (in this case a covering made of a thick layer of leaves) we analyze the performance of each covering by calculating its increase of sensation temperature in relation to that in the vegetation covering.

Figure 13 shows the results for 7 different coverings.

If has been assumed zero transmissivity and no overheating for the reference situation.



4. SPECIFIC ACTIONS FOR CONDITIONING (WALKWAYS).

Apart from the use of an appropiate covering, the main action to be done for conditioning a walkway is the treatment of the adjacent surface in order to lower its temperature, and to reduce the reflected solar radiation. A good choice for that is the use of lawn or water films (ponds).

Concerning the lowering of the air temperature, the characteristic length of pedestrian walkways is too small and usually, they are not confined. Thus, the performance of the walkway is very sensitive to the wind (even light), and there is no a real chance in lowering the air temperature.

One exception is the use of jets and fountains in ponds adjacents to the walkway. During the experiments, it was made clear that this combination is one of the most powerful conditioning technique.

First, the pond provides a cold surface with low solar reflectivity. One the other hand, the jets work as a natural fan and the fountains (of sprayed water) as a means to cool simultaneously the water and the surrounding air.

The result is a continous flow of cool air towards the walkway which creates a very pleasant sensation (Figura 14).

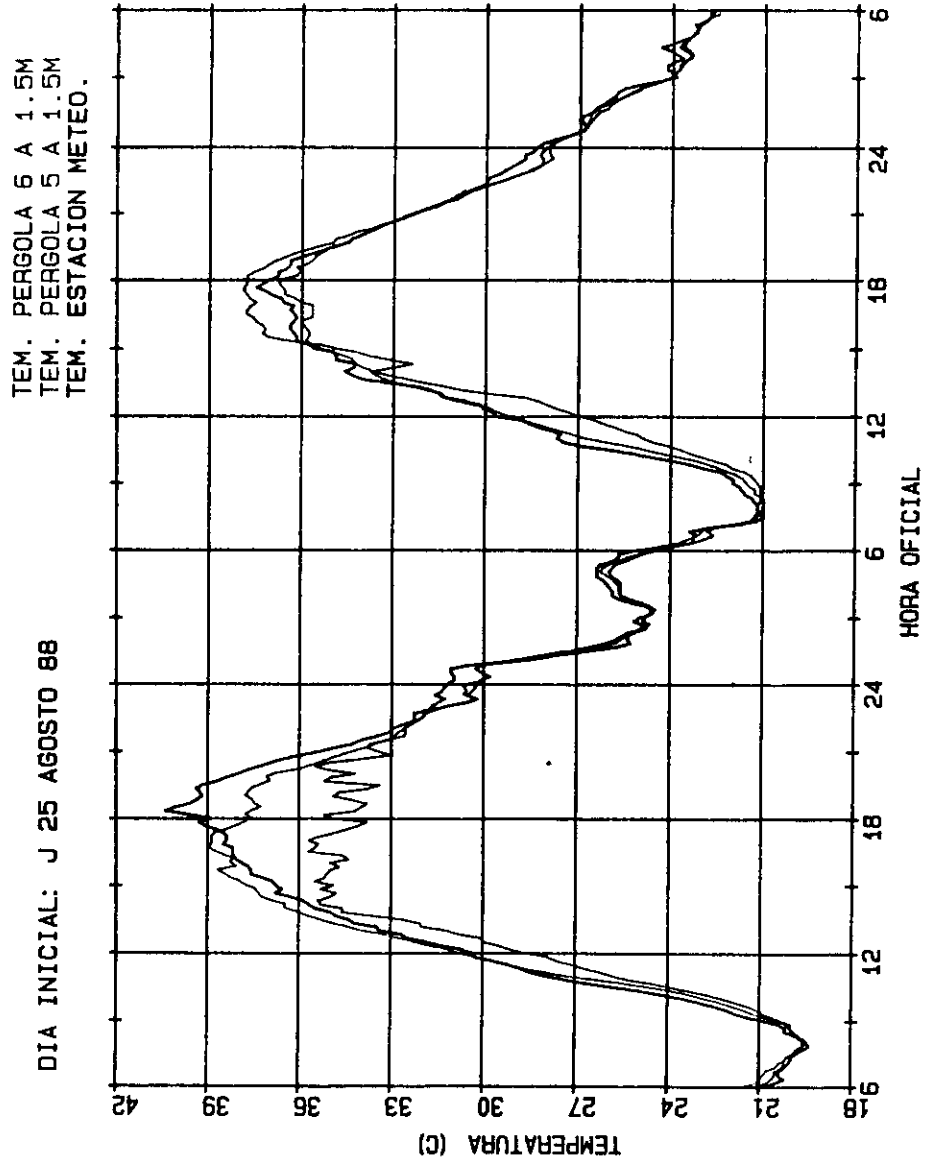


Figure 14

5. SPECIFIC ACTIONS FOR CONDITIONING (REST ZONES)

The table above shows the relationship between the criteria for conditioning and the specific actions to be done in rest zones.

CRITERIA	ACTIONS
Blocking the solar radiation	Covering
	Confinement of the occupied space
Lowering the temperature of surrounding surfaces	Cold pavements
	Water falls
Lowering the air temperature	Evaporative cooling
	Sensible cooling

During the summer of 1.989, a full scale experiment was erected to check the performance of different systems oriented to the conditioning of a rest zone called "Bioclimatic Rotonda".

Apart from a white PVC covering, the Bioclimatic Rotonda incorporates the following systems:

* Cascades and cold pavements (Figure 15)
  Concept.- Lowering the temperature of surfaces.

* Air treatment unit (Figure 16)
  Concept.- Packing fill evaporation (mechanical evaporative cooling).

* Micronizers in trees (Figure 17)
  Concept.- Suspended droplets evaporation (Natural convection).

* Micronizers in tower (Figure 18)
  Concept.- Droplets evaporation (Forced convection; driven force-fan).

* Micronizers in peripheral rings (Figure 19 and 20)
  Concept.- Droplets evaporation (Forced convection; driven force; wind).

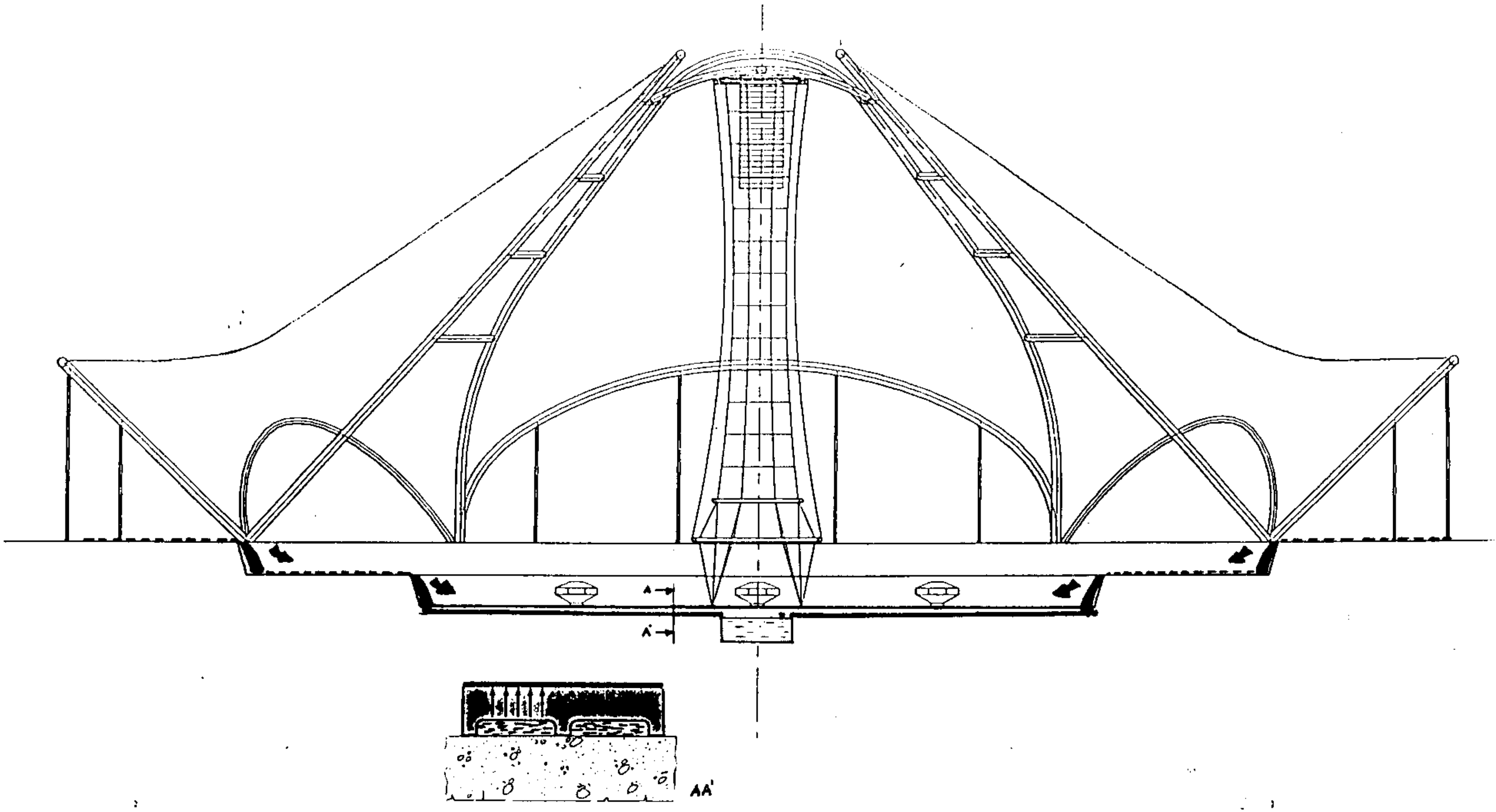


Figure 1$_5$

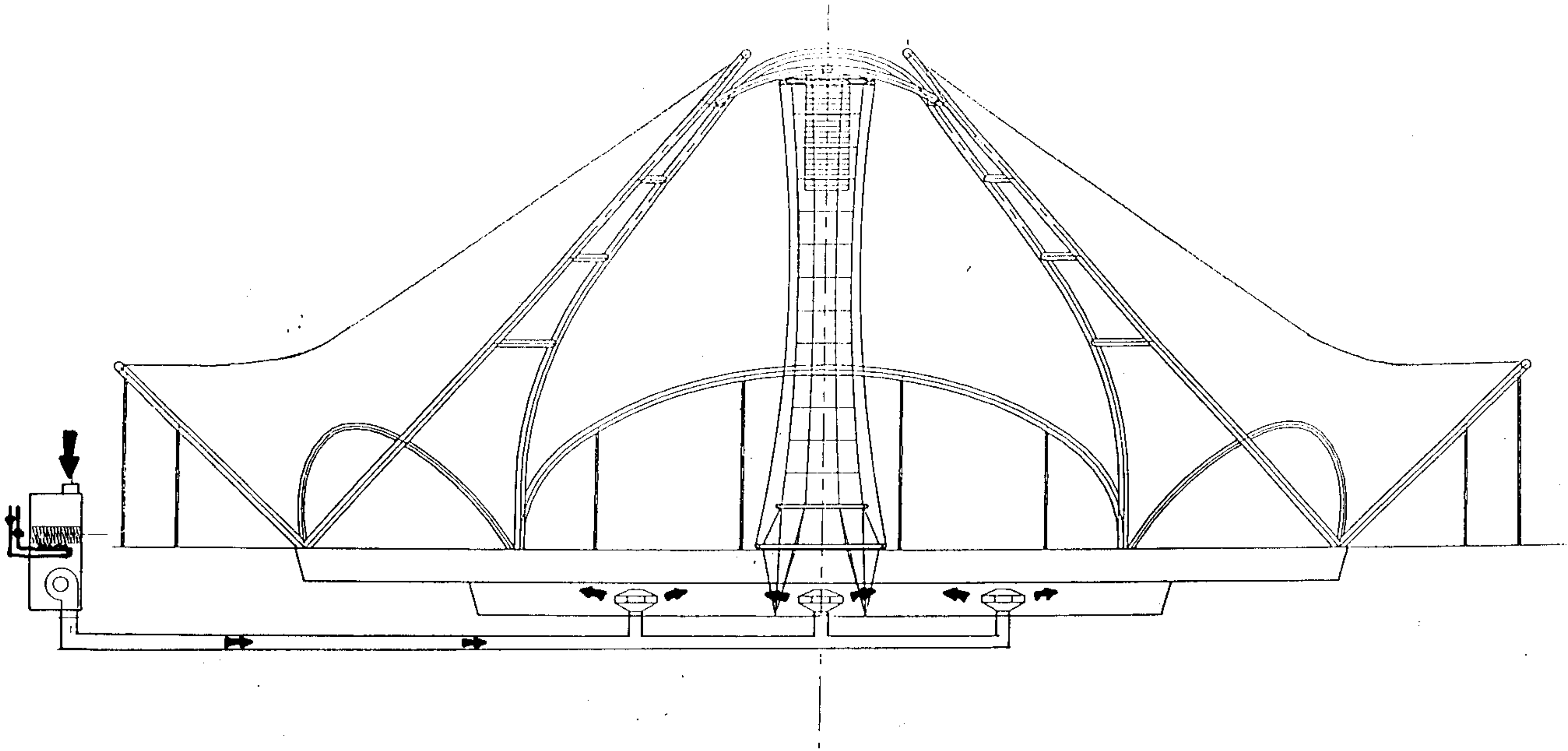


Figure 16

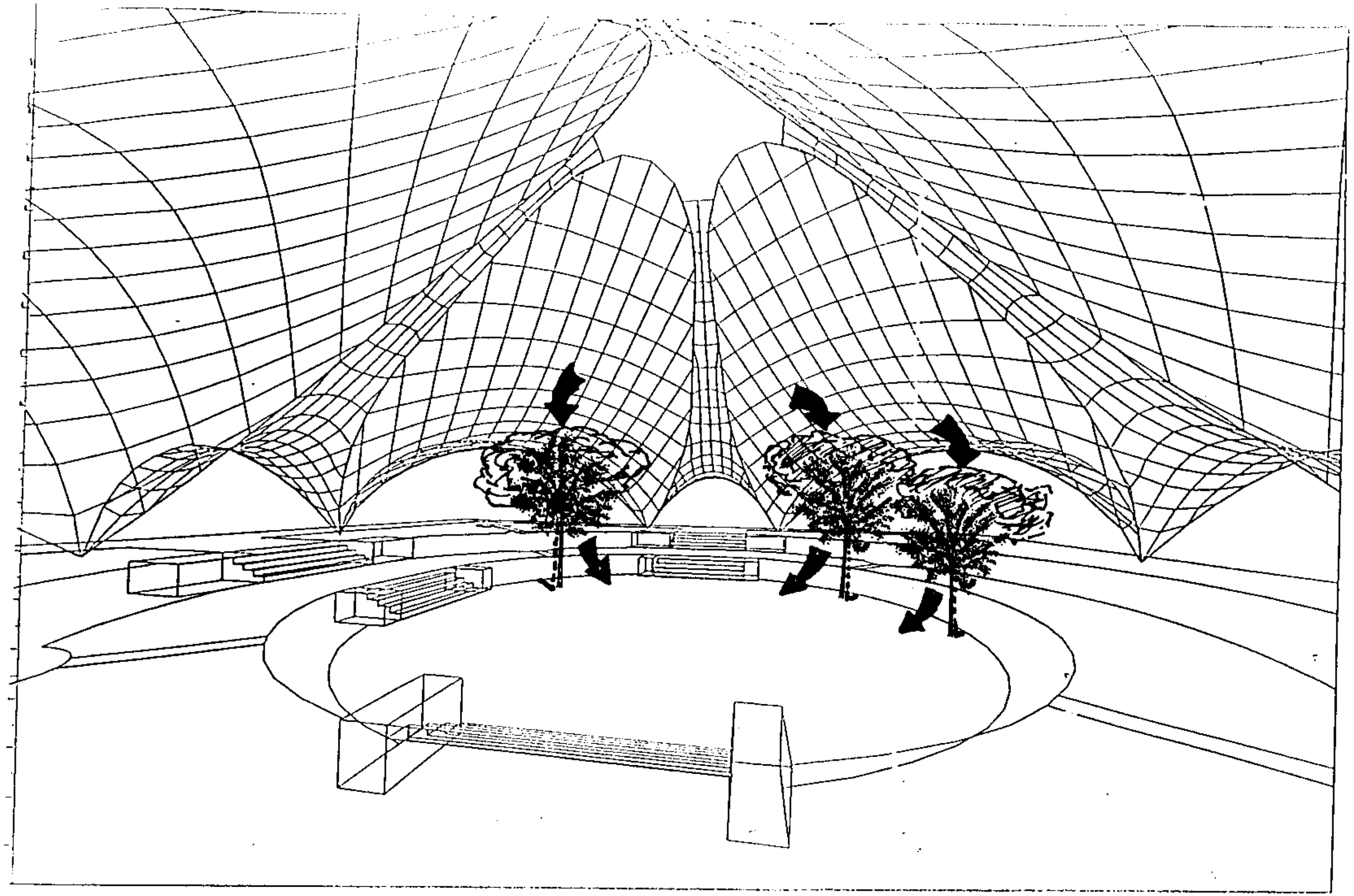


Figure 17

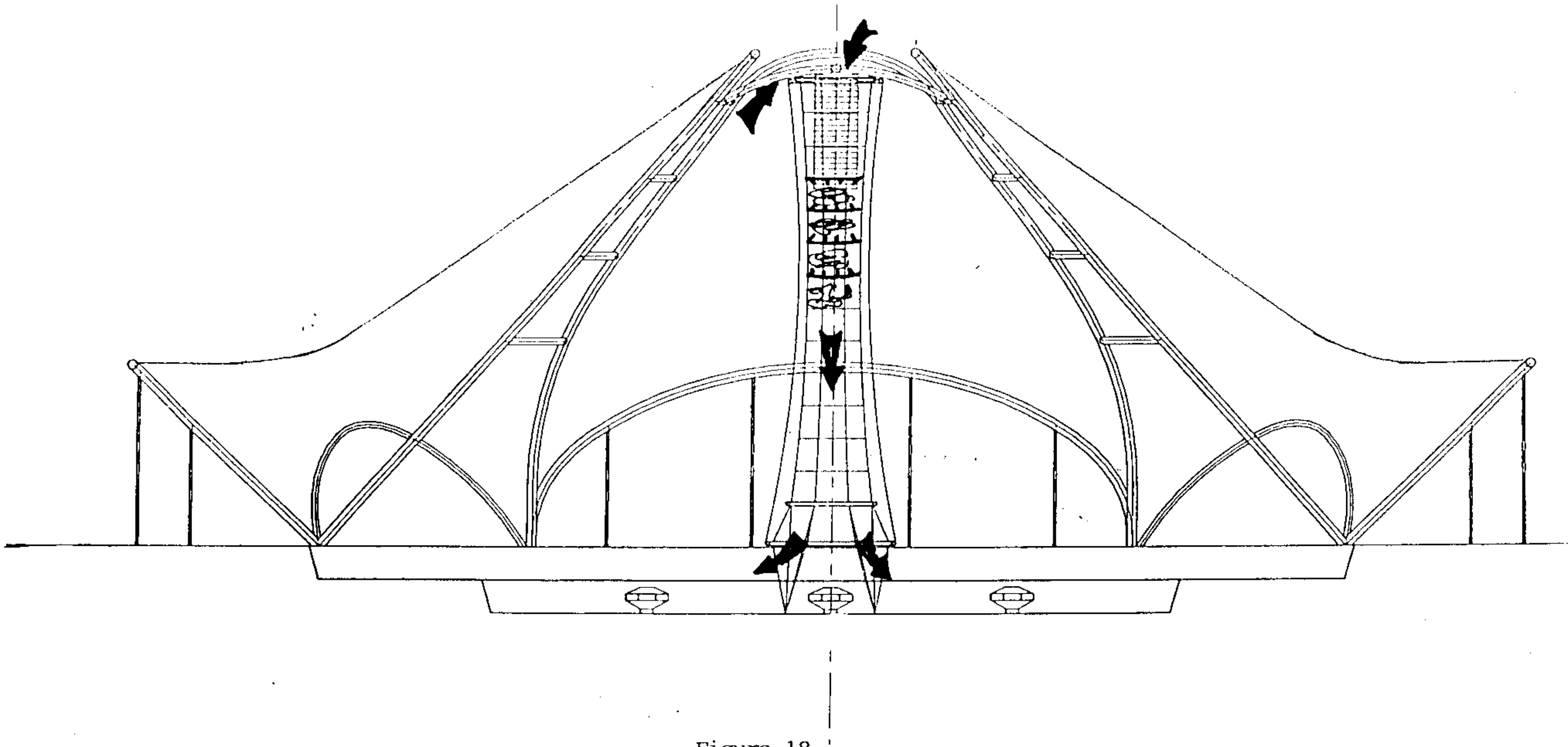


Figure 18

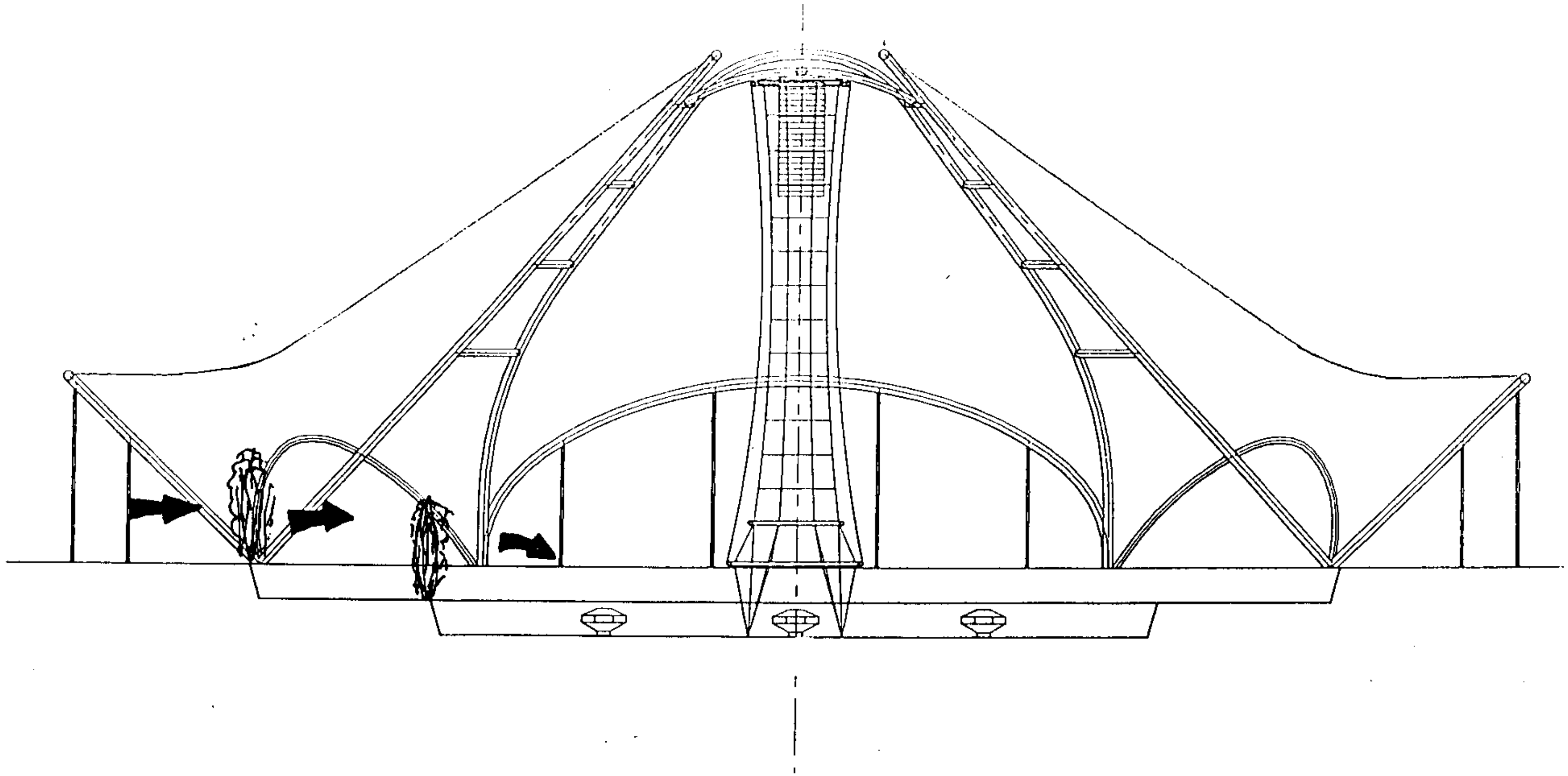


Figure 19

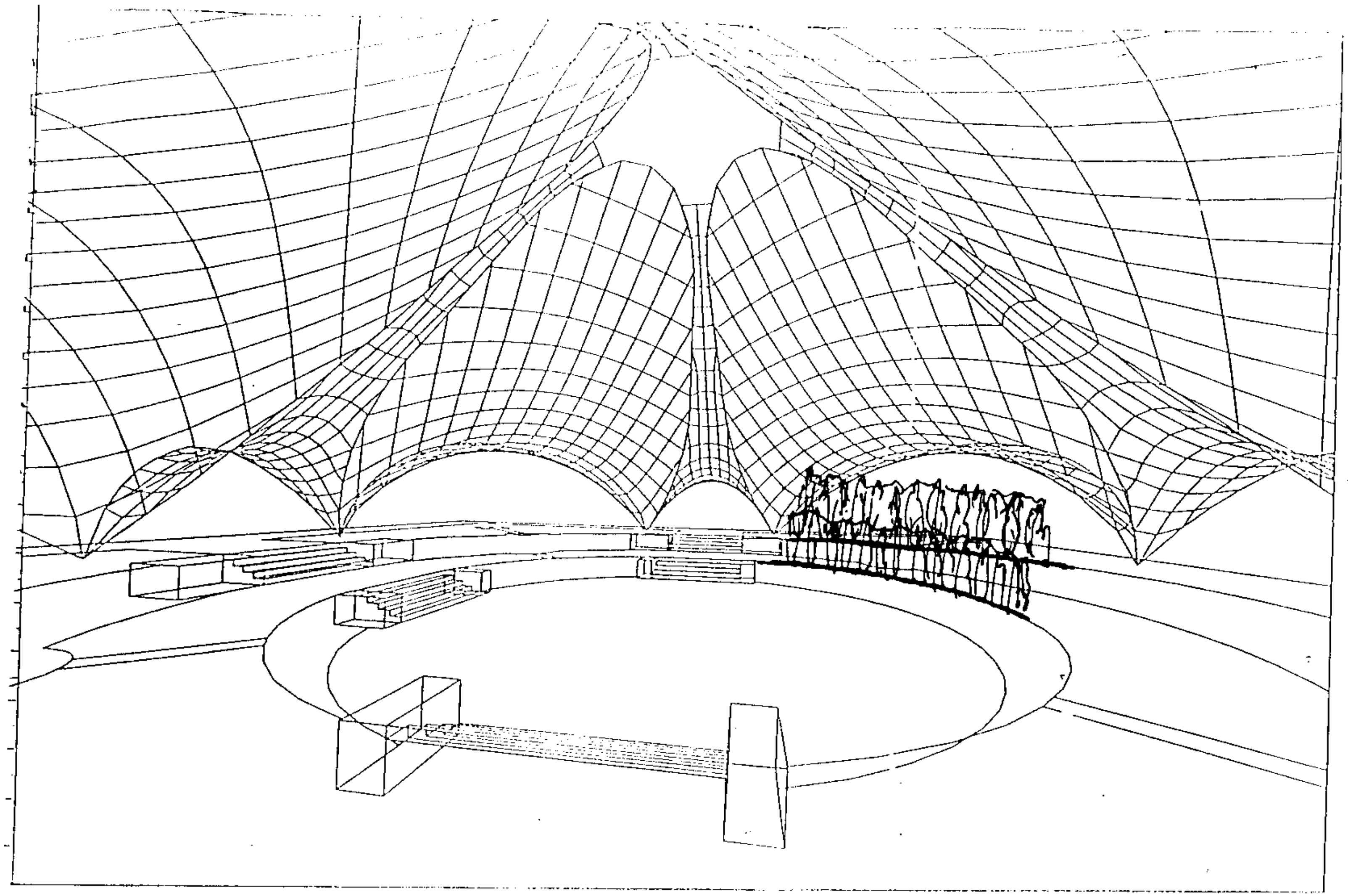


Figure 20