PASSIVE COOLING TECHNIQUES IN INDUSTRIAL BUILDINGS: A SIMULATION AND EVALUATION STUDY

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ABSTRACT. This paper presents an analysis of the thermal conditions in an industrial building, carried out with a view to improving the level of comfort inside the building by means of passive cooling techniques. In its original state, the temperature inside the building at the height of Summer surpassed 40 °C. The S3PAS computer programme enabled us to reveal the source of the problem. At the same time, we were able to simulate the thermal behaviour deriving from each passive cooling measure, prior to final implementation, and thereby select the most suitable one for the usage of the building. Monitoring of the building, once the proposed measure was implemented, reveals a close approximation between the results forecast by S3PAS and those actually obtained. A reduction of the interior temperature to a maximum of 34 °C was achieved.

1. Introduction

In general, industrial buildings are not designed so as to obtain reasonable levels of comfort therein. A particularly important aspect, given its contribution towards discomfort, is the lack of insulation in the building. This factor causes the interior surfaces of the enclosure to reach extremely high temperatures.

Construcciones Aeronáuticas S.A. have, at their Seville factory, industrial buildings inside which the temperature surpasses 40 °C on the hottest days of the Summer. In this paper we study the levels of comfort within one of these buildings and of the possible passive cooling techniques which would lead to a reduction in the resultant inside temperature.

The problem was analyzed with the aid of the S3PAS computer programme [1]. The building was simulated, with the outdoor conditions pertaining on a severe Summer's day, as laid down by Spanish regulations, in its original state and following implementation of a series of passive cooling techniques. The simulations performed revealed the source of the problem and enabled us to select the most suitable technique considering the usage of the building.

2. Description of the Building. Original State

The building under study [2] is an industrial building of approximately 1650 m^2, forming a 31×55 m rectangle. The main axis runs NE-SW. All the enclosing walls are exterior with the exception of the NW one which is adjacent to an air-conditioned office building.

The building is divided into two areas: a Warehouse of approximately 1300 m^2 and a

S. Alvarez et al. (eds.), Architecture and Urban Space, 761–766.

Table 1: Areas by Orientation (m^2)

	SE	SW	NW	NE	Roof	Floor
Warehouse	297^a	175^a+50^b	225^e	225^a	1250^c+125^d	1364^f
Printing Works	75^a	225^e	200^a+25^b	200^a+25^b	300^c+40^d	286^f

Table 2: Constructional Features

Walls	U ($W/m^2 K$)	Weight (kg/m^2)
^{a} Exterior	1.47	376.
^{b} Metal doors	5.8	
^{c} Roof	0.72	96.
^{d} Skylights	4.30	
^{e} Partition	3.31	122.
^{f} Floor	1.74 W/mK	480.

Printing Works which occupies some 350 m^2. The average height of the building is 7.3 m. The area of each confining surface is shown for each orientation in Table 1. The construction features are shown in Table 2.

The building is occupied by 6 to 8 people when in use, which is from 5 to 14 hours (solar time). During this period the illumination is 0.88 W/m^2 in the Warehouse and 3.52 W/m^2 in the Printing Works, where there is equipment with an installed capacity of 37 kW.

The Warehouse area is naturally ventilated whereas in the Printing Works there is forced ventilation by fans which renew the air 6 times each hour. The doors are open when the premises are occupied.

The S3PAS programme was used to simulate the interior conditions of the building on a design Summer's day in Seville (percentile 1 %), both at a constant interior temperature and allowing this to fluctuate freely. The former conditions enable us to ascertain which constructional aspects influence the thermal load to a greater extent. The latter permit comparison of the simulated and actual interior conditions, given that the building has no air-conditioning equipment. The distribution of the load components as determined by S3PAS is shown in Table 3.

Figure 1 shows the resultant interior temperatures in the Printing Works and in the Warehouse, together with the exterior temperature for reference purposes. A situation of obvious discomfort may be observed (maximum temperatures of 39.7 °C in Warehouse and 41.5 °C in the Printing Works), elimination of which is the purpose of this work.

Table 3: Principal Load Components (kWh per day)

	Printing Works	Warehouse	TOTAL
Conduction (Roof)	218	909	1127
Conduction (other Walls)	217	535	752
Radiation	47	194	241
Occupancy	2	6	8
Illumination	14	15	29
Equipment	370	0	370
Ventilation	81	57	138
TOTAL	949	1716	2665

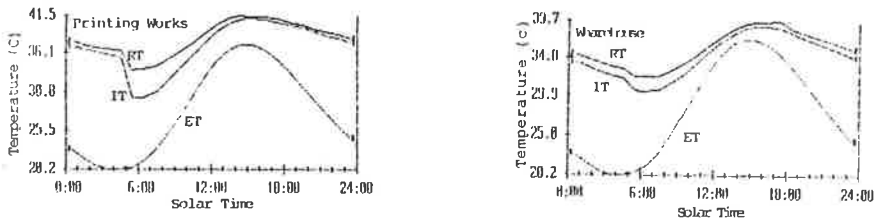

Figure 1: Resultant Interior Temperatures in the Original State. ET: Exterior Temperature, IT: Interior Temperature, RT: Resultant Temperature

3. Selection of Passive Cooling Techniques

Analysis of the thermal loads at constant interior temperature (Table 3) reveals that the principal load component is conduction via the roof. (In the Printing Works, the greatest load is that of the equipment, but this component cannot be reduced). The cause of the high resultant temperatures is the high roof temperature.

In order to reduce heat transfer via conduction in general terms, and particularly via the roof, together with the interior surface temperature thereof, the following techniques may be utilised:

a) Insulation of the exterior walls,
b) Installation of a false ceiling beneath the roof,
c) Insulation of the roof with 4 cm of insulation,
d) Installation of an irrigation system on the roof,
e) Installation of a false ceiling with 4 cm of insulation and mechanically ventilated.

Each measure was evaluated from the point of view of the thermal load at constant

Table 4: Maximum Values of Total Load and Roof Temperature

Technique Simulated	Max. load (kW)	% Reduction	Max. Temp.
initial situation	223	-	38
a	207	6.8	38
b	186	16.4	33
c	167	24.9	30
d	118	47.2	27
e	110	50.7	26.5

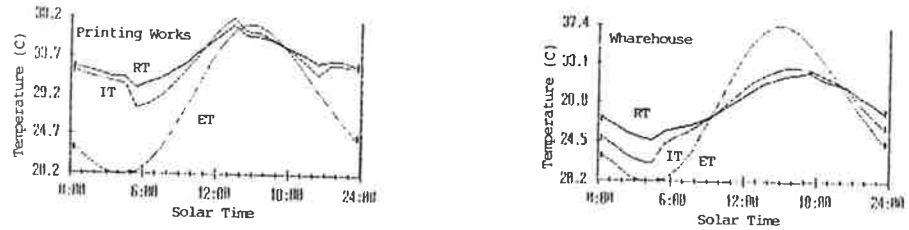

Figure 2: Resultant Interior Temperatures After Simulation of Technique e). ET: Exterior Temperature, IT: Interior Temperature, RT: Resultant Temperature

interior temperature with the S3PAS programme. Table 4 shows the maximum daily values of the total load and the maximum temperature obtained on the interior surface of the roof (or of the false ceiling when present).

The last-mentioned technique, the installation of an insulated and ventilated false ceiling, has the advantage of being simple to install, requires no special maintenance and appears to be sufficient on its own to achieve the desired effects.

4. Free Fluctuation of the Interior Temperature

Figure 2 shows the free fluctuation of the temperature in the two areas following the installation of the proposed technique, technique e), obtained by simulation with S3PAS. With respect to the initial values (Fig. 1), a reduction of 4 °C in the resultant temperature in the Printing Works may be observed, and 6.5 °C in the Warehouse.

Analysis of Figure 2 shows that the outdoor temperature is inferior to the inside temperature at night, so the resultant inside temperature could be reduced still further by ventilation of the building at night.

Figure 3 shows the temperatures obtained by simulation assuming forced ventilation for 6 renewals per hour at night-time. A reduction of the resultant temperature of an additional 1 °C is achieved in the Warehouse and 4 °C in the Printing Works.

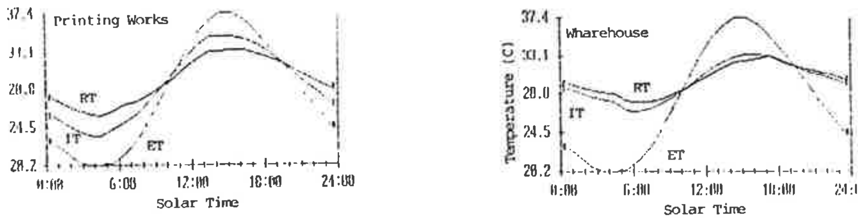

Figure 3: Resultant Interior Temperatures After Simulation of Technique e) plus Night Ventilation. ET: Exterior Temperature, IT: Interior Temperature, RT: Resultant Temperature

This situation is better than the initial technique e, therefore technique e) with night ventilation was recommended for implementation in the building: An insulated false ceiling of 4 cm of glass fibre was installed, with spaces for translucent panels beneath the skylights, ventilated mechanically by means of a group of extractors located above the false ceiling on the SE wall. Renewal of the air is carried out via grilles situated at ground level in the SE wall.

The extractors will operate continually in the Printing Works. In the Warehouse, all the extractors will operate when the outside temperature is inferior to the inside temperature; otherwise only two of the extractors will operate to enable ventilation of the false ceiling without causing an excessive increase in the ventilation load of the building.

5. Monitoring of the Building

After implementation of the proposed technique, in the Summer of 1990, the two areas of the building were monitored.

The records obtained are shown in Figures 4 and 5 for the Warehouse and Printing Works respectively. Maximum temperatures of 33 and 34 °C are seen, which are much lower than the original values. Furthermore, the values recorded are fully in accordance with those obtained by simulation with the S3PAS computer programme.

6. Conclusions

This research permits us to draw the following conclusions:

1. In this case, the mere use of insulation and ventilation is sufficient to reduce the temperature inside an industrial non-conditioned building.
2. The results obtained with the S3PAS programme are satisfactorily close to those actually occurring.
3. The S3PAS computer programme is sufficiently versatile to enable its usage as a building design and evaluation tool.

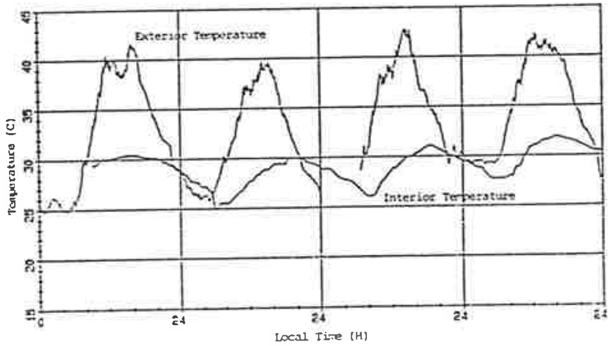

Figure 4: Recorded Exterior and Warehouse Interior Temperatures

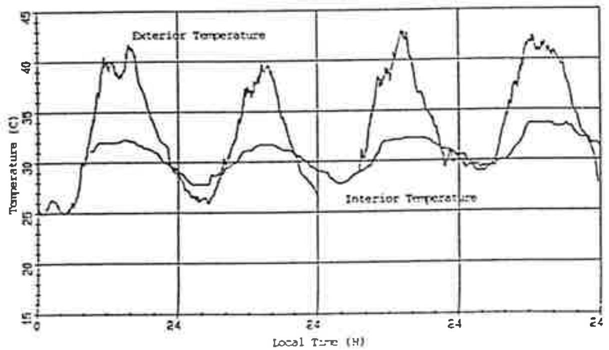

Figure 5: Recorded Exterior and Printing Works Interior Temperatures

References

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2 Guerra, J.J., Molina, J.L. (1989) 'Estudio de Evacuación de Calor en Almacén Postventa de Construcciones Aeronáuticas S.A. Factoría San Pablo' Final Report. Cátedra de Termotecnia, Sevilla