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USING AIR FLOW AND COMFORT ANALYSIS TO AVOID AIR CONDITIONING IN SPAIN

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ABSTRACT

New office buildings in Spain are nearly always designed to be air conditioned. The architect Emilio Miguel Mitre Associates (EMMA) has designed a building which avoids air conditioning, thereby reducing energy demand. The design uses the principles of high thermal mass combined with night ventilation, reduction of solar gain during the summer months, high levels of insulation, evaporative cooling, and buried pipes to provide cooling when the external temperature rises above 30°C.

ECD Energy and Environment were commissioned to investigate the effects of these measures on the predicted internal temperatures and energy consumption using the computer simulation package, TAS. The analysis showed the internal temperatures will be acceptable when external temperatures are below 30°C. When temperatures rise above 30°C the cooling effect of the air which has passed through the buried pipes will be effective in keeping the internal temperatures below 30°C. It was also demonstrated that the predicted energy consumption of the building will be less than one quarter of its air conditioned equivalent.

1.0 INTRODUCTION

The majority of new office buildings in Spain are designed with air conditioning. The architect Emilio Miguel Mitre Associates (EMMA) has designed a building which avoids air conditioning, thereby reducing energy demand. The building, INTECO 1, will be built in Valladolid. Valladolid is located approximately 170km north-west of Madrid in the centre of Spain at an altitude of 700m.

ECD were commissioned by Edificios INTECO S.L to undertake an energy, comfort and air flow analysis using the computer simulation package, TAS , in order to demonstrate that the principles incorporated into the design will be successful and that summertime temperatures will be acceptable.

2.0 METHODOLOGY

The building is approximately 100m long and 50m wide and consists of the following areas:

1 Four storeys of offices to the south of the building.
2 A central double height office space on the ground floor of the building.
3 A double height office space with a mezzanine floor covering approximately half of the floor area.
4 Two atria running all the way along the building.
5 A reserve space to the north of the building

2.1 Construction details

The construction details of the building elements input into the model were provided by the architect. The majority of the walls consist of, 240mm of perforated blockwork internally, 100mm insulation, 200mm ventilated air gap and a steel shingle finish on a steel structure. The U-value of this structure is 0.26 W/m^2K .

The ground floor slab consists of 250mm of reinforced concrete with 100mm of insulation to give a U-value of 0.29 W/m^2K . Upper floor slabs are hollow core concrete slabs with a thickness of 250mm. The office spaces generally have raised floors and false ceilings, apart from the south facing offices where the floor slab is exposed to encourage heat absorption by the fabric. On the top floor the ceiling is also exposed on the south side to increase the amount of thermal mass available. The surface area of exposed thermal mass is also increased by having parallel ceiling fins running along the ceiling. The roof consists of the hollow concrete slab below 6Omm of lightweight slope mortar, 120mm of insulation and 120mm of grass on turf which gives a U-value of 0.26 W/m^2K.

The windows throughout the building will be double glazed with a low emissivity coating to reduce heat loss. All the frames will be aluminium with a thermal break. The U-value of this glazing is 1.77 W/m^2K.

2.2 Ventilation Strategy

The ventilation strategy is split into three stages[1]:

a) When the external temperature is less than 26°C the office will be naturally ventilated.

b) When the external temperature is greater than 26°C but less than 30°C, the window opening will be reduced to a minimum, whilst still providing the fresh air required.

c) When the external temperature rises above 30°C, all the windows will be fully closed, including the internal partitions and air will be supplied to the offices by mechanical ventilation, cooled through the underground pipes, up through the internal columns and into the space through grilles in the columns.

In all three of the above situations the building fabric will be cooled down using night-time ventilation.

2.3 Weather data

Valladolid has a mild continental climate with long, humid and moderately cold winters and short and hot summers. The intermediate seasons are very short and variable. There are large temperature variations, particularly in summertime. The prevailing winds are from the north-east and west southwest.

The standard weather data files which are available for use with the TAS system are the Test Reference Years (TRY's) which were compiled by the Commission of European Communities to standardise weather data. However the project did not cover Spain. As a result comprehensive weather data was difficult to obtain. The most useful data was supplied by the architect from data sheets produced by the *Instituto Nacional de Meteorologia* [2]

The main difficulty arose from the fact that only monthly averages for maximum temperatures were available. This meant that the weather data which was created using these monthly average maximum values did not accurately represent periods when temperatures exceeded this maximum value. For example for July where the average monthly maximum temperature is 30.6°C, the absolute maximum temperature is 37.2°C.

In order to compensate for this shortfall, the analysis was split into two distinct parts. The first is to analyse the performance of the building when the external temperature is below 30°C and the second is when the external temperature rises above 30°C. This approach, by coincidence fits in well with the ventilation strategy which has been proposed for the building.

2.4 Shading strategy

The following strategy has been adopted to utilise solar gain in the winter and to reduce solar gain in the summer. All of these features were included in the model.

The south facade is shaded by means of a shading device that blocks summer sun but not winter sun. The amount of daylight entering the space is increased by the use of a lightshelf. There is also a solar collector on the south facing wall of the offices which traps the heat and releases it in to the south facing offices during the winter. The solar collector consists of a single pane of glass on the outside, an air gap which can be ventilated to the inside and a highly absorbent black aluminium sheet on the inside.

Two folding foil curtains, spaced at 1m apart, will be used in both atria to provide shading and reduce heat gain during the summer and also reduce heat loss during the night. These folding foils curtains have consequences on both the daylighting and ventilation strategies.

3.0 BUILDING CHARACTERISTICS AND PEAK TEMPERATURES

3.1 External temperatures below 30°C

The minimum ventilation rate is that which provides sufficient fresh air and ensures the removal of $C0_2$, moisture and odours. Above this level a balance is reached between providing sufficient ventilation to reduce the build up of heat from internal gains and restricting the flow of hotter external air so that the building fabric can absorb the heat slowly throughout the day.

Table 1 shows the effects of a number of variations which were investigated. Resultant temperatures were used in this analysis. Resultant temperatures are a combination of both the air temperature and the average radiant temperature of all the internal surfaces and are accepted as the most appropriate way of measuring comfort conditions.

Base case - The base case was taken with the following conditions: the opening in the atrium roof all fully open; 10% of the upper windows open during the day and night; 20% of the lower windows open during the night but closed during the day; 20% of the internal partitions available for air to flow through.

Changing openings in internal partition walls - Firstly the openings sizes of the internal partitions were altered. When they are fully open the overall temperature increases by an average of 0.22°C due to the increased ventilation and ingress of hot air. As the opening is closed down the temperature decreases and then starts to increase again when the partition becomes too small and internal heat gains are allowed to build up. This shows that the optimum size is approximately 20%.

Windows in external walls - When the upper windows are open 20% of their total opening size instead of 10%, the temperatures increased by an average of 0.3°C. When this is increased further to 50% the temperatures again by 0.56°C.

Table 1 - Peak resultant temperatures variations for various options assuming that there is no wind and with a peak external temperature of 30°C at 1600hrs. The areas which are shaded are those which are different to the base case.

	Opening sizes (% of total opening)				
	Atrium	upper window day and night	lower window at night	partitions	average temp difference from base case
Base case	100%	10%	20%	20%	/
Partition walls	100%	10%	20%	100%	0.22
	100%	10%	20%	50%	0.06
	100%	10%	20%	10%	0.00
	100%	10%	20%	0%	0.14
daytime ventilation	100%	20%	20%	20%	0.3
	100%	50%	20%	20%	0.56
atrium opening	50%	10%	20%	20%	0.32
	20%	10%	20%	20%	0.9
night ventilation	100%	10%	50%	20%	-0.04
	100%	10%	0%	20%	0.22
	100%	0.1 day only	0%	20%	7.48
Increased thermal mass	100%	10%	20%	20%	-0.94
With wind	100%	10%	20%	20%	0.16
	50%	10%	20%	20%	0.4

Atrium roof openings - With only 50% of the total available openings used the temperatures increase by an average of 0.32°C and when this opening size is reduced still further to 20%, the temperatures increase by an average of 0.9°C . This clearly shows the importance of removing the heat which collects at the top of the atrium.

Night ventilation - Increasing the amount of ventilation at night by increasing the opening size of the lower window from 20% to 50% decreased the temperatures very slightly. This shows the diminishing returns associated with increasing the night ventilation once the building fabric is cooled down by a certain amount. With a reduced rate of night ventilation, achieved by only opening 10% of the available openings in the upper window, the temperature increases by 0.22°C. When there is no night ventilation at all the temperatures increase by more than 7°C to above the external temperature.

Thermal mass- By replacing half of the lightweight internal partitions with blockwork with higher thermal mass the temperatures are reduced by almost 1°C.

Wind - The building was then modelled with a typical wind of 2.5 m/s from the north east. The temperatures were increased slightly due to the increased ventilation rates. Again the importance of the opening sizes of the atrium roof is demonstrated as when the opening sizes are reduced to 50% the temperatures are increased by 0.4°C.

3.2 Cooling through buried pipes using mechanical ventilation when the external temperatures rise above 30°C.

In order to analyse how the building performs when the external temperatures rise above 30°C a sequence of hot weather was generated culminating in a series of four days when the temperatures reach 36°C.

The cooling effect of the pipes and the ventilation rates were represented in the building model by a chiller with mechanical ventilation. In order to calculate the equivalent cooling capacity of this chiller a computer model called "Summer: a tool for the passive cooling of buildings" developed by the University of Athens for the European Commission's SAVE program was used. This computer model can be used to demonstrate the temperature reduction through the buried pipes. With an air flow rate of 7m/s the temperature reduction along the pipe is around 7°C. This is equivalent to a chiller with a rating of 25 kW.

The model was then run using a chiller with a capacity of 25 kW to represent the ground cooling and an air change rate of 0.5 air changes per hour. The internal temperature stays below 28°C

4.0 Air Flow And Heat Distribution

An analysis was carried out of the air flow and temperature distribution within the building at 3pm when the external temperature reached a maximum of 30°C and there is no wind. The air flow patterns show hot external air flows in from the north atrium down into the building and then across to the south facing offices and exits the building on the south facade. There is no real flow of air into the building from the south atrium.

Analysis of the resultant temperatures shows that the lower floors stay considerably cooler than the upper floors. In addition it supports the idea of using folding foils in the atrium roofs (particularly the south atrium) in order to cut out solar gains and stop hot air from penetrating down into the building. However a proportion of the folding foils on the north atrium would need to be opened in order to ensure that the building is sufficiently ventilated.

5.0 Predicted Conditions

With the opening sizes of the various apertures established in order to minimise the internal temperatures in each zone, the building model was then run for a typical year to produce the predicted yearly temperature profile. For the purposes of this study the internal resultant temperatures are compared to the following three comfort standards[3]:

- 25°C for 5% of the occupied period (Netherlands, 1979)
- 27°C for 2.5% of the occupied period (CIBSE Guide A8, 1986)
- 28°C for 1 % of the occupied period (Netherlands, 1979)

Whilst the standards give some indication of the levels which would be acceptable, they were developed for the UK and the Netherlands which have lower external temperatures. Temperatures in Valladolid are around 7°C higher during the summer months. The comparison with these standards is shown in Table 2 below. It is likely that occupancy during the month of August will be minimised as this is a traditional holiday period.

Table 2

	Percentage of time above a certain temperature				
Temperature	Standard	Ground south	Upper central	Upper south	Ground central
25	5.0	5.8	14.0	18.6	5.5
27	2.5	0.0	6.5	7.6	0.0
28	1	0.0	5.3	6.7	0.0
With heavyweight internal partitions					
25	5	4.3	9.9	12.3	5.8
27	2.5	0.0	6.3	6.7	0.0
28	1	0.0	3.9	4.8	0.0

This analysis shows that the building would perform well when the temperatures stay below 30°C. It is predicted that the highest temperature will occur in the upper south facing office, in other areas 28°C will be exceeded for only about 5% of the total occupied hours if there are lightweight partitions This is reduced if heavyweight internal partitions are used.

6.0 Energy Use

The predicted energy use of the building has been compared to the same building with a standard variable air volume air conditioning system, with a standard lighting system and no specific energy efficient features. Table 3 below shows that the predicted breakdown of energy used in the building, is approximately 21% of that of an air conditioned equivalent building[4].

Table 3

Breakdown	Energy use (kWh/m2) Naturally ventilated	Air conditioned
Heating	21	76
Lighting	15	38
Cooling	0	67
Fans and pumps	2	38
Small power	11	11
Total Energy	49	230

7.0 CONCLUSION

This study has shown that the architectural company, EMMA has produced a well designed and bioclimatically excellent building. When the temperatures are below 30°C the internal temperature do not go above 28°C. In periods of extreme weather it has been shown that the cooling using buried pipes will prevent the temperatures rising above 28°C. This is achieved using high thermal mass, solar shading devices and well controlled lighting systems to minimise internal gains.

It has been demonstrated that the building will use less than one quarter of the energy of an equivalent air conditioned building.

In order to achieve these conditions it is essential that the building is well commissioned and controlled and that occupants are made aware of how the building is ventilated and cooled.

8.0 REFERENCES

1 Ventilation strategy of INTECO 1 - Emilio Miguel Mitre Associates
2 Estacion de Valladolid - Instituto Nacional de Meteorologia
3 CIBSE guide Vol A - Design data, CIBSE London 1986
4 ASHRAE/IES 90.1 - 1989 Energy Efficient Design of New Buildings except New Low Rise Residential Buildings