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EVAPORATIVE COOLING FOR SUMMER COMFORT IN OFFICE BUILDINGS

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ABSTRACT : In France, air conditioning of offices is often required, especially in areas with high noise levels and in the Mediterranean climates.

Evaporative cooling systems appear able to give a cost effective solution to the growing demand for summer comfort : hence, the CSTB and Gaz de France are currently conducting a joint research on the efficiency of such systems.

On the basis of a comfort criteria, this has been done by computer simulations taking into account differents kinds of systems, buildings, and climatic areas. As a general rule, the comfort level proved to be sufficient except in some cases, especially when the outdoor air humidity is high. A peculiar attention must yet be paid to the building design (thermal inertia, solar protection).

Tests in the Gaz de France experimental building and a full scale operation near Paris have confirmed the simulation results.

1 - CONTEXT

Air-conditioning of offices in the French temperate climate is necessary in a certain number of cases, especially in areas of high noise and in the south. The use of refrigeration units is not always the only alternative to obtain comfort in summer, and furthermore, they are often expensive to install and operate.

For this reason, GAZ DE FRANCE and the CSTB decided to study products able to satisfy, from both technical and economic points of view, the growing demands for comfort in summer as well as in winter. In this context, single and double flux air systems with adiabatic humidification have been studied and are the subject of this paper.

2 - APPROACH

The performances, in terms of comfort and energy consumption, of the systems included in this study depend on the thermal characteristics and geographic location of the building in which they are installed. It was therefore necessary to develop detailed models of typical office buildings, of the cooling installations under study and their control systems.

In addition, comfort was characterized by means of an original criterion which has been the subject of a specific study.

Finally, tests were conducted in july 1988 in the GAZ DE FRANCE experimental building and a pilot operation followed up in summer 1989 in order to examine the behaviour of one of these systems in full scale operation.

3 - THE SYSTEMS STUDIED

3.1 - Representative buildings

A typological survey was made to select two reference buildings representative of a large share of modern office buildings. These two buildings differ only by their thermal inertia and the amount of solar input they receive. The first building has low inertia (100 kg/m^2 according to the Th-B rules from the CSTB) and receives little solar input (the ratio of glazed areas to the floor surface is 4 %). The second has moderate inertia (250 kg/m^2) and receives moderate amounts of solar input (10 %).

All the other parameters are identical. They include : 5000 m^3 volume, 1500 m^2 office area, North-South orientation, Coefficient of volume losses through walls G1 = 0,5 W/m^3.°C, Controlled mechanical ventilation. A scenario of occupation and internal heat input was also established.

3.2 - Different cooling systems

Reference case (system 1)

In order to determine the performances of different systems, a reference case was established : non-cooled building in which the occupants open the window as soon as the inside temperature exceeds both 24°C and the outside temperature. The air change rate is in this case 7 volumes per hour. The windows remain closed during the innocupied periods.

Night-time ventilation (system 2)

One way to cool the building is to make use of its inertia and night-time cooling. Control is simple : as soon as the inside temperature exceeds the outside temperature, the maximum flow rate (4, 7, 12 or 20 vol/h were tested) is triggered. Otherwise, the flow rate is nul when the building is inoccupied and at 0,8 volumes per hour when occupied.

Simple flux with direct humidification (system 3)

A first improvement of the system 2 is to cool the fresh air by direct humidification. However it is necessary to limit this humidification to avoid condensation problems. The air humidification acts if :
- the indoor air temperature exceed 24°C,
- the indoor relative humidity is less then 70 %.

Double flux with humidification of exhaust (system 4)

When a system of warm air heating with double flux ventilation is used, a heat exchanger between supply air and exhaust air must be installed. This equipment can be used during the summer if a humidifier is fitted on the exhaust air before the exchanger. A simple control method, based on temperature thresholds, was developed. It is described in figure 1.

Double flux with humidification of the exhaust air and fresh air (system 5)

In order to fully exploit the air network, it was deemed worthwhile to test additional fresh air humidification.

This additional stage is triggered if the inside temperature exceeds 24°C, providing that relative humidity in the officies is not greater than 70 %.

<u>non occupation</u>

Indoor temperature (Ti °C)	humidifier	heat exchanger	flow air rate
	A	A	0
19	A	A	0 if $T_s>T_i$ 1 else
20	M	A if Taeh>Te M else	0 if $T_s>T_i$ 1 else
21	M	A if Taeh>Te M else	O if $T_s>T_i$ 2 else

<u>occupation</u>

	A	A	1
22	M	A if Taeh>Te M else	1
23	M	A if Taeh>Te M else	1 if $T_s>T_i$ 2 else

A : off
M : on

Ts : supply air temp
Te : outdoor air temp
Taeh : air temp behind humidifier

0 = nul
1 = 0,8 vol/h
2 = maximum

Figure 1 : cooling system control.

3.3 - <u>Location stations</u>

Three types of contrasting climate were selected according to hygrometry and temperature differences between day and night. The stations chosen are TRAPPES, AGEN and NICE.

4 - <u>CRITERION FOR COMFORT ASSESSMENT</u>

In an initial approach, based on the ASHRAE standard 55-81, a comfort zone was defined with the possibility of exceeding limit conditions during a certain number of hours.

This zone is defined by an effective temperature limit (operative temperature at 50 % relative humidity) of 26°C, a relative humidity limit of 70 % and an absolute humidity limit of 13 g/kg of dry air.

A simple calculation of the number of hours during which the threshold of 26°C is exceeded gave an initial evaluation of systems. This method takes account of the duratior of discomfort but not its degree.

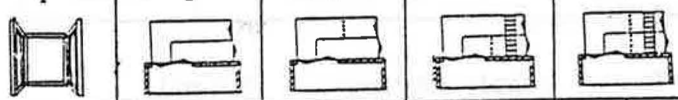
For this reason, a criterion taking account of both parameters (duration and degree of discomfort) based on the work conducted at the JB Pierce Foundation (P. GAGGE) and the Technical University of Denmark (P.O. FANGER), was chosen. At any moment, the effective temperature, the PMV (Predicted Mean Vote) and the PPD (Predicted Percentage of Dissatisfied) are determined on the basis of operative temperature and humidity.

A mean discomfort duration is calculated over the entire hot season by integrating the difference (PPD - 0,10) when PPD is greater than 0,10 (the comfort zone corresponding to a PPD value less than 0,10). By separing warm and cold mean discomfort duration (WMDD or CMDD), it is then possible to make a more accurate classification of the systems.

5 - SIMULATION RESULTS

The tool used for this study is the ASTEC 3 software package, an algebrodifferential system solver developped initially for the description and simulation of electric circuits. The models are thus described in the form of electric circuits using the electric thermal analogy. The different modules developed for this study are used to examine in detail the dynamic behaviour of the systems in question.

The simulation results have been studied using the mean discomfort duration (MDD) criterion. Energy and water needs have also been evaluated. As an exemple, figure 2 indicates the WMDD value for Trappes site according to the building and system type and the orientation (South or North facing).



inertia	orientation	1	2		3		4		5	
		7 vol/h	4	7	4	7	4	7	4	7
med.	N	23	17	11	8	2	9	3	5	1
	S	30	25	16	14	4	14	5	10	2
low.	N	29	30	21	16	6	18	8	11	4
	S	38	43	28	24	10	28	12	18	6

Figure 2 : Warm mean discomfort duration (hours) for different cooling systems, airflow rate and buildings at Trappes

For the three weather stations, the system 5 which is the most complete is also the most efficient. Systems 3 and 4 give close results. The system 2 doesn't give sensibly better results than the reference case and will not be further considered. Detail results are the following :

Trappes :For the low inertia building and an efficient solar protection, systems 3, 4 and 5 need 7 vol/h air flow. For a medium inertia building systems 3, 4 and 5 can be used with a 4 vol/h air flow if the solar protection is good.

Agen : The possibilities are the same as above if the solar protection is very efficient, and if internal heat gain are low. If not, low inertia building need a 12 vol/h air flow and medium inertia building a 7 vol/h air flow.

Nice :A 7 vol/h air flow can be used only for the medium inertia building with very efficient solar protection and low internal heat gain. For others buildings, a 12 vol/h or 20 vol/h air flow is needed.

6 - TESTS IN THE GAZ DE FRANCE EXPERIMENTAL BUILDING

The building comprises 25 inoccupied apartments on five floors, in which thermal equipment and systems are tested. The main aim of the tests was to verify the simulation results for the indirect evaporative cooling system. On three floors of the building, the air network was used to distribute air from a central unit equiped with a double flux system with exhaust air humidification at a rate of 4 office volume/h. The top and bottom floors were not cooled. The same occupation scenario as for the numerical simulations was adopted for all floors. A control similar to that of the simulations was applied. These tests gave first informations on the comfort improvement, and on the running characteristics of the air cooling system (humidifier and heat exchanger efficiencies).

7 - PILOT OPERATION

A pilot operation carried out at Senlis near Paris has been followed up during the summer of 1989. The three level building has a floor area of 3000 m^2. The floors are free of inside walls, except for some rooms situated in the corners of the building. Two indirect evaporative systems have been settled up respectively for the north and the south part of the building.

Air temperature and humidity were mesured in the air cooling units and in some points inside the building.

Though the outdoor air temperatures have been sensibly warmer than for a mean summer, indoor air temperature remains generally between 20°C and 26°C, with a daily variation less than 4°C. (fig. 3 shows the different air temperatures for a warm day). These values are in good agreement with the simulation results.

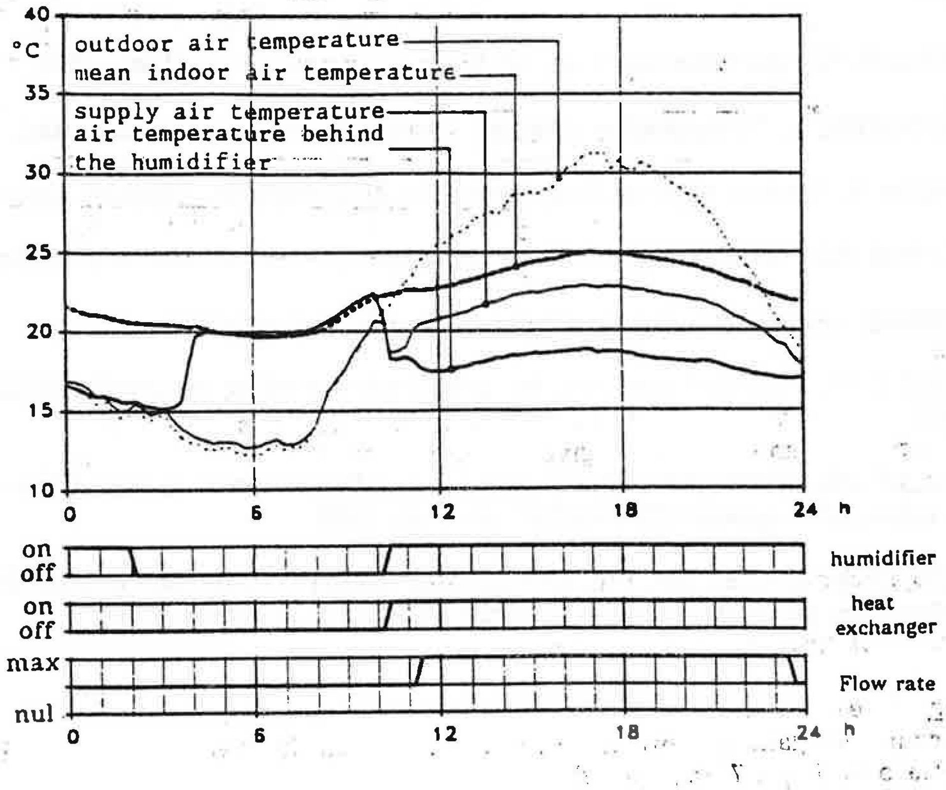


Figure 3 : Air temperatures for a warm day in the Senlis pilot building.

Air temperatures are higher in the South and West oriented room, which are situated in the corner of the building and have large window area. Very efficient window solar protection is needed for these rooms to obtain the same comfort level than for the rest of the building.

We have also pointed out the necessity of verifying precisely the regulation set point temperatures : the cooling effect being limited, it is important that the different running stages performs as intented. The electricity and water consumptions have been of about 13 kWh and 40 l per floor m^2 for the summer period.

8 - CONCLUSION

These studies have shown that it is possible to obtain satisfactory comfort in summer by using evaporative cooling systems. The efficiency will yet depend on the thermal characteristics of the building (solar window protection, thermal inertia) and of the site. This implies that for these systems the building and the cooling system have to be designed at the same time.

For the Paris district and in a building with moderate inertia, the flow rate required (4 office vol/h) is perfectly compatible with an air heating system, and the slight additional cost is mainly due to the humidifier. For hotter regions such as Agen, the air flow rate must be higher (up to 7 vol/h) but remains acceptable, whereas in Nice (Mediterannean coast) a network with a flow rate of 12 vol/h or more would be difficult to implement.

Experimental studies have confirmed the simulation results both for obtained comfort level and electricity and water consumptions. Further researches are now conducted on the use of dessicant wheels to improve comfort and lower required air flow rates, and on others techniques such as cooled water circulation in floors or ceilings.

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