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AIR-CONDITIONING IN OFFICE BUILDING WITHOUT A REFRIGERATION UNIT

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ABSTRACT :

In the French temperate climate, air-conditioning is needed in a certain number of cases, especially in areas with high noise levels and in the south. However, air-conditioning by means of refrigeration units may incur high investment and operating costs. For this reason, GAZ DE FRANCE and the CSTB decided to develop products which are able to meet, from both technical and economic points of view, the growing demands for comfort in summer as well as in winter.

Research is being conducted into double-flux air cooling systems without a refrigeration unit. The operating principle of these systems is simple : the building is ventilated at night so that cool outside air may lower the temperature of the structure and reduce the heat accumulated during the day. At the same time, cold air is produced by adiabatic humidification of the return air and exchange with outside air (indirect evaporative cooling).

The first stage of the study involves characterization of the efficiency of such systems and their controls, by numerical simulation. Particular attention is paid to parasitic energy consumption, mainly due to fans.

The study also involves the determination of a comfort criterion to classify the different technical solutions.

Meanwhile, the compatibility of technical requirements for winter heating and summer cooling, the behaviour of air diffusers, control systems, the comfort of the occupants (air velocity, gradient,...) and noise levels are examined.

Moreover the study of an indirect evaporative cooling system on an experimental site (DETN Experimental Building) was conducted in the summer of 1988. This enabled us to verify the conclusion of the simulation study and to monitor the actual performance of the system in its environment : output, efficiency, energy consumption,...).

The final stage will involve the setting of pilot operations.

"CLIMATISATION SANS GROUPE FRIGORIFIQUE DES IMMEUBLES DE BUREAUX"

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RESUME.

La climatisation des bureaux sous le climat tempéré français est nécessaire dans un certain nombre de cas notamment en zone de bruit ou dans le sud. Cependant la climatisation par groupes frigorifiques peut entraîner des coûts d'investissement et d'exploitation élevés. C'est pourquoi GAZ DE FRANCE et le CSTB ont décidé de développer des produits technico-économiquement adaptés à l'exigence croissante du confort en été comme en hiver.

Ainsi des recherches sont menées sur des systèmes aérauliques double-flux de rafraîchissement sans groupe frigorifique. Le fonctionnement de tels systèmes est simple : d'une part on s'appuie sur un stockage nocturne de froid par ventilation pour réduire les pointes de chaleur de la journée, d'autre part on produit du froid par humidification adiabatique de l'air extrait et échange sur l'air neuf.

La première étape de cette étude est la caractérisation, par simulation numérique, de l'efficacité de ces systèmes et de leur régulation. Une attention particulière est portée sur les consommations d'énergie dues principalement aux ventilateurs.

Cette étude passe aussi par la détermination d'un critère de confort permettant de hiérarchiser les différentes solutions techniques possibles.

En parallèle, on examine la compatibilité des exigences techniques en chauffage et en rafraîchissement, en particulier le comportement des bouches de soufflage, la régulation, le confort de l'occupant (vitesse d'air, gradient, ...), et l'acoustique.

De plus, lors de l'été 1988, le système de rafraîchissement évaporatif indirect a été testé sur un site expérimental (Immeuble Expérimental de la DETN). Cela a permis de vérifier les résultats des simulations, le comportement réel du système dans son environnement, et les caractéristiques techniques du système (puissance, efficacité, consommations énergétiques, ...).

L'étape ultime est la réalisation d'opérations pilotes.

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 promote products able to satisfy, from both technical and economic points of view, the growing demands for comfort in summer as well as in winter.

Research is currently under way to adapt cooling systems to gas heating systems. In this context, single and double flux air systems with adiabatic humidification have been studied and are the subject of this paper. It is also planned to examine the possibilities of water circulation in floors and ceilings.

2 - APPROACH.

<u>A bibliographic study</u> was conducted to examine different existing systems and the criteria and methods used for sizing and assessment of thermal comfort.

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 <u>detailed models</u> of typical tertiary sector buildings, of the cooling installations under study and their control systems.

In addition, <u>comfort is characterized</u> by means of an <u>original criterion</u> which has been the subject of a specific study.

Finally, <u>tests</u> were conducted in July 1988 in the GAZ DE FRANCE experimental building in order to examine the behaviour of one of these systems in full scale operation.

3 - THE SYSTEMS STUDIED.

3.1 - <u>Representative buildings</u>.

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 :

- Volume 5000 m^3
- Office area 1500 m^2
- North-South orientation
- Coefficient of volume losses through walls G1 = 0,5 W/m^3 °C
- Controlled mechanical ventilation.

The building plans are shown in figure 1.

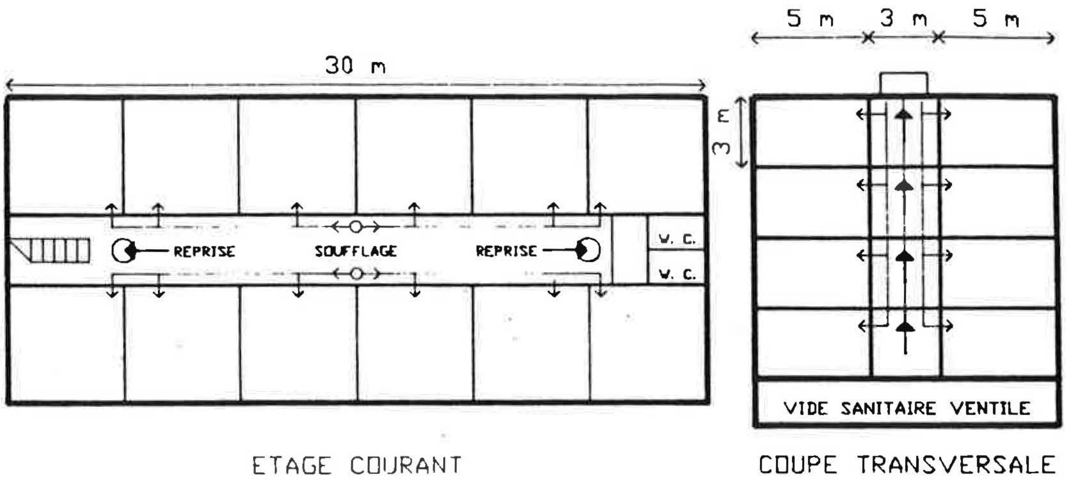

Figure 1 : Plan and cut-away view of the reference building.

A scenario of occupation and internal heat input was established :

- occupation 5 days per weeks from 8h to 18h,
- 20 W/m^2 of internal heat input in offices (body heat of occupants, lighting, machines...), 10 W/m^2 in the corridors,
- 50 g of water vapour per hour and per occupant.

3.2 - Different cooling systems.

3.2.1 - The reference.

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 the outside temperature. The air change rate is in this case 7 volumes per hour. After 18h and at the week-end, the windows remain closed.

3.2.2 - Night-time ventilation.

One way to cool the building is to make use of its inertia and night-time cooling.

In this way, the judicious use, in the day and at night, of a ventilation network sized for larger flow rates (warm air heating network for example), leads to significantly improved comfort during the day.

Different flow rates were tested : 4, 7, 12 and even 20 volumes per hour. Control is simple : as soon as the inside temperature exceeds the outside temperature, the maximum flow rate is triggered. Otherwise, the flow rate is nul when the building is inoccupied and 0,8 volumes per hour when occupied.

3.2.3 Double flux with humidification of exhaust.

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 to advantage during the summer if a humidifier is fitted on the exhaust air before the exchanger, as shown in figure 2.

This arrangement avoids humidification of fresh air, which may be a source of discomfort.

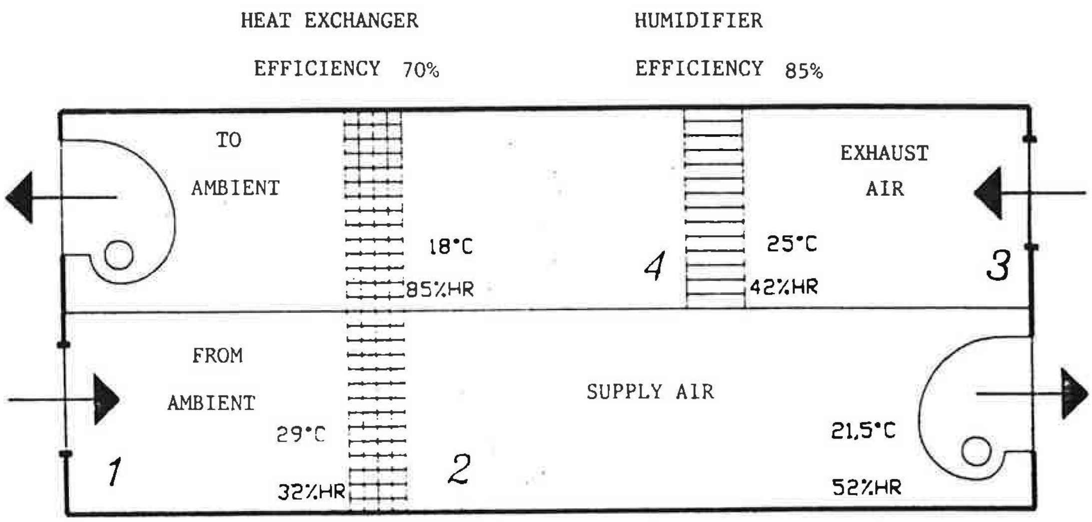

Figure 2 : diagram of cooling system.

As the air passes through the humidifier, it is charged with water vapour as it cools. The real variation on a psychrometric chart is shown in figure 3.

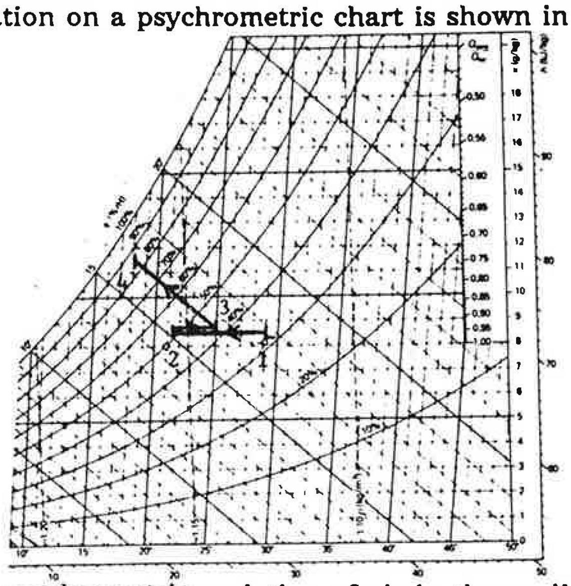

Figure 3 : psychrometric variation of air in the cooling system.

The above-mentioned method of night-time ventilation is, of course, conserved.

A simple control method, based on temperature thresholds, was developed. It is described in figure 4.

	Indoor Temperature T_i [°C]	Humidifier	Heat Exchanger	Flow rate
non-occupation	18	A	A	0
	19	A	A	0 if $T_s > T_i$ 1 else
	20	M	A if $T_{aeh} > T_e$ M else	id
	21	M	id	0 if $T_s > T_i$ 2 else
occupation	21	A	A	1
	22	M	A if $T_{aeh} > T_e$ M else	1
	23	M	id	1 if $T_s > T_i$ 2 else

A : OFF ; M : ON

* FLOW RATE
  0 : nul
  1 : 0,8 vol/h
  2 : maximum

T_s : Supply air temperature

T_e : Ambient air

T_{aeh} : Air temperature behind humidifier

Figure 4 : Control of the cooling system.

3.2.4 - Double flux with humidification of the exhaust air and fresh air.

In order to fully exploit the air network described in figure 2, it was deemed worthwhile to test the idea of additional fresh air humidification.

This additional stage is triggered if the inside temperature exceeds 24°C, providing that relative humidity in the offices is not greater than 70%. Further limitation of absolue humidity may prove necessary and has been accounted for.

3.3.5 - Location stations.

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 - CRITERION FOR ASSESSMENT OF COMFORT.

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 gives an initial evaluation of systems. This method takes account of the duration 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 by the JB Pierce Foundation (P. GAGGE) and the TUD (P.O. FANGER), was chosen.

At any moment, effective temperature, the PMV (Predicted Mean Vote) and the PPD (Predicted Percentage of Dissatisfied) are determined on the basis of operative temperature and humidity.

The PPD is then integrated over time for the entire hot season. This integrated value is then used to make a more accurate classification of the systems studied.

5 - MODELS.

The tool used for this study is the ASTEC 3 software package, an algebro-differential 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.

6 - SIMULATION RESULTS.

For all the results, the temperature is the operative temperature in the south facing zone.

Bât 1 represents the building with low inertia and solar input.
Bât 2 represents the building with moderate inertia and solar input.

The systems considered are designated A, B, C, D :

A : night-time ventilation
B : A + Indirect evaporative cooling
C : B + Direct evaporative cooling (relative humidity inside offices limited to 70 % and absolute humidity inside offices limited to 13 g/kg dry air).
D : B + Direct evaporative cooling (relative humidity limited to 70 %, no limit to absolute humidity).

6.1 - TRAPPES weather station.

The curves in figure 5 show the variation in outside temperature and the variation in operative temperature in the south facing zone in the reference case (window opening scenario) and in the case of system B operating at 4 Vol/h for the building with moderate inertia and solar input.

We note that the use of night-time ventilation and the humidifier significantly limits overheating. Figure 6 shows the inside temperature histograms for the two above cases during the entire hot season (21 june- 12 September). A considerable improvement in comfort due to indirect evaporative cooling is observed.

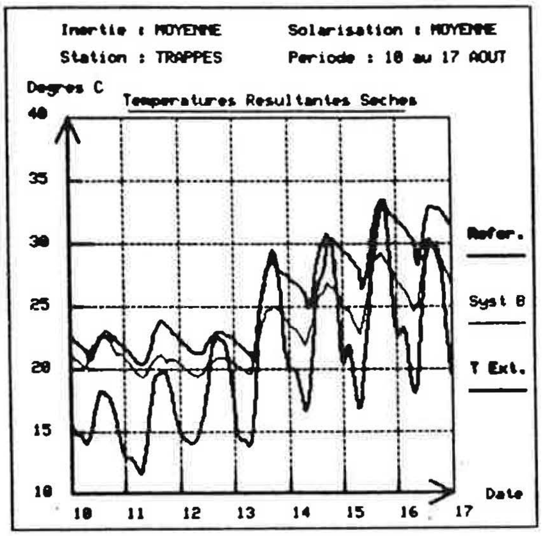

Figure 5 :

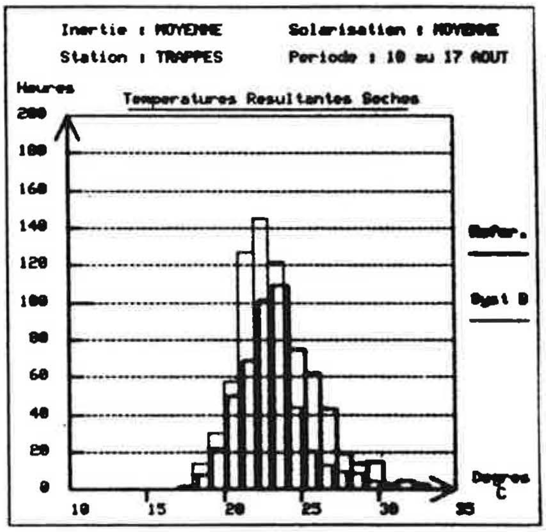

Figure 6

Finally, on the table of figure 7, the performances of the different systems for the two buildings with two different flow rates are compared.

For the building with low inertia and solar input, satisfactory summer comfort is obtained with systems C and D operating at 4 vol/h and with all systems if the flow rate is increased to 7 vol/h.

REFERENCE Bât 1 : 101 - Bât 2 : 93				
Taux	4		7	
Système	Bât 1	Bât 2	Bât 1	Bât 2
A	94	65		
B	90	42	40	21
C	57	33		
D	49	33	19	10

TRAPPES :
Number of hours where the temperature exceeded 26°C during occupation
Total duration of occupation : 600 hours.

Figure 7

6.2 - AGEN weather station.

As above, the table in figure 8 classifies the different systems and determines minimum flow rates.

Hence, for building 1, 7 vol/h or even 12, are needed whereas for building 2, 7 vol/h are sufficient for adequate comfort.

REFERENCE Bât 1 : 216 Bât 2 :272								
Taux	4		7		12		20	
Système	Bât 1	Bât 2	Bât 1	Bât 2	Bât 1	Bât 2	Bât 1	Bât 2
A	194	187		105			104	62
B	187	134	119	52	61		27	
C	160	116	91	40	47			
D	83	70	58	8	20			

AGEN : Number of hours where the temperature exceeded 26°C during office occupation.
Total duration of occupation : 600 hours.

Figure 8

6.3 - NICE weather station.

The small difference between day-time and night-time outside temperature and the high relative humidity in NICE require high flow rates to obtain satisfactory comfort levels. Figure 9 shows that 12 vol/h are needed for building 2 and the system B, and that 20 vol/h is the minimum needed for building 1.

REFERENCE	Bât 1 : 383				Bât 2 :482			
Taux	4		7		12		20	
Système	Bât 1	Bât 2	Bât 1	Bât 2	Bât 1	Bât 2	Bât 1	Bât 2
A	340	350					210	102
B	315	305	240	155	150	35	55	2

NICE : Number of hours where the temperature of 26°C was exceeded during office occupation.
Total duration of occupation : 600 Hours.

<u>Figure 9</u>

A system involving heat exchange between fresh air and humiditied outside air was tested but did not give better results than system B.

Humidification systems are not efficient in NICE.

7 - TESTS IN THE GAZ DE FRANCE EXPERIMENTAL BUILDING.

7.1 - Description of the building.

The building comprises 25 inoccupied apartments (studies, one and two bedroom apartments) on five floors, in which thermal equipment and systems are tested. Occupation can be simulated by different scenarios of internal heat input. Each room is equipped with a large number of sensors to measure variations in thermal environment.

7.2 - Tests.

The main aim of the tests was to verify the gain in comfort obtained by indirect evaporative cooling. On three floors of the building, the air network was used to distribute air from a central unit equipped with a double flux system with exhaust air humidification at a rate of 4 office volume/h (approx 6000 m^3/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.

7.3 - Résults.

Figure 10 shows the outside temperature variation and the temperatures on a cooled floor and a non-cooled floor. The rectangles indicate the periods of occupation and the temperature of 26°C.

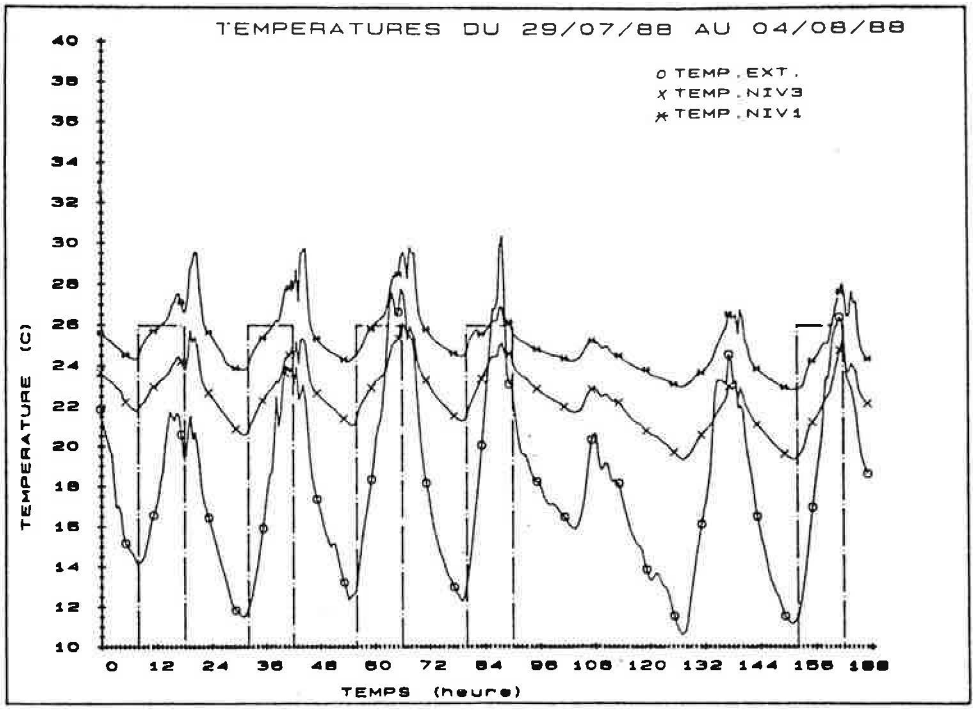

Figure 10 : level 3 cooled
level 1 non-cooled

During occupation, the temperature drops by about 3°C and the relative humidity remains at around 50 % for the cooled floor.

8 - CONCLUSION.

The studies have shown in particular that it is possible to obtain satisfactory comfort in summer without using a refrigeration unit. For the Paris region and in buildings 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 due mainly to the humidifier. For hotter regions such as AGEN, the flow rate must be higher but remains acceptable, whereas in NICE a network with a flow rate of 20 vol/h would be difficult to implement.

At present, research work is concentrating on two main areas. Firstly, the blowing of fresh air through diffusers designed for heating may be a source of discomfort and for this reason the behaviour of air streams will be studied in the controlled environment test room. Secondly, the criteria of comfort taking account of effective temperature and humidity will be defined in more detail.