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ADAPTATION OF A FAN COIL UNIT TO OPERATING CONDITIONS FOR OPTIMUM COMFORT

DANIEL MARCHAL, PIERRE BARLES

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CENTRE TECHNIQUE DES INDUSTRIES AERAULIQUES ET THERMIQUES
CETIAT
27 - 29, Boulevard du 11 Novembre 1918
BP N° 2042
69603 VILLEURBANNE CEDEX
FRANCE

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Centre Technique des Industries Aérauliques et Thermiques (CETIAT)
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SYNOPSIS

The work discussed here concerns the conditions of comfort obtained in a room cooled by a fan coil in relation to the form of air flow obtained. It is based both on practical experiment and on numerical simulation using CFD code. Combining these methods allowed a large number of configurations to be studied, in association with different operating conditions for the appliance.

Using the results in combination enabled a relation to be established between the problem data, the device characteristics and the comfort conditions obtained. A simple rule was derived from this, which can be used in practice in air-conditioned premises, in order to make the right choice or scaling of the air-conditioning appliance depending upon its conditions of use.

LIST OF SYMBOLS

f : width of the fan-coil unit supply grille (m)
g : gravity acceleration (m/s^2)
h' : vertical distance between blowing plane and ceiling (m)
V : air blowing velocity (m/s)
β : air volume coefficient of thermal expansion (K^{-1})
Δt : temperature difference between intake and blowing (K)
ν : cinematic viscosity of air (m^2/s)
Re : Reynolds number
Fr : Froude number

1. INTRODUCTION

To cool inhabited premises that are subject to heat loads, cold-air ventilation is generally used. Cold air is denser than the ambient air, and tends to fall, making it difficult to distribute to places where it is needed. To remedy this difficulty, the property of air jets to adhere to the walls, termed the Coanda effect, is resorted-to. Thus, for a fan coil unit like the one shown in the diagram in figure 1, the cold-air jet from the blower is directed towards the ceiling, to which it adheres right up to the end of the room, which is thus enveloped with cooled air, ensuring a satisfactory degree of comfort.

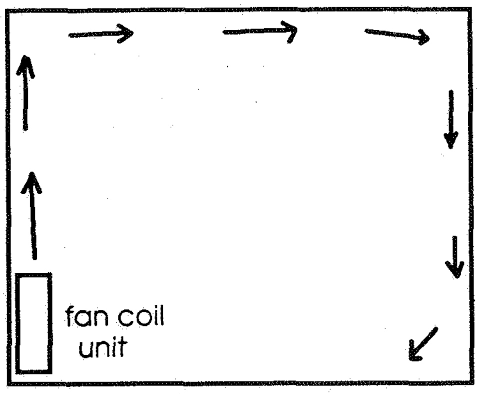

Figure 1

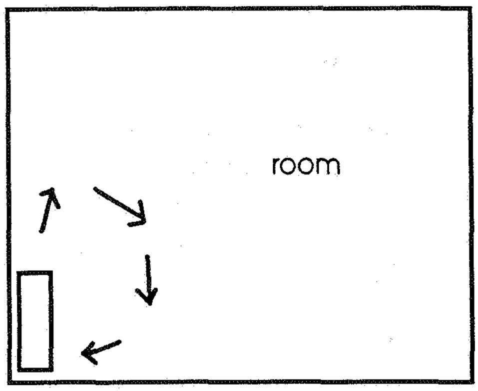

Figure 2

However, for this to operate correctly, certain conditions must be fulfilled, otherwise the flow shown in the diagram in figure 2 would be obtained, resulting in two zones with different conditions, e. g. cold in the vicinity of the appliance and hot elsewhere in the room.

The work discussed here is designed to define the conditions for correctly adapting the fan coil to its use. It is based on both experience and numerical simulation, the latter being used as a means of extending the scope of the experimental results. The study achieves a non-dimensional presentation of the results, which can be used in many situations for practical design of appliances.

2. EXPERIMENTAL STUDY AND COMPARISON WITH SIMULATION RESULTS

Reference [1] indicates the operating method used in a test room with scope for varying the heat loads and the operating conditions of the convector-ventilator installed. Two types of measurement were taken : measurements relating to the flow of the cold-air jet from the device, and the measurement of velocities and temperatures in the occupied area of the room. The latter measurements enabled the usual criteria to be used to describe the comfort of occupants, particularly the ADPI criterion [2], which takes account of both the homogeneousness of temperature and the lack of excessively ventilated areas.

The experimental work covered a number of situations, albeit limited by the dimensions of the test chamber and the air-conditioning appliance chosen. To extend the scope of the findings, we went on to use numerical simulation, performed using CFD code available on the market (*FLUENT*). The principle involved was of numerically integrating the Navier-Stokes equations in the field under study. The use for this purpose of the finite-volumes method requires prior meshing of the three-dimensional space represented. Other factors taken into account are turbulence, using a two-equation model (k-ε), heat transfer and the effects of gravity which entail gravity forces that vary with local air density.

The experimental results enabled the accuracy of the simulations to be verified for a number of cases, as regards both the velocity and temperature profiles in the air jet, and the temperature and velocity fields in the occupied zone, from which is derived the comfort criterion. Thus, the values of the measured and the computed ADPI criterion could be found to be identical, to within one point on an 80-point scale.

3. USING THE NUMERICAL-SIMULATION FINDINGS

Numerical simulation was then used to explore a large number of situations which may arise in practice. All the cases studied concerned empty, oblong rooms, with heat loads applied one the one hand by conduction through the upper part of the building-front against which the fan coil is installed (glazing), and on the other hand to the greatest extent, by internally-generated heat assumed to be uniformly distributed in the occupied zone. The study consisted of systematically varying the parameters listed in table 1, which shows the interval explored, representing some twenty configurations.

Variable (unit)	Minimum value	Maximum value
Room length (m)	3.0	6.0
Room width (m)	2.5	4.5
Room height (m)	2.5	3.5
Heat load (W)	650	1 600
Blower nozzle length (m)	0.5	1.2

In each of these cases, several simulations were performed in which the blowing velocity of the fan coil (assumed to be vertical and uniform) was varied simultaneously with the corresponding temperature, so as to compensate the heat load in order to achieve always the same air-intake temperature (25°C). This exploration of each configuration was so conducted as to highlight the transition between the two types of operation diagrammatically represented in figures 1 and 2.

4. COMBINING THE RESULTS

Figure 3, relating to an average configuration (a room with dimensions of 4.5 x 3.5 x 2.8 m; blower nozzle dimensions 0.8 x 0.06 m; heat load 1600 W) shows the behaviour of the ADPI comfort criterion when the blower flow rate and temperature are simultaneously varied, in the manner indicated at the end of the previous paragraph. The value :

$$X = \frac{1}{\mathrm{Re}(f).\mathrm{Fr}(h')}$$

of the abscissa variable is the reciprocal of the product of two non-dimensional numbers :

– the Reynolds number relating to the width f of the supply grille of the device :

$$\mathrm{Re}(f) = \frac{f.V}{\nu}$$

in which V and ν refer to the blowing velocity and the kinematic viscosity of air, respectively ; and

– the Froude number relating to the height h' to which the air jet have to rise :

$$\mathrm{Fr}(h') = \frac{V^2}{h'.g.\beta.\Delta t}$$

where h' is the vertical distance separating the blowing plane of the device from the ceiling, g the acceleration due to gravity, β is the volume coefficient of thermal expansion of air, and Δt the temperature difference between the intake and blowing parts of the appliance.

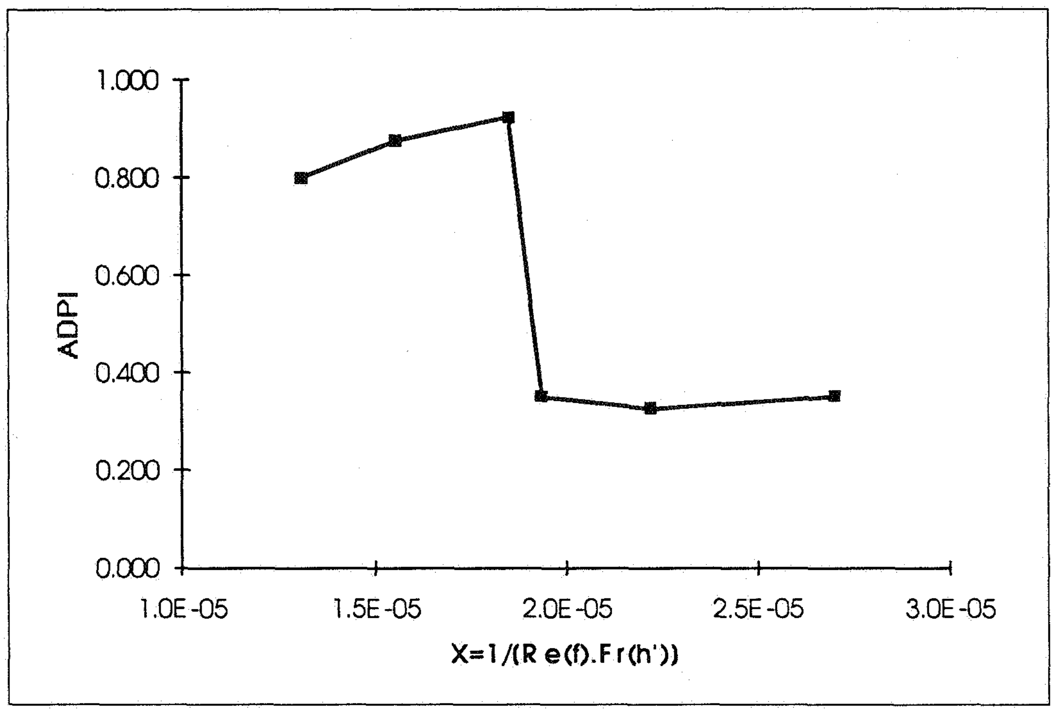

Figure 3

The choice of this expression of X, of which the value increases when the temperature difference is increased at the expense of velocity, is designed to account satisfactorily for the effects of inertia, diffusion and gravity, which involve forces the relationships of which taken in pairs are represented by the Reynolds and Froude numbers.

Figure 3 shows the rapid change in the ADPI criterion around a value for X of approximately $1.9\ 10^{-5}$, which corresponds to the transition between the two flow situations described in figures 1 and 2. The right-hand part of the curve ($X > 1.9\ 10^{-5}$) corresponds to the uncomfortable situation (ADPI < 0.4), in which only the immediate vicinity of the appliance is cooled. Conversely, if $X < 1.9\ 10^{-5}$, a satisfactory degree of comfort is obtained (ADPI > 0.8), with a slight degradation if X is further reduced, on account of the increased air velocities generating local discomfort.

The interest in choosing parameter X, in preference over another non-dimensional expression (e.g. the so-called Archimedes number often used in the literature), can be seen when the geometrical parameters of the problem are varied.

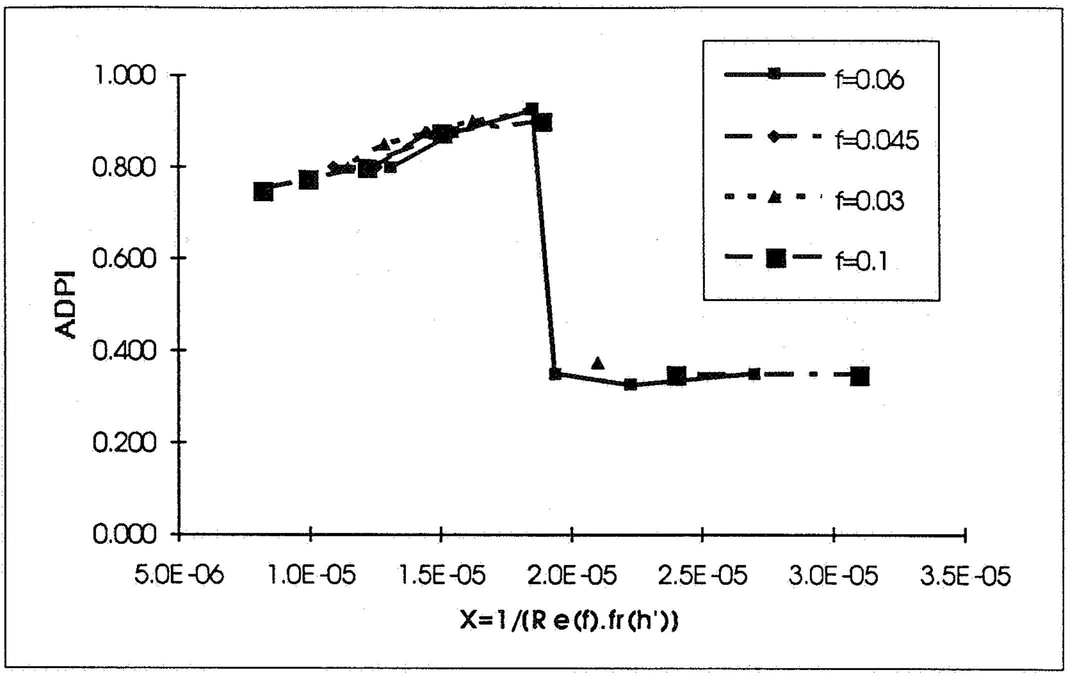

Figure 4

Thus, in figure 4 representing variations in the ADPI criterion, as in the previous figure, but here with different values for the width f of the supply grille, it can be seen that the transition between comfortable and uncomfortable situations takes place at about the same value of X as previously noted.

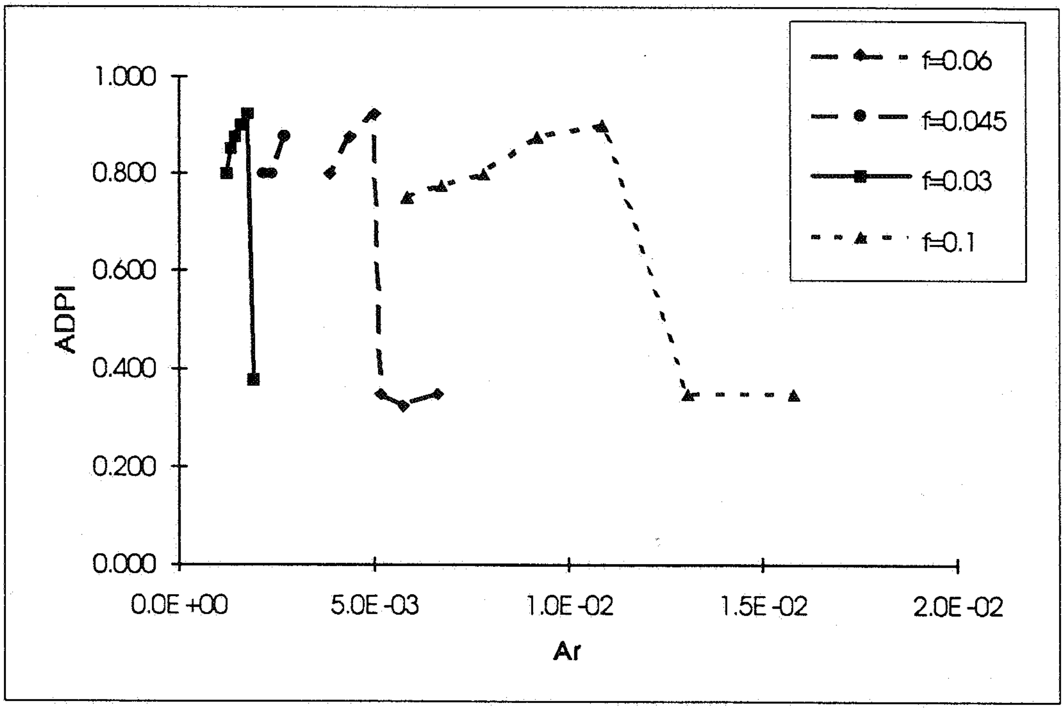

Figure 5

A similar representation using as the abscissa variable the Archimedes number :

$$\mathrm{Ar} = \frac{1}{\mathrm{Fr}(f)} = \frac{f.g.\beta.\Delta t}{V^2}$$

leads to the chart in figure 5, in which it will be noted that the dispersion of the characteristic curves does not allow generalisation. The inability of this number to represent the behaviour in all the situations is probably due to the fact that the Froude number Fr(f) on its own expresses only the relationship of the forces of inertia to the forces of gravity. It cannot therefore also allow for the effects of diffusion, and these are essential to the behaviour of the air jet.

The height h' through which the cold-air jet from the appliance must rise in order to reach the ceiling is also one of the important parameters of the problem. Its effect is correctly described by the number X, as shown in the chart in figure 6 in which it can be seen that, for all the values of h' considered, the transition between zones of discomfort and of comfort occurs for the same value of $X \approx 1.9\ 10^{-5}$.

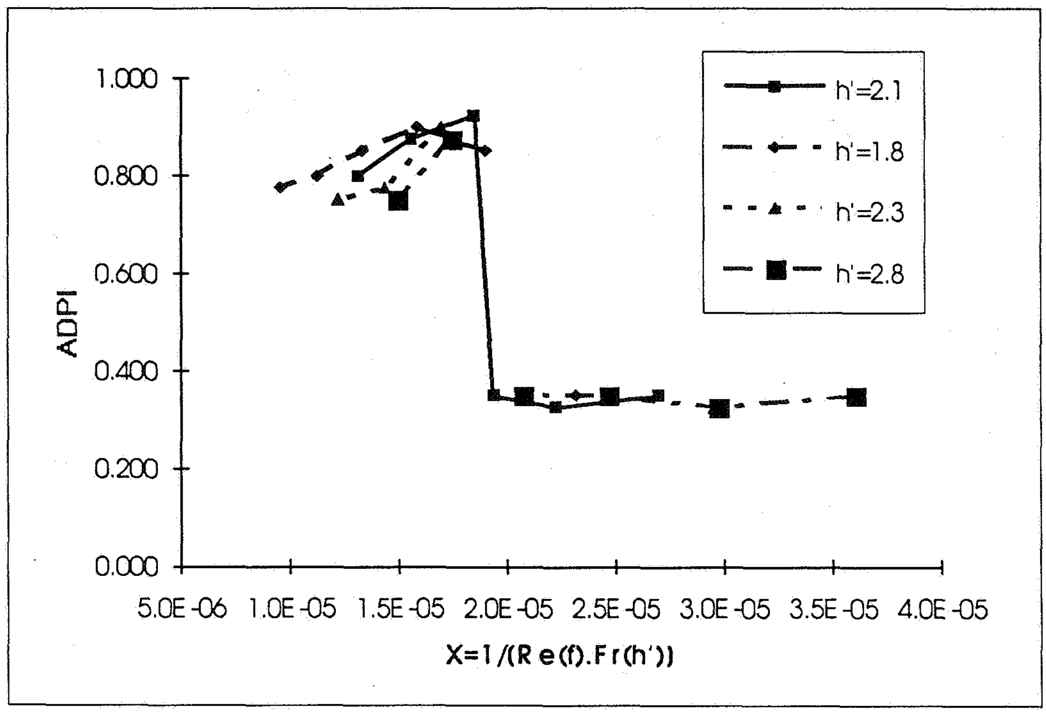

Figure 6

We also studied the effect of the room length, finding that it only slightly affects the value of X at which the transition occurs between discomfort and comfort, as shown in table 2.

Table 2

Room length (m)	Transition value of X
3	$2.4 \, . \, 10^{-5}$
4,5	$1.9 \, . \, 10^{-5}$
6	$1.8 \, . \, 10^{-5}$

The results obtained show that the other parameters listed in table 1 also only exert secondary effects on the change in flow conditions. Accordingly, as the single condition for a satisfactory degree of comfort in terms of the ADPI, the following can be adopted :

$$\mathrm{Re}(f).\mathrm{Fr}(h') > 5.6.10^4$$

For shorter rooms (3 m or less), a lower value ($\approx 4.5 \; 10^4$) can be acceptable for this product.

5. CONCLUSION

The study presented leads to a non-dimensional relationship which allows foreknowledge of the flow behaviour caused by a fan coil unit used for air-conditioning an inhabited room, and the resulting comfort rating. This law derived from combining the results can be used in practice for the purposes of real-life projects for air-conditioned premises, in order to make the correct choice or scaling of the air-conditioning appliance, allowing for the conditions of its use.

The reliability of the formulation presented here obviously depends on the assumptions followed, basically regarding the homogeneousness of the air flow from the appliance blower nozzle, and that of the heat loads in the occupied area of the room. Although many ordinary situations do not meet these conditions, these assumptions are necessary for purposes of a general study, otherwise the diversity of cases to be studied would negate any attempt at generalisation. For these reasons, the results presented must nevertheless be applied with caution.

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