Influence of the jet initial inclination angle on the performance of an air curtain device

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ABSTRACT
In the present paper, the influence of the initial inclination angle of the jet on the efficiency of a vertical downward air curtain is analysed. The air curtain device was mounted over an overture, in the wall between two equal contiguous rooms, with the typical dimensions of a door. Between the two rooms there is a temperature difference, simulating a situation where there is the intention of isolating a comfortable room from a warmer outside environment.

The sealing efficiency provided by the air curtain was determined, for different inclination angles and initial velocities of the air jet, through the tracer gases technique. The velocity and temperature fields were obtained, in interest zones, with a set of low velocity thermal anemometry probes. For some of the studied configurations, flow visualizations were carried out using an infrared thermographic camera.

Some interesting findings about the influence of the orientation of the jet in the performance of the air curtain device are presented.

INDEX TERMS
Air curtain; Measurement technique; Test room; Tracer gas; Air exchange rate

INTRODUCTION
In commercial and industrial activities, there is often a need for reducing or controlling the heat and mass transfer between the outside environment and an indoor compartment with controlled atmosphere—where environmental parameters (air temperature, relative humidity, pollutants concentrations, etc.) should be kept within limits compatible with human presence—warranting, simultaneously, an easy circulation of people and equipments. In practical terms, the confinement of a given space can be achieved with aerodynamic barriers—usually named air curtains devices (ACD)—constituted by one or more air jets. The reduction of the energy consumption and the people's appetence for more comfortable environments create a broad set of conditions that justify the installation of this kind of devices.

The results of part of an experimental work that was focused on the study of the influence of various geometric and dynamic parameters on the performances of an air curtain device are here presented. The studied configurations correspond to typical aerodynamic sealing situations, applied in commercial or residential spaces, where there is the intention of keeping a comfortable environment out of the influence of cold or hot outside conditions.

For the used type of ACD—plane, non-recirculating, downward jet—it is known (Hayes and Stoecker, 1969a) that the cumulative effects of the injection (generation of a pressure difference between two compartments) and aspiration (occurrence of a higher angular

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momentum in the impinging room) will deflect the jet to the side of the compartment where the device is installed, even if the rooms are at the same temperature or the jet is vertically discharged.

The so-called ‘stack-effect’ created by the difference in air densities on the two sides of the doorway generates an additional pressure difference across the air curtain when it separates regions of different temperature. The conjugation of these two phenomena amplifies the jet deflection. As stated also by those authors, for the non-isothermal cases there is a possibility that the jet will not extend completely to the floor and have there an impact zone. To overcome this, it is usually recommended that the outlet velocity be chosen to provide the required stability of the curtain and the nozzle discharge be directed towards the warm side, in an angle between 15° and 30°. In the following paragraphs, the influence of this parameter on the performance of an air curtain device will be shown.

METHODS

Studied Case

The research was carried out in the Industrial Aerodynamics Laboratory of the University of Coimbra, using two contiguous equal rooms (6 m × 6 m × 3.27 m for each), with a connection opening in between, with the typical size of a door (H_d = 2.25 m, W_d = 1.12 m), as schematically represented in Figure 1.

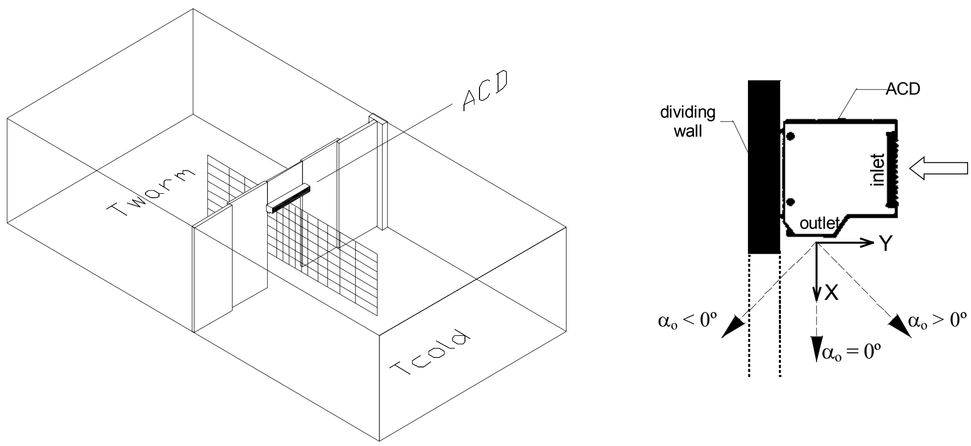

Figure 1 Geometry of the studied situation (left); Reference axes and angles used (right).

The ACD was mounted over the door opening, generating a plane air jet through a rectangular nozzle with a width slightly larger than the door and a thickness b_0 = 0.04. The middle section of the jet is 0.06 m away from the dividing wall which supports it.

Before each test, the door opening was sealed with a plastic sheet. One of the rooms was warmed up to 30°C, while the other one was kept at 20°C by an air-conditioning unit. Each test started in the moment when the plastic sheet was removed.

Methodology

The various complementary measuring techniques, used during the experimental work, are following briefly described. A more detailed description can be found in Silva *et al.* (2002).

Tracer gas techniques

With the use of tracer gas methods it is possible to get, in an expedite way, an important set of information about the gaseous exchanges between two compartments. From the different techniques involving the use of tracer gases the 'concentration decay method' was selected. To implement it, a certain amount of tracer gas is previously released and evenly diluted in one of the studied compartments. Once the test is started, air samples are periodically collected and the respective concentration of the gas is measured and recorded by an infrared photo-acoustic spectroscopic gas analyser. The main parameter derived from these tests was the air exchange rate n, defined, for two consecutive data points, by

$$n = \frac{\ln\left(\frac{C_{t+1}}{C_i}\right) - \ln\left(\frac{C_t}{C_i}\right)}{\Delta t} \tag{1}$$

where C_i is the gas concentration in the initial instant and Δt is the time interval between the instants t and $t + 1$. For a given working condition N_j of the ACD, its sealing efficiency η_v can be defined, based upon the volumetric exchanges flow rates, having as reference the situation N_0 (ACD switched off)

$$\eta_v = \frac{n_0 - n_j}{n_0} \tag{2}$$

where n_0 and n_j are, respectively, the air exchange rates of the reference and the analysed situations. It is also possible to calculate the effectiveness of the sealing process E_v as

$$\mathrm{E}_v = \frac{1}{1 - \eta_v} \tag{3}$$

where $E_v = 1$ corresponds to a null sealing effect (open door and ACD switched off), while the ideal sealing (door hermetically closed) would be $E_v \to \infty$.

Detection of the impact point on the floor

For all the studied situations, measurements of the flow velocity were done in a transversal line at the middle of the door, at a distance of 10 mm from the ground, with the objective of localizing the position of impact point of the jet on the floor. The measuring stations, from 0 up to 750 mm to the right of the point where the mean vertical plane of the ACD touches the ground ($y = 0$), were attained by means of an automatic one-axis type traversing mechanism driven by one-step motor, carrying one low velocity thermal anemometer probe.

Infrared thermographic visualizations

In this study, a 'whole-field' measurement method was used to register accurate temperatures and to visualize the airflow pattern in the whole near-zone of the air jet. With this method (see Cehlin *et al.*, 2000), physical quantities are measured simultaneously with high resolution over a large area in contrast to traditional point measuring methods, using a screen in conjunction with infrared thermography. As measuring screen, a large white sheet of paper was used, placed vertically in a location similar to the measuring plane of the flow field surveys, e.g. perpendicular to the door and parallel with the main airflow direction. Some strips of self-adhesive aluminium foil were placed on the screen as position-markers for the vertical plane of the ACD air jet. The temperatures were recorded with an IR-camera with a resolution of 320 × 240 pixels placed almost perpendicular to the measuring screen. When working in its maximum sensitivity, its specified resolution in temperature is 0.1°C.

EXPERIMENTAL RESULTS

Results of the scanning tests performed for a set of isothermal (ISOT) and non-isothermal (AVAC) conditions, with one velocity probe scanning transversally the jet at a very short distance over the floor, for two values of the ACD mounting height *H*, are presented in Figure 2. This figure confirms that the location of the impact point (*d*) for isothermal conditions is invariable with the initial velocity of the jet (U_0) and it is an asymptotical limit for the non-isothermal cases, as reported by Costa and Oliveira (2002).

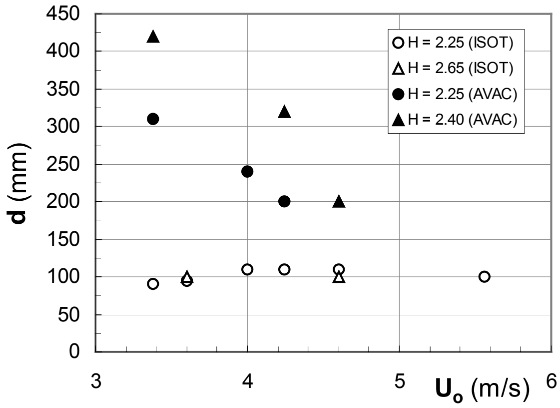

Figure 2 Localization of impact point as a function of the jet initial velocity for isothermal and non-isothermal cases, with (α_0 = 0°).

A temperature field map, resulting from measurements performed all over the grid displayed in Figure 1, is presented in Figure 3, in conjunction with an infrared thermographic picture made for a similar situation. The main features arising from the image analysis are the clear deflection of the jet into the direction of the compartment where ACD is located and the confirmation that the air that was originally entrained from the other room spills back into it again at the floor.

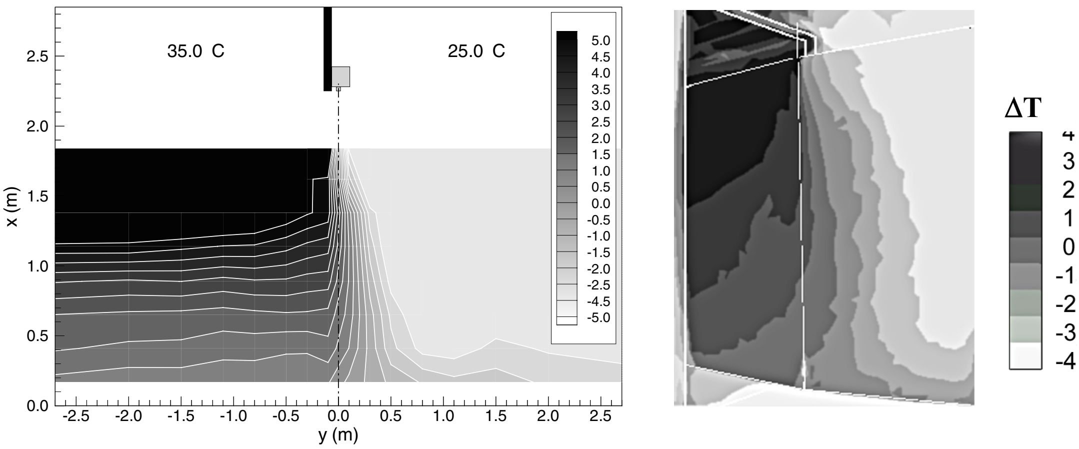

Figure 3 Temperature distribution maps on a transversal vertical plane (flow field mapping with probes—left; infrared camera—right) for $U_0 \approx 5$ ms^{-1}, H = 2.10 m, ΔT = 10º and α_0 = 0º.

In order to evaluate the influence of the initial inclination angle of the ACD a set of experimental tests was carried out for the configuration H = 2.25 m, ΔT = 10°C, for different initial velocities of the jet and for values of α_0 between 0° and –20° varying in 5° steps. Figure 4 illustrates the effect of jet initial angle (α_0) and velocity (U_0) on the location of the impact point on the floor (d) and on the maximum achieved sealing efficiency (E_v).

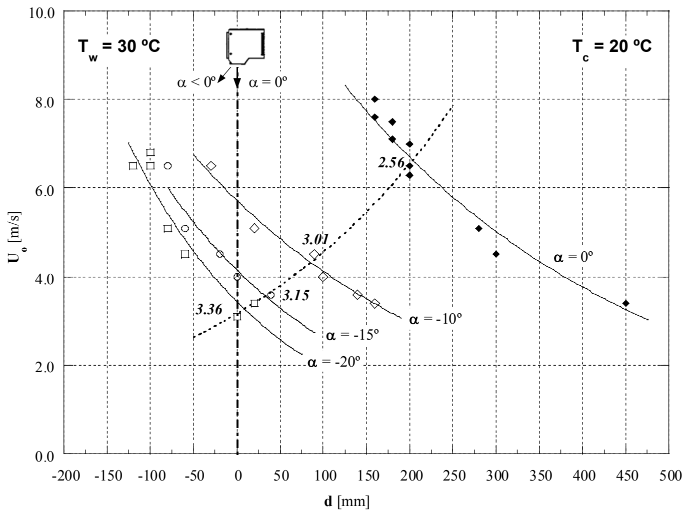

Figure 4 Effect of jet initial angle (α_0) and velocity (U_0) on the location of the impact point on the floor (d) and on the maximum achieved sealing efficiency (E_v).

For α_0 = 0º, for the lowest initial velocity, the distance d of the impact point from the vertical projection of the nozzle middle line reaches 450 mm. It diminishes as U_0 increases, till a value slightly larger than 150 mm for the maximum velocity that it was possible with the studied ACD. The best sealing efficiency, for α_o = 0°, was E_v = 2.56, attained for U_0 = 6.5 m/s and d = 200 mm (cf. point depicted in Figure 4). Tilting the jet 10° into the side of the warm room, it is possible to shorten significantly the distance impact point to the door. Not only the maximum sealing efficiency is got for lower initial velocities of the jet ($U_0 \approx$ 4.0 m/s), but also it reaches higher values (E_v = 3.0). The best sealing efficiency was achieved for the maximum possible inclination angle (20°), for this ACD, for an initial velocity of the jet as low as 3.4 m/s.

The same conclusions can arise from the analysis of Figure 5, where it can be seen that, for each inclination angle, there is an optimum velocity of the impinging jet that gives the maximum sealing effect, minimizing, thus, the heat flux between the two rooms, as stated by Hayes and Stoecker (1969b) and Costa and Oliveira (2002).

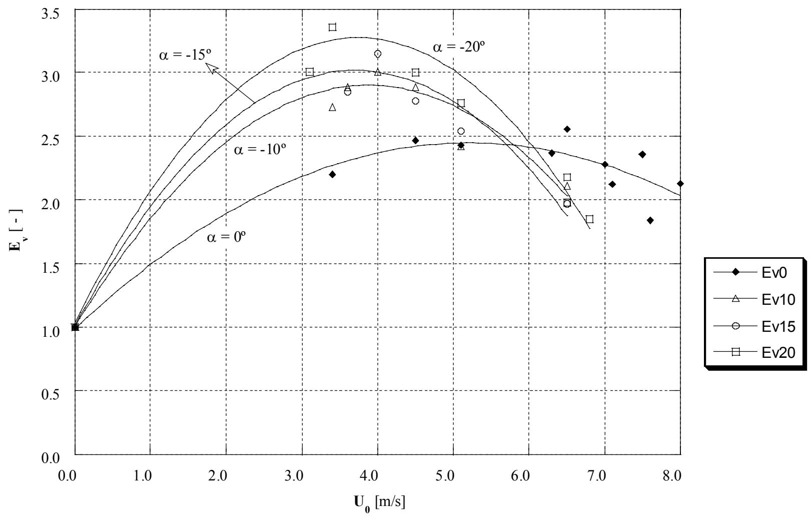

Figure 5 Effect of the velocity (U_0) and the initial angle of the jet (α_0) on the sealing efficiency (E_v).

CONCLUSION AND IMPLICATIONS

It was demonstrated that the performance of ACDs can be optimized if the right combination of working parameters is chosen.

As previously reported by other authors, the sealing efficiency is improved when the ACD jet has an initial velocity just enough to reach the ground and have there an impact zone. However, setting the device for this case is not very usual, because it is quite unstable and a small perturbation is enough to cause a change in the flow topology, reducing drastically the effectiveness of the sealing effect. Thus, an initial velocity of the jet slightly higher is a good compromise.

It was confirmed that there is an advantage of orientating the discharging jet to the opposite size of the room where the ACD is installed, at an angle between15° and 20°, which increases 25–30% the sealing efficiency and, cumulatively, allows a reduction of jet initial velocity (40–45%), minimizing the energy consumption and the discomfort due to draught sensation. Furthermore, the possibility of occurrence of a loss of contact of the air curtain with the floor is decreased.

Although assays for values of α_0 over 20° have not been done, it can be affirmed that its indiscriminate increase can take the jet faraway from the door section, allowing that air masses escape through the extremities, reducing the sealing effect.

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