

Use of air curtains on acclimatized commercial establishments – critical analysis

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SUMMARY

This article presents details on the techniques and methodologies used and results obtained in an experimental work focusing the study of the influence of various geometric and dynamic parameters on the performances of an air curtain device. The studied configurations correspond to typical aerodynamic sealing situations, applied in commercial spaces, where it is intended to keep a comfortable environment without the influence of exterior conditions.

After some recommendations on selection, installation and operation, the energy and finance savings for open public spaces that use this kind of fence are estimated and some results of technical inspections conducted in commercial establishments are presented.

KEYWORDS

Thermal confinement, Air curtains, Sealing efficiency, Energy savings

INTRODUCTION

Over the last few years there was a significant increase on the use of air curtain devices (ACD) as a way to thermally fence in acclimatized commercial spaces regarding an inhospitable outdoor environment. The advantages of the application and use of this kind of solution are well known (Hetsroni, 1963; Howell and Shibata, 1983; Lawton and Howell, 1995): to limit, as much as possible, the inevitable thermal energy loss through a door that should be kept open and clear, making the best of all the benefits that are subsequent and that are not accounted for here – aesthetics, ease of access and also thermal comfort existing inside the commercial establishment, which encourages clients to walk around and potentiate sales.

However, air curtains proliferation was not followed by an adequate concern regarding its selection, installation and operation, thus being frequent to find installations that do not comply with the demanded requisites for a good performance. This assumption arises from an extended series of measurements done on a real size experimental installation (Silva et al. 2002; Neto, 2006), where an air curtain device was installed over a door that separates two rooms, contiguous and with the same dimension, in order to try to keep them with different temperature levels.

On the first part of the present article, and after a brief explanation of the techniques and methodologies used, some enlightening examples of the influence of some geometric and dynamic parameters on sealing efficiency are presented, referring automatically to some recommendations on selection, installation and operation.

On the second part some examples of energy and finance savings are presented which were accomplished with the use of this kind of device as a mean to fence open public acclimatized spaces.

On the third and last part, the preliminary results of some technical inspections conducted in commercial establishments that use this kind of solution are presented.

INSTALLATION AND EXPERIMENTAL METHODOLOGY

Experimental installation

The characterization of the aerodynamic fence promoted by an air curtain device was conducted on a real scale experimental installation. This installation was composed by two contiguous rooms with the same dimension (figure 1a), connected through a hole with the typical width of a door but with a variable height ($2.10 < H_P \text{ [m]} < 2.65$). Above this hole an air curtain device was installed which produces a plane, non-recirculating, downward jet through a rectangular nozzle with 1.20m width and 0.04m thick (figure 1b).

During the preparatory phase of each test the hole was sealed by a plastic film. While one of the rooms was kept at a temperature of $T_F = 20^\circ\text{C}$, the other was warmed up to a higher temperature ($25 < T_Q \text{ [}^\circ\text{C]} < 35$). Tests conducted for each initial jet velocity adjustment ($0 < U_0 \text{ [m/s]} < 8$) and each jet's discharge angle ($-20 < \alpha_0 \text{ [}^\circ\text{]} < +15$) began right in the moment when the thermal fence of that door was made by the air curtain device.

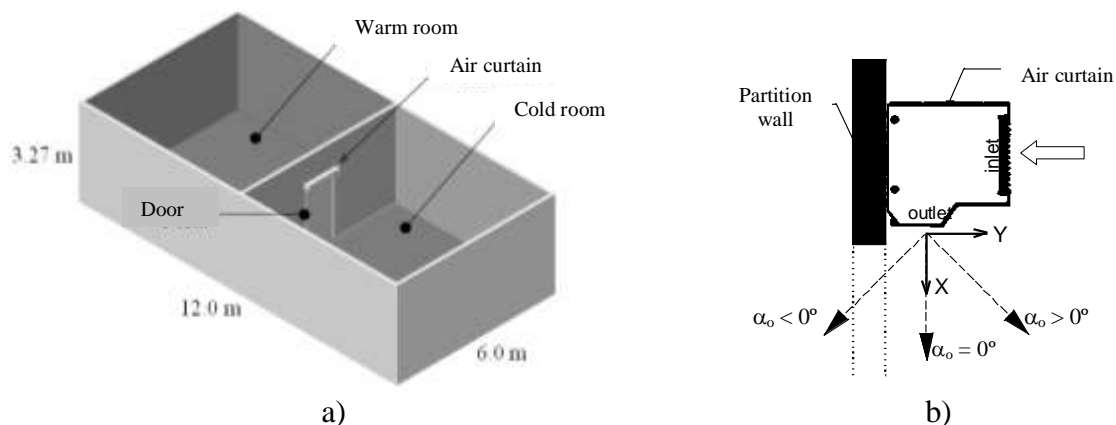


Figure 1. a) Experimental installation scheme; b) Convention used for axes/angles.

Experimental methodologies and techniques

For the accomplishment of this work some experimental techniques were used, different although complementary, that are briefly described. A more detailed description can be found in Neto (2006).

Two low velocity thermal anemometry systems, gathering a total of sixteen probes, were used in the flow field mapping of a vertical transversal plane located in the middle of the door, according to the measurement grid represented on figure 2a.

In order to register accurate temperatures and to visualize the airflow pattern in the whole near-zone of the air jet, a 'whole-field' measurement technique was used. 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' techniques – 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 (figure 2b). The temperatures were recorded with an IR-camera placed 4m apart and almost perpendicular to the measuring screen. When working in its maximum sensitivity, its specified resolution in temperature is 0.1°C and the obtained thermographic images corresponds to a range of vision of 2.9m × 2.2m with a spatial resolution of 9 mm × 7 mm.

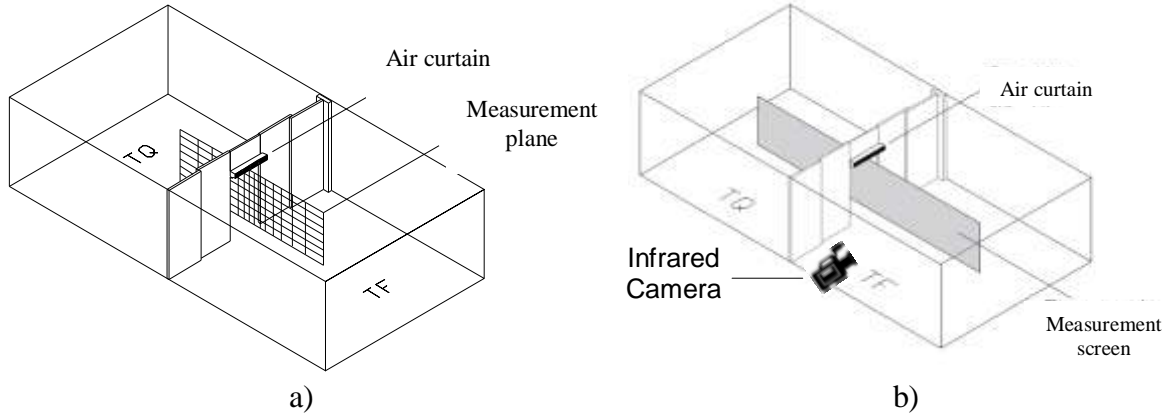


Figure 2 – a) Measurement grid used to account for the air velocity and temperature fields; b) Experimental setup for infrared thermographic visualizations.

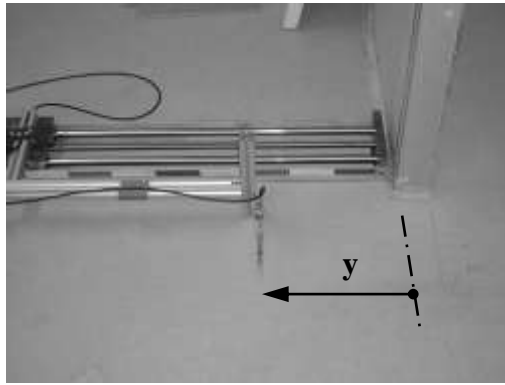
With the use of tracer gas methods it is possible to get, in an expedite way, an important set of information about the gaseous exchanges between two compartments. From the different techniques involving the use of tracer gases the ‘concentration decay method’ was selected. To implement it, a certain amount of tracer gas (N_2O) 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 definition, the air exchange rate represents the number of times per unit of time that the air volume contained in a given closed division is replaced by exterior air. If we designate by n_j the air exchange rate that occurs for a given initial jet velocity, U_j , and by n_0 the correspondent value in a situation where the air curtain is switched off (e.g. $U_0 = 0$), we can define the Sealing Efficiency (η_v) and the Effectiveness of the Sealing Process (E_v) through the following equations:

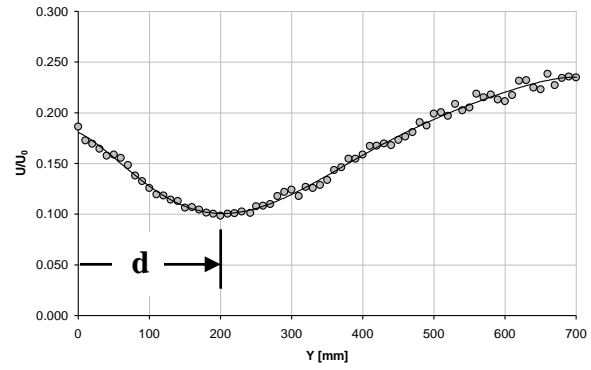
$$\eta_v = \frac{n_0 - n_j}{n_0} \quad ; \quad E_v = \frac{1}{1 - \eta_v} \quad (1)$$

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 $E_v \rightarrow \infty$.

For all the studied situations, measurements of the flow velocity were done in a transversal line at the middle of the door in order to determine exactly the location, d , of the jet’s impact on the floor. The measuring stations, from $0 < y$ [mm] < 750 to the right of the point where the mean vertical plane of the ACD touches the ground, were attained by means of an automatic one-axis type traversing mechanism driven by one-step motor, carrying one low velocity probe at a very short distance over the floor (figure 3a).



a)

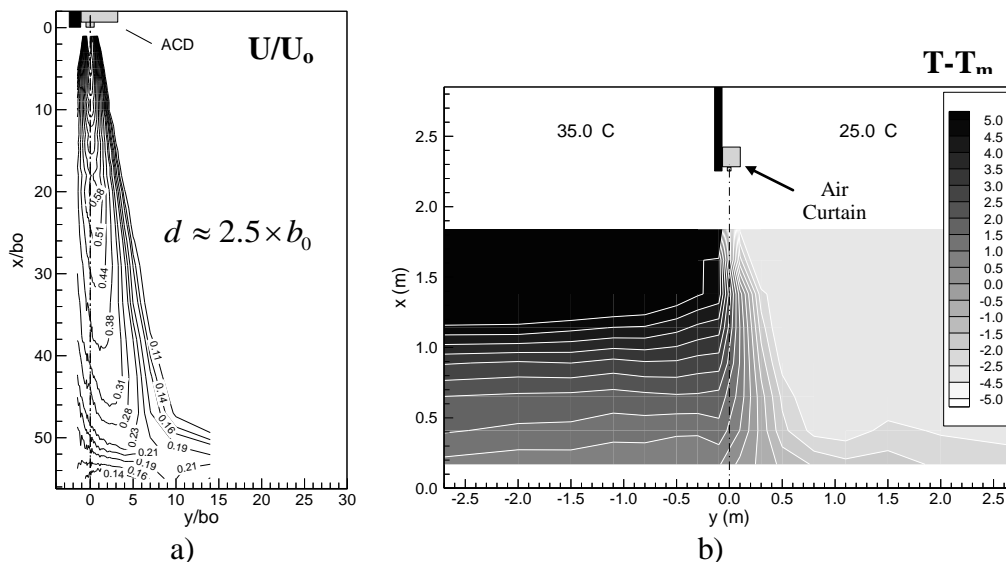


b)

Figure 3 – a) System used to determine the jet's impact point location on the ground; b) Modulus of air velocity, as a function of distance from central plane, near the floor.

EXPERIMENTAL RESULTS

Figure 4a shows a very detailed flow field mapping of the ACD velocity jet for an isothermal situation and figure 4b shows a temperature field map resulting from measurements performed all over the grid displayed in Figure 2a. Both images reveal a clear deflection of the jet into the direction of the compartment where ACD is located and confirm that the air that was originally entrained from the other room spills back into it again at the floor. According to (Hayes and Stoecker, 1969) this kind of behavior is typical of non-recirculating ACD devices because the cumulative effects of air injection (generation of pressure difference between the two rooms) and aspiration (impression of a higher angular momentum in the compartment where aspiration takes place) deflect the jet to the compartment where ACD is mounted. This happens even though the air jet is initially discharged in a vertical plane ($\alpha_0 = 0^\circ$) and/or that both rooms are at the same temperature (figure 4a), clearly accentuating with the temperature difference between both rooms (figure 4b).



a)

b)

Figure 4. a) Velocity and temperature distribution along the plane transversal to the door for $H_P = 2.10$ m, $U_0 \approx 5$ m/s, $\alpha_0 = 0^\circ$: a) $\Delta T = 0^\circ\text{C}$, b) $\Delta T = 10^\circ\text{C}$.

According to (Hayes, 1968), sealing capability of a vertical non-recirculating air curtain depends on the equilibrium between the initial momentum of the jet and the transversal forces acting to neutralize its effect. The first thermographic image on figure 5 shows what happens when the jet's initial velocity is too weak in view of the fenced door height and of the

temperature difference between both areas. As we can see, the jet is almost instantly deflected by the transversal forces that are due to the thermal impulsion, leading to its “break”, failing to reach the ground and the creation of an impact area. For this condition, the tracing gas technique revealed that there is no sealing effect and that, in fact, the air renewal rate in the “cold” room is of about 25% higher to the one collected in a situation where the air curtain is switched off. As we increase the jet’s initial velocity, the curtain’s performance becomes more stable, being evident that the air jet’s impact point on the ground tends to get closer to the doorpost.

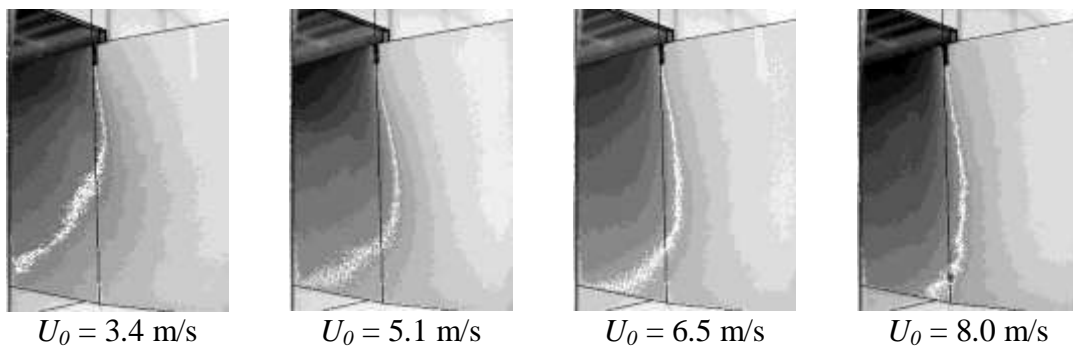


Figure 5. Thermographic sequence obtained for the increased values of the initial velocity of the jet, five minutes after the start of each of the tests accomplished for $H_p = 2.65$ m, $\Delta T = 10^\circ\text{C}$, $\alpha_0 = 0^\circ$.

Another way to bestow more stability and efficiency to the air curtain is to incline the jet from 15° to 30° towards the “exterior” side, as it is shown in figure 6. For $\alpha_0 = 0^\circ$ and for a minor jet initial velocity, the air curtain impact point on the ground can get to a distance of $d = 450\text{mm}$ from the central axle of the nozzle, starting to decrease with the increase of U_0 and reaching a value slightly higher than 150mm when this reaches its maximum. The fence’s maximum effectiveness accomplished was of $E_v = 2.56$ obtained for $U_0 = 6.5$ m/s and $d = 200\text{mm}$. By tilting the jet to $\alpha_0 = -10^\circ$ we can get the impact point closer to the doorpost, the fence’s maximum effectiveness is not only obtained with lower jet’s velocity ($U_0 \approx 4.0\text{m/s}$), but also its value is higher ($E_v = 3.0$). For $\alpha_0 = -20^\circ$ we obtained the higher sealing effect ($E_v = 3.4$) for the studied configuration, which occurred with a jet’s initial velocity as low as 3.4m/s .

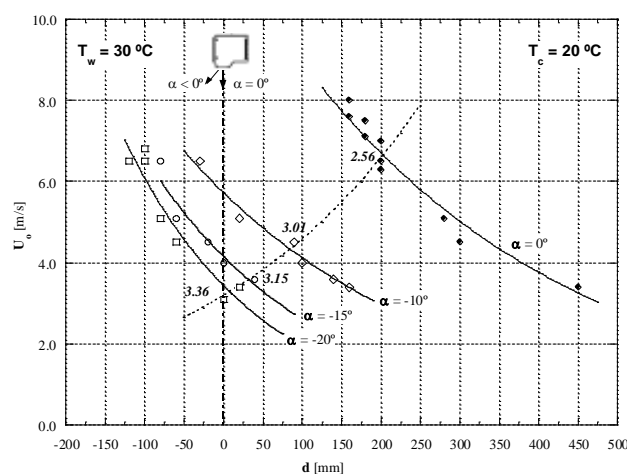


Figure 6 – Angle (α_0) and jet’s initial velocity (U_0) effect on the location of the curtain’s impact point on the ground (d) and on the maximum effective value of the sealing efficiency (E_v) obtained ($H_p = 2.25\text{m}$, $\Delta T = 10^\circ\text{C}$).

USE OF AIR CURTAIN DEVICES IN ACCLIMATIZED COMMERCIAL ESTABLISHMENTS

Energy and financial savings

One way to access the “benefit” resultant from the different working conditions of an air curtain device is to estimate the amount of thermal energy transferred through the door protected by the air curtain, \dot{Q}_j , and compare it to the energy that would be transferred in that same situation hadn't the door been protected, \dot{Q}_0 . This “energy costs” ratio is expressed through the equation (2), which also takes in consideration the electric power needed to set the air curtain motor working ($\dot{Q}_{AirCurtain}$).

$$\left(\dot{Q}_j + \dot{Q}_{AirCurtain}\right) / \dot{Q}_0 \times 100 \quad (2)$$

For most conditions in which these devices are used, the energy losses associated to the air “leaks” through the door can be reasonably estimated through the sensitive heat component. As for the unprotected doors (Gosney and Olama, 1975) suggest the use of equation (3), which takes in consideration not only the door characteristics but also the air thermal properties existing in both sides:

$$\dot{Q}_o = F_c \cdot A_D \cdot c_p \cdot (T_{out} - T_{in}) \cdot \rho_i \cdot \left(1 - \frac{\rho_{out}}{\rho_{in}}\right)^{0.5} \cdot \sqrt{g \cdot H_p} \cdot \left(\frac{2}{1 + (\rho_{in} / \rho_{out})^{1/3}}\right)^{1.5} \quad (3)$$

In this equation A_D [m²] represents the area of the door passage, H_p [m] is the door height and F_c [-] is a correction factor that includes the door discharge coefficient and the thermal effects resultant from the mixture between the in and out flowing (0.221 for IS units).

In the cases where the door is protected by an air curtain, the sensitive heat “leak” can be accounted through:

$$\dot{Q}_j = \rho_{in} \cdot \left(\frac{n \cdot V_{room}}{3600}\right) \cdot c_p \cdot (T_{out} - T_{in}) \quad (4)$$

or, alternatively, through the values obtained for the sealing efficiency (E_v) during the tests accomplished with tracer gas techniques, since:

$$E_v = \frac{n_0}{n_j} = \frac{\dot{Q}_0}{\dot{Q}_j} \rightarrow \dot{Q}_j = \frac{\dot{Q}_0}{E_v} \quad (5)$$

Table 1 shows some obtained results during the tests accomplished with a 2.65m door height and for a temperature difference of 10°C between both doors.

In the reference configuration the thermal power “leaking” is of almost 7.3kW, but the air curtain is able to reduce significantly the thermal power leak (even when it is not properly regulated) and the energy savings are even more significant while the jet's initial velocity gets closer to the optimum value.

Table 1. Energy savings obtained with an air curtain device on a door with $H_p = 2.65$ m and $\Delta T = 15$ °C.

	U_o [m/s] (E_v)				
	0.0 (1.0)	3.4 (1.5)	4.5 (3.5)	5.1 (3.1)	6.5 (3.0)
\dot{Q} [W]	7280	4853	2080	2333	2435
$\dot{Q}_{Air\ Curtain}$ [W]	–	120	120	120	120
\dot{Q}_{Total} [W]	7280	4973	2200	2453	2555
[%]	100%	68%	30%	34%	35%

If the price of the electrical power and the coefficient of performance (COP) of the air conditioning unit used in the inner space acclimatization are known, the energy costs reduction may be assessed by:

$$\frac{\dot{Q}_0 - \dot{Q}_j}{COP} \times \text{€/kWh} \quad (6)$$

If we consider 0.1€/kWh for the price of electricity and a COP of 2.9, each working hour represents a saving of about 0.18€ regarding the situation where the door is open and unprotected. To this amount we should also add 0.012 €/hour due to the 120 W of the air curtain motor used on tests and the hourly invoice should decrease in about 0.617€. In a commercial establishment that works with an open door, 8 hours per day and 22 days per month, this corresponds to the initial investment amortization of the acquisition/installation of the air curtain device in about 5 months!

Technical Inspections

In order to assess the real working conditions of air curtain devices, several inspections to commercial establishments that use this kind of solution were accomplished (*vd. Centeio et al. 2005*).

Unfortunately the data gathered in 36 inspections leads to a no-optimistic scenario since only 4 of the establishments were classified as having a “good installation”. The remaining 32 presented several deficiencies and/or insufficiencies briefly described below:

Deficiency no 1: Bad ACD selection. Example: the discharge nozzle is insufficient regarding the door width. Consequence: leak of important air masses through one or both sides of the air jet.

Deficiency no 2: Incorrect installation of the ACD due to physical and/or aesthetical reasons. Example: discharge nozzle too separated regarding the doorpost which was intent to fence. Consequence: outlet and/or inlet of important air masses behind the jet.

Deficiency no 3: Inadequate selection of the initial jet velocity regarding the air curtain manufacturer’s recommendations and/or by comparison with results obtained in experimental tests for analogous conditions. Consequence: (in insufficiency) the air curtain cannot prevent the leak of important air masses below a “broken” jet; (in excess) besides the excessive electric power use, the proper ACD promotes the dragging and the mixture of the different air masses, increasing the thermal energy transferred through the door which was initially intended to fence.

Deficiency no 4: Impossibility to alter the jet's discharge angle (bigger percentage), or having that possibility (only 4 cases), that alteration was not done. Consequence: impossibility to contradict the jet's natural deflection, obtaining "broken" jets or with a impact point too distant from the doorpost, leading in both cases to the invalidation of the fencing effect in the door's inferior part.

Deficiency no 5: Existence of "obstacles" very near or even in the interior of the door to fence. Consequence: impossibility to develop a plane and contiguous air jet to the ground with the consequent invalidation of the wished fencing effect

Deficiency no 6: Lack of regular cleaning of inlet and outlet grids and other components of the ACD and degradation of the characteristics of the motor-ventilator (e.g. initial jet velocity much inferior to the specified values on the manufacturer's catalogue). Consequence: impossibility for the ACD to reach the ground and to have an impact area on the floor.

CONCLUSIONS

This study demonstrates that the sealing efficiency can be maximized when the velocity and the discharge angle of the air curtain are thoughtfully selected regarding the door height and the existing temperature difference. Although this type of adjustment may lead to considerable energy and financial savings, the reality has shown that most of the times those factors aren't taken in consideration regarding the selection, installation and working conditions of this type of equipment.

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