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(71) Applicants:
- **RIOX, Industrias Metaloeléctricas, S.A.**
  4415-199 Pedroso (PT)
- **France Air Portugal, Equipamentos de Climatizaçäo, LDA**
  2625-085 Povoa de Santa Iria (PT)

(72) Inventors:
- **GODINHO VIEGAS, João Carlos**
  1700-066 Lisboa (PT)
- **DE MELO GOMES, José Manuel**
  4200-399 Porto (PT)
- **CERQUEIRA MENDES CAMPOS, Vasco Alexandre**
  4835-077 Guimarães (PT)

(74) Representative: **Ferreira, Maria Silvina**
Clarke, Modet & Co.
Rua Castilho, 50-9°
1269-163 Lisboa (PT)

(54) AIR CURTAIN FOR SMOKE CONTROL

(57) The present application discloses an air curtain combined with a mechanical extraction of smoke, released by a fire in a room, which comprises a vertical or horizontal plane jet with appropriate slope, generated by a cylindrical rotor fan enclosed in a housing with two openings, one outside the room and the other on the lower side.

In this manner, this technology is useful for confining the flow of smoke, produced in fire situations in buildings, only to the room of fire origin, without the need of closing the passage ways with smoke doors, and without being necessary to set speeds for the air flowing through those passages, within the same range of the speed of the smoke flow, this being the technical problem solved.

The usage of this system is compatible with current smoke exhaust means to be applied to buildings, and makes it unnecessary to inflate fresh air inside that room, once this is now done through the passage way, which remains protected by the air curtain.

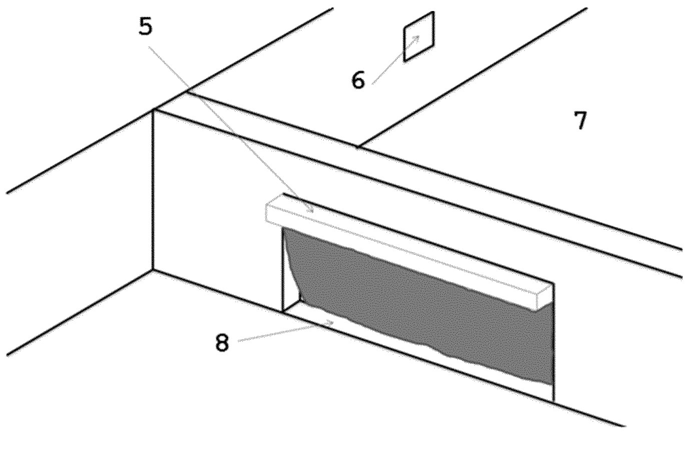

Figure 3

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Description

TECHNICAL FIELD

[0001] The present application describes an air curtain for smoke control, namely in cases of fire and in smoke flow confinement.

BACKGROUND

[0002] Air curtains are a particularly useful resource, when the use of rigid barriers, as for example walls, doors, curtains, etc., is not acceptable in terms of practical usage, technical terms, economical terms, or for safety reasons, as for instance, in the event of evacuation. Many examples of usage can be found, as referred in [1]. However, one can still ascertain that the study and usage of air curtains, as a way of reducing or confining the smoke flow and heat transmission through convection, are limited. Sakurai et al. [2] refer the usage of such type of systems in building corridors. These usages were based upon the use of horizontal air curtains relying on the push-pull principle. Cumo et al. [3] have researched the possibility of use and efficiency of vertical ascending air curtains, also based upon the push-pull principle. Unlike Sakurai et al. [2], these authors have proposed the use of high push-pull nozzles, in order to increase air flows. Several authors have studied the performance of some air curtains, in its version to be applied in tunnels, generally considering the configuration in which it is to be used only with one curtain (Dufresne de Virel et al. [4], Altinakar and Weatherill [5], Gugliermetti et al. [6], Sawley et al. [7] and Hu et al. [8]). Hu et al. [8] have carried out trials in a reduced scale channel and have made comparisons with computational simulations (CFD), having to that end used the free computer code Fire Dynamics Simulator (FDS). They have concluded it is possible to obtain smoke confinement on one side of the vertical curtain, relying for that purpose on the temperature and CO field analysis. They have ascertained that the contamination reduction follows an exponential trend line by increasing the curtain speed.

[0003] The use of a single air curtain has the disadvantage of only preventing the smoke flow in one single direction, that is, in the opposite direction to the air curtain slope, when the jet angle is fixed, which is not compatible with the possibility of the fire originating from any side of the curtain. Given that in many building spaces the fire origin can occur in any of the adjoining rooms separated by the air curtain, Gupta et al. [1] have compared and discussed the efficiency of several air curtain configurations, bearing in mind the smoke bilateral confinement. They have studied simple and double jet configurations, with opening ratios between 10 and 20 and speeds in the range of 1 m/s to 10 m/s. Throughout this application, opening ratio is considered to be the ratio between the thickness and the length of the jet at its origin. They have ascertained that the efficiency of the system is improved by the use of recirculation. They have also studied the transition between the laminar and turbulent schemes and have ascertained that the turbulent scheme shows an asymptotic behaviour. They have pointed out that air curtain performance relies a great deal on operating conditions. Their results show that the volume flowrate of the smoke passing through the curtain can vary between 3% and 25% of the volume flowrate of the air in the curtain.

[0004] Felis et al. [9] have experimentally studied the possibility of using a double air curtain to confine the smoke flow. The basic idea consists in having two parallel curtains, symmetrically arranged in relation to the confining spaces. Each of these curtains sucks air from the adjoining space, whereupon one flows smoke and the other flows fresh air. The problem they have tried to solve was to clarify in which conditions it is possible to limit the mixture of smoke with new air between these curtains, in order to confine the smoke. They have carried out temperature and speed measurements, using thermocouples and Laser anemometers (Laser Doppler Anemometer - LDA), and have studied jets with a Reynolds number of 1000. Their results have pointed out the importance of longitudinal turbulent heat flows for heat transmission, which is increased in the region where the jet interferes with regular surfaces on its plane. They have concluded that the usage of such type of systems for confining the smoke in corridors and tunnels is feasible.

[0005] Other authors have also used tools in the scope of Computational Fluid Dynamics (CFD) for studying the performance of air curtains. I et al. [10] have studied their use in accident conditions, by fire and explosion, in a clean room. Yang-Cheng Shih et al. [11] have recently developed studies including an experimental part and numeric simulations, with the purpose of analysing the use of air curtains to confine the dispersion of a contaminant, in an emergency situation in clean rooms. They have shown a good match between experimental results and simulations, and have further emphasised the promising performance of the air curtains under study, which were able to protect more exposed operators in about 90 s. They have studied curtains with speeds between 5 m/s and 15 m/s and have obtained a confinement efficiency of 0.87.

[0006] In Portugal, Luis Neto [12] has experimentally studied the influence of several geometric and dynamic parameters over the performance of an air curtain apparatus installed above a communicating door, between two adjoining rooms kept at different temperatures, but well below the ones occurring in a fire situation. The efficiency of the sealing provided by the air curtain has been determined through a trace gas technique. In some cases, flow mappings have also been carried out, in terms of air speed and temperature. Through the obtained results, he has concluded that the experimental methods used allowed to assess the performance of the aerodynamic sealing by the air curtains. The detailed parametric study has demonstrated that, for the same air curtain, the sealing efficiency can be maximized, if the optimal ratio is achieved between the air speed at curtain exit and the difference between the temperatures of the rooms to be sealed.

[0007] Although in Portugal there has been some work developed in the scope of air curtain usage in confining different environments [12], it has not been possible to find references to the study on its usage in the fire scope. The state of the art points out that the use of air curtains for smoke confinement is feasible, but that it still requires the detailed study of practical application to a very low smoke permeability and of easy use in building environment.

[0008] There are no industrialized usages of the air curtain technology known for the confinement of the smoke flow in buildings. Such technology is embryonic as for its usage in tunnels, and there are scientific publications in this field; however, the total smoke retention has proven difficult, due to the strong thermal stratification in a fire situation. Thus, the confinement of the smoke flow is the most important feature of the technology now being disclosed, which represents a significant step in the state of art progress, since it attains large effectiveness in such confinement, using the appropriate combination with the smoke exhaust existing in the fire source room. Such technology can be placed in both sides of the passage way, in order to confine the smoke flow originating from either of the two contacting rooms.

SUMMARY

[0009] The present application describes an air curtain for controlling smoke originating from a fire in a room, which comprises a plane, vertical or horizontal air jet with a slope suitable for the plane of the communicating opening between at least two rooms, in which the referred air jet is generated by at least one cylindrical rotor fan enclosed in a two opening housing, one outside the room and the other on the lower side.

[0010] In an embodiment, the cylindrical rotor fan used in the air curtain is activated by an electrical supply engine.

[0011] In another embodiment, the length of the fan rotor used in the air curtain equals the opening width.

[0012] In a further embodiment, the cylindrical rotor fan used in the air curtain is mounted on a supporting structure, sustained over a rotation axis.

[0013] In an embodiment, the thickness and the slope angle of the air curtain jet in relation to the vertical plane are defined by analytical expressions, depending on the released heat output and the geometry of the opening to protect, in each particular fire situation.

[0014] In another embodiment, the jet speed used in the air curtain is calculated by an algorithm, which is based on the analytical expressions of the presented variables, such as, smoke temperature, estimated smoke thickness, geometry of the opening, pressures on the door, among others.

[0015] Still in another embodiment, the jet speed along the entire length of the air curtain nozzle is evened by the cylindrical rotor.

[0016] In an embodiment, the housing comprising the cylindrical rotor in the curtain contains two openings in that:

- the opening on the outside of the room carries out the air intake;
- the lower opening expels the air, consequently forming the plane jet.

[0017] In a further embodiment, the air curtain is installed in the upper or side section of the room opening, on the outside and operates together with the mechanical smoke exhaust system of the room.

[0018] The present application further describes the use of the air curtain in smoke control, in rooms and/or escape routes in fire situations.

GENERAL DESCRIPTION

[0019] The present application describes an air curtain combined with a mechanical smoke extraction for smoke control in rooms in a fire situation. Current smoke control systems require that smoke doors or fire doors be used, and kept closed, in communicating openings between adjoining spaces or that flow speeds be set at values equal or higher than the smoke flow speed, and in reverse direction, in order to prevent the smoke from flowing through those openings. The external air intake through those openings is achieved by the exhaust existing in the fire source room. The smoke flow speed is high, which requires the fresh air speed at the openings to be also high and the exhaust flow in the fire source room to be high as well. With the usage of a plane jet at the door, the smoke is prevented from flowing to the outside of the fire source room, imposing exhaust flows in the fire source room much lower than the ones needed to obtain the same effect, when a plane jet is not used at the opening.

[0020] It is the purpose of the technology now disclosed to prevent the smoke generated by a fire from flowing from the fire source room to the adjoining room, without the need to close the passage way with doors or gates. Such effect is achieved through a plane air jet, descending approximately parallel to the door plane. The present technique is useful to confine the smoke flowing through the open passage ways, without the need to reverse the smoke flow with a fresh air speed equal or higher than the one of the smoke, being thus possible to prevent the smoke from flowing through the passage way, without the need to have very high exhaust flows in the fire source room.

[0021] The inhalation of smoke is the major cause of death in building fires. A large contribution for such a consequence comes from the significant speed that smoke flow can achieve inside the buildings, hence often resulting in the occupants being caught off guard by the setting of inappropriate environments to carry out the evacuation of the building. With the purpose of confining the smoke flow, restraining it to the vicinity of the fire source, different technologies have been developed for smoke control. Such technologies are generally based on the existence of physical barriers against the flow, as for example, walls, fire doors, smoke proof curtains etc., for imposing pressure hierarchies, being the pressure higher in the rooms one intends to preserve from the smoke flow and at the smoke exhaust to the outside, as close to its source as possible, necessarily compensating with the fresh air intake, which contributes to the creation of more suitable environments for occupant transit.

[0022] A problem related to the use of physical partitioning consists in the obstruction that necessarily occurs in the passage ways, among which are the escape routes. In some cases, for example in covered parking lots, the closing of the passage ways can become impossible due to vehicle circulation; in other cases, poor maintenance can result in an obstruction to the passage way closing or, in other cases, making it difficult for running occupants to open doors leading to escape routes, who tend to interpret such resistance to opening as the door being locked. In this context, the idea has come up to use vertical plane air jets, sweeping the opening plane, commonly designated as air curtains, in order to promote smoke tightness, without the existence of physical barriers to the circulation of people or vehicles and without limiting the visibility.

[0023] The idea of using air curtains is common in separating environments having different climates and also common in reducing the contamination among different rooms; however, in the case of fire, the requirement for not having a significant contamination between the room with smoke and the adjoining room is very high, once that the safe evacuation of occupants and intervention of firemen depends thereon. Apart from that, the high smoke temperature, which stratifies in the upper section of the rooms, in contrast with rather lower temperatures occurring on the cold lower layer, generates a strong pressure gradient increasing with the height, with no parallel in usages of air curtains in air conditioning.

[0024] Several research projects have been accomplished in the field of applying air curtains to confine the smoke flow. Vertical jets as well as sloped jets have been studied; however, the situations under study generally do not pay much attention to the possibility of combining air curtains with other smoke control means, which are necessarily present in buildings, and that together can in fact significantly improve the performance of curtains which are being used alone. In this technique an air curtain with a plane jet is combined, approximately on the door plane, with smoke control systems, which may impose the inlet through the openings of fresh air flows into the smoke filled rooms.

[0025] To preserve the momentum, the jets go on entraining ambient air on both sides of the opening. Should one of these environments contain a pollutant, it tends to be mixed into the jet, in particular when it is totally turbulent. When the jet reaches a surface, as for example the floor, in the case of vertical descending jets, it subdivides into two sections, each of them being deflected to each side of the jet plane. Should the pollutant contaminate the entire jet, it will be entrained into the room intended to be kept clean. The air curtain can thus contribute disadvantageously to the smoke dispersion towards the areas intended to be kept clean. In this technique, the rejection of the curtain air into the smoke free room is eliminated by adopting a suitable jet slope towards the interior of the damaged room and due to the existence of exhaust inside that room.

[0026] One can see that many of the smoke control systems used in buildings are based on the smoke exhaust at the fire source location and on the fresh air intake at the adjoining locations. In general, the flow speeds in the passage ways are not sufficiently high to avoid the smoke flow, being therefore necessary to proceed with the partial or total closing of those passage ways. While in other research papers air curtains have been generally seen as the sole means to ensure smoke tightness, here one intends to use air curtains as a way of improving tightness, in order to may reduce the air flow passing through the passage way, needed to prevent the smoke from flowing through it.

[0027] The present application discloses the usage of an air curtain composed of a plane air jet, approximately parallel to the plane of the communicating opening of a fire source room with the adjoining room. The air jet is generated by a cylindrical rotor fan enclosed in a housing with the approximate door width and having two openings, one on the outside of the room, through which the air intake is accomplished and another one on the lower section, through which that air is expelled, forming a plane jet. Typically, the horizontal air curtain can be used in openings having widths between 0.80 m and 3.00 m, but it can be adapted to openings having other dimensions. The fan is activated by an electrical supply engine. This device is installed on the upper or side section of the opening, on the outside. This air curtain operates together with the mechanical smoke exhaust system pertaining to the room, resulting in the smoke exhaust required by regulation, which completes the operation of this technology, being a characteristic of this technique the setting of ratios specifying which jet angle to the vertical and its speed according to the fire heat release rate, the smoke exhaust flow of the room and the geometry of the passage way. The configurations of this technology are the ones mentioned above, but its specific geometry depends on the referred parameters.

[0028] The analytical method is an intrinsic part of this invention, which enables to calculate the jet speed and its angle in relation to the vertical, according to the fire heat release rate and the geometry of the opening. Next, such method will be described. For each specific case, the rotor length is the same as the opening width, being possible in some cases to combine more than one fan for wide openings, and the angle of the output nozzle and the operating speed of the fan are adjusted. Pre-configured air curtains with a fixed angle and speed can also be used, provided the respective values are higher than the ones resulting from de application of the analytical method.

[0029] The air curtain now disclosed has the ability to confine the smoke flow at temperatures which may vary between room temperature and temperatures ranging 500°C. Experimentally, the performance has been proven at a temperature range varying between room temperature and 250°C.

[0030] Throughout the present application room temperature means what is usual for a person skilled in the art, at which the person is used to work in a comfortable way, and it may vary approximately between 15 and 30°C, preferably between 20 and 25°C, still more preferably between 21 and 23°C, nonetheless without restricting temperatures above or below such limits, and provided they are acceptable and recognized as room temperature or "chamber temperature", i.e. inside the building.

[0031] This smoke control system also includes smoke exhaust through mechanical means, which is needed to compensate the thermal expansion of the smoke, due to its heating generated by the heat release. Such exhaust also generates the low pressure needed for fresh air suction to occur through the external opening of the room.

Brief Description of the Figures

[0032] For an easier understanding of the technique a figure is attached, that depicts a preferred embodiment of the invention, which does not however intend to limit the object of the present application.

Figure 1: Schematic representation of the air curtain, adjusted to the minimum slope angle of the jet, where the following elements are depicted, in which the reference numbers indicate:

1 - supporting structure;
2 - adjustment of inflation angle;
3 - adjustment of jet thickness;
4 - rotation axis.

Figure 2: Schematic representation of the air curtain, adjusted to the maximum slope angle of the jet, in which the reference numbers indicate:

3 - adjustment of jet thickness.

Figure 3: Schematic representation of the air curtain usage in parking lots, in which the reference numbers indicate:

5 - air curtain;
6 - smoke exhaust;
7 - fire area;
8 - jet preventing the smoke from entering the adjoining room.

Figure 4: Schematic representation of the curtain usage in an access to a room, in which the reference numbers indicate:

5 - air curtain;
6 - smoke exhaust;
8 - jet preventing the smoke from entering the adjoining room.

Figure 5: Schematic representation of the curtain usage in an escape route, in which the reference numbers indicate:

5 - air curtain;
6 - smoke exhaust;
8 - jet preventing the smoke from entering the adjoining room.

Description of embodiments

[0033] The present application describes an air curtain combined with a mechanical smoke extraction for smoke control in rooms in a fire situation.

[0034] According to the illustrations in figures 1 and 2, the fans are mounted on a supporting structure (1), sustained over a rotation axis (4), which allows the adjustment of the inflation angle (2). The air moved by the fans is then directed towards the exit, through a structure that allows the adjustment of the jet thickness (3).

[0035] According to the illustration in figure 3, the curtain is installed at the communication between two rooms of a parking lot. As remains demonstrated in this embodiment, the main advantage in the usage of the curtain, rather than the fire gate, is that it does not obstruct the circulation of people in case of fire.

[0036] According to the illustration in figure 4, the usage of this curtain can also be carried out at the entrance of whatever room and/or chamber, in order to prevent the smoke from flowing to the escape route.

[0037] According to the illustration in figure 5, the usage of this curtain can also be carried out in an escape route, in order to prevent the smoke from flowing through it.

Pressure balance at the door

[0038] The smoke tightness ensured by an air curtain is based on the balance of the momentum of the curtain flow and of the smoke flow.

[0039] Let us consider a descending plane jet, with the nozzle placed at the level of a door lintel or of other type of vertical passage opening, and making an angle $\propto_0$ with the vertical plane, on which the opening is located. The jet momentum J_0 per width unit is given by the expression (1).

$$J_0 = \rho b_0 u_0^2 \qquad (1)$$

being ρ the mass density of the fluid, $\mathbf{b}_0$ the jet thickness at its origin and $\mathbf{u}_0$ the jet speed at its origin. As usually, in this expression it is assumed that the jet is conservative. Given that the smoke flow, intended to be retained, is normal to the opening plane, being horizontal in this case, it merely matters to compare with the momentum, due to the horizontal component of the jet speed, according to the expression (2).

$$J_{0h} = \rho b_0 u_0^2 sen \propto_0 \qquad (2)$$

[0040] The effect of this momentum per width unit of the jet, over the pressure $\Delta\mathbf{P}$ can be determined by the expression (3), in which h corresponds to the vertical height along which the horizontal component of the jet speed is annulled, that is, where the jet bends and becomes vertical.

$$\Delta P_a = \frac{\rho b_0 u_0^2 sen \propto_0}{h} \qquad (3)$$

[0041] When there is a difference of mass density between the inside of a room and the outside, assuming that in each environment the mass density is uniform, the value for the pressure difference between the two environments is given by the expression (4).

$$\Delta P_s = gH(\rho_0 - \rho_1) \qquad (4)$$

being H the height considered above the neutral plane. It is to be noted that, assuming the difference of mass densities is uniform, the pressure difference varies linearly with the height. Once the jet effect is relevant only above the neutral plane, situation in which the pressure inside the room is higher than the external pressure, then h in expression (3) is the height of the opening lintel above the neutral plane. On the other hand, the pressure difference due to the thrust is maximal for the upper section of the opening. Therefore, the height h above the neutral surface is the one for which the pressure balance is most critical. The pressure ratio given by the expressions (3) and (4) is a measurement of the curtain performance, as presented in expression (5):

$$\frac{\Delta P_a}{\Delta P_s} = \frac{\rho_0 b_0 u_0^2 \operatorname{sen}\alpha_0}{gh^2(\rho_0 - \rho_1)} \qquad (5)$$

[0042] Expression (6) is defined as the deflection module $\mathbf{D_m}$ [12], which is proportional to the expression (5).

$$D_m = \frac{\rho_0 b_0 u_0^2}{gh^2(\rho_0 - \rho_1)} \qquad (6)$$

[0043] Since in this process it is necessary to have a complementary exhaust flow, the flow intake passing through the opening, with the speed $\boldsymbol{u_a}$, shows a momentum which contributes to the referred pressure balance, whereupon equation (5) takes the following form:

$$\frac{\Delta P_a}{\Delta P_s} = \frac{\rho_0 b_0 u_0^2 \operatorname{sen}\alpha_0 + \rho_0 h u_a^2}{gh^2(\rho_0 - \rho_1)} \qquad (6a)$$

[0044] It is to be noted that the density difference can be expressed in terms of the temperatures in each environment, taking into account the equity of expression (7), which can be obtained by simplifying the ideal gas equation.

$$\rho_0 T_0 = \rho_1 T_1 \Leftrightarrow \rho_0 \frac{T_0}{T_1} = \rho_1 \qquad (7)$$

[0045] Combining expressions (5) and (7) and assuming that the pressures should be balanced, it is possible to obtain an estimate of the speed value, which prevents the smoke from flowing to the outside of the room, through expression (8):

$$u_0 = \sqrt{\frac{Bgh^2\left(1 - \frac{T_0}{T_1}\right) - \rho_0 h u_a^2}{\rho_0 b_0 \operatorname{sen}\alpha_0}} \qquad (8)$$

being $B = \frac{\Delta P_a}{\Delta P_s}$ a constant, which value is between 1.0 and 5.0, more preferably between the values of 2.0 and 3.0, which is here introduced to allow the empirical adjustment of this law and to enable the introduction of a safety factor.

Setting the smoke exhaust flow

[0046] When it is considered that the room with the heat source only has one opening, connecting it to the outside, it can easily be surmised that it is impossible to prevent the smoke from flowing through that opening to the outside, due (i) to the existence of a thermal expansion of the fluid inside the room and (ii) to the entrainment of external flow by the jet. This way, it is only possible to design the flow confinement at the door, combining an air curtain with the smoke exhaust, existing in many locations with mechanical smoke control systems. The problem of the exhaust flow estimate can thus be formulated based on the assumption of the referred items.

[0047] Thermal expansion of a fluid $\Delta\dot{V} = \dot{V}_1 - \dot{V}_0$, with subscripts 0 and 1 representing the initial and final states, due to the convected heat release rate $\mathbf{\dot{Q}_c}$, can be estimated bearing in mind that the equation of thermal energy preservation can be set in simple terms as follows:

$$\dot{Q}_c = \dot{M}\overline{C_p}(T_1 - T_0) \qquad (9)$$

being $\mathbf{\dot{M}}$ the mass flow of the fluid, $\mathbf{\overline{C_p}}$ the average specific heat at constant pressure, noticing there is a simplification here, which will not have significant consequences once the obtained expressions will be adjusted through empirical coefficients, $\mathbf{T_1}$ the absolute temperature of the hot fluid and $\mathbf{T_0}$ the initial temperature. Using expression (7), expression

(9) can be rewritten as follows:

$$\dot{Q}_c = \dot{V}_0 \rho_0 \overline{C_p} \left(\frac{\rho_0}{\rho_1} - 1\right) T_0 \tag{10}$$

then resulting in expression (11)

$$\frac{\dot{Q}_c}{\rho_0 \overline{C_p} T_0} = \dot{V}_0 \left(\frac{\rho_0}{\rho_1} - 1\right) = \dot{V}_1 - \dot{V}_0 = \Delta \dot{V} \tag{11}$$

[0048] The plane jet flow V is given by expression (12) [14]:

$$\dot{V} = 0{,}44 \left(\frac{x}{b_0}\right)^{0{,}5} \dot{V}_0 \tag{12}$$

being x the distance to the origin, $\mathbf{b_0}$ the jet thickness at its origin and $\mathbf{\dot{V}_0}$ the jet flowrate at its origin. The minimal smoke exhaust flow from the fire source room should be the one corresponding to the sum of the thermal expansion with at least half of the jet flow. It is to be noted that in the jet there is flow entrained from the environments on both sides of the plane jet. The entrained flow from the interior of the room represents an exchange of internal mass to the room itself, whereupon it does not increase the exhaust flow. Such smoke flow contaminates the jet, so one should consider that the whole flow carried in the jet should be drained into the interior of the room, and therefore such flow increase should be drained to the outside by the smoke control system, so that there is no inside pressure increase in the room, which would rapidly compromise the tightness of the air curtain. Thus, the minimal exhaust flowrate $\mathbf{\dot{V}_{exhaust}}$ includes a fraction corresponding to the thermal expansion, a fraction corresponding to half of the jet flow and another fraction corresponding to half of the jet flow at its origin, according to expression (13):

$$\dot{V}_{exaust} = \frac{\dot{Q}_c}{\rho_0 \overline{C_p} T_0} + \left(0{,}22 \sqrt{\frac{2x}{b_0}} + \frac{1}{2}\right) u_0 b_0 w \tag{13}$$

being u_0 the jet speed at its origin and w the opening width. This expression was simplified to:

$$\dot{\mathrm{V}}_{\mathrm{exaust}} = \frac{\dot{\mathrm{Q}}_{\mathrm{c}}}{\rho_0 \overline{\mathrm{C_p}} \mathrm{T}_0} + \mathrm{C}\left[0{,}22 \left(\frac{2x}{b_0}\right)^{0{,}5} + 0{,}5\right] u_0 w b_0 \tag{13b}$$

being C a constant, which value is between 1.0 and 4.0, more preferably between the values of 1.5 and 2.5, which is introduced here to allow the empirical adjustment of this law and to enable the introduction of a safety factor.

[0049] It is to be noted that only the flow entrained from the interior of the room is internal to the system, the half jet flowrate already considered includes half of the flowrate at its origin and the flowrate entrained from the exterior, whereupon there would be still missing half of the flowrate at its origin.

Smoke temperature estimate

[0050] Expression (8) includes temperature $\mathbf{T_1}$ as an independent variable, which corresponds to the average temperature of the hot layer settling inside the fire source room. Such temperature depends on the convected heat release rate, here assuming that at the initial stage of the fire the whole radiated energy is being absorbed by the surroundings, therefore not contributing to the smoke and exhaust flow heating. The estimate of convected heat output results from the fire scenario analysis through Fire Safety Engineering techniques, representing an input data for the air curtain dimensioning. Expression (9) is used to estimate the average smoke temperature, which represents the thermal energy balance, but now taking the specific heat values at constant pressure corresponding to initial $\mathbf{C_{p0}}$ and final temperature $\mathbf{C_{p1}}$, originating expression (14):

$$\dot{Q}_c = \dot{M}\left(C_{p1}T_1 - C_{p0}T_0\right) \qquad (14)$$

[0051] Since exhaust fans set an approximately constant volume flowrate, it is convenient to represent expression (14) in function of the volume flowrate rather than the mass flowrate, originating expression (15):

$$\dot{Q}_c = \rho_1 \dot{V}_{exhaust}\left(C_{p1}T_1 - C_{p0}T_0\right) = \rho_0 \frac{T_0}{T_1} \dot{V}_{exhaust}\left(C_{p1}T_1 - C_{p0}T_0\right) = \rho_0 T_0 \dot{V}_{exhaust}\left(C_{p1} - C_{p0}\frac{T_0}{T_1}\right) \qquad (15)$$

$$C_{p0}\frac{T_0}{T_1} = C_{p1} - \frac{\dot{Q}_c}{\rho_0 T_0 \dot{V}_{exhaust}} \qquad (16)$$

$$T_1 = \frac{C_{p0}T_0}{C_{p1} - \frac{\dot{Q}_c}{\rho_0 T_0 \dot{V}_{exhaust}}} \qquad (17)$$

[0052] It is to be noted that expression (17) only depends upon the fluid initial state, excepting in what concerns the exhaust volume flowrate, convected heat release rate and specific heat at constant smoke pressure. Once the latter depends upon the final temperature of the fluid, the solution has to be iteratively determined.

Exhaust mass flowrate estimate

[0053] After knowing the smoke temperature, it is possible to estimate the exhaust mass flowrate, needed to set the mass balance on the hot layer, considering the following equity:

$$\dot{M}_{exhaust} = \rho_1 \dot{V}_{exhaust} = \rho_0 \frac{T_0}{T_1} \dot{V}_{exhaust} = \rho_0 \frac{C_{p1} - \frac{\dot{Q}_c}{\rho_0 T_0 \dot{V}_{exhaust}}}{C_{p0}} \dot{V}_{exhaust} \qquad (18)$$

[0054] After simplification, from this equation results equity (19):

$$\dot{M}_{exhaust} = \frac{\rho_0 T_0 C_{p1} \dot{V}_{exhaust} - \dot{Q}_c}{T_0 C_{p0}} \qquad (19)$$

Interface height estimate

[0055] One of the possible formulations for estimating the smoke flowrate at the plume [15] assumes that the flow differs, depending on the flame touching or not the hot layer. It is considered as a reference height the one given by expression (20) :

$$z_1 = 0{,}166\dot{Q}_c^{\,2/5} \qquad (20)$$

[0056] The flow is then given by (21):

$$\dot{m} = \begin{cases} \left(0{,}071\dot{Q}_c^{\,1/3} z^{5/3}\right) + 0{,}0018\dot{Q}_c & se\ z > z_1 \\ 0{,}032\dot{Q}_c^{\,3/5} z & se\ z \le z_1 \end{cases} \qquad (21)$$

[0057] Knowing that the hot layer height corresponds to the balance between the exhaust mass flowrate and the smoke mass flowrate on the plume, in equation (21) $\dot{\mathbf{m}}$ can be replaced by $\dot{\mathbf{M}}_{\mathbf{exhaust}}$, then obtaining the following interface height estimates between the hot and cold layers:

$$z = \begin{cases} \left(\dfrac{\dot{M}_{exhaust} - 0{,}0018\dot{Q}_c}{0{,}071\dot{Q}_c^{\,1/3}} \right)^{3/5} & se\ z > 0{,}166\dot{Q}_c^{\,2/5} \\ \dfrac{\dot{M}_{exhaust}}{0{,}032\dot{Q}_c^{\,3/5}} & se\ z \leq 0{,}166\dot{Q}_c^{\,2/5} \end{cases} \qquad (22)$$

[0058] Since there are several formulations of semi-empirical origin, at this point another formulation can be used.

Algorithm for jet speed estimate

[0059] Bearing in mind the former equations is then possible to set an algorithm for estimating the jet speed, needed to confine the smoke flowing through a vertical passage way, as follows:

1. Considering, as first approach, a jet speed at its origin $\boldsymbol{u}_0$;
2. Setting the minimal exhaust volume flowrate, according to expression (13b);
3. Estimating the average smoke temperature, according to expression (17);
4. Estimating the exhaust mass flowrate, according to expression (19) ;
5. Estimating the interface layer height, according to expression (22);
6. Assuming that the interface layer height, by approximation, is very close to one of the neutral plane, calculating the initial speed of the jet, according to expression (8);
7. The u_0 value obtained in the previous step is used as an estimate in step 1 and the cycle is restarted;
8. Steps 1 to 7 are repeated until reaching convergence.

[0060] In order for the process to be stable, it may be necessary to use under-relaxation techniques.

Bibliography

[0061]

[1] S. Gupta, M. Pavageau, J.C. Elicer-Cortes - Cellular confinement of tunnel sections between two air curtains, Building and Environment 42 (2007) 3352-3365.
[2] H. Sakurai, T. Hayashi, M. Shibata, K. Kanehara - Researches on air shutter for fire defence, Fire Safety Journal 2 (1979/80) 9-16.
[3] F. Cumo, S. Rossetti, G. Guidi - 3D simulation of dynamic barriers against fume and gaseous toxic substances, Proceedings of the Ventilation 2000 6th International Symposium on Ventilation for Contaminant Control, 4-7 June, Helsinki, Finland.
[4] M. Dufresne de Virel, C. Solliec, L. Guyonnaud - Mise en sécurité contre fumées d'incendie, Revue Face au Risque 348 (1998) 13-18.
[5] M.S. Altinakar, A. Weatherill - Use of an inclined air curtain for preventing smoke propagation in a tunnel during fire emergency, Proceedings of the 4th International Conference on Safety in Road and Rail Tunnels, 2001.
[6] F. Gugliermetti, L. Santarpia, G. Zori - Air curtain applied to fire smoke pollution control, air pollution 2003, 11th International Conference on Modelling, Monitoring and Management of Air Pollution, September 17-19 2003, pp. 541-549, Catania, Italy.
[7] M. Sawley, B. Greveldinger, A. Drotz - Numerical flow simulation of an air curtain for road tunnel fire safety, Supercomputing Rev 14 (2004) 3-6.
[8] L.H. Hu, J.W. Zhou, R. Huo, W. Peng, H.B. Wang - Confinement of fire-induced smoke and carbon monoxide transportation by air curtain in channels, Journal of Hazardous Materials 156 (2008) 327-334.
[9] F. Felis, M. Pavageau, J.C. Elicer-Cortés, T. Dassonville - Simultaneous measurements of temperature and velocity fluctuations in a double stream-twin jet air curtain for heat confinement in case of tunnel fire. International Communications in Heat and Mass Transfer 37 (2010) 1191-1196.
[10] I YP, Chiu YL, Wu SJ - The simulation of air recirculation and fire/explosion phenomena within a semiconductor factory. J Hazard Mater 2009; 163: 1040 - 51.

[11] Yang-Cheng Shih, An-Shik Yang, Chang-Wei Lu - Using air curtain to control pollutant spreading for emergency management in a clean room. Building and Environment 46 (2011) 1104 - 1114.
[12] Luis Paulo Coelho Neto - Estudo de sistemas de vedação aerodinâmica do tipo cortina de ar. Coimbra: Faculdade de Ciências e Tecnologia da Universidade de Coimbra, Departamento de Engenharia Mecanica, 2006. Dissertação para Doutoramento em Engenharia Mecanica (Aerodinamica).
[13] Walton GN, Dols WS - CONTAM. User Guide and Program Documentation, NISTIR 7251. Gaithersburg: National Institute of Standards and Technology; 2013.
[14] Blevins RD. - Applied fluid dynamics handbook. Van Nostrand Reinhold Company Inc., New York, USA (1984).
[15] VIEGAS, Joao Carlos - Utilização de ventilação de impulso em parques de estacionamento cobertos. Lisboa: Laboratório Nacional de Engenharia Civil, 2008. Série Teses e Programas de Investigação, 55.

[0062] Naturally, the present embodiment is not in any way restricted to the embodiments described in this document, and a person with average knowledge in the field can anticipate many possibilities of modifying it, without losing track of the general idea, as defined in the claims.

[0063] All above described embodiments can obviously be combined together. The following claims additionally define preferred embodiments.

Claims

1. Air curtain for controlling smoke generated by a fire, comprising a vertical or horizontal plane air jet, with a slope suitable for the plane of the communicating opening between at least two rooms, in which the referred air jet is generated by at least one cylindrical rotor fan enclosed in a housing having two openings, one on the outside of the room and the other on the lower section.

2. Air curtain according to the previous claim, wherein the cylindrical rotor fan is activated by an electrical supply engine.

3. Air curtain according to any of the previous claims, wherein the length of the rotor used in the fan is the same as the opening width.

4. Air curtain according to any of the previous claims, wherein the cylindrical rotor fan is mounted on a supporting structure sustained over a rotation axis.

5. Air curtain according to any of the previous claims, wherein the exhaust smoke flow rate from the fire source room is related with the thickness and the slope angle of the jet in relation to the vertical plane, by the expression

$$\dot{\mathrm{V}}_{\mathrm{exaust}} = \frac{\dot{\mathrm{Q}}_{\mathrm{c}}}{\rho_{\,0}\overline{\mathrm{C}_{\mathrm{p}}}\mathrm{T}_0} + \mathrm{C}\left[0{,}22\left(\frac{2x}{b_0}\right)^{0{,}5} + 0{,}5\right]u_0 w b_0$$

being $\mathbf{u_0}$ the jet speed at its origin, **w** the opening width, C a constant, which value is between 1.0 and 4.0, x the distance to the origin, $\mathbf{b_0}$ the jet thickness at its origin, ρ the mass density of the fluid, $\mathbf{b_0}$ the jet thickness at its origin, $\mathbf{T_0}$ the initial temperature, $\dot{\mathbf{Q}}_{\mathbf{c}}$ the convective heat release rate and $\overline{\mathbf{C_p}}$ the average specific heat at constant pressure.

6. Air curtain according to any of the previous claims, wherein the necessary jet speed is calculated by the following expression:

$$u_0 = \sqrt{\frac{\mathrm{Bgh}^2\left(1-\frac{\mathrm{T}_0}{\mathrm{T}_1}\right) - \rho_{\,0}\mathrm{hu}_{\mathrm{a}}^2}{\rho_{\,0}\mathrm{b}_0 \mathrm{sen}\,\alpha_0}}$$

in which $\mathbf{u_0}$ is the jet speed at its origin, $B = \frac{\Delta P_a}{\Delta P_s}$ a constant with a value between 1.0 and 5.0, h the opening lintel height above the neutral plane, $\mathbf{T_1}$ the absolute temperature of the hot fluid, $\mathbf{T_0}$ the initial temperature, ρ_0 the density of the fluid at $\mathbf{T_0}$ and $\propto_0$ the angle between the jet and the vertical plane where the opening is located.

7. Air curtain according to claim 1, wherein the housing comprising the cylindrical rotor contains two openings in which:

- the opening on the outside of the room carries out the air intake;
- the lower opening expels the air and consequently forms the plane jet.

8. Air curtain according to any of the previous claims, installed on the upper or side section of the oom opening, on the outside thereof and operating in combination with the active smoke exhaust system of the room.

9. Use of the air curtain described in any of the previous claims, to control the smoke in rooms and/or escape routes, in fire situations.

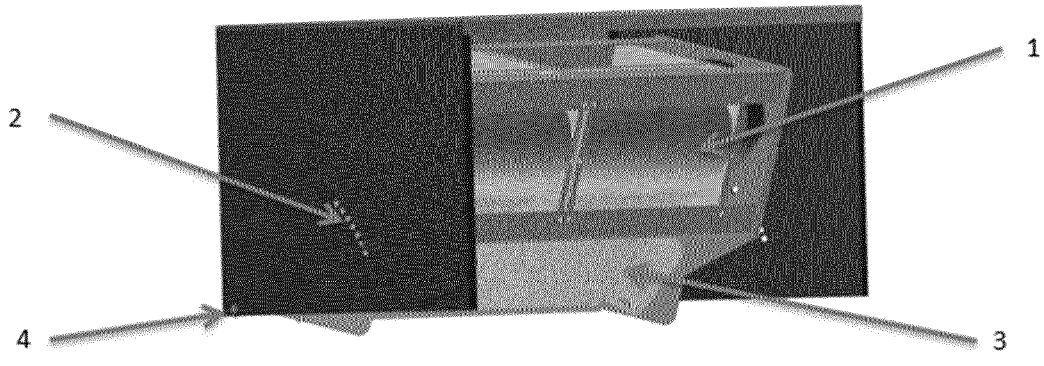

Figure 1

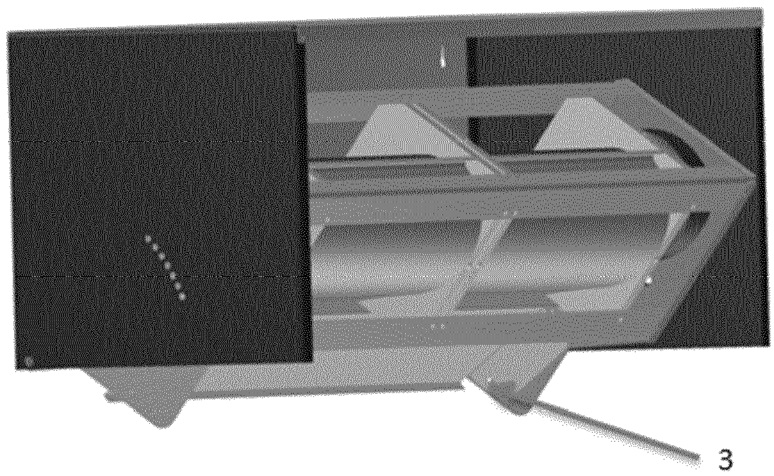

Figure 2

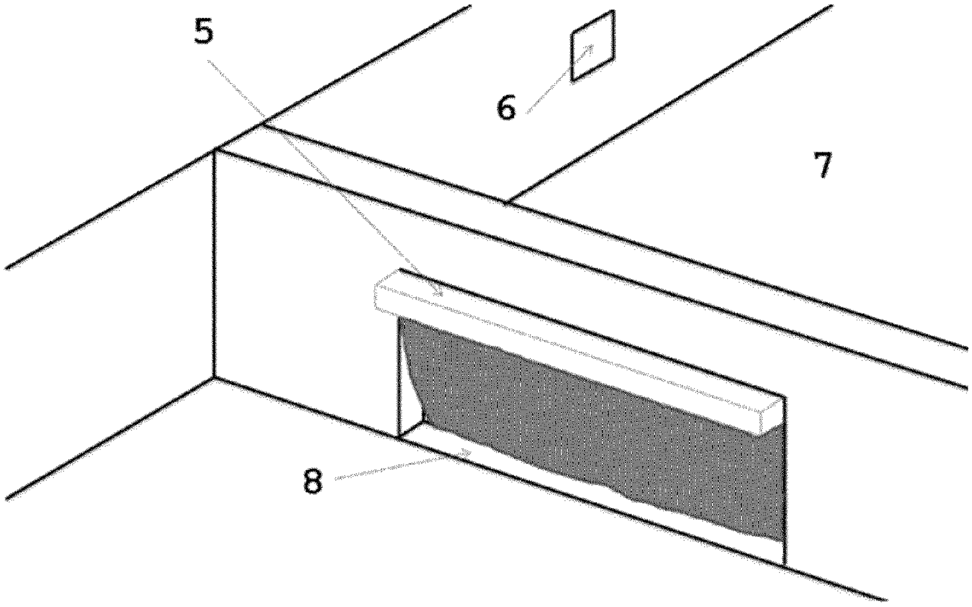

Figure 3

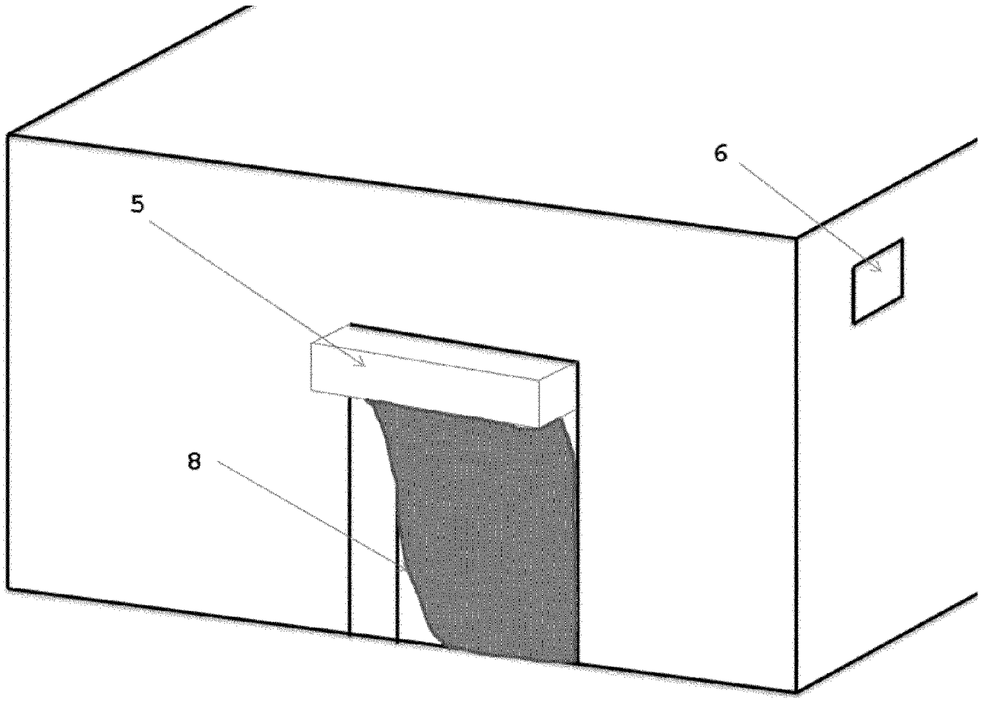

Figure 4

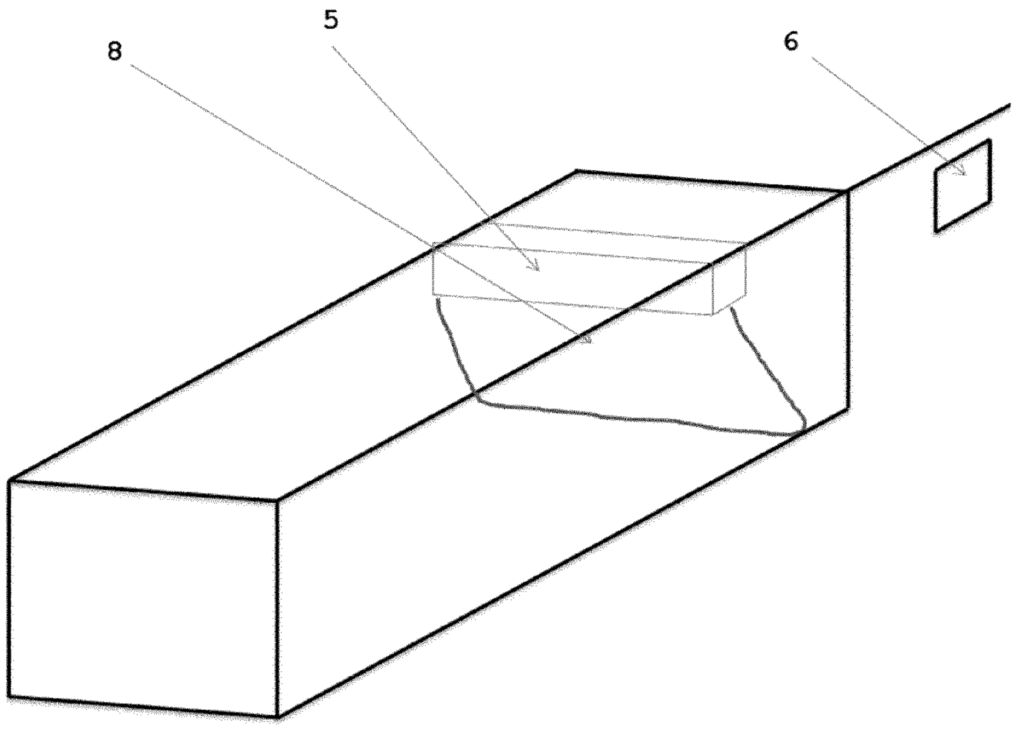

Figure 5

REFERENCES CITED IN THE DESCRIPTION

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Non-patent literature cited in the description

- **S. GUPTA ; M. PAVAGEAU ; J.C. ELICER-CORTES.** Cellular confinement of tunnel sections between two air curtains. *Building and Environment,* 2007, vol. 42, 3352-3365 **[0061]**
- **H. SAKURAI ; T. HAYASHI ; M. SHIBATA ; K. KANEHARA.** Researches on air shutter for fire defence. *Fire Safety Journal,* 1979, vol. 2, 9-16 **[0061]**
- **F. CUMO ; S. ROSSETTI ; G. GUIDI.** 3D simulation of dynamic barriers against fume and gaseous toxic substances. *Proceedings of the Ventilation 2000 6th International Symposium on Ventilation for Contaminant Control,* 04 June 2000 **[0061]**
- **M. DUFRESNE DE VIREL ; C. SOLLIEC ; L. GUYONNAUD.** Mise en sécurité contre fumées d'incendie. *Revue Face au Risque,* 1998, vol. 348, 13-18 **[0061]**
- **M.S. ALTINAKAR ; A. WEATHERILL.** Use of an inclined air curtain for preventing smoke propagation in a tunnel during fire emergency. *Proceedings of the 4th International Conference on Safety in Road and Rail Tunnels,* 2001 **[0061]**
- **F. GUGLIERMETTI ; L. SANTARPIA ; G. ZORI.** Air curtain applied to fire smoke pollution control, air pollution 2003. *11th International Conference on Modelling, Monitoring and Management of Air Pollution,* 17 September 2003, 541-549 **[0061]**
- **M. SAWLEY ; B. GREVELDINGER ; A. DROTZ.** Numerical flow simulation of an air curtain for road tunnel fire safety. *Supercomputing Rev,* 2004, vol. 14, 3-6 **[0061]**
- **L.H. HU ; J.W. ZHOU ; R. HUO ; W. PENG ; H.B. WANG.** Confinement of fire-induced smoke and carbon monoxide transportation by air curtain in channels. *Journal of Hazardous Materials,* 2008, vol. 156, 327-334 **[0061]**
- **F. FELIS ; M. PAVAGEAU ; J.C. ELICER ; CORTÉS, T. DASSONVILLE.** Simultaneous measurements of temperature and velocity fluctuations in a double stream-twin jet air curtain for heat confinement in case of tunnel fire. *International Communications in Heat and Mass Transfer,* 2010, vol. 37, 1191-1196 **[0061]**
- **I YP ; CHIU YL ; WU SJ.** The simulation of air recirculation and fire/explosion phenomena within a semiconductor factory. *J Hazard Mater,* 2009, vol. 163, 1040-51 **[0061]**
- **YANG-CHENG SHIH ; AN-SHIK YANG ; CHANG-WEI LU.** Using air curtain to control pollutant spreading for emergency management in a clean room. *Building and Environment,* 2011, vol. 46, 1104-1114 **[0061]**
- **LUIS PAULO COELHO NETO.** Estudo de sistemas de vedação aerodinâmica do tipo cortina de ar. Coimbra: Faculdade de Ciências e Tecnologia da Universidade de Coimbra, Departamento de Engenharia Mecanica. *Dissertação para Doutoramento em Engenharia Mecanica,* 2006 **[0061]**
- CONTAM. **WALTON GN ; DOLS WS.** User Guide and Program Documentation, NISTIR 7251. Gaithersburg: National Institute of Standards and Technology, 2013 **[0061]**
- **BLEVINS RD.** Applied fluid dynamics handbook. Van Nostrand Reinhold Company Inc, 1984 **[0061]**
- Utilização de ventilação de impulso em parques de estacionamento cobertos. **JOAO CARLOS.** Série Teses e Programas de Investigação. Lisboa: Laboratório Nacional de Engenharia Civil, 2008, 55 **[0061]**