Fire issues for natural ventilation

Predicting the movement of smoke in a naturally ventilated building is a difficult process for architects and design engineers alike. A software model developed by the Fire Research Station may provide a solution.

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This article forms part of a DETR 'Partners in Innovation' project entitled 'Overcoming conflicts between environmental natural ventilation and fire safety in atrium office-type buildings'. The BRE's project partners are Ove Arup & Partners and Colt International.

References

[1]Cook J and McEvoy M, "Naturally ventilated buildings: simple concepts for large buildings", *Solar Today*, March/April 1996, pp22-25.
[2]Hansell G O and Morgan H P, "Design approaches for smoke control in atrium buildings", *BRE Report BR258*, 1994.
[3]"Natural ventilation in non-domestic buildings", *CIBSE Applications Manual AM10 (Part F)*, 1997.
[4]Hansell G O and Morgan H P, "Smoke control in atrium buildings using depressurisation – Part 1: design principles", *Fire Science and Technology*, Volume 10, Nos 1 and 2, 1990, pp11-26.

The contemporary atrium is often a tall, open space within a multi-storey building. Atriums have a variety of functions, but they are mainly used to naturally ventilate office-type buildings by using pressures generated by external wind and air temperature differences[1].

A downside of such open spaces is that smoke from a fire can invade adjacent areas. While there are various fire safety strategies using smoke control[2], there is a perceived conflict between natural environmental ventilation and fire safety strategies – which presents a barrier to the uptake of low energy, naturally ventilated atrium buildings.

To try and help reconcile natural environmental ventilation with smoke ventilation for atrium office buildings, the BRE has developed a simple assessment model/tool.

The design model

The technique developed by the BRE is based on the 'inverse openings' model. This uses simple algorithms to identify the opening sizes (both inlet and outlet) required for natural environmental ventilation[3].

The model requires input parameters in order to define the building, the atrium space and the prevailing weather conditions. These parameters will include:

- ☐ the number of floors;
- ☐ building height;
- ☐ floor area per storey;
- ☐ floor-to-ceiling height per storey;
- ☐ slab-to-slab height per storey;
- ☐ room temperature;
- ☐ required air change rate per storey;
- ☐ wind pressure coefficients (for both the inlets and the roof vent – outlet);
- ☐ the height of the roof vent above ground.

The atrium can be considered as a single space of homogeneous temperature, or it may be divided into horizontal slices to incorporate a temperature gradient. Each slice needs to be defined by:

- ☐ the number of slices;
- ☐ vertical length of each slice;
- ☐ the temperature of each slice;
- ☐ the height of neutral pressure level above ground.

The neutral pressure plane is the height in the atrium at which the pressure is equal to the external air pressure. Air flows in below this height, and out above it.

In addition, the weather conditions need to be recorded, such as outside temperature, wind speed, the terrain (rural, city, etc) and whether local or meteorological weather data is being used.

The model will then give an output of the required inlet opening sizes needed per storey (both with and without the effect of wind) and the required size of the roof vent.

Figure 1 shows the geometry of a ten-storey atrium building used in the BRE tests. Each storey is 3·5 m high with a plan area of 480 m² on either side of a central atrium. This geometry

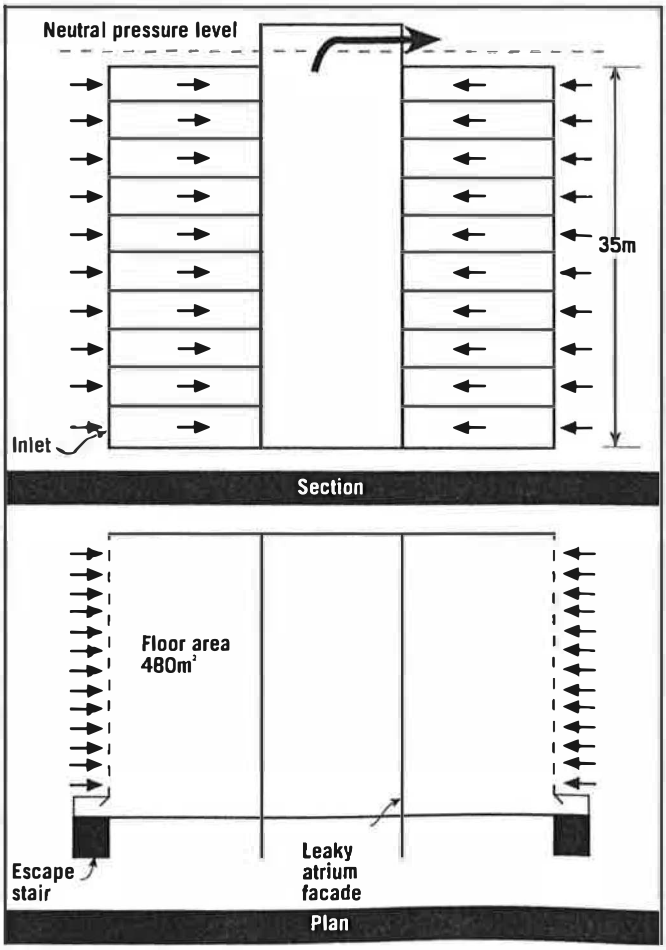


FIGURE 1: The geometry of the ten-storey building used as part of the BRE's test procedure. Each storey is 3·5 m high, with a plan area of 480 m².

was chosen because in the event of a fire, phased evacuation is possible for atrium office buildings above 30 m in height. This means that rooms adjacent to the atrium must be kept free of smoke for an extended period.

The example building has inlets on each storey on both its windward and leeward sides. The example assumes that the offices have unsealed windows fronting onto the atrium or other small ventilation openings enabling air movement between the offices and the atrium.

The neutral pressure level was fixed above the highest storey to ensure that air enters the atrium on both the windward and leeward side of the building. This would also prevent smoke from travelling into the office accommodation from the atrium in the event of a fire, by keeping the leakage paths across the leaky atrium facade under 'suction'. In this way the ventilation paths would act as an atrium depressurisation system.

The scenario also assumes that the temperature of the atrium is constant for its entire height. For the natural environmental ventilation case the temperature of the stack was set at 24°C, with an external temperature of 20°C. Wind pressure coefficients were assigned to the inlets (0·65 for windward inlets and -0·45 for leeward inlets).

The wind pressure coefficient for the roof vent was set at -0·6, and the required air change rate per storey was based on a natural ventilation strategy for summer with a volume flow rate of 8 litres/s/person (based on 1 person/10 m²). This corresponds to an hourly air change rate per storey of 0·914. The external windspeed was set at 3 m/s.

Identical input parameters were also used for the fire scenario, with the exception of the temperature in the atrium and the required air change rate per storey.

Reconciliation procedure

To reconcile natural environmental ventilation with smoke ventilation for atrium office buildings, the designer will need to take several iterative steps.

The opening sizes required for a natural environmental ventilation strategy must be determined by using the spreadsheet model (both stack and wind ventilation). This should be repeated with identical neutral plane level and geometry conditions, but with an elevated temperature in the atrium to take account of a fire.

The air change rate should be adjusted for each floor until a match is achieved with the inlet opening sizes obtained for the natural environmental ventilation case. This will give a new minimum size of roof vent.

In a fire scenario, it is likely that a door will be open from the atrium on the lowest storey for means of escape. To take an open door into account, the air change rate on this storey can be adjusted for by calculating the volume flow needed to maintain the same pressure difference as with a closed door.

This will enable a roof vent size to be determined for both the natural environmental ventilation and fire cases for identical inlet areas. Designers should then compare the roof vent sizes obtained for the natural ventilation and fire case.

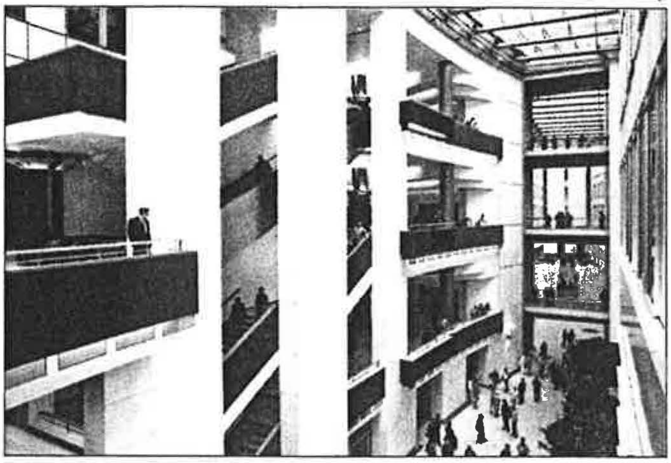
The air change rate should be adjusted for on each floor until a convergence is achieved for the new inlet areas.

Table 1 shows the roof vent sizes obtained for the natural environmental ventilation case, and for a number of elevated temperatures in the atrium (50-100°C). These correspond to fire sizes of approximately 1·5 to 3·0 MW in the atrium.

The roof vent sizes were obtained by matching the inlet openings determined for no wind. In this case, the minimum openings were larger and hence can be considered a worst case.

Design implications

Table 1 shows that for this particular geometry, the roof vent size for the natural environmental ventilation case is 18·6 m². In the event of a fire, the vent opening size increases as the elevated temperature in the atrium increases.



A powered smoke and heat exhuast system has been applied in the recently-opened EuroParliament building in Brussels.

With a door closed on the lowest storey, the outlet opening size required is 20·9 m² for a temperature of 100°C in the atrium. The worst case scenario is with an open door on the lowest storey and an atrium temperature of 100°C.

Table 1 also shows that the outlet opening size for this scenario is 28·3 m². This demonstrates that an extra 10 m² on the roof vent area is required in the event of a fire, compared to the natural environmental ventilation case for this scenario. Here, the designer has the option of including an extra roof vent opening (of 10 m²), openable on detection of a fire.

Alternatively, the roof vent could be made deliberately large to cope with a fire, although this would have the effect of increasing the air change rate per storey under normal ventilation conditions.

This result is for a very particular scenario. Further simulations need to be carried out to determine the effect of parameters such as wind speed and wind pressure coefficients on the size of the openings.

Note that the spreadsheet model requires the user to assign trial values to the air change rate on each storey, and manually iterate to achieve a result. This process is not ideal, as it can be time consuming and error-ridden.

To simplify the approach for the fire condition, the BRE has coded a new model (in Visual Basic) from algorithms described in previous work[4]. This model uses the smoke control strategy of atrium depressurisation, which uses essentially the same principles as natural environmental ventilation to keep the leakage paths across the leaky atrium facade under 'suction'.

This prevents smoke leaking into the atrium from the office accommodation. The fire model requires the inlet areas on each storey as an input parameter and will determine the required roof vent (outlet) area.

These two models should be used as a single design tool. The simple design tool is still being developed at the BRE – a design guidance document will soon be published complete with a copy of the model on disk.

TABLE 1: ROOF VENT SIZES FOR THE ZERO WIND CASE

	Roof vent size (m²) (Door closed on the lowest storey)	Roof vent size (m²) (Door open on the lowest storey)
Natural ventilation case	18·6	–
Fire in atrium (50°C)	19·4	26·3
Fire in atrium (60°C)	19·7	26·7
Fire in atrium (70°C)	20·0	27·1
Fire in atrium (80°C)	20·3	27·5
Fire in atrium (90°C)	20·6	27·9
Fire in atrium (100°C)	20·9	28·3