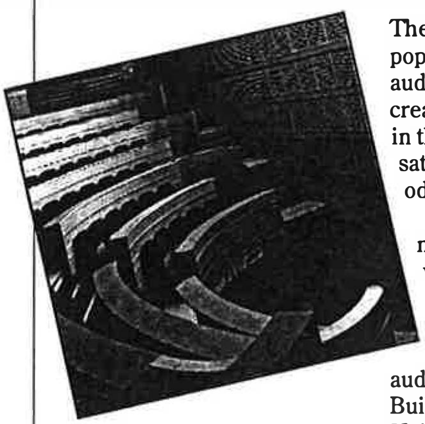
Research scientists at the BRE and De Montford University have carried out tests examining the performance and operation of stack ventilation systems in auditoria.

ANDREW HOWARTH REPORTS

Stack ventilation in auditoria



The intermittently high populations associated with auditoria and lecture theatres create a challenge for designers in their task of ensuring the satisfactory removal of heat, odours and carbon dioxide.

Over the last 25 years mechanical ventilation, often with air conditioning, has become commonplace for environmental control.

However, for the auditorium at the Queens Building, De Montfort University[1,2], the overriding design objective was to avoid the use of fans and refrigeration, instead placing great importance on effective natural ventilation.

The research programme aimed to assess the performance of the auditorium in terms of ventilation rates and temperatures for thermal comfort. In making this assessment, the suitability of the design tools was also tested.

Figure 1 shows the auditorium in plan and cross-section. Ventilation air enters an underfloor void via adjustable intake louvres through upward sloping ducts. It then enters the auditorium through openings in continuous strips beneath each row of seats. Finned tube heat exchangers behind the openings heat the air before it enters the auditorium.

The air leaves through two high-level rectangular openings in the foot of two 13·7 m-high rhombic section ventilation stacks with four adjustable, top-hinged windows forming the exit at the top (total vertical distance from inlet to outlet centres is 17·6 m). Table 1 shows the areas of the various interzonal openings in the air path and the free areas of the adjustable inlet and outlet openings in their 25%, 50%, 75% and fully-open positions.

TABLE 1: AREAS OF INLETS/OUTLETS/INTERMEDIATE OPENINGS IN FLOW PATH

BMS setting	Air intakes (m^2)	Grilles under seats (m^2)	Stack inlets (m^2)	Stack outlets (m^2)
100%	7·90	14·67	6·11	7·49
75%	6·30	14·67	6·11	6·91
50%	3·40	14·67	6·11	4·64
25%	1·44	14·67	6·11	2·30

Design tools

The original design was based on the methods outlined in CIBSE *Guide A* and described by Thomas[3], using conventional buoyancy theory to determine the available pressure for overcoming the system resistance estimated from pressure drop data in sources such as the CIBSE *Guide C*.

The conditions which are least likely to provide driving forces for buoyancy-driven natural ventilation occur in summer when designers may assume 'zero' wind assistance as a worst-case scenario.

In the case of the Queens Building, additional design tools were used to assess the temperatures and airflows during this critical period.

These are summarised by Eppel *et al*[4] who describes the use of computer simulation (esp) to predict the number of occurrences of high temperatures through the year.

This technique provides a good assessment of the beneficial effect of the high thermal capacity of the building, underlining the importance of this aspect of the building in maintaining summertime temperatures.

The ventilation airflow, internal heat gains and temperature distribution were also studied at model scale using salt bath modelling.

There was good agreement between esp and salt bath model predictions of mean temperature (eg 26·9°C versus 27·6°C) and reasonable agreement for ventilation rate (eg 9·2 ac/h versus 6·6 ac/h).

The minimum required ventilation rate for a full auditorium was 5 ac/h (1·2 m^3/s), assuming 150 people requiring 8 l/s per person and an internal volume of 870 m^3.

The air exchange rates were measured using the BRE's Autovent system described by Etheridge & Gale[5]. This system uses a tracer gas injection and monitoring technique, in this case with a series of single short injections, following which the concentration fell due to dilution with 'fresh' incoming air. Overall and local ventilation rates were calculated.

Temperature was continuously recorded at several locations and, in some tests, air speeds in the stack monitored with low velocity anemometers.

Heat generated by up to 100 occupants was simulated using 100 W lamps.

Collaborators working within the IEA Annex 26 project undertook some work on cfd modelling, and the validity of cfd as a design tool was considered (Annex 26 expects to publish its findings shortly).

Winter ventilation

Figure 2 shows the overall ventilation flow rates measured in winter for a wide range of weather conditions and the full range of damper settings. For comparison, it shows both experimental results and values calculated, assuming ventilation driven by buoyancy alone, using the CIBSE *Guide A* procedure. DT denotes inside-outside temperature difference, T ave is the mean absolute temperature.

It can be seen that a wide range of airflow rates is achievable, usually greater than required for full occupancy (1·2 m^3/s). This indicates that finer control at smaller openings would be preferable in cold conditions.

Occupants in seats near the three underfloor air inlets experienced some chill discomfort in cold weather caused by air by-passing the pre-heat units. This happened on occasions even when the

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References

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[3] Thomas R, *Environmental design*, E & FN Spon, 1996.

[4] Eppel H and Lomas K J, "Simulating the thermal performance of naturally ventilated spaces: a case study", *Proceedings of the FLEA conference 'Architecture and urban space', 1991.*

[5] Etheridge D and Gale R, "Automatic measurement of air change rates", *Proceedings of the International Gas Research conference, London, 13-16 June 1983.*

This paper is based on measurements of the ventilation and thermal performance at the Queens Building, De Montfort University carried out between 1993 and 1996. The work was jointly funded by BRE/DETR – as part of the Energy-Related Environmental Issues (EnREI) research programme – and De Montfort University. It is linked to international collaborative work carried out within the framework of International Energy Agency project (Annex 26) on the energy efficient ventilation of large enclosures.

dampers were nominally fully closed, which appeared to be due to leakage around the louvres.

Summer ventilation

The key requirement for ventilation in summertime was to meet the needs for air quality, rather than preventing overheating which was achieved by the high thermal mass.

Figure 3 shows that ventilation in summer was again broadly adequate (above the 1·2 m^3/s minimum). One exception shows that the airflow was less than this, even with fully-open dampers, which may present an occasional problem for a full auditorium. The considerable data scatter is indicative of wind effects, even when notionally 'still' weather conditions prevailed.

Results recorded in other still conditions showed that when ambient temperature was higher than internal, and reverse flow down the stacks could be expected, such flows were not observed. It would appear that the air movement generated in the urban environment during the summer has an important impact in inducing ventilation at the large openings.

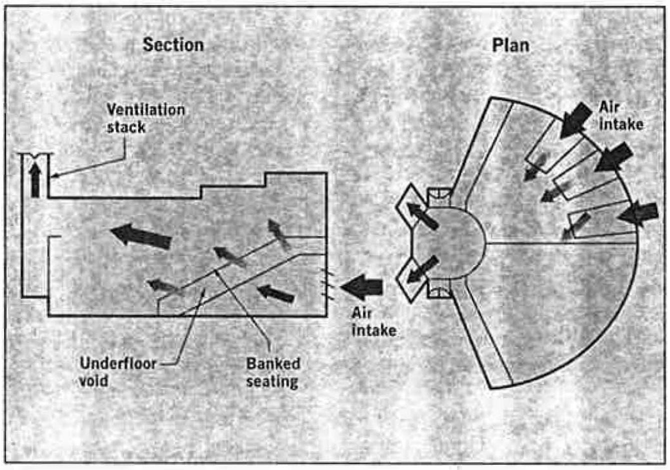

FIGURE 1: Section and plan of the auditorium at the Queens Building, De Montfort University, showing the general directions of air movement.

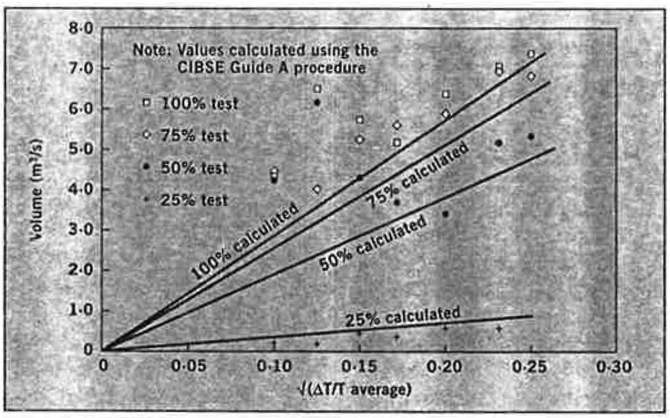

FIGURE 2: Measured and calculated winter airflow rates.

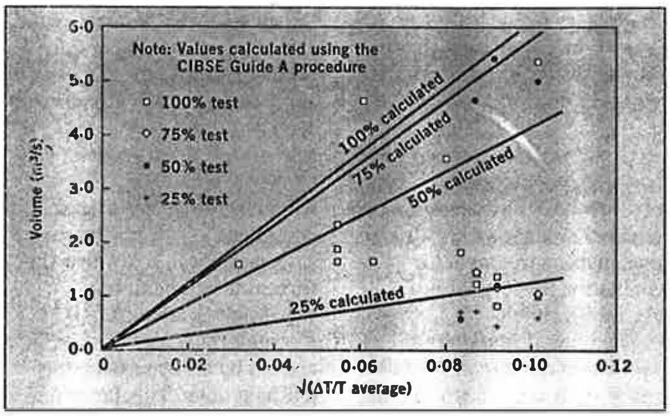

FIGURE 3: Measured and calculated summer airflow rates.

There is a noticeable damping effect due to the thermal mass of the building structure. Exploratory measurements indicated that the concrete surfaces of the underfloor void played an important part in pre-cooling ventilation air during the day. Observations suggest this process was enhanced by night-time ventilation.

Performance summary

The auditorium stack ventilation system has been shown to provide adequate ventilation throughout most of the year.

It achieves this largely by use of the buoyancy forces when available, but results suggest that external air currents make an important contribution to the generation of ventilation in hot weather. Further research in this area is required to better understand and harness these effects.

At times of high buoyancy force, thermal comfort conditions (ie reduced cold draught) in the auditorium could be achieved by finer control at smaller damper settings than was provided by the bms settings at the time.

More uniform air temperatures would have been provided by an improved design for pre-heat, ensuring better contact between the air and heater batteries, and by reduced leakage at the inlet louvres.

These particular aspects need not detract from the success of the stack ventilation system design. There is no doubt that the heavyweight construction of the building itself plays an important part in preventing summer overheating. The use of night-time ventilation amplifies this benefit.

A further aspect of the research revealed that different skills must be acquired by facilities managers who have responsibility for the passive stack systems. The control algorithm generally worked well but there were difficulties in understanding the workings and needs of the system as a whole.

Effectiveness of the design tools

The traditional – CIBSE *Guide* – methods used for the design resulted in the intended ventilation airflows. It is likely, however, that overdesign could occur due to inadequate data on low velocity pressure drop flow path systems as found in naturally ventilated buildings.

There remains a question about the hot weather driving forces. The thermal modelling approach has been shown to give essential design information, though it was not possible to reproduce the modelled conditions in this work. The effects of thermal capacity are particularly well represented by this more sophisticated approach.

The salt bath model was also shown to be effective in predicting mean temperatures. However, a key feature of this model was that displacement ventilation occurred, associated with a step change in temperature variation with height, which was never seen in the full-scale measurements. Nevertheless, the physical representation provided by salt bath models enhanced the confidence of the designer.

Although cfd modelling was not employed in the design process, international collaborators in IEA Annex 26 provided a limited range of cfd data compared with measured data. The cfd modelling usually provides detailed velocity data, whereas the full scale measurements were primarily of overall air change rates which presented some difficulties for making comparisons.

For the particular case modelled, agreement was poor but there is no doubt that, with carefully selected boundary conditions, cfd could be applied to the prediction of buoyancy-driven air change rates.

The research has shown that the passive stack system provides adequate ventilation for the challenging case of intermittently highly-occupied spaces. Conventional (CIBSE) and more recent design tools can provide useful guidance.

Comfort in operation depends upon greater attention being paid to aspects of control, leakage and preheating, and simplicity of control algorithms and their modification.

Wind effects in nominally still weather and pressure drops in low velocity ventilation systems are areas which could benefit from further research.