Will natural ventilation work?

Building Services reports

The new School of Engineering at De Montfort University could prove to be an exemplar for passive engineering. But the building's natural ventilation had to be modelled to show it would work. Here's how it was done.

De Montfort University's School of Engineering (see this month's Building Analysis) is one of the largest naturally ventilated buildings in Europe, and could become a seminal example of how to rely upon temperature and air pressure differences to drive ventilation.

The building contains a variety of spaces including two auditoria, drawing studios, laboratories and classrooms (figure 1). Many spaces in the building have potentially high gains and little outside wall area – in particular the enclosed auditoria – and it was not clear if these spaces could be adequately ventilated by natural means. For these zones, tall chimneys were proposed to increase the effective stack height, and low level vents were provided to allow displacement ventilation to operate.

Two significant lines of research were undertaken, one looking at the energy flows and the estimation of environmental conditions in the proposed building[1], the other using laboratory modelling to predict the performance of the chimneys in enhancing air buoyancy[2].

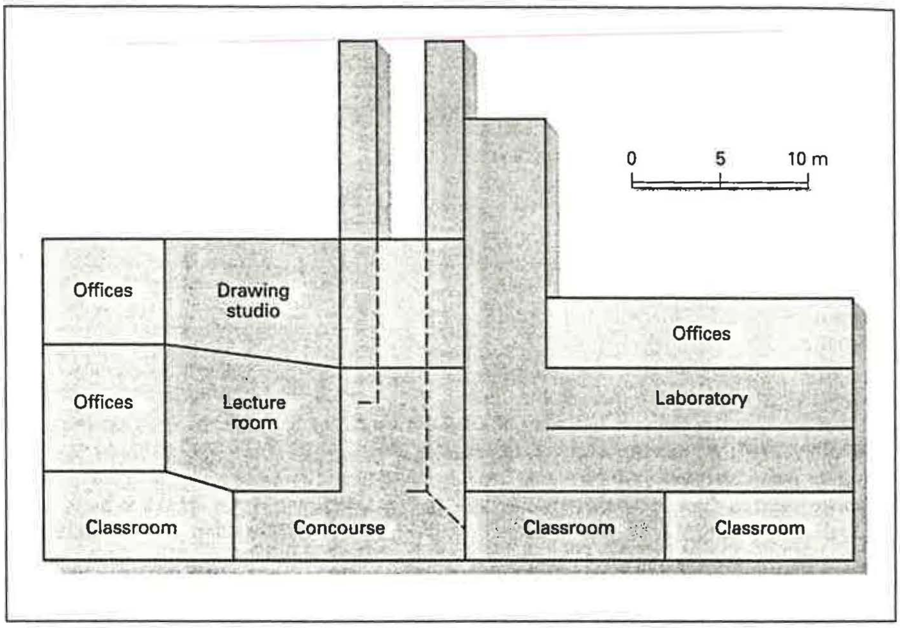

Figure 1: Simplified section of the engineering school. The shaded rooms were those modelled.

Computer modelling

Research into the daylighting, ventilation and thermal performance strategies was carried out by the Environmental Computer Aided Design and Performance (ECADAP) Group at De Montfort University's own School of the Built Environment.

The primary objective was to find out whether the natural ventilation scheme for the two auditoria would be adequate to prevent summertime overheating.

The two 870 m^3 auditoria were designed for 150 people for 8 h/day, 5 days a week. Each occupant was assumed to produce 100 W of heat, together with 15 W/m^2 from lighting and 500 W from equipment. This resulted in an internal heat load of 18·3 kW – nearly 100 W/m^2 of floor area.

Ventilation for these two lecture theatres comes from a plenum below the raked wooden staging supporting the seats. This is fed with outside air, which is then supplied through grilles below the seats.

Extract air is exhausted through a 13·3 m-high chimney, connecting an attenuated air extract grille at the front of the auditoria to the outside above roof level (figure 2).

The complex interactions of convective and radiant heat flows, and heat transfer in and out of the heavyweight concrete side walls and ceiling, was determined by running a set of scenarios through the ESP dynamic simulation program.

Weather data for a typical, hot sunny day (derived from 310 July days measured at Kew between 1959-1968) was used to study hourly variations in temperatures and air flow rates. This created a base case against which design and operational changes could be compared. Finally, the performance of the two auditoria were studied over a typical weather year.

Dynamic computer simulation showed the strong relationship between the rate of heat generation and induced air flow. For the base case, air change rates of over 6 ac/h occurred during the occupied periods. The progressive warming of the structure during the day caused peak resultant temperatures to occur in late afternoon.

Nine design and operational variations were then investigated to see what effect they would have on the base case. By looking at the peak dry resultant temperature, the researchers made the observations shown in figure 3.

Figure 2: Natural ventilation scheme for one of the auditoria.

It is evident that a large fall in the dry resultant temperature was predicted to occur during days of reduced occupancy. At 60% of the design value, the fall was 1·3°C. Another major factor was the provision of windows, where a single 5 m^2 opening reduced the peak dry resultant temperature by 0·8°C.

Enlarging the plenum inlet and particularly the chimney cross-sectional area resulted in a reduction of 1·2°C, although heating the chimney to enhance the stack effect reduced the temperature by only 0·5°C – night-time venting only produced a 0·1°C drop.

Fitting acoustic tiles was predicted to raise the peak dry resultant temperature by 0·8°C, with values towards the rear of the lecture theatre much higher leading to greater discomfort – the rear of the room is higher and nearer to the stratified layer of hotter air.

Using the 27°C overheating criterion contained in *Design Note 17*[3], the peak dry resultant temperatures on the hot, sunny days were close to or below 27°C for many of the scenarios studied.

A final, rigorous assessment was then carried out by applying the summer weather data measured at Kew for the period 1 May to 30 September 1967; no corresponding data for Leicester were available, but the researchers reasoned that if anything it would be cooler, so the results were judged to be conservative.

The ESP simulation predicted that for the basic design with acoustic tiling, there would only be 9 h/y with dry resultant temperatures above 27°C, and none of these would occur during academic term time. Increasing the air inlet and outlet areas reduced the number of occupied hours in which summertime overheating occurs by 50%, while the addition of a window reduced this by a further 20%.

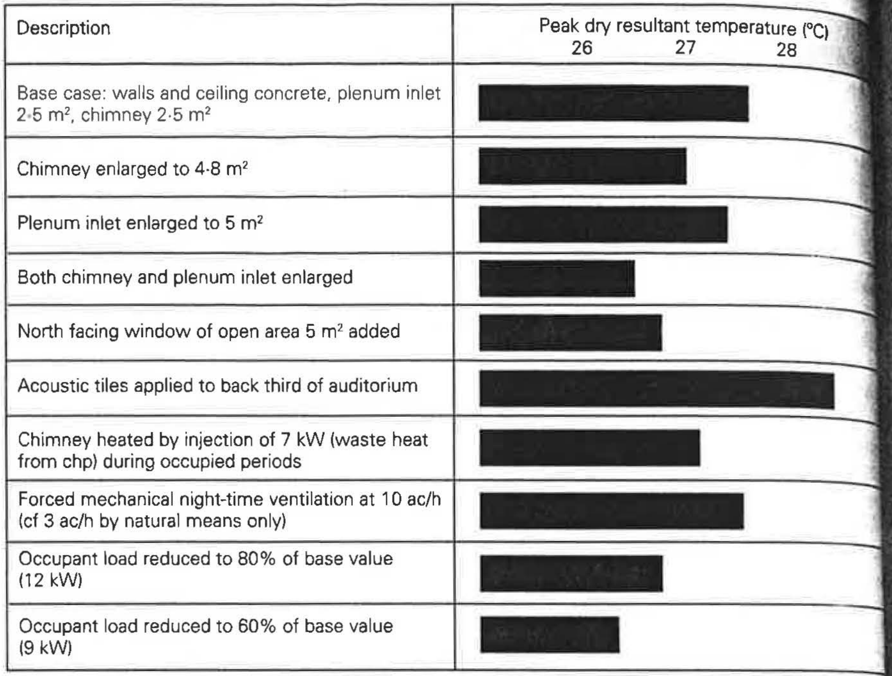

Figure 3: Comparison of peak dry resultant temperatures.

Chimney efficiency

Complementary research into the performance of the ventilating chimneys was undertaken by the Department of Applied Mathematics and Theoretical Physics at Cambridge University[2].

The team examined several areas of the building. With the notable exception of the laboratories, most of the estimated heat gains within each space came from occupancy, and were as follows:

☐ auditoria: 15 kW each;
☐ laboratories: 20 kW;
☐ drawing studios: 3 kW;
☐ classrooms: 3 kW;
☐ central concourse: up to 40 kW.

The effects of a 5 kW fire in the concourse were also included in the study.

Modelling the flows relied on a 1:75 scale clear perspex model. This was suspended upside down in a tank of water, with heat sources represented by samples of salt solution. The falling of the salt solution in the model represented the rising of warm air in the building.

The brine was dyed and a side elevation filmed using an inverted video camera. Samples of fluid were taken during the experiments, and their salt density measured to give an index of equivalent temperature for the full-scale building.

Corrective factors were applied to account for the time, viscosity and density differences of the model compared to the real building – for example, the flows occurred five to ten times faster in the model.

A variety of ventilation areas and positions were tried for each space (table 1). The study found that adequate air flow rates could be achieved in all spaces – if anything, the proposed classrooms were over-ventilated.

By studying the video the researchers identified a potential problem with the mezzanine floor in the laboratory where, due to stratification, the air temperature could reach an estimated 8°C above ambient even with all the available vents open.

As well as experiments with isolated systems, tests were conducted where different spaces shared the same vents. Problems were found, especially when the concourse and lecture room shared the same chimney vents. Hot air flowed from one space to another, varying significantly with only slight changes in the heat gains and vent areas of the two spaces.

Given this, and the implications for smoke movement in the event of a fire, the researchers recommended that the concourse and lecture room have separate vents. The results of the fire tests depended on the location of the fire, but in all cases the research demonstrated a rapid smoke layer build-up at the top of a space which would reach the occupied zone in around three minutes. To delay this time, the researchers recommended additional emergency vents with an area of at least 15 m².

ESP versus salt solution

So how did the findings of the ESP simulation model compare to the physical model? ESP is dynamic and takes into account the thermal mass of the structure, radiant exchange mechanisms and wind effects. However, such thermal models have difficulties in dealing with temperature stratification and complex geometries.

Perspex models are suited to temperature distribution within complex spaces, but are inherently steady state, and so it is difficult to account for dynamic processess. So although the two approaches are complementary, a precise comparison is difficult.

By spatially averaging the air temperatures predicted by the salt model, and assuming the same surface temperatures, an average dry resultant temperature can be calculated. This was found to be 26·9°C for the lecture room, with an air change rate of 9·2 ac/h. Corresponding values predicted by the ESP were 27·6°C and 6·6 ac/h, deemed an "encouraging level of agreement".

Table 1: Examples of results from the Cambridge modelling study

Room	Occupancy (people)	Gains (kW)	Vent area (m²)	Stack height (m)	Flow rate (l/s)
Drawing studio	30	3	4·5	6·5	1300
Lecture room	150	15	3	19	2200
Laboratory	50	20	6	16	5400
Classroom	30	3	1	22	4000
Concourse	100	10	3	22	2100

References
[1] Eppel H, Mardaljevic J and Lomas K J, "Computer simulation for low energy building design", ECADAP Group, School of the Built Environment, De Montfort University, 1993.
[2] Lane-Serff G F, Linden P F, Parker D J and Smeed D A, "Laboratory modelling of natural ventilation via chimneys", Proceedings of PLEA '91 Conference, Sevilla, 1991.
[3] *Design Note 17*, "Guidelines for environmental design and fuel conservation of natural ventilation in educational buildings", Department of Education & Science, 1981.