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)ynamic designs ɔn atria

ſlark Seymour explains how dynamic thermal modelling and omputational fluid dynamics help to devise a suitable ventilation trategy at the design stage.

One method of adding a touch of quality to a building is to include atria in its design. Atria, besides providing a dra-ıatic architectural feature, can provide buffer between surrounding parts of the uilding and the outdoor environment. urthermore, they can enhance building ficiency by taking advantage of potential ıssive solar heating and daylighting. The ıues relating to fabric design, orienta-ın, heat gains, daylighting and chosen ntilation strategy all interrelate and thus ıst be addressed as one for the atria sign to become successful.

The emerging design tool, FLOVENT, sed on computational fluid dynamics :d) techniques has been used to provide insight and visualisation of airflow pat-ns and temperature distribution. Plans and elevations through 3-D building models use coloured arrows (vectors), whose length give the 2-D velocity in the particular plan or elevation, and the colour the 3-D velocity from the left hand side of the adjacent colour bar.

Similarly coloured contours (isotherms or lines of constant temperature) can be super-imposed to display temperature variations. The contour fills provide a dramatic representation of temperature distribution and its continuous variation throughout the plan or elevation chosen.

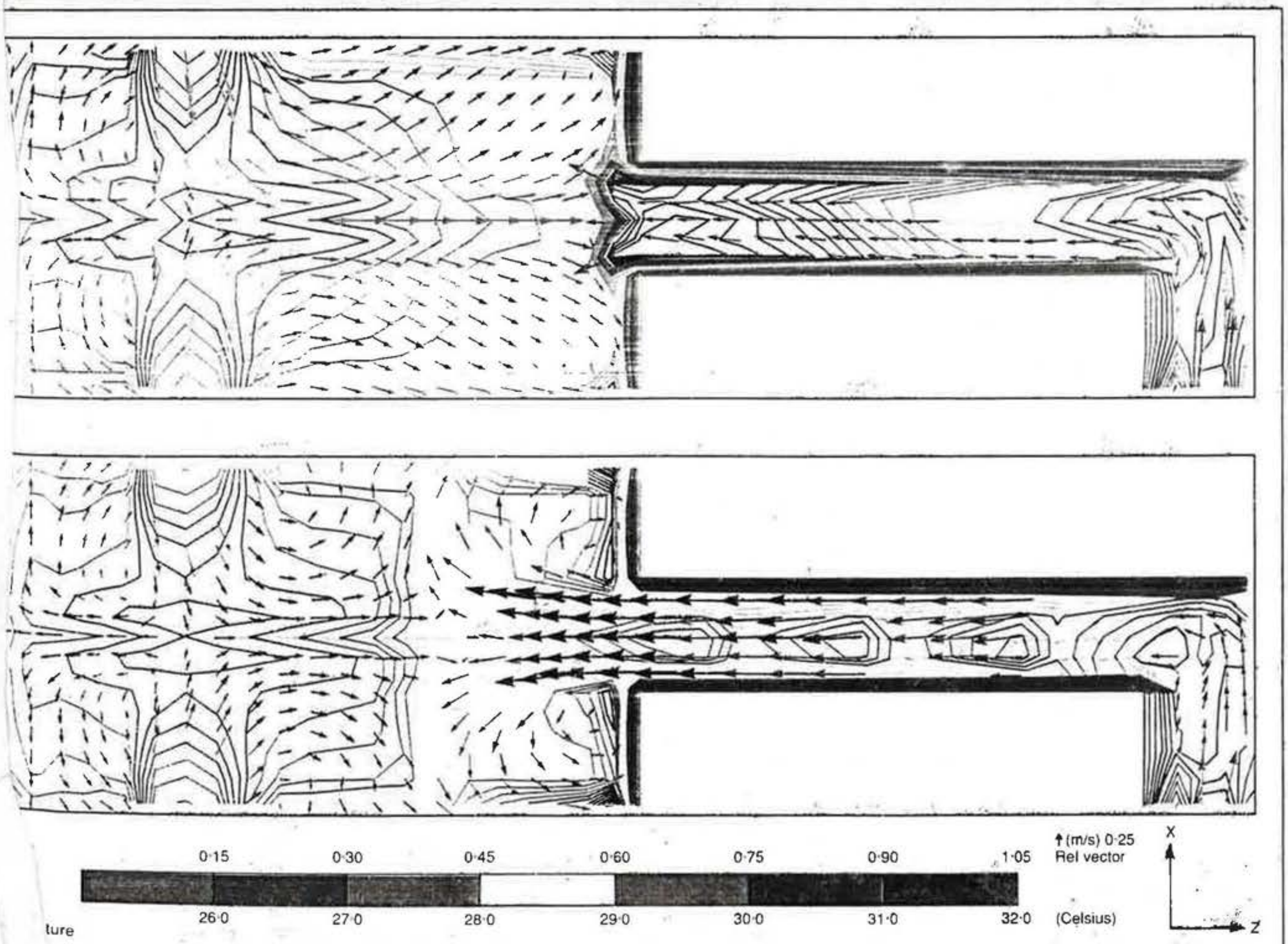
In both methods the temperature is derived by relating the colour to the scale on the right hand side of the colour key. Although calculation of mean radiant temperature and comfort temperature is possible (including the solar component), all diagrams provided here show air temperature.

Building construction

There are three key factors in the building construction: orientation, shading and thermal mass.

The choice of orientation depends largely on the local climate. It is chosen so that compromise between daylighting and passive solar heating is optimised. For a hot climate, a north facing orientation should be chosen for glazing so that there will be no direct solar gain but still considerable daylighting through diffuse light admission. The latter is also likely to enhance

ow, figures 1 and 2: Figure 1 shows temperature and air movement for a large glazed area with three nings and a glazed walkway, while figure 2 *below*, shows a similar layout but with a ventilated walkway.



energy efficiency and cooling requirements by reducing the need for lighting.

In contrast, in a cool climate the design aim would be to obtain free heating and lighting by facing glazing in a more southerly direction, where direct solar radiation can enter. Such a design must pay careful consideration to the potential for overheating. For example, in the UK, direct solar radiation could result in a heat gain of 750 W/m^2 falling on a horizontal surface. With single glazing this intensity may be reduced to 80% of the value, but this still provides a substantial cooling load.

The choice of south facing glazing rather than east or west allows the use of shading to eliminate the high summer sun but admits the lower winter sun. This is also important in human comfort terms as well as cooling loads, since the radiant effect of the sun can give the impression of overheating and thus occupant discomfort.

A wide range of glazing options are available to limit the degree of solar heating through direct solar radiation. These are well documented in performance terms by the manufacturers. Glazing options have the advantage of simplicity and leaving the view unaffected, except perhaps for colour, over the whole glazed area.

The disadvantages are that it equally affects the whole year's solar gain and diminishes the winter gain when it could be utilised for solar heating, and the colouring sometimes produces the continuous impression of dull outdoor conditions.

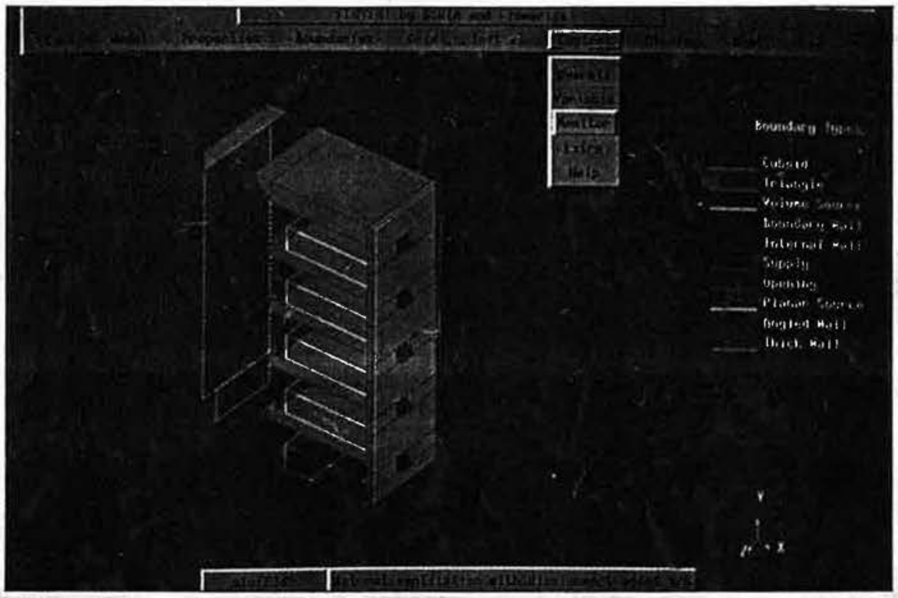
Physical shading can be introduced in external, mid-pane or internal positions. These types of shading can either be controllable to provide movement for varying solar and ambient conditions, or be designed to limit the high summer sun but still allow diffuse daylighting and unobstructed occupant visibility in, say, the horizontal direction.

The internal position, although preventing direct radiation to occupants and other parts of the structure, does not prevent the solar gain from entering the space. For it to be effective its material properties governing re-radiation, and the airflow patterns, must be such that the large majority of convected and radiated heat does not reach the occupied zone.

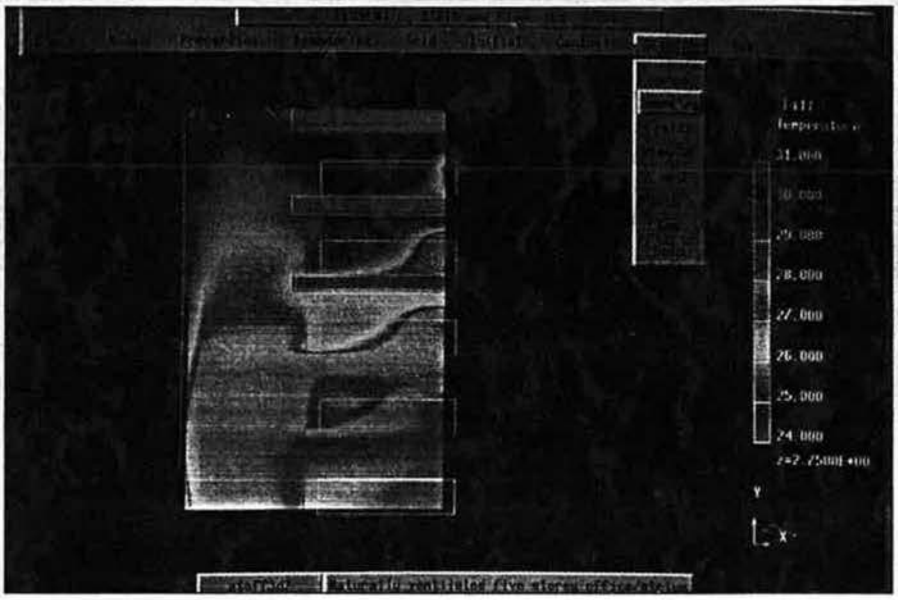
Mid-pane shading can reduce heat gains further, since the direct solar radiation is stopped before entering the space and some will be reflected out through the outer pane. Limited ventilation and thus the build-up of heat between panes will result in some of the gain being transmitted by conduction, convection and radiation.

External shading is the most effective form since the elements are continually cooled by natural convection (sometimes wind assisted), thus minimising the potential for conduction/convective and radiative gains to the space.

Whatever the position of the shading its design can be such that its angle and projection mean that only sun on a low track can enter through the glazing, or in the extreme, no direct solar shading at all. On a shopping mall this may, for example, be the vertical glazing set back from the face of the building with the roof and external balconies providing such shading with architectural interest.



Above, figure 3: A five storey atrium modelled on the FLOVENT computational fluid dynamics system at BSRIA. The following diagrams are based on this layout.



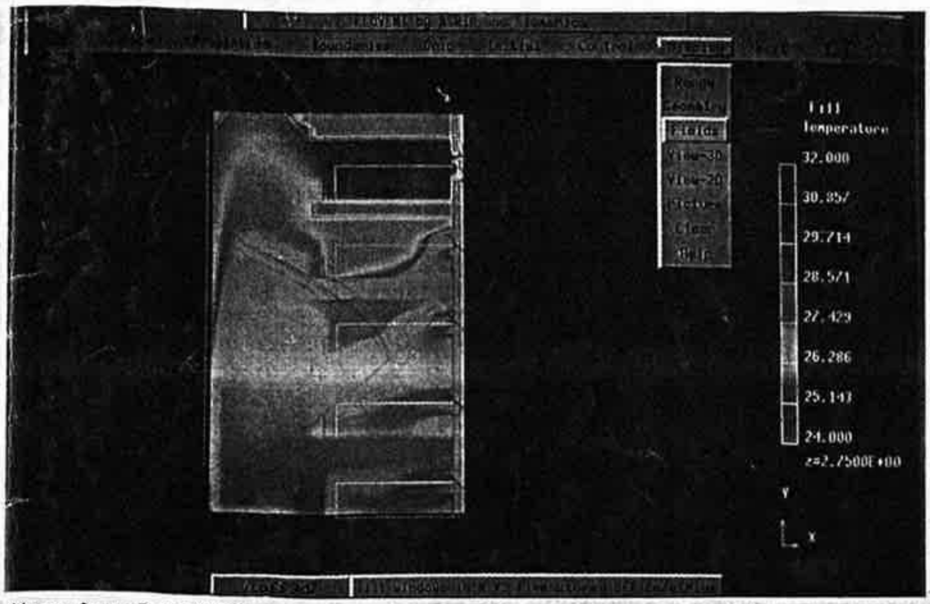
Above, figure 4: By using FLOVENT, it is revealed that ventilation from windows decreases in effect as you go up the atrium. A concomitant rise in temperature results.

The materials from which the atrium structure is formed are also important. In such a building it is often acceptable to have exposed masonry which can be cooled by night-time ventilation and then allowed to absorb daytime heat gains, thus providing thermal inertia and limiting the temperature peaks. This can be combined with increased night-time ventilation and controlled daytime ventilation where the indoor temperature may be lower than that of the outdoor.

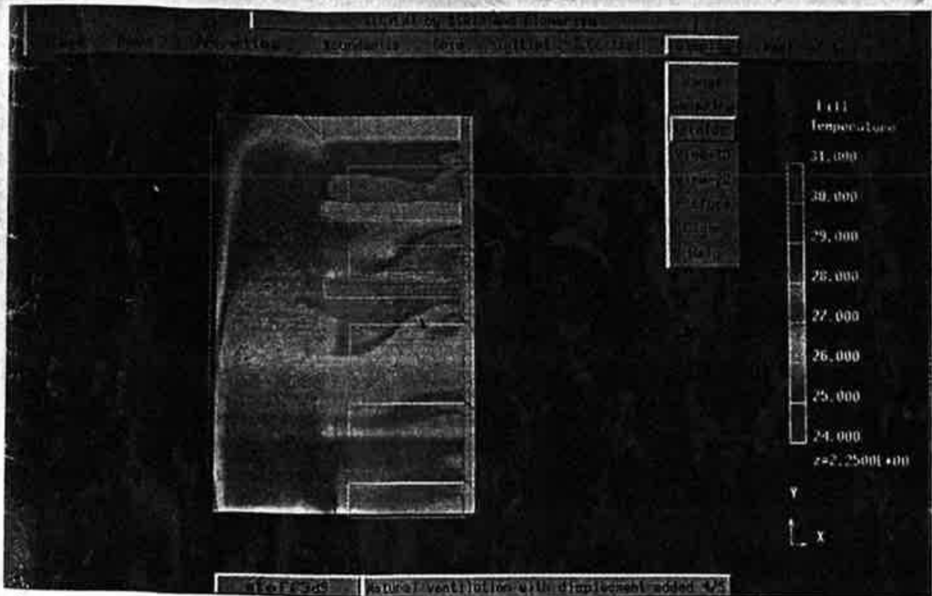
Ventilation strategy

Traditionally, the rate of ventilation has been considered to depend on the height of the stack, the temperature difference, and the resistances at inlets and outlets.

As such the airflow rate Q (m^3/s) through the openings can be described by



Above, figure 5: FLOVENT demonstrates the effect of horizontal centre, pivoting glazing on the hypothetical atrium. The effect of ventilation is exaggerated at high level.



Above, figure 6: The effect of displacement ventilation. Summer peak temperatures are reduced while ventilation rates at low level are maintained.

the following power law equation:

$$Q = k(\Delta p)^n$$

where Δp is the pressure difference across the opening (Pa), k is the flow coefficient giving a measure of size of opening, and n is the flow exponent which typically might be 0·6 to 0·7 dependent on the level of turbulence.

The accumulation of these flows for many openings is difficult and calculations are normally lumped together and repeated for different pressure values. Pressure values themselves will be dependent on the square of wind speed. Furthermore, the flow rate will be affected by pressures generated by temperature difference and the resulting stack effect such that:

$$Ps \propto \left[\frac{1}{Te} - \frac{1}{Ti}\right] \times h$$

where Ps is the stack induced pressure (Pa), Te is the external temperature (K), and Ti is the internal temperature (K).

Equations of this type can be developed to provide a more sophisticated representation of connected openings, but they cannot be expected to account for air circulations between zones, only bulk air movement from one to another.

The only method then, to predict performance without erecting the building or a scale model, is the combined use of dynamic thermal modelling and cfd modelling.

Two short case studies demonstrate features which can be assessed during the design stage.

Central and entrance malls

Figures 1 and 2 show plan views of temperatures and velocities at approximately head height in a central shopping mall complete with entrance walkway. Roof ventilators are present in the central mall.

Figure 1 shows the effect of solar gain in the walkway. Temperatures are unacceptably high and have a detrimental effect on the conditions in the central mall. A model of the central mall without the entrance walkway, but with three access doors at low level, would show a relatively acceptable environment, despite the stack inducing some high velocities through the entrances.

One solution to combat the solar gain, may be to include natural ventilators in the walkway (figure 2). However, although this reduces walkway temperatures, central mall temperatures rise as a result of air being drawn in through the entrance mall roof ventilators, thus flushing the heat into the central area. In this case the preferred design may be to mechanically ventilate the central area thus pressurising it and reducing the quantity of air drawn in from the walkway.

Five storey office atrium

The five-storey office atrium shown in figure 3 is a module 5 m wide, 16·7 m high (3·5 m slab to slab) and 10 m deep (atrium glazing to office perimeter/ventilation). Ventilation openings are through a door at low level on the perimeter of the atrium, single windows in each office, and roof ventilators at the top of the atrium section.

The atrium plan is 4 m by 5 m and office plan 6 m by 5 m. Each office has a 1 m high glazed safety rail set 1 m in from the edge.

Solar gain is through the full height glazed wall of the atrium with equipment and occupancy gains on every floor between the rail and perimeter wall.

All pictorial results are for an elevation through the opening window.

Figure 4 shows that the further up the atrium the less ventilation is achieved through the window, and thus the more unacceptable the temperature rise. Indeed the warm atrium air is circulating into and out of the upper floor over the safety rail and out at high level. For some applications the design of glazing can enhance ventilation. Figure 5 shows the effect of horizontal centre pivoting glazing. In this case they simply exaggerate the effect at high level and induce high velocities in marginal ventilation areas, for example the second floor. Of course one solution is simply to increase the height of the 'chimney' by increasing the building height and thus reducing the pressure in the highest offices. This is one potential solution but there is the risk of inducing unwanted higher velocities elsewhere.

It should be recognised that this type of building can probably be adequately serviced by introducing mechanical ventilation in those areas requiring additional cooling without necessarily inducing any detrimental effects in other areas. Figure 6 (compared with figure 5) shows limited displacement introduced to the third and fourth floors. This considerably reduces the summer peak temperatures without reducing ventilation rates at low level, thus providing a low energy solution to minimising summer time over heating.

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