ENGINEERING AND INGENUITY – TOWARDS ENVIRONMENTAL DESIGN

SUMMARY

The starting point for designs which respond to our worsening environmental situation is a study of building form with particular emphasis on the façade and section and on materials. Only after these have been resolved to optimise the solar potential, to make the best use of daylight , to provide controllable assisted natural ventilation (including night cooling), to attenuate noise (if necessary) and to produce an attractive building should the design team as a whole turn to HVAC systems. To summarise, the plant is only part of the strategy and the smaller part the better. The application of this approach are illustrated by three varying case studies: the BRE Environmental Building, Garston, Watford – a new build office; the Contact Theatre – an assisted naturally ventilated theatre in urban Manchester; and Snape Maltings Concert Hall – a building in the countryside with a supply only ventilation system with borehole cooling. The scope for engineering ingenuity in furthering environmental design is significant.

INTRODUCTION

The premise of this paper is that the chosen subject of the conference- " a global review of state of the art HVAC" - is too narrow. The principal reason for this contention is that state of the art HVAC is the wrong starting point. Instead, the beginning for designs which contribute to our environment and ensure the comfort of occupants should be the building form. Particular emphasis needs to be given to site, orientation, facade and section design, and materials. Only after these have been resolved to optimise the solar potential, to make the best use of daylight, to provide controllable assisted natural ventilation (including night cooling), to attenuate noise (if necessary) and to produce a stimulating building should the design team as a whole turn to HVAC systems. The scope for engineering ingenuity in developing such buildings is significant.

To summarise, the plant is only part of the strategy (and the smaller the part the better). The sooner this approach is recognised as the most valid the sooner engineers will be in a position to make a greater contribution to environmentally-friendly buildings.

The applications of this approach will be illustrated by three varying U.K. case studies:

1. The BRE Environmental Building
2. The Contact Theatre .
3. Snape Maltings Concert Hall.

These buildings address a full range of HVAC issues in both new and refurbished buildings and in settings from city centres to rural land.

THE ENVIRONMENTAL BUILDING (EB)

Sited 300m from a major motorway (the M1) in Garston, about 15km north-west of London, the Environmental Building (see Figure 1) is one of the most innovative buildings in the UK (1).

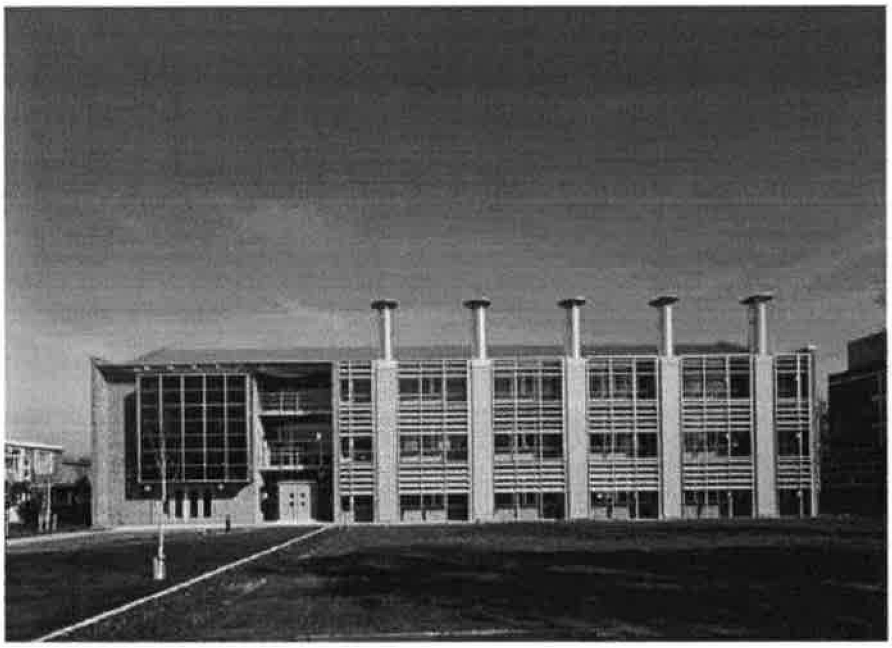

Figure 1 The Environmental Building

Its brief, which resulted from collaboration between the Building Research Establishment Energy conservation Support Unit (BRECSU) and the Energy Efficient Office of the Future (EOF) Group, called for a landmark building combining the highest architectural standards with the latest innovations in energy efficient design.

Spatially, it had to provide 1300m2 of offices for about 100 staff and 800m2 or so of seminar and associated facilities. The offices are 30m x 13.5m on plan with the short axis running almost due north-south.

To the south of the building there is a clear space of about 30m; thus there was ample opportunity to use solar energy.
The site is fairly open and consists mainly of two or three storey buildings with the occasional block of five or six storeys. Although winds come from all directions, those from the south-west are somewhat more common than others.

Perhaps the greatest significance of the EB is that it is one of the first buildings to result from a holistic view of construction. It takes advantage of all the available local sources of energy (sun, wind and groundwater), and in addition goes beyond this by incorporating a philosophy of which materials should be used and how the building should be constructed (and at the end of its life, recycled).

Energy Use, Comfort and Form

Energy consumption was targeted at 47 kWh/m^2 yr for delivered gas and 36 kWh/m^2 yr for delivered electricity; this criterion was based on a 30 % improvement in best practice in 1994/95 when the brief was being developed. The corresponding total CO_2 figure was $34kg/m^2$ yr. Since electricity consumption produces about three times as much CO_2 as gas use, developing the design was partly a matter of playing off one factor against another. For example, more glazing results in more natural light; thus, in principle, less electricity is needed for artificial lighting and less CO_2 is produced. This is balanced again more CO_2 resulting from burning gas for increased heating (due to glazing being worse for insulation than typical wall constructions).

One of the most stimulating aspects of the brief for the design team was that in addition to limiting energy use, comfort criteria were set of not exceeding 28°C in the offices for more than 1% of yearly working hours, i.e 20 hours and not exceeding 25°C for more than 5% of yearly working hours. The importance of these two criteria is that they provide a clear-cut approach for designers - any design proposal can be tested to ensure that both conditions of the brief are met. It has been said that the comfort temperatures are somewhat arbitrary and numerous alternatives could be proposed, but the key point is to have such conditions.

The design team first considered what form of building construction could meet the brief. It was agreed that solar energy and daylight should be used as much as possible to reduce the energy demand in winter and the need for artificial lighting throughout the year. This, along with site constraints, led to a narrow plan, three storey building with generous floor to ceiling heights and a long south-facing facade with about 50% glazing.

More glazing on the south side would have tended to increase the hours above the target temperatures.

It was clear that it would be difficult to meet the energy criteria if the building were sealed and air-conditioning were used. Thus, it became critical to ensure that the offices had sufficient thermal mass and a ventilation strategy to deal with heat gains during the day and allow for cooling at night using lower temperature air. It was decided to use an exposed concrete slab on the ground and first floors and timber boarding on the top floor. Timber was selected for a number of reasons, including aesthetic appeal, the use of a renewable resource, and the avoidance, on both structural and cost grounds, of heavy concrete in the roof.

Ventilation Strategy

For the EB, there were several starting points to the ventilation strategy. The first was to minimise the energy use associated with ventilation. This favoured either cross ventilation or stack-effect ventilation or a combination of both; in addition there was the possibility of providing some low-powered mechanical ventilation in the form of, say, a simple fan. It also favoured high thermal mass to smooth cooling (and heating) loads.

A second point was to link the ventilation path with the thermal mass to take advantage of night cooling, and a third was the normal requirement that a space for heating pipes, electrical cables and so forth had to be found.

An essential element of the ventilation strategy is that it is 'loose-fit' and has numerous air paths. In the summer cross ventilation is facilitated by the shallow floor plan. Air can come in under BMS control through openings at the edge of the slab or through the high level windows, or the side hung windows can be opened manually. In areas with cellular offices, the sinusoidal slab lets air pass over them thus permitting ventilation of the open plan areas. The attractive, structurally efficient slab (shown in Figure 2) was the result of close co-operation among the architect, structural engineer and environmental engineer.

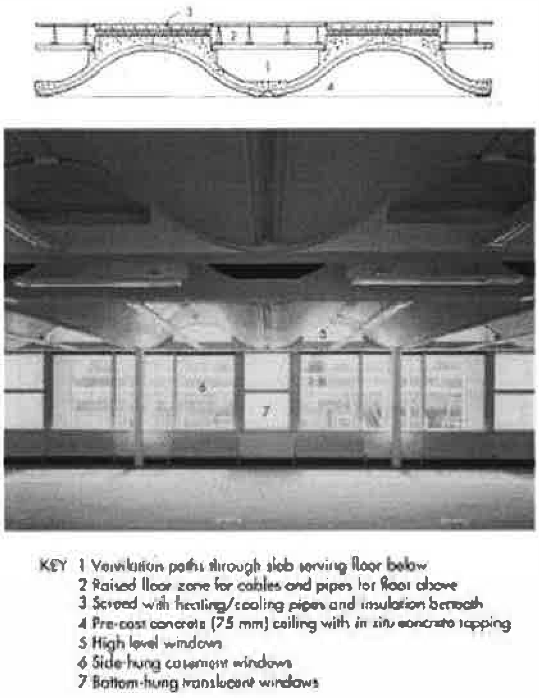

Figure 2 Sinusoidal slab section and view of a typical bay

The solar offices themselves are principally ventilated from one side by their windows. The vertical shafts on the south facade shown in Figure 1 allow stack effect ventilation. They operate simply as stacks in no wind conditions - when there is wind it will induce flow up the shafts thus assisting the stack effect. Figure 3 shows a typical summer air path on a day with little or no wind.

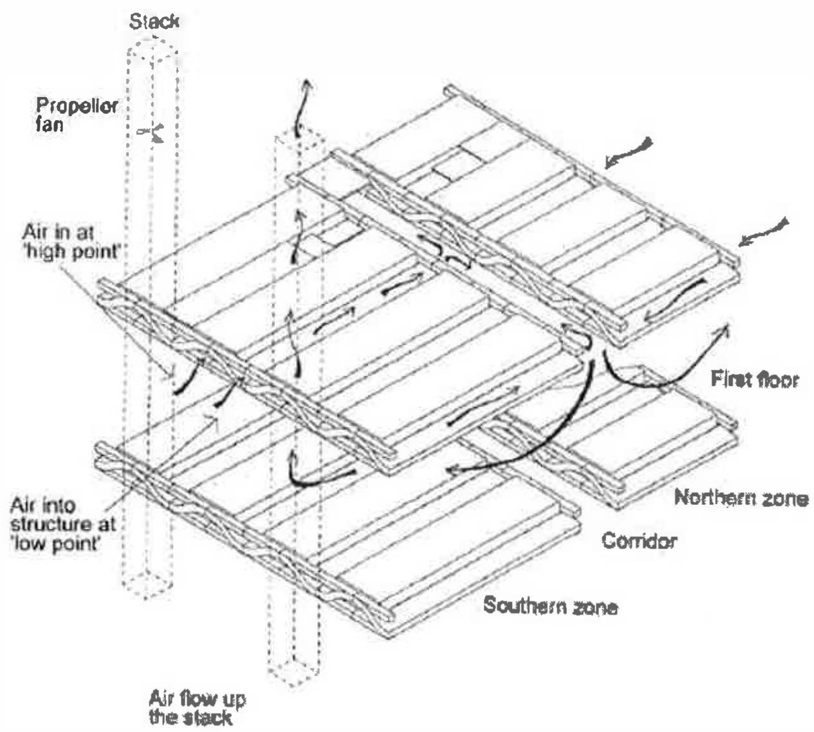

Figure 3 Air flow on a summer day

Extensive computer modelling throughout the design stage influenced key decisions such as percentage of glazing, the selection of the solar shading system, slab thickness and corridor position.

Heating and Cooling

Computer simulations indicated that it would be possible to meet the requirements of the brief for the offices area without any additional cooling (and this indeed proved to be the case), but for the main seminar room it would be much more difficult. A number of different options including a cooling coil linked to a dry air cooler were studied and a borehole system was selected as most in keeping with the overall project philosophy. It then made sense to link the borehole system to the offices' area pipework to provide a low cost improved environment that bettered the brief.
Figure 4 shows the schematic.

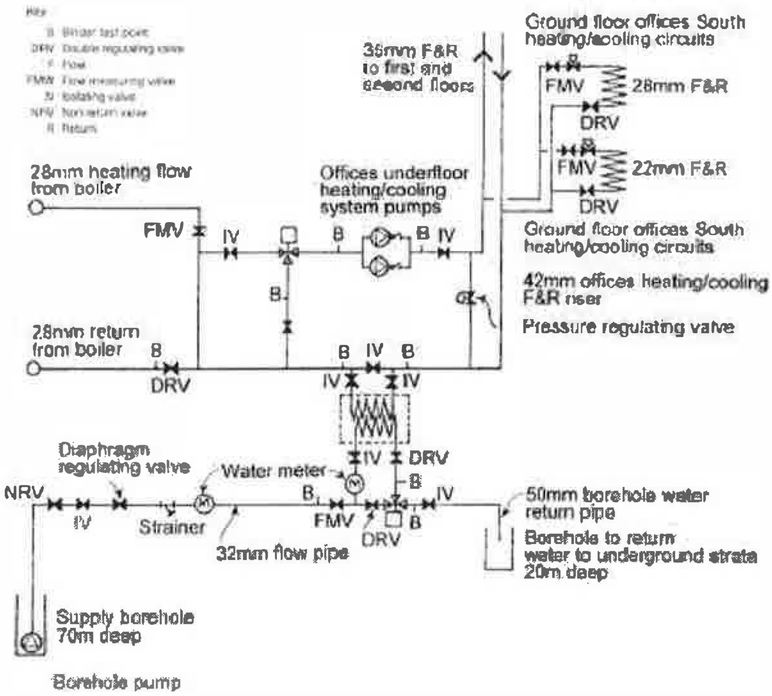

Figure 4 Simplified heating and cooling schematic

Results

The Environmental Building has highly engineered systems with a reduced plant or 'hardware' content. This has been achieved by the use of orientation, form, and appropriate materials to moderate internal conditions.

Internal conditions have been very good. Figure 5 shows that the temperatures on the ground and first floors are approximately 5°C or more below external peak temperatures in exceptionally hot weather conditions. On the top floor (which has less thermal mass in the ceiling) the corresponding figure is 4°C or more.

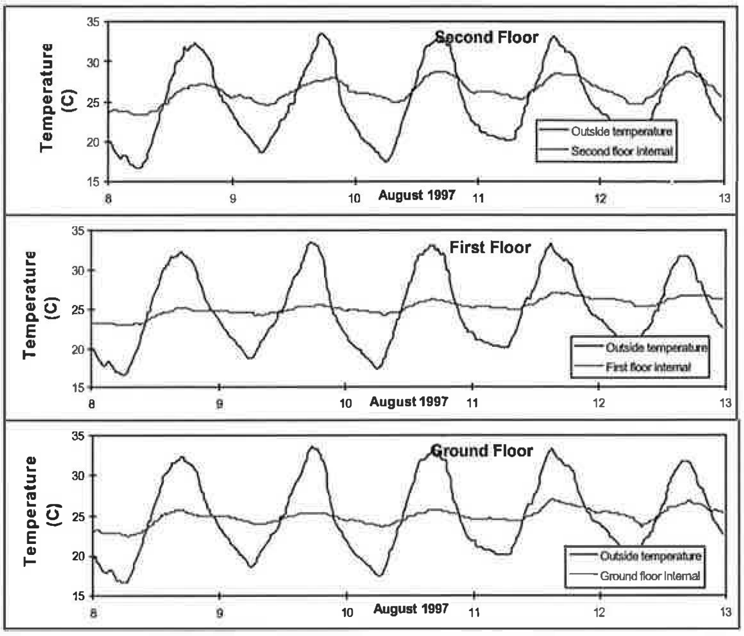

Figure 5 Temperature recordings

A key element in the strategy is that the mechanical systems are only run when needed. Thus, for example the occupants find that the borehole cooling system is only needed occasionally.

THE CONTACT THEATRE

The Contact Theatre (2,3) is a masonry building from 1963 located on the Manchester University campus, close to a busy road. Its dramatic redevelopment (see Figure 6) included refitting the main auditorium to seat 380 people and improving the lighting and acoustic arrangements. The exposed brickwork walls remained unchanged, but the woodwool roof construction was revised and improved by the addition of a new external roof covering and insulation layer.

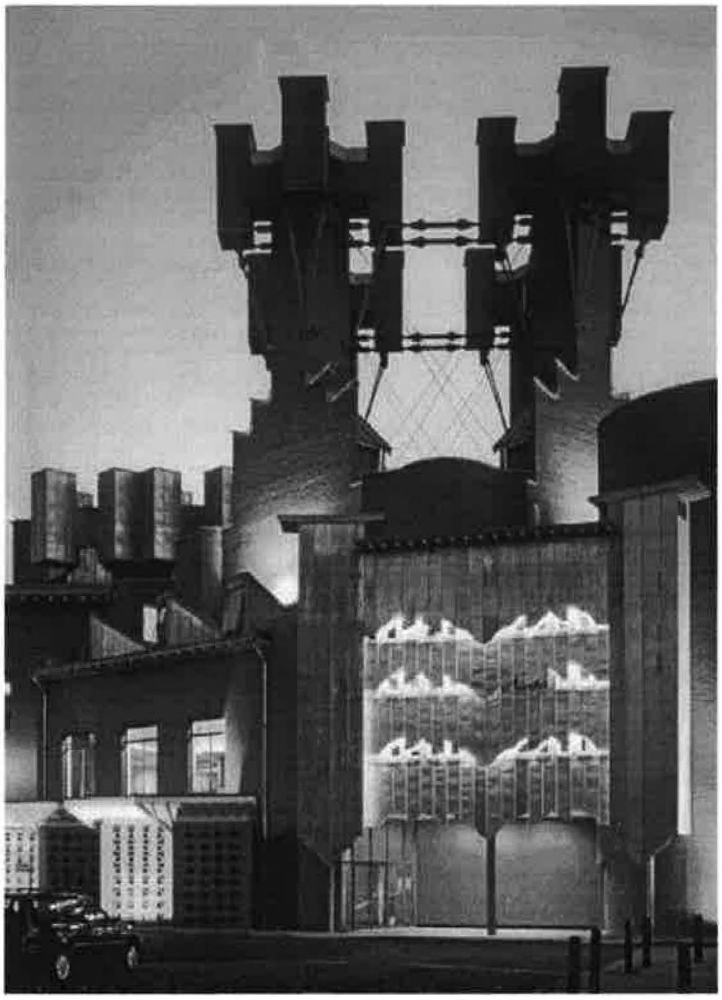

Figure 6 The Contact Theatre

As with the Environmental Building the design for the refurbishment was based on the close collaboration of the architect, structural engineer, environmental engineer and, additionally in this case, the acoustic consultant.

The principal decision made was that it would be possible to do away with the original mechanical ventilation system which had not functioned adequately for years and replace it with a stack effect system with assistance from simple extract fans in the stacks. Air conditioning was considered but not chosen on the grounds of high capital costs and ongoing maintenance and energy costs which theatres often have difficulty meeting. Additionally, both the design team and the client favoured a more environmentally-friendly solution.

It was agreed with the client that the design target would be to ensure that the temperature in seated areas did not exceed the outside summer peak temperature by more than 3C and this criterion played a key role in the development of the design which was assisted by extensive computer modelling. Loadings from occupants and lighting were calculated to be a substantial 200 W/m^2.

Noise from the nearby Manchester University student concert venue and the busy main road near the site played a key role in designing the assisted natural ventilation system (see Figure 7). The air inlet was sited in a relatively quiet area (approximately 60-70 dBA 1m from the air inlet grilles). Air is then led through attenuators and past concrete walls of high thermal mass for cooling. Next it passes underneath the rear seats (see Figure 8) and into the auditorium, then out through the H-pot chimneys which are equipped with three-bladed axial fans(for use in peak conditions) and attenuators. Night cooling is used when required.

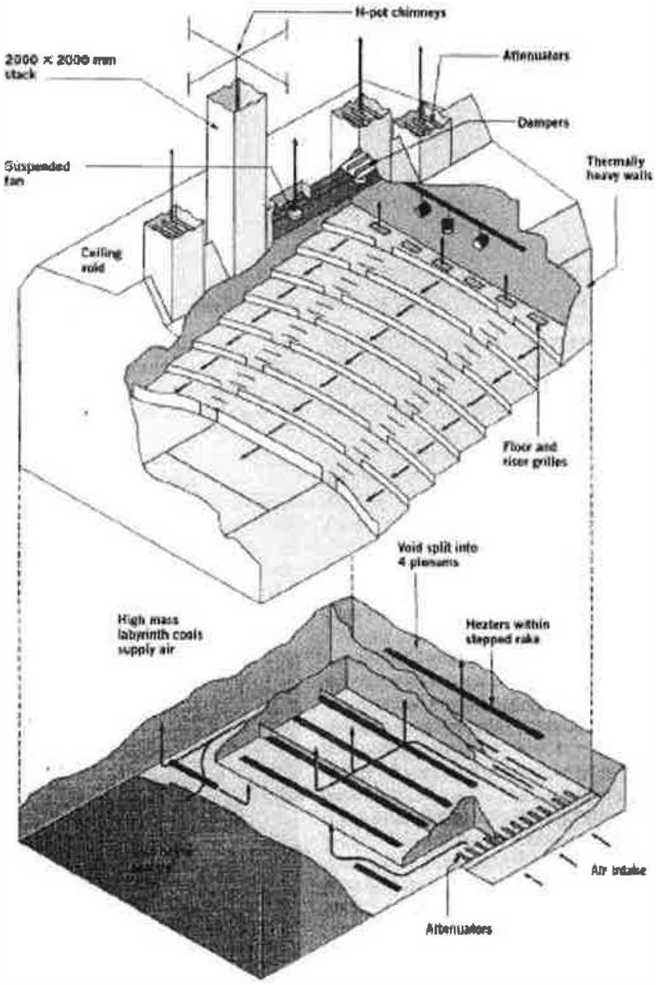

Figure 7 Ventilation system

Figure 8 Interior of the Theatre

Results

Results from a heat load test during commissioning showed that the 3C maximum temperature uplift criterion was satisfied. Monitoring during actual performances during the summer of this year has provided further evidence that the building is performing as anticipated. For evening, full performance temperatures are approximately 2°C below the external peak to 1°C above depending on the position in the theatre.

The theatre has proven to be a great success with audiences and actors. Energy use is low, no CFCs or HCFCs are used and comfort is high - all in all, an excellent performance.

SNAPE MALTINGS CONCERT HALL

The Concert Hall at Snape Maltings in Suffolk(see Figure 9), situated in coastal wetlands and next to the bank of the River Alde, is a well-loved building with renowned acoustics in a rural location of exceptional beauty. Conversion from redundant maltings to what was originally intended to be a facility for a short summer concert season was carried out in the late 1960s. Success led to a full calendar of events and a desire to improve summer internal conditions beyond what had been first envisaged. A combination of public and private funding was found for refurbishment work including cooling for the hall.

Figure 9 Snape Maltings

Figure 10 shows the inside of the Hall. The thermal mass is not great because although the walls are of exposed brick, the roof is relatively lightweight, consisting only of a 40mm thick exposed timber board ceiling with an external slate covering. A full audience with orchestra amounts to about 850 people.

Figure 10 Interior of the Hall

In the 1960s the heating and ventilation system installed consisted of a two speed supply fan, filter, heater and attenuators. The supply ductwork was generously sized (air velocity was 1.7 m/s at low speed) and the grilles carefully designed to keep noise down. Measurements indicated that NR 18 was being achieved with the fan at low speed. Extract was, and still is, by opening dampers in high level outlets (known as bluffs) in the Hall.

The design team first looked at the building to see if any significant changes could be made to improve thermal comfort. Both increased thermal mass in the roof to reduce peak temperatures and higher levels of insulation (perhaps in connection with an air gap) to reduce solar gains were considered. However, constraints of structural loading, appearance and cost meant that the main roof structure had to be left unchanged- it was, possible though to put additional acoustic insulation into the high level outlets to reduce incoming external noise.

A principal challenge of the refurbishment thus became how to increase the volume of air supplied and cool it (without degrading the acoustic performance). The solution, arrived at after a significant amount of analysis, was to modify the grilles and silencers and introduce a variable speed drive for the fan thus allowing a greater air volume with no additional noise. Figure 11 shows the principal elements of the system.

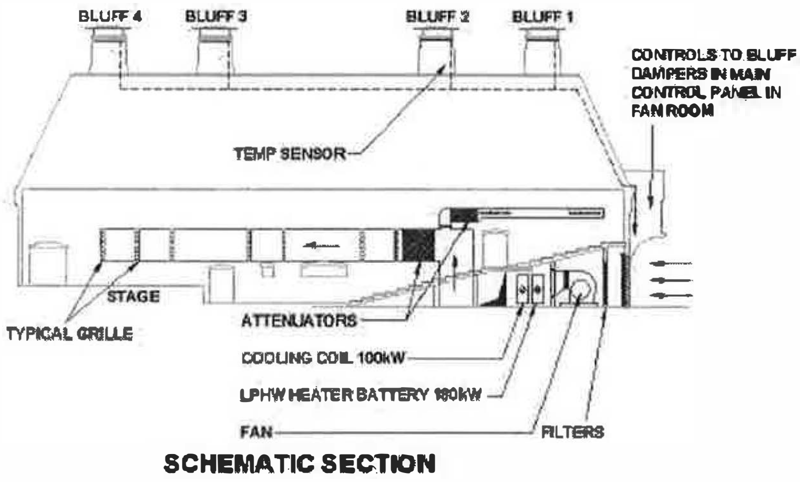

Figure 11 Schematic Section in the Hall

In discussion with the client it was agreed to aim for an internal temperature of approximately 2-3°C below the external peak ambient temperature. Various options for cooling were investigated including a conventional chiller. Eventually a borehole system was selected for its environmental advantages of reduced energy use and avoidance of CFCs and HCFCs and also because it did not have the noise associated with chillers.

Cooling for the auditorium is provided by passing air over a heat exchanger that is chilled by ground water from a nearby 10m deep 200mm diameter borehole. The air is cooled by as much as 10°C by the water, which is pumped out of the ground at a temperature of about 10°C. To avoid peaks of water consumption for cooling the auditorium during performances, water from the aquifer is slowly pumped into a sprinkler tank in the courtyard of the concert hall over the course of a whole day. This ensures that there is no significant drawdown of the aquifer water level, so that the level of nearby wells is not affected and also so that sea water does not penetrate into the aquifer, which was a main concern of the Environment Agency.

Heating, ventilation and cooling are under the control of a building management system. Night cooling is used when necessary.

Results

In its first two seasons in use the system has proved successful in reducing peak temperatures while maintaining excellent acoustic conditions. Monitored results indicate, for example, that on days with peak temperatures of approximately 28°C, internal conditions during full concerts were in the range of 24 to 27°C.

Snape Maltings thus offers us a variation on the theme of the Contact Theatre. Instead of extract fans there is a supply fan, the acoustic criteria are more stringent and the comfort conditions required the provision of cooling.

CONCLUSION

One of our goals as engineers should be to provide comfortable, efficient, healthy and attractive indoor spaces in ways that use less energy and appropriate materials.

The buildings discussed above provide comfortable and stimulating internal environments in ways that reduce their impact on the external environment. And they do so while meeting demanding performance criteria. They are the outcome of an approach which is positive rather than negative i.e. they are not based on dictates such as "No fans" or "No air-conditioning". Instead, they are characterised by the following:

1. Thought. Analysis is based on first principles rather than inappropriate or out-of-date models.
2. The building is the basis of the design.
3. Close integration of the work of the architect, the structural engineer, the environmental engineer and the acoustician from the outset.
4. Computer modelling and analysis at the design stage.
5. Use of thermal mass.
6. Highly engineered but "low-hardware" systems controlled by computers. Mechanical ventilation is used, but sparingly.
7. "Natural" cooling strategies such as night cooling and borehole cooling to deal with peak situations

The results help to remind us that the words engineering and ingenious are related and give us the outline of a vision of the direction of our profession.

Notes:

1. Design Teams:

	The Environmental Building	Contact Theatre	Snape Maltings
Architects	Feilden Clegg Architects	Short and Associates	Penoyre and Prasad
Structural Engineers	Buro Happold	Modus	Price and Myers
Q.S	Turner & Townsend	Dearle & Henderson	Hyams & Partners
Acoustician	Arups	Cambridge Architectural Research	Arup Acoustics
Environmental Engineers.	Max Fordham & Partners	Max Fordham & Partners	Max Fordham & Partners

REFERENCES

1. Thomas, R.(ed.) (1999) Environmental Design. E&FN Spon, London.

2. Quincey,R.,Knowles,N. and Thomas,R.(1997) The design of assisted naturally ventilated theatres. Proceedings of the 1997 CIBSE National Conference.

3. Palmer,J.(1999) First contact. Building Services, 21(10),31-34.

Photographic Acknowledgements

Figure1 Dennis Gilbert

Figure 2 Dennis Gilbert/ Feilden Clegg Architects

Figure 3 Feilden Clegg Architects

Figure 4 Max Fordham & Partners

Figure 5 Max Fordham & Partners

Figure 6 Ian Lawson

Figure 7 Building Services Journal, October 1999

Figure 8 Ian Lawson

Figure 9 Max Fordham & Partners

Figure 10 Max Fordham & Partners

Figure 11 Max Fordham & Partners