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THE DESIGN OF ASSISTED NATURALLY VENTILATED THEATRES

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As experience with assisted naturally ventilated buildings (1) has increased designers have extended the approach to larger and more demanding building types. This paper looks at two very different theatre projects where assisted natural ventilation systems have been designed, examines the design tools used, illustrates the solutions and shows how the built form was influenced.

INTRODUCTION

Theatres are characterised by intermittent heavy occupancy and high stage lighting loads. Theatre auditoria are generally quite high and of large volume, do not usually have windows and require strict blackout conditions.

Air conditioned solutions for theatres have relatively high running and maintenance costs. Where appropriate, an assisted naturally ventilated solution can offer dramatic savings; however it should be recognised that although the capital and maintenance costs of the mechanical plant for such an approach are lower, the building costs can be higher.

Naturally ventilated solutions require a high degree of coordination and integration between the design team members at an early stage. The need for the services engineer to analyse many preliminary solutions quickly, but with an acceptable level of confidence, has tended to present a difficulty for designers. With this in mind, this paper discusses the approach taken on two projects.

THE PROJECTS

The projects considered are Bedales Theatre, set in rural Hampshire, and the Contact Theatre in central Manchester. In both projects the design brief was agreed early on with the client. The brief included the goal of restricting summertime temperatures in occupied areas to a maximum of 3^0 C above the external ambient level.

EDAS (2) funded scheme design studies for both projects were carried out to investigate the expected peak internal summertime temperatures, given differing patterns of use and control regimes.

The projects pose similar environmental problems, but they differ considerably in their requirement for noise separation to and from outside. The resultant design for each building clearly reflects the solutions selected to these problems.

The building form is affected in two principal ways; the high fresh air requirement means large openings and the summertime temperature goal is only achievable by the use of a night - time cooling regime coupled with significant exposed thermal mass. Each project addresses these issues in a different way.

In both projects a balance was sought between the size of openings, their effect on the construction and the running costs of using fan assistance.

BEDALES THEATRE

Bedales School new theatre, in rural Hampshire, seats an audience of 270. The building has a traditional peg jointed oak frame with a sandwich wall construction of lapped wooden boards and insulation. This wooden construction sits on a concrete undercroft.

Ventilation is primarily by stack effect in the tall space; however a slow speed punkah fan in the stack operates in conditions of high temperature to increase ventilation or at night for cooling the structure. The fan also operates in reverse in the wintertime to reduce stratification.

The auditorium is heated using steel finned tubes, located in the undercroft, which heat the incoming air. The coils are fed by a LTHW injection circuit.

Lighting in the theatre is generally at high level and was assumed to contribute about 30 kW of heat gain to the occupied areas. The main features of the building are illustrated in Figure 1.

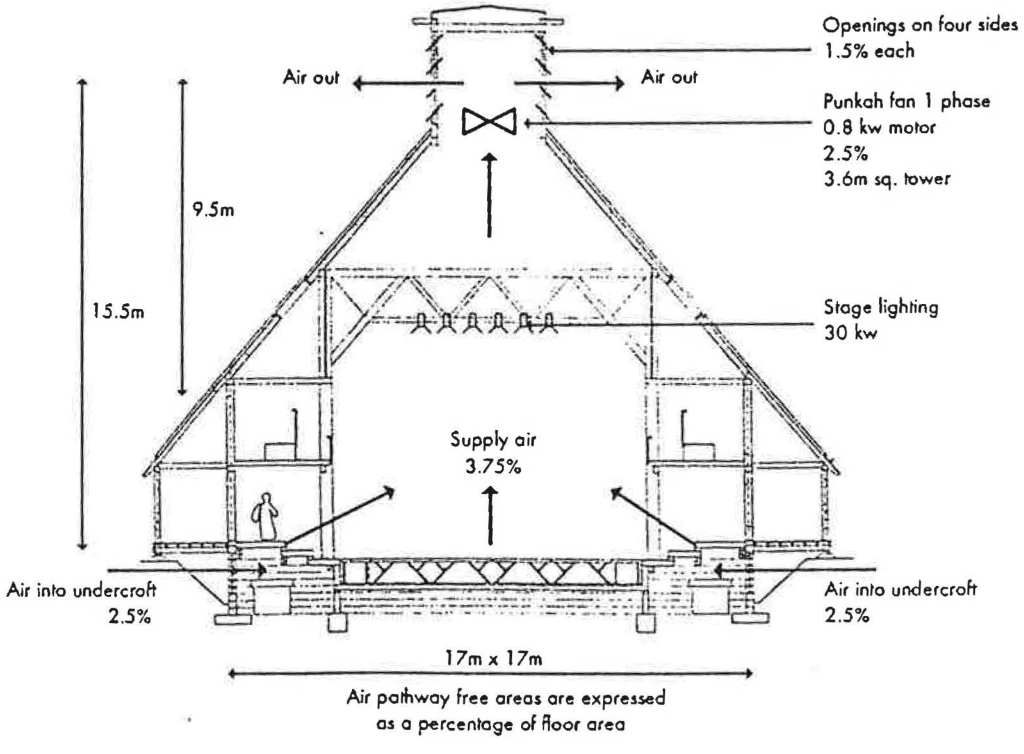


Figure 1. Short section through building.

Preliminary calculations on the building involved the use of the CIBSE standard admittance procedure (3). A more detailed analysis using computational fluid dynamics (CFD) was carried out at a later stage to obtain a better picture of the temperature gradient in the space (Figure 2) and to indicate to what extent temperature stratification occurred.

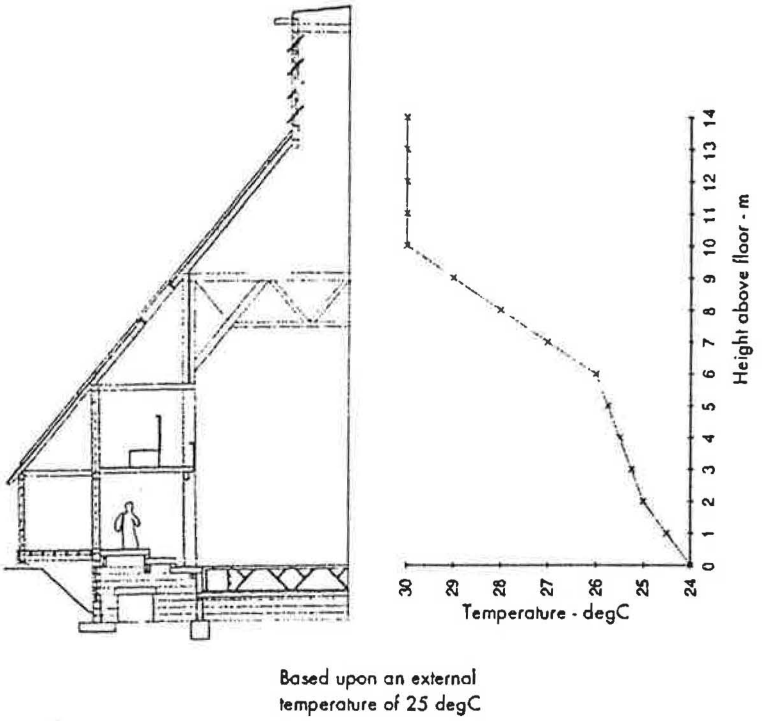


Figure 2. Temperature gradient as determined by CFD study.

In order to control the space temperature the building requires significant thermal mass and a night time cooling regime. A large proportion of the thermal mass provided is located in a divided concrete undercroft which acts as the fresh air intake. Fresh air is drawn through this undercroft from two opposing sides of the building and then rises in the back of the seats.

The ventilation is controlled by a BMS. Important control features include:

- The exhaust damper opening range is restricted in windy and rainy conditions to provide better control of the air change rate and to prevent rain ingress;
- The ventilation exhaust dampers open fully and the fan operates in a fire alarm condition, to aid smoke extraction;
- Each side of the extract tower is individually controlled to allow windward openings to be closed to prevent downdraughts in the tower;
- A temperature sensor within the undercroft concrete slab is used in conjunction with the space temperature sensors to optimise night-time cooling;
- Velocity sensors mounted under the seats limit the air velocity to avoid discomfort;
- The air change rate is controlled on the monitored carbon dioxide level and the measured space temperature;

CONTACT THEATRE

The Contact Theatre is an existing masonry building located on the Manchester University campus, close to a busy road. Its redevelopment includes refitting the main auditorium to seat 380 people and improving the lighting and acoustic arrangements. The exposed brickwork walls remain unchanged, but the woodwool roof construction is being revised and improved by the addition of a new external roof covering and insulation layer.

Ventilation is primarily by stack effect in the tall space. There are slow speed axial fans, one in each stack, which are designed to operate in conditions of high temperature to increase ventilation or at night for cooling the structure. A single air intake is located at ground level in a courtyard away from road traffic. The extract towers for the auditorium are built on top of the existing roof. Both contain acoustic splitters selected for a low pressure drop (Figure 3).

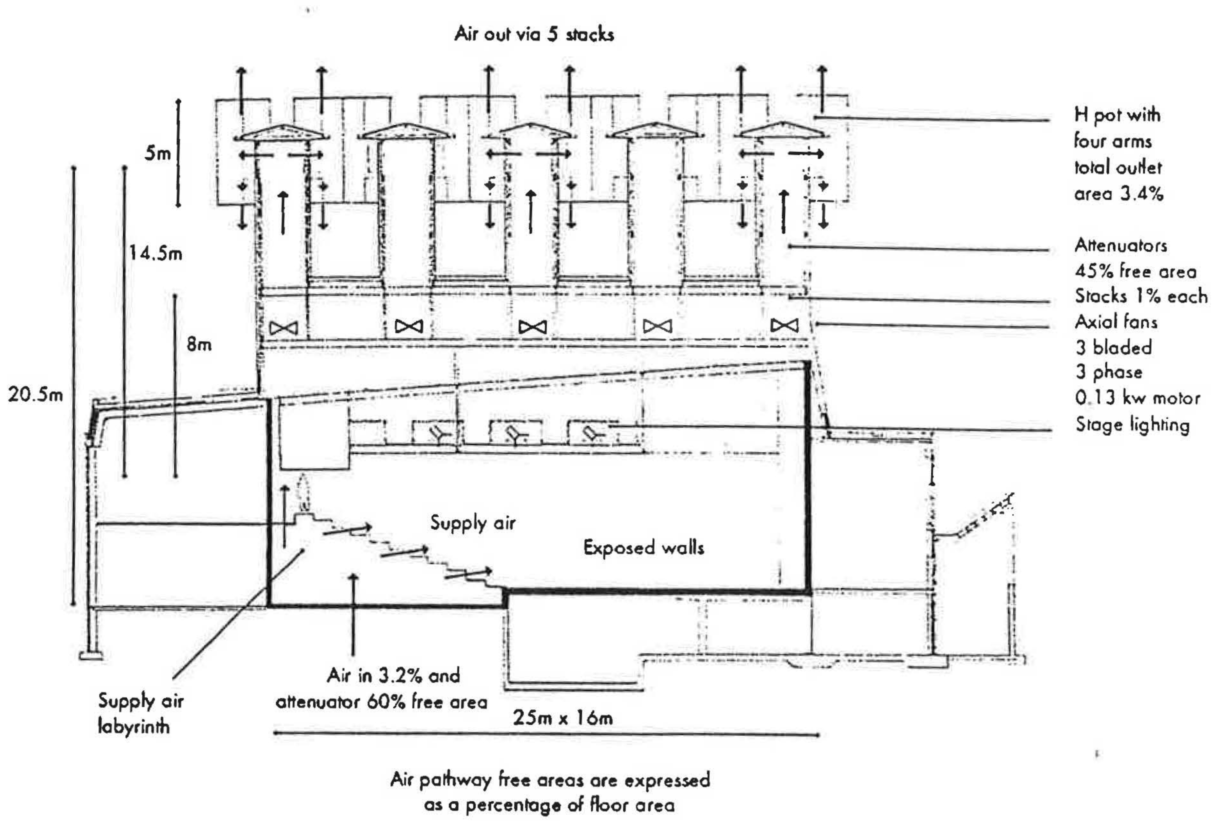
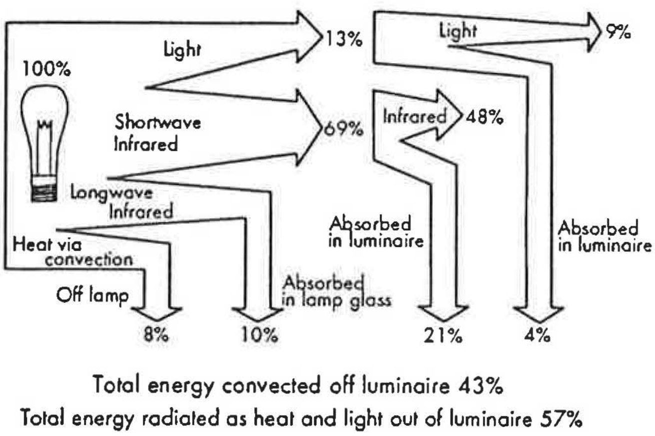


Figure 3. Long section through auditorium.

An investigation was carried out to determine the heat load expected from the stage lighting. It is clear from measured readings taken from a similar theatre (4) that stage lighting loads can vary dramatically between different shows (about 2:1 max/min) and throughout the show (about 5:1 max/min). An analysis of the heat generated by a typical stage luminaire was considered (Figure 4a) and the average electrical consumption from the measured theatre lighting rig used to decide the heat load arrangement in the space (Figure 4b).



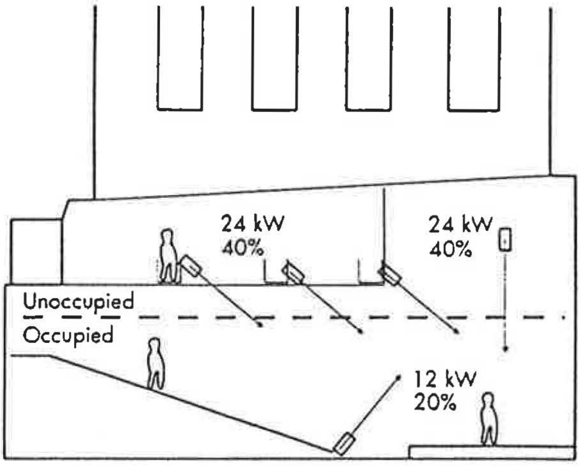


Figure 4a. Energy output from stage luminaire

Figure 4b. Heat load arrangement.

The CFD analysis on Bedales Theatre showed a high level of stratification. Preliminary calculations on the Contact Theatre involved the use of a variant of the CIBSE admittance procedure (5) to estimate this stratification. The method adopted divided the theatre into horizontal layers and applied the procedure to each layer in turn (Figure 5).

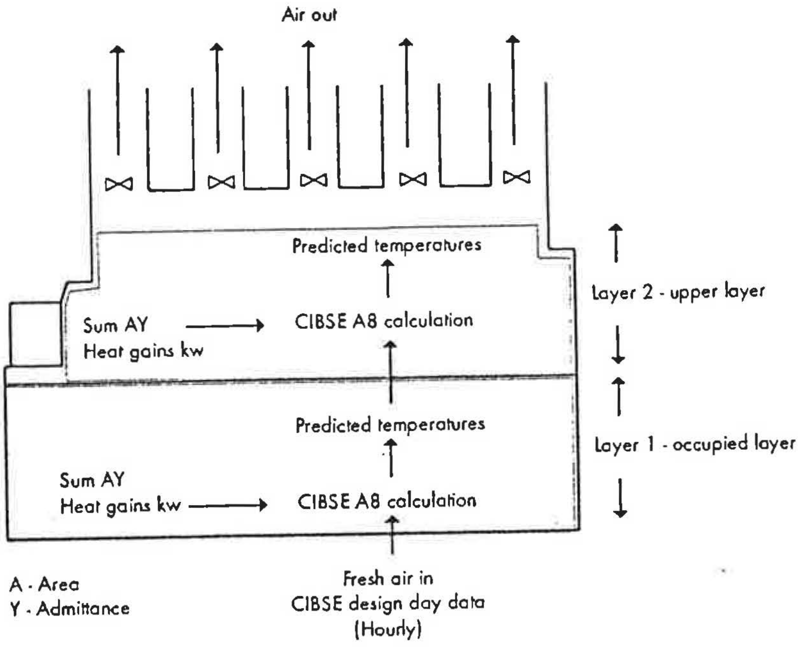


Figure 5. Diagram of layered admittance procedure.

This method was used to quickly examine a wide range of alternative schemes and to determine an optimum solution that takes into account the major constraints affecting the built form. A design air change rate limit of 10 per hour was chosen as a higher rate does not appear to significantly lower temperatures in the occupied areas (Figure 6) and would risk unacceptable air velocities below the seating.

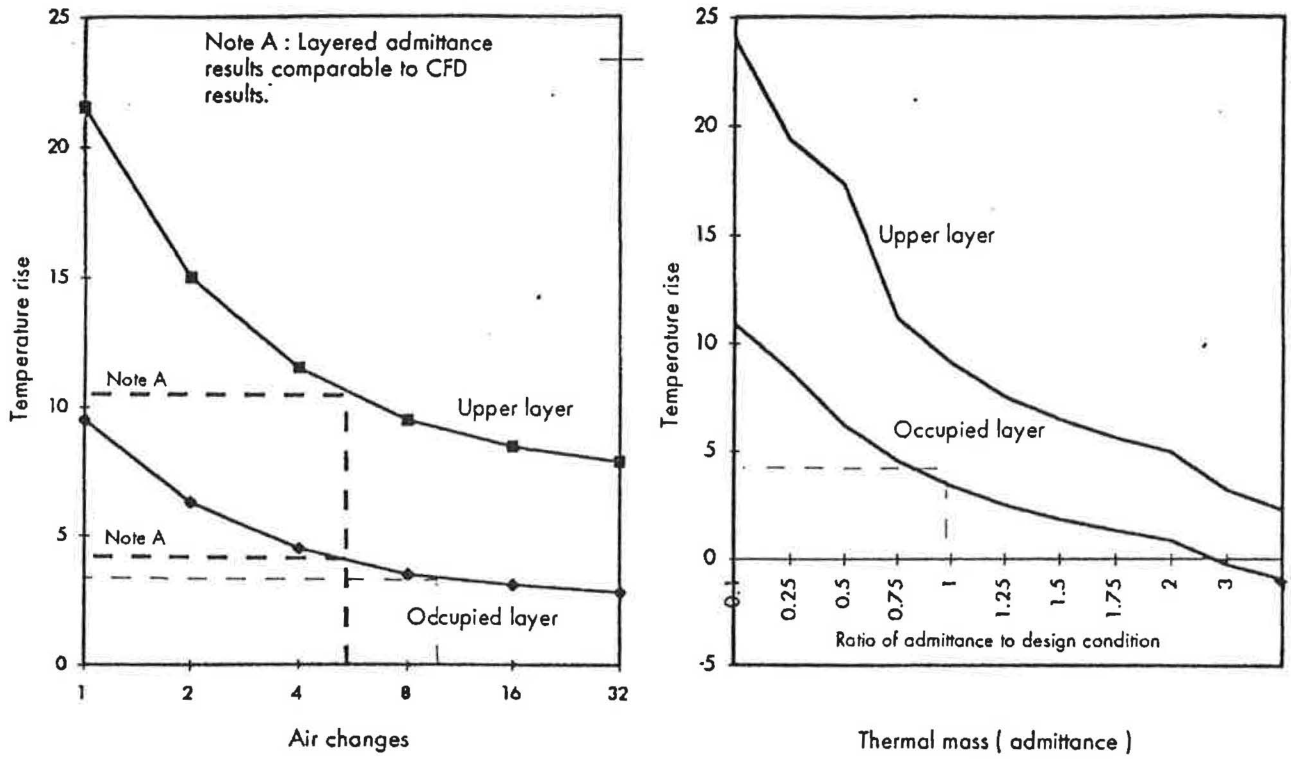


Figure 6. The effect of ventilation and admittance on temperature rise in the space.

A CFD analysis was then carried out by Design Flow Solutions on the final design arrangement: to check the layered admittance results, to provide a better picture of the temperature gradient (Figure 7) and to look at the airflow patterns in the space. The CFD results indicated that the layered admittance procedure provides a useful design tool.

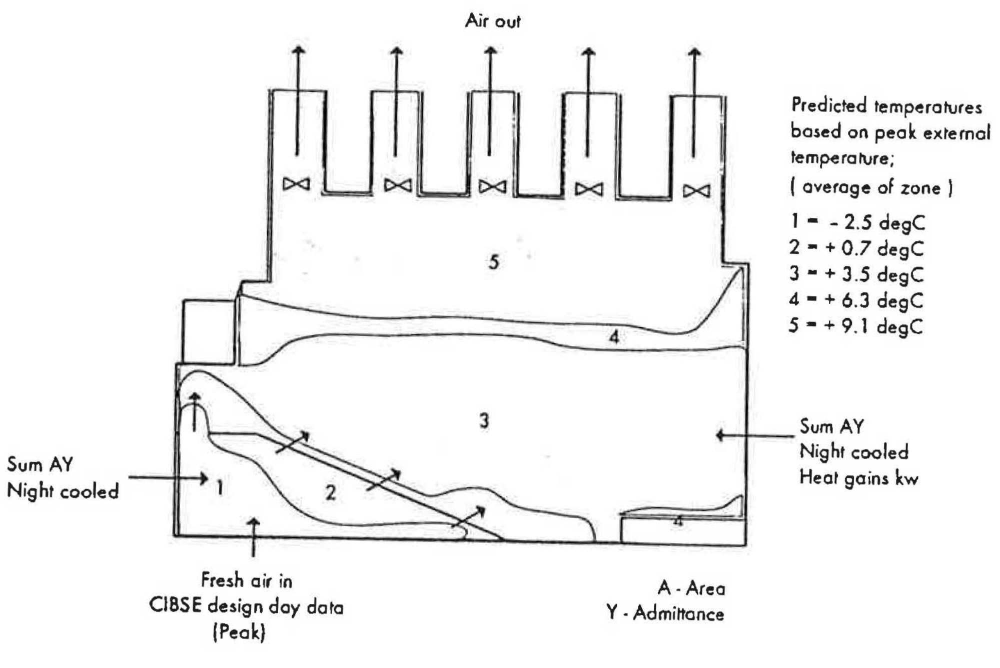


Figure 7. Summary diagram of CFD results with stage lighting on.

The CFD analysis predicted that adding the stage lighting heat load into the simulation increased stratification and stack effect with a subsequent higher ventilation rate. In this situation the CFD analysis predicted that temperatures in the occupied areas increased only marginally.

The amount of thermal mass in the intake plenum is particularly important as it is expected to provide about 2 degC of precooling to the incoming air, when a night cooling regime is used.

During the development of the design there was concern that the wind conditions on the site, which has a number of large adjacent buildings, might adversely affect airflow at the intakes and out of the extracts. A wind tunnel test carried out by The Welsh School of Architecture confirmed that adverse wind gradients, between the intake and extract openings, would occur in certain wind conditions, mainly as a result of the single sided intake arrangement. The stack height was raised to improve the situation. The stack termination design was considered to be particularly important and it was decided that an H - pot arrangement (6) would provide good operation in all wind conditions and good rain protection.

The controls used in this project are very similar to those at the Bedales Theatre, however:

- The BMS is able to speed control the fans to minimise power use and noise;
- The range of both the air intake and extract dampers is restricted in windy conditions;
- The IAQ (Indoor air quality) sensor specified is complemented by a staff operated manual occupancy control as an override and as a fail safe feature.

SUMMARY OF AUDITORIUM DATA

A comparison of the dimensions, occupancy and surface area in both projects is summarised in the table below; the lower half of the table expresses the data on a per person basis. Note the different distribution between the projects of admittance between the undercroft and auditorium.

	Bedales Theatre	Contact Theatre
Floor area m^2 including balcony & stage.	435	390
Room volume m^3	2421	4100
Occupancy	270	380
Stack height m	15.5	20.5
Max air change per hr	15	10
Supply undercroft surface area m^2	805	250
Auditorium surface area exc fittings m^2	1220	1642
Supply undercroft admittance W/K	3081	1500
Auditorium admittance W/K	3072	6199
Floor area / person m^2	1.6	1
Room volume / person m^3	9	10.8
dm^3 /s /person max.	37	30
Undercroft surface area per person m^2/p	3.0	0.7
Auditorium surface area per person m^2/p	4.5	4.3
Undercroft admittance per person W/K/p	11.4	4.0
Auditorium admittance per person W/K/p	11.4	16.3

CONCLUSIONS

Assisted natural ventilation offers a practicable solution to the satisfactory ventilation of theatres. The predicted temperatures for these projects indicate that acceptable temperatures can be achieved in theatres using assisted natural ventilation and a night time cooling regime.

These projects illustrate a number of interesting points:

- Large low resistance air paths in and out of the building are required;
- Opening sizes for air intakes and exhausts of about 5 % each (free area) of floor area offer a reasonable starting point during early design;
- Acoustic constraints will dramatically affect the air intake and exhaust free areas. In the Contact Theatre the acoustic splitters and limitations set by the existing building reduce the free area available and increase the resistance to airflow. When high ventilation rates are required fan assistance is used;
- The CFD analyses (Figures 2 & 7) predict a high level stratified layer of hot air. All occupants should be located below this layer and in the case of the Contact Theatre this precluded the use of a balcony;
- The Contact Theatre CFD analysis predicted that the stage lighting heat load increased stratification and stack ventilation with only a small increase in temperature in the occupied areas;
- The layered admittance calculations (Figure 6) clearly show a diminishing return as ventilation or admittance is increased. For the Contact Theatre it indicates that an air change rate greater than 10 per hour does not result in significantly lower peak internal temperatures;
- Air Intake and exhaust openings need to be designed for local wind conditions.

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Quantity Surveyor	Bedales School	Dearle and Henderson
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