#6314

SIMULATING THE THERMAL PERFORMANCE OF NATURALLY VENTILATED SPACES: A CASE STUDY

Herbert Eppel and Kevin J. Lomas
School of the Built Environment
Leicester Polytechnic
PO Box 143
GB - Leicester LE1 9BH

ABSTRACT. In order to be as energy efficient as possible, the new building for the School of Engineering and Manufacture at Leicester Polytechnic was designed to be naturally ventilated, as far as possible. Computer simulation was used to test whether this could be achieved, and design optimisation and performance assessments studies for the auditoria were undertaken. The results indicated that a suitably controlled natural venting strategy could work, and the final design was based on this approach.

1. Introduction

The new building for the School of Engineering and Manufacture at Leicester Polytechnic, which is described in a companion paper (Ford & Short, 1991), was designed to be as energy efficient as possible. To minimise energy consumption for lighting and temperature control, maximum use was to be made of natural light and the building was, as far as possible, to be naturally ventilated.

Research into whether, and how best, the latter could be achieved, was commissioned by the Energy Technology Support Unit of the UK Department of Energy. The Environmental Design Unit at Leicester Polytechnic undertook work using computer simulation and the results are reported in this paper. Complementary work was undertaken by the Department of Applied Mathematics and Theoretical Physics at Cambridge University, using a perspex model suspended in a salt solution; their work is described in another companion paper (Lane-Serff et al., 1991)

2. Research Brief

It was uncertain whether natural ventilation would be adequate to prevent summertime overheating in the two densely occupied auditoria, so mechanical ventilation, and perhaps full air-conditioning, had to be considered. Research at Leicester concentrated on this issue and on design optimisation and performance assessment of the auditoria.

The $870m^3$ auditoria are designed to seat 150 people, and the brief indicated this level of occupation for 8 hours a day, 5 days per week. The heat produced by the occupants (100W each), together with $15W/m^2$ from lighting and 500W from equipment, result in an internal heat load of 18.3kW.

S. Alvarez et al. (eds.), Architecture and Urban Space, 749–754.

The natural ventilation scheme consists of a plenum below the raked wooden staging supporting the seats. This plenum is fed from the outside, and the air enters the auditoria through grills below the seats. The air outlet consists of a 13.3m high vertical chimney, connecting an air extract grill at the front of the auditoria to the outside above roof level (Figure 1). In winter, heating is provided by fin convectors behind inlet grills in the seating risers. To try and prevent excessive temperature fluctuations, the side walls and ceiling were made of heavy-weight concrete.

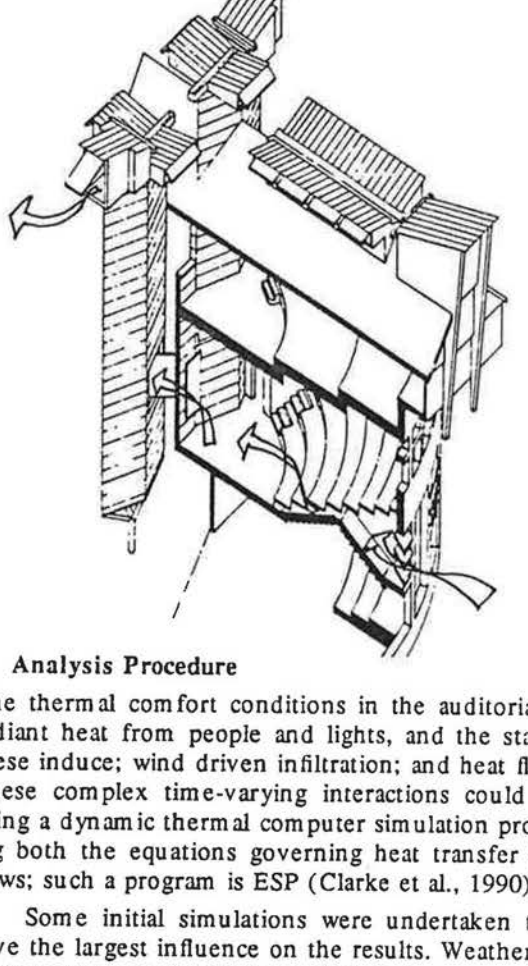


Figure 1:
Natural ventilation scheme for the auditorium

3. Analysis Procedure

The thermal comfort conditions in the auditoria are dictated by: the convective and radiant heat from people and lights, and the stack (buoyancy) driven airflows which these induce; wind driven infiltration; and heat flow into and out of the thermal mass. These complex time-varying interactions could only be adequately investigated by using a dynamic thermal computer simulation program capable of simultaneously solving both the equations governing heat transfer and the equations describing the air flows; such a program is ESP (Clarke et al., 1990).

Some initial simulations were undertaken to identify the factors, which would have the largest influence on the results. Weather data for a typical hot sunny day was used to study the influence of design changes on the hourly variations in temperatures and air flow rates. In the next stage, design optimisation, the design options were refined and simulation results compared with a reference, or base case. An attempt was made to compare these simulation results with the results obtained from the physical model used at Cambridge. Finally, the occurrence of warm conditions in the auditoria was studied for a typical year.

4. Initial Results and Design Optimisation

The 'summer sizing' weather data used in this stage of the work was devised by analysing the 310 July days in the 10 years of hourly weather data collected at Kew, London, from 1959 to 1968 (Loxsom 1985/86). Only 1% of July days were hotter and sunnier. Analysis of the CIBSE banded weather data (CIBSE, 1986) shows, that no more than 5 July days, and no more than 10 days in the whole year, can be expected to be hotter than this design day.

The computer simulations clearly illustrated the strong relationship between the rate of heat generation and the induced air flow (Figure 2). For the base case, air change rates of over 6ach^{-1} occurred during the occupied periods. The progressive warming of the structure during the day leads to peak dry resultant temperatures occurring in late afternoon.

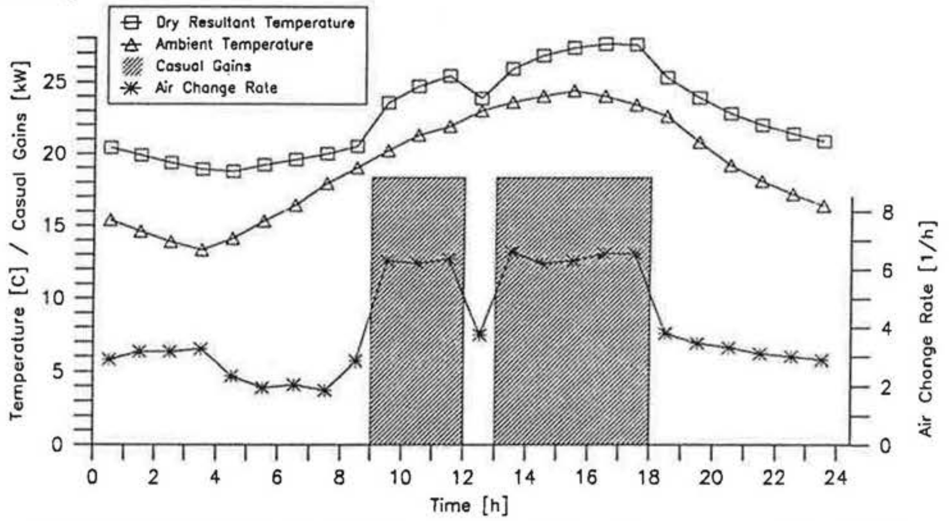


Figure 2: Hourly variation of environmental conditions for the base case auditorium

Nine cases (design and operational variants) were investigated in detail and compared with the base case. Concentrating on the peak dry resultant temperature (Figure 3), the following observations can be made.

(a) Large reductions in the dry resultant temperature would occur during days of reduced occupancy. At 60% of the design value, this reduction was 1.3°C. (At 80% occupancy the reduction was 0.9°C).

(b) Of the design variants studied, the provision of windows was the single most effective temperature reducing measure. A 5 m^2 window opening reduced the peak dry resultant temperature by 0.8°C.

(c) However, if both the plenum inlet and chimney cross-sectional area were enlarged, then a reduction of 1.2°C in peak dry resultant temperature could be realised. Of these two design changes, enlarging the chimney cross-sectional area had the greater effect.

(d) Heating the chimney reduced the peak dry resultant temperature by only 0.5°C and night time mechanical venting reduced it by only 0.1°C. One must therefor set the complexity and cost of these measures against these marginal environ mental improvements.

(e) Mechanically ventilating the structure at night to reduce the temperature of th structure, and increasing the chimney height (results not shown), had littl impact on the peak dry resultant temperatures.

(f) Acoustic tiles around the back third of the auditorium raised the peak dry resul tant temperature by 0.8°C. However, it should be noted, that this valu represents the average for the auditorium as a whole. Locally higher values wi occur in spaces surrounded by the tiles, leading to greater discomfort towards th rear of the auditorium. The rear of the auditoria is already higher and so closer t the warmer, stratified, air below the ceiling. Opening windows at the rear of th auditorium, which has an outside wall, would give greater local benefits in thi region (but at the expense of the acoustic qualities of the space).

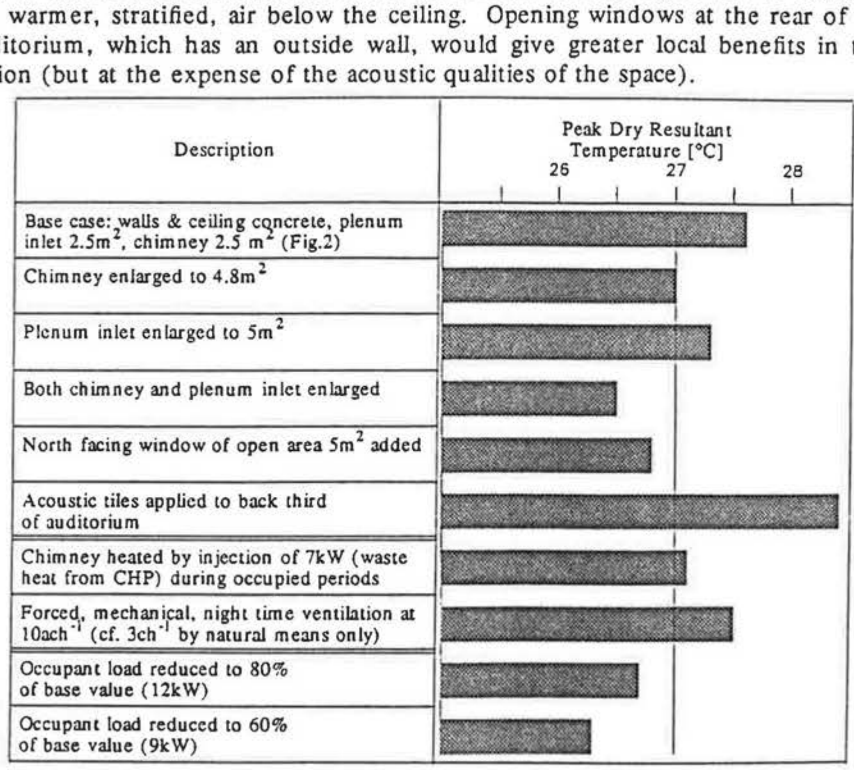


Figure 3: Comparison of peak dry resultant temperatures

A design guide for educational buildings (Design Note 17, 1981) states, that "it is undesirable that the resultant temperature should exceed 27°C during normal working over the school year, but an excess for 10 days during the summer is considered to be a reasonable predictive risk". The peak dry resultant temperatures on the hot sunny design day were close to, or below, 27°C for many of the scenarios studied. It was felt therefore, that a design based on natural ventilation could succeed, and so a more rigorous performance assessment investigation was undertaken.

5. Performance Assessment

The occurrence of warm conditions in a typical year was studied by simulating the 'summer' period from 1st May to 30th September using the weather data for Kew, London, collected in 1967. (This is the single year closest to the average of the 10 years of data collected at Kew between 1959 and 1968.) No corresponding data for Leicester were available, (but it is reasonable to assume it will be cooler if anything, so the results will be conservative).

The design options most likely to be adopted were used in this study. The results were plotted as the cumulative number of occupied hours (lecture periods), for which the dry resultant temperature exceeded 20°C, 21°C, 22°C etc. (Figure 4).

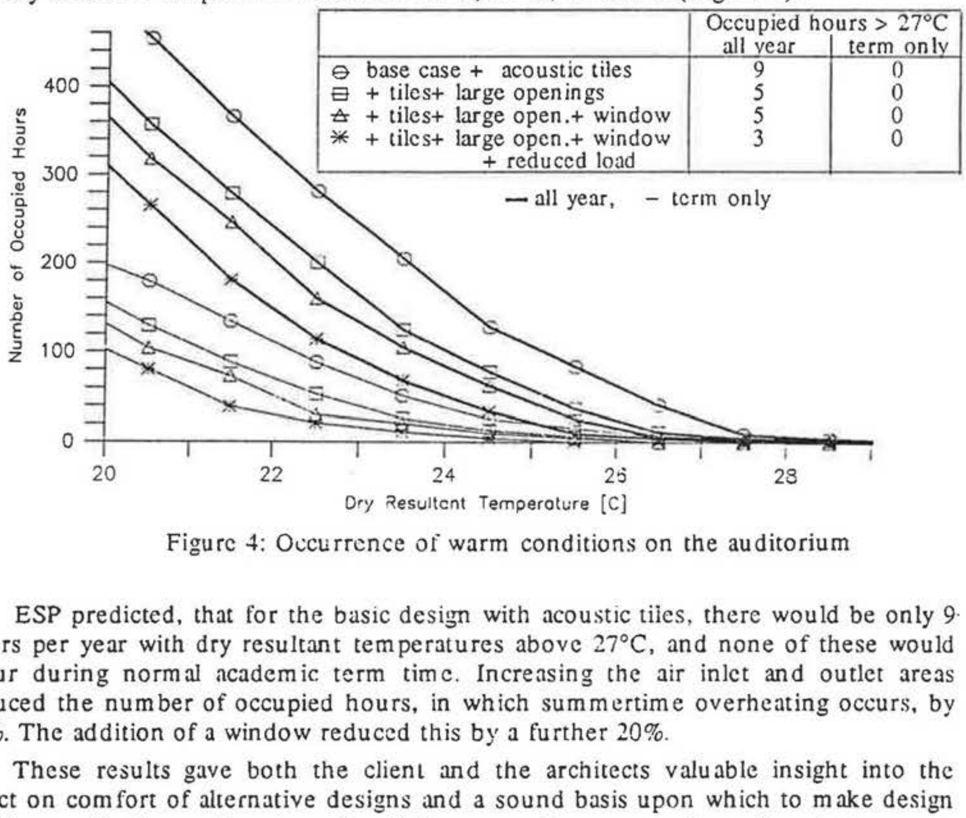


Figure 4: Occurrence of warm conditions on the auditorium

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

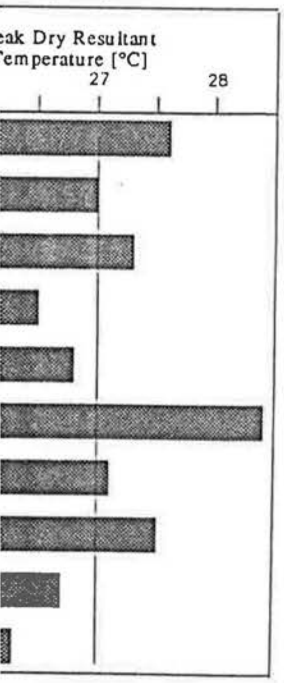
These results gave both the client and the architects valuable insight into the effect on comfort of alternative designs and a sound basis upon which to make design decisions. Partly on the strength of these results, a natural venting strategy was adopted.

6. Comparison of Thermal and Physical Modelling

The explicit finite difference program ESP is inherently a dynamic, time-varying model, which takes into account the thermal mass of the structure, radiant exchange mechanisms and wind effects. However, thermal models such as ESP have difficulties in dealing with temperature stratification and complex geometries. Conversely, whereas the perspex model is well suited to study the temperature distribution within complex spaces, it is inherently a steady-state model, and none of the dynamic temperature by only 0.5°C, 0.1°C. One must therefore nst these marginal environ-

luce the temperature of the ılts not shown), had little

n raised the peak dry resul- be noted, that this value e. Locally higher values will ater discomfort towards the eady higher and so closer to windows at the rear of the reater local benefits in this the space).



emperatures

7, 1981) states, that "it is °C during normal working ummer is considered to be eratures on the hot sunny enarios studied. It was felt l succeed, and so a more en.

5. Performance Assessment

The occurrence of warm conditions in a typical year was studied by simulating the 'summer' period from 1st May to 30th September using the weather data for Kew, London, collected in 1967. (This is the single year closest to the average of the 10 years of data collected at Kew between 1959 and 1968.) No corresponding data for Leicester were available, (but it is reasonable to assume it will be cooler if anything, so the results will be conservative).

The design options most likely to be adopted were used in this study. The results were plotted as the cumulative number of occupied hours (lecture periods), for which the dry resultant temperature exceeded 20°C, 21°C, 22°C etc. (Figure 4).

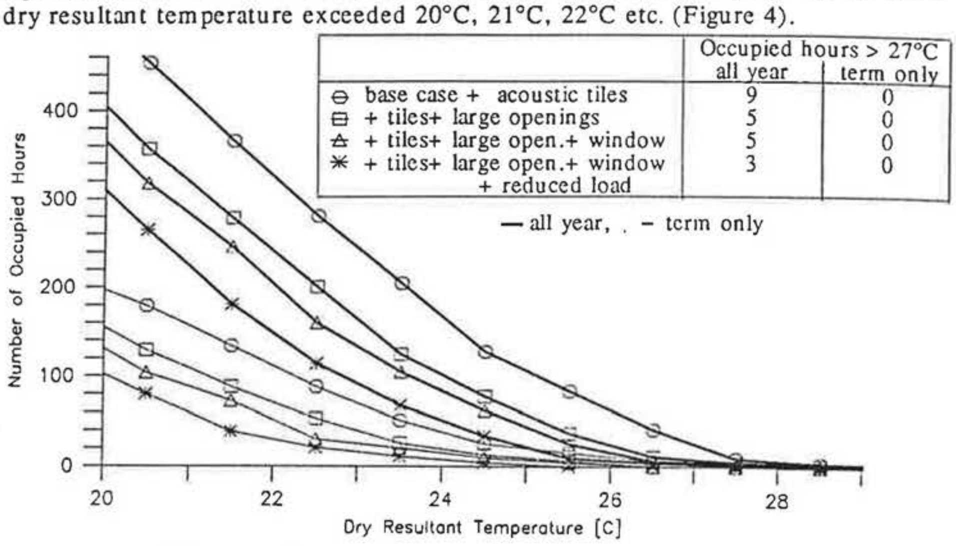


Figure 4: Occurrence of warm conditions on the auditorium

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

These results gave both the client and the architects valuable insight into the effect on comfort of alternative designs and a sound basis upon which to make design decisions. Partly on the strength of these results, a natural venting strategy was adopted.

6. Comparison of Thermal and Physical Modelling

The explicit finite difference program ESP is inherently a dynamic, time-varying model, which takes into account the thermal mass of the structure, radiant exchange mechanisms and wind effects. However, thermal models such as ESP have difficulties in dealing with temperature stratification and complex geometries. Conversely, whereas the perspex model is well suited to study the temperature distribution within complex spaces, it is inherently a steady-state model, and none of the dynamic processes mentioned above can be treated adequately. Therefore, the two approaches are complementary, since neither method can deal with all the physical processes occurring in a real building.

It is difficult to undertake a precise comparison of the results obtained with the two methods. Nevertheless, by averaging spatially the air temperatures predicted by the salt model and assuming the same surface temperatures, an average dry resultant temperature can be calculated. This was 26.9°C, and the air change rate was 9.2ach^{-1}. Corresponding values predicted by ESP were 27.6°C (Figures 2&3) and 6.6ach^{-1}. This level of agreement is encouraging, but the reasons for the differences are worthy of investigation.

7. Conclusions

Combined thermal and air flow simulations gave valuable insight into the complex dynamic variations of the temperatures inside the auditoria. These studies provided a sound basis for refining the design and for assessing the overheating risk.

In so far as this work made comparisons possible, ESP and the salt model agreed reasonably well. However, little work has been done to assess the applicability and bsolute accuracy of these design tools. Funds for monitoring the environmental performance of the building are being sought.

The results confirmed that a suitably controlled natural venting strategy was viable, even in the densely occupied auditoria. The final design evolved trough close co-operation between the architects and the researchers. This makes the new School of Engineering and Manufacture one of the largest naturally ventilated buildings in Europe.

Acknowledgements

Funding by the Energy Technology Support Unit of the UK Department of Energy under a pilot study for the new energy design advice scheme is acknowledged.

References

CIBSE Guide, 1986, Volume A: Design Data, The Chartered Institution of Building Services Engineers, London

Clarke, J., Hand, J. and Strachan, P., 1990, 'ESP - A building and plant simulation system', Version 6 Series, ESRU Manual U90/1, Energy Simulation Research Unit, University of Strathclyde, Glasgow

Design Note 17, 1981, 'Guidelines for environmental design and fuel conservation in educational buildings', Dep. of Education & Science, Architects & Buildings Branch

Lane-Serff, G.F., Linden, P.F., Parker, D.J. and Smeed, D.A., 1991, 'Laboratory modelling of natural ventilation via chimneys', Proc. PLEA'91 Conference, Sevilla

Loxsom, F., 1985/86, 'Meteorological data for the Passive Solar Programme', Polyt. of Central London, Collection of reports for ETSU model refinement study

Ford, B. and Short, A., 1991, 'Design of a naturally ventilated laboratory building in Leicester, England', Proc. PLEA'91 Conference, Sevilla