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(Title) STACK EFFECT VENTILATION OF AN INFANT'S SCHOOL

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SYNOPSIS

This paper presents the results of monitoring the ventilation in Netley Infants School in Hampshire. The study was carried out on behalf of the Department of Trade and Industry as part of the Energy Performance Assessment Project, as managed by the Energy Technology Support Unit.

The school was designed so that during the summer the solar heating of a south facing conservatory would enhance the stack effect and induce ventilation in the adjacent classrooms. It was expected that ventilation rates would be adequate to maintain comfort conditions and air quality.

The monitoring was carried out over a period of two months in 1991 and incorporated one-off measures of ventilation rates, short term tests of the ventilation strategy and long term monitoring of carbon dioxide to assess air quality. The measurements were carried out using an automated NDIR analyser sampling from points throughout the school, and a weather station erected in the school grounds.

The results show a general background infiltration rate of 0.4 ach with ventilation rates of about 1.5 ach when the building was operated as designed. The more normal operation, which involved opening the doors between the classrooms and conservatory, raised the ventilation rate to approximately 2 to 4 ach. This still fell short of the recommended fresh air rate of $30m^3$/person/h. Over periods of high ambient temperatures and solar radiation the external fire doors of the classrooms were opened to augment the vents: satisfactory ventilation was then achieved.

1. INTRODUCTION

Netley Abbey Infants School is a single storey building with a gross floor area of $1035m^2$ - including the conservatory. The primary aim of the design was to use as conservatory to provide solar heated air for the classrooms in the heating season. In doing this it was recognised that the solar gain in summer could be used to drive stack effect ventilation to the classrooms[1]. The client for the school was the Hampshire County Council, and the design was developed by the Martin Centre of Cambridge University[2].

The school was studied as part of the Energy Performance Assessment Project of the Department of Trade and Industry[3]. The solar ventilation pre-heating strategy was very successful and is reported elsewhere[4]. This paper reports on the detailed study of the air movement and ventilation.

The school is sited in Hampshire, England, on the edge of a residential area. Figure 1 shows the orientation and the floor plan.

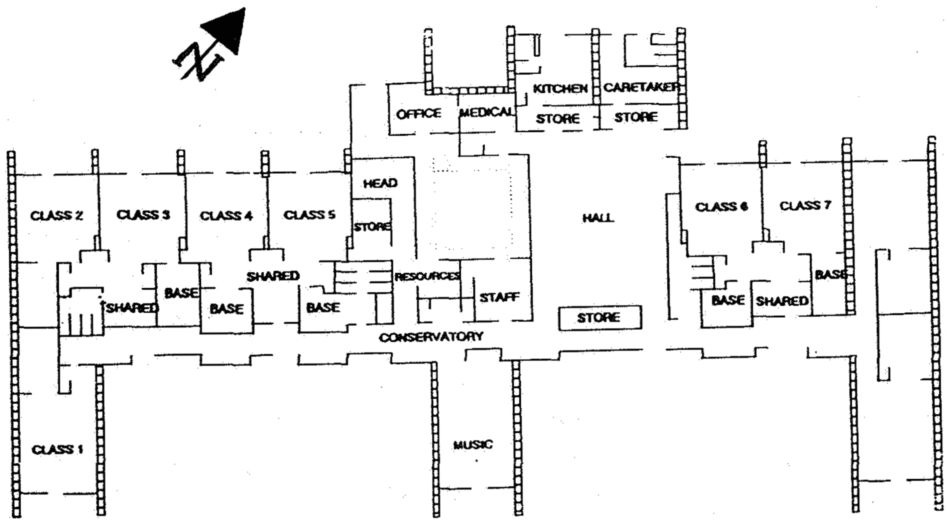

Figure 1. Plan of Netley Abbey School

2. VENTILATION

The warm air mechanical heating and ventilation system only operates in the winter. Each teaching area has an air heater battery which delivers warm air to the classrooms via ductwork suspended below ceiling level. The building is designed to be naturally ventilated outside the heating season.

During the summer, teaching areas were designed to be supplied with fresh air by natural ventilation generated by stack effects within the conservatory and wind over the ridge vents. Stack effects draw air into the building, through vents in the north wall of each teaching space, and thence via louvres in the south facing glazing of the classrooms to the conservatory. Figure 2 illustrates the air flow.

The movement of air from the conservatory to the roofspace and out via ridge vents was temperature controlled by hinged flaps in the ceiling above a mezzanine floor in the conservatory. These were fitted with 'wax-stats' and opened when the air temperature reached a pre-set value.

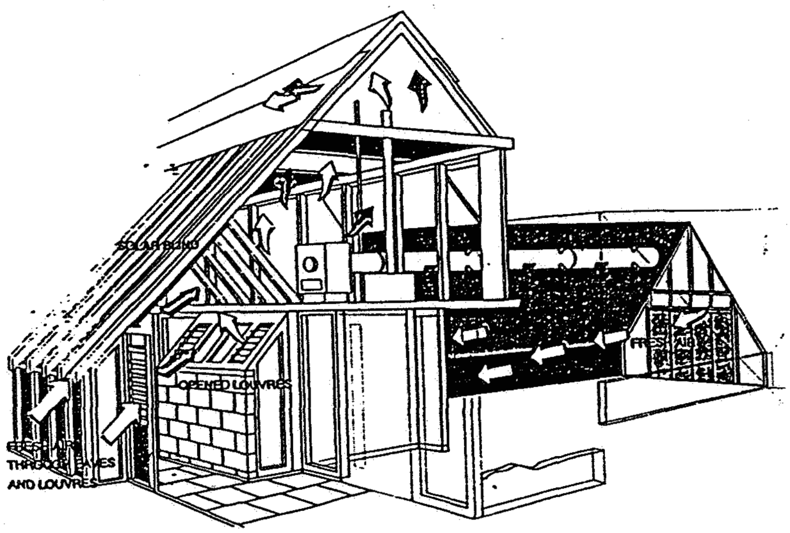

Figure 2. Section of school showing air movement in summer

2.1 Monitoring Objective

The objective of this evaluation was to test the design intent of providing adequate natural ventilation to the classrooms as described above. This was done by undertaking short and long term tests. Classrooms 2,3,4 and 5 where taken as representative.

The short term tests were concerned with attempting to measure the ventilation rates in the classrooms under known conditions. The tests were carried out by tracer gas tests using carbon dioxide introduced into the classrooms and recording its decay through time.

Long term tests were concerned with attempting to quantify ventilation rates under different weather conditions and looking at amenity issues such as air quality and overheating. For the long term tests it was decided to use occupant generated carbon dioxide as the tracer gas. There are disadvantages to this in that a detailed knowledge of occupancy and metabolic rates are needed for accurate computation of ventilation rates for occupied periods. Also there is a fairly high, and variable, background concentration which needs to be taken into account.

Other researchers have used this method for assessing ventilation rates, notably Penman[5], and it had a number of practical advantages. It did not have to be introduced into the spaces, there would be no objections from the school, and the analyser and other equipment had been used previously for long term monitoring and had been found to be very reliable. The level of carbon dioxide also gives an indication of air quality. It was therefore considered that this method would provide reasonable estimates of the ventilation rates.

A weather station was set up adjacent to the school. This measured external temperature, horizontal global and diffuse solar radiation, wind speed and wind direction.

3. MEASUREMENTS AND FINDINGS

3.1 Short Term Tests

The short term tests were conducted on one day, over which period the external temperature varied between 19°C and 22°C, the measured wind speed varied between 1.3 m/s and 1.8 m/s and the wind direction varied between SSE and SW. The temperature of classrooms 2 & 3 varied from 23°C to 24°C, that of classrooms 4 & 5 varied between 24°C to 25°C, the conservatory temperature ranged from 24°C to 26°C and the mezzanine level temperature was 36°C at the start of the tests (12.30pm) and had dropped to 25°C by the end of the tests (5.30pm).

Four tests were undertaken in each pair of classrooms. For each test the vents in the mezzanine ceiling were checked and found to be fully open. The test conditions were as follows:

3.1.1. Design conditions, i.e. the sliding shutters over the north gable grilles were open, in classrooms 4 and 5 the louvres to the conservatory were opened and the rooflight was opened in classrooms 2 and 3. Doors were closed.

3.1.2. All grilles, louvres, windows and doors closed to get an indication of the background leakage.

3.1.3. 'Normally used' conditions, i.e. as test one, but including the entrance door to each pair of classrooms open.

3.1.4. To simulate the reported operation during very hot weather. This was as in the previous test but with the fire door in the north gable also opened.

At the end of each decay test, smoke tests were carried out to assess the direction of air flow through the vents, louvres, windows and floors. This was done in conjunction with a hot wire anemometer to get an indication of the air speed.

Table 1 below gives the ventilation rates found from the decay tests. These are only really applicable to the weather and internal conditions occurring at the time of the test.

Table 1. CO_2 Decay Test Ventilation Rates

Test No.	Ventilation Rates			
	Classroom 2 and 3		Classroom 4 and 5	
	ach	*m^3/h/person	ach	*m^3/h/person
1	1.48 ± 0.14	8.4	1.62 ± 0.24	8.2
2	0.42 ± 0.04	2.4	0.44 ± 0.07	2.2
3	3.19 ± 0.39	18.0	2.21 ± 0.17	11.2
4	12.2 ± 4.1	69	13.7 ±5.2	69

* Based on 30 children/classroom with volume of classrooms 2 and 3 being $339m^3$ and classrooms 4 and 5 being $303m^3$. To provide the recommended rate of $30m^3/h$/person[6] approximately 6 ach are required.

As can be seen the ventilation rates for the design conditions were very similar in each pair of classrooms at about 1.5 to 1.6 ach. When these figures are related to fresh air supply per person they are equivalent to about $8m^3/h$/person.

Background leakage rates of each pair of classrooms were again similar with ventilation rates of just over 0.4 ach. This is a little higher than the background ventilation rate of 0.32 ach measured at Walmley Schools[7].

The results for test 3, showed that for classrooms 2 and 3 the ventilation rate more than doubled to 3.2 ach when the classroom entrance door was opened. For classrooms 4 and 5 the effect was less dramatic with a small rise in ventilation rate to 2.2 ach. The fresh air supply rates were equivalent to $18m^3/h$ and $11m^3/h$ respectively. Figure 2 below shows the air flows.

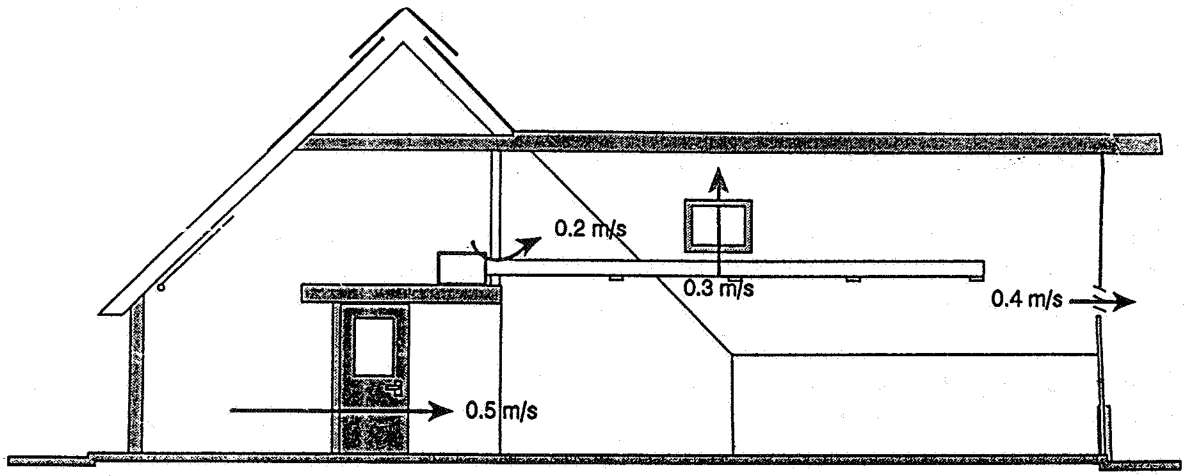

Figure 2. Air movement in Classrooms 2 and 3 - Test 3.

Ventilation rates in excess of 12 ach were found in both pairs of classrooms when the fire door was opened for test 4. This is equivalent to about 70 m^3/h/person.

Throughout the tests the air flowed out of the classrooms through the vents on the north of the building and not through the conservatory ridge. Clearly the wind dominated the flow under the prevailing conditions.

3.2 Long Term Tests

The long term tests were extended over a period of 33 days, in June and July, of which 18 were occupied. The weather was normal with reasonable levels of solar radiation and external temperature, apart from two very warm days in early July. With the exception of those two days average classroom temperatures were below 25°C. The mezzanine temperature, as would be expected, is very sensitive to levels of solar radiation. Although there are a number of days where the average temperature difference between the mezzanine level and outside is about 10°C, with a ridge hieght of approximately 4 metres the pressure differences generated by the stack effect will be low.

The average carbon dioxide levels in the classrooms, conservatory, the mezzanine level and externally for occupied days between 8am and 4pm are shown in Figure 3.

Figure 3 indicates that some fairly high average concentrations of carbon dioxide were found in the classrooms, particularly during mid July. What is also noticeable about this figure is the fall in CO_2 levels at lunchtime. It was confirmed by the teachers that the children were normally out of the classrooms between 12.30 and 1.30 pm. Therefore the ventilation rate for this period was computed using the standard decay equation for each of the occupied days for each pair of classrooms. The results for classrooms 4 and 5 are given in Figure 4.

Calculations using CIBSE A4[8], with typical measurements, show that the areas available at low and high levels would provide approximately 4 ach. The measured areas for the air inlet grilles in the northern gable wall were about 0.5m^2, which served two classroom areas: if this were to be increased to 1m^2 then the recommended rate is predicted.

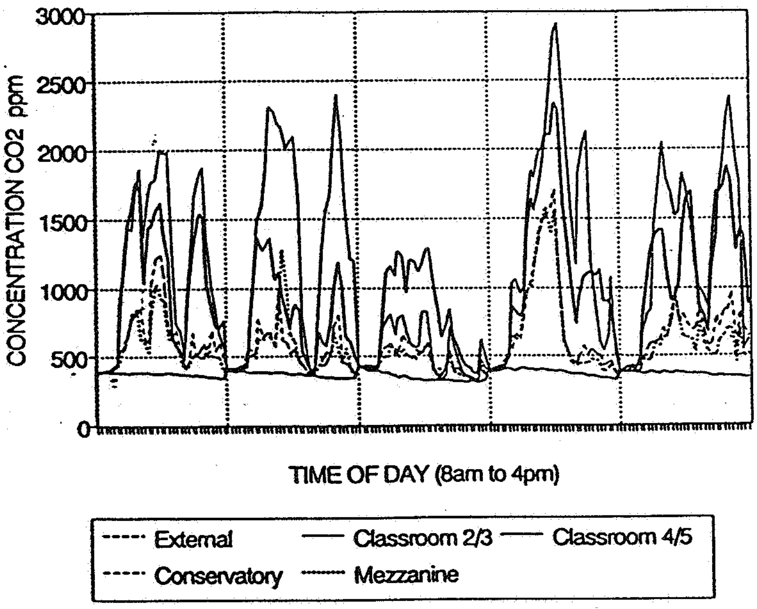

Figure 3. CO_2 Levels for 15th to 19th July 8am - 4pm

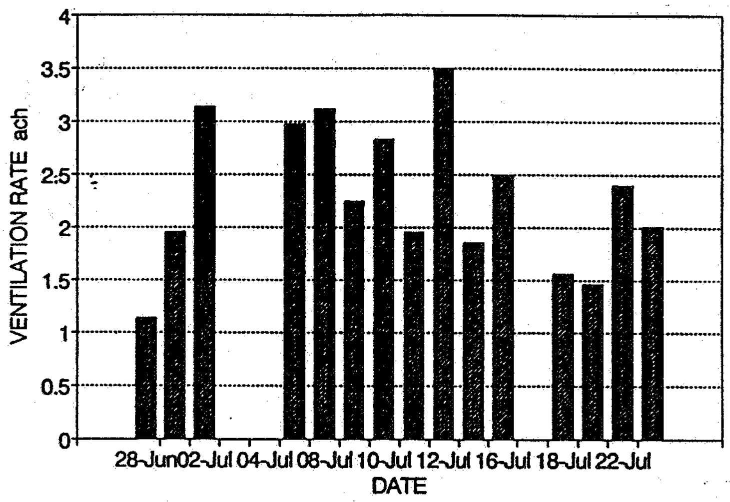

Figure 4. Lunchtime Ventilation Rate for Classrooms 4 and 5

Both of these figures indicate lunchtime ventilation rates of between 1 ach to 3.5 ach. From conversation with the teachers and observations by the monitoring team, it was discovered that the classrooms were unoccupied at lunchtime with the vents and louvres left in the same configuration as the morning. The entrance door from the conservatorywould normally remain wedged open and the fire door would be shut. It was also reported that the conservatory louvres would often be shut at lunchtime to stop the children playing with them. The ventilation rate figures obtained, correspond reasonably well to those found during the one time tests.

Further analysis was undertaken in an attempt to arrive at an average ventilation rate for the period while the school was occupied. This was done by assuming an average production rate of CO_2 by the occupants[9]. The ventilation rates computed for the days referred to above are given in Table 2.

Table 3.6. Average Ventilation Rates for 1st to 5th July

Date	Classrooms 2 & 3 ach	Classrooms 4 & 5 ach
1st July	1.2	2.4
2nd July	2.2	1.8
3rd July	5.5	4.3
4th July	7.9	9.1
5th July	16.2	5.3

4. CONCLUSIONS

The short term tests indicated that, ventilation to the classrooms was dominated by wind effects, the design mechanism having little or no effect on air movement. As the test day was less than averagely windy it is to be assumed that the wind would normally be the dominant driving force for the ventilation.

The tests also indicated that under the designed operating conditions, ventilation rates were only one quarter of those recommended by Design Note 17. Under the normal operating conditions, in which doors from the classroom to the conservatory were propped open, ventilation rates were between 1 and 3 ach, still below the recommended rate. This indicates the limited opportunity for air to pass into the conservatory with the doors closed. The only way of achieving the recommended level was to open the emergency exit door in the north gable wall.

The long term tests suggested that this strategy was used by the occupants, particularly on sunny afternoons, and that it proved effective in providing sufficient ventilation to keep internal temperatures close to ambient. However, it suggests that the ventilation openings in the north gable are insufficient.

Although the average temperature difference between the mezzanine level of the conservatory and ambient was frequently in the region of 10°C, the pressure difference due to the stack effect would be low due to the limited height and restricted free area available. It is likely that the wind effects would often dominate as found in the short term tests.

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