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Energy Efficiency Demonstration Scheme
Report

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ENERGY EFFICIENCY DEMONSTRATION SCHEME

VENTILATION CONTROL BY MEASUREMENT OF CARBON DIOXIDE LEVELS IN PUBLIC ENTERTAINMENT BUILDINGS

A demonstration in a cinema and a bingo and social club operated by the Rank Organisation plc

Prepared by the ECD Partnership
for the Energy Technology Support Unit (ETSU)
AERE Harwell, Oxfordshire, acting on behalf
of the Energy Efficiency Office of the
Department of Energy

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CONTENTS

MANAGEMENT SUMMARY

In most mechanically-ventilated buildings, fresh air is supplied at a constant rate which is determined from data related to the maximum number of people the building can accommodate. In many buildings, however, the level of occupancy can vary considerably and, at times of low occupancy, ventilation can become excessive and result in the unnecessary extraction and loss of warm air. This, in turn, can lead to the unnecessary consumption of heating fuel.

To determine the fuel cost savings that would result from reducing ventilation rates during periods of low occupancy, the Rank Organisation retrofitted a variable fresh air ventilation system, controlled by a carbon dioxide (CO_2) detector, at a social club and cinema. The detector is linked to dampers which adjust the flow of fresh air into the building to maintain CO_2 levels within limits set to provide an acceptable internal environment.

Both the social club and cinema are heated mostly by warmed fresh air, with additional heating being provided by a relatively small separate radiator circuit. Such an arrangement is sometimes referred to as a 'split' system. Before conversion neither the air heating system nor the radiators were thermostatically controlled (other than manually via the boiler thermostat). Therefore the conversion to CO_2-controlled ventilation included three main components:

- an air temperature controller;
- a variable fresh air ventilation system;
- a CO_2 detector.

The radiator circuit initially remained uncontrolled at both sites, but after the first year of operation, themostatic radiator valves were fitted at the cinema.

All the equipment was installed in approximately one month without difficulties and only minor disturbance, at an average cost of £5,403 per site.

During the monitoring period the equipment worked well and there were no complaints regarding air quality. There were some problems relating to poor temperature control, but these were due to an undersized air heater battery at the cinema, lack of temperature control on the radiators and insufficient commissioning of the temperature controller. No problems were experienced with the variable ventilation controller.

Whilst carrying out the monitoring exercise it was found that the mechanical ventilation system at the cinema was used much less than originally thought. This had the effect of reducing the originally calculated ventilation losses and, consequently, the savings achieved by the new equipment.

As a result of these problems fuel savings were 17.4% at the club and 11.4% at the cinema, ie somewhat less than the 25% expected. Costs were also marginally greater than anticipated and both effects combined to increase payback periods to 2.4 years for the club and 4.8 years for the cinema.

The net present value of the resultant savings is estimated at approximately £19,800 in the first ten years of operation, after allowing for maintenance costs and assuming real interest and fuel inflation rates of 4% and 2% respectively.

Because of recent modifications to the equipment, resulting in a reduction in costs, payback periods for the club and cinema would reduce under otherwise identical circumstances to 2.1 and 4.3 years respectively. In new buildings or buildings where some of the ancillary equipment, eg the temperature controller, already exists, installed costs and associated payback periods would be significantly reduced.

1. INTRODUCTION

Background to the project

Under current building design practice, the supply of fresh air to mechanically-ventilated buildings is fixed at a constant level, determined in accordance with the maximum occupancy capacity of the premises. Depending on the season, this air has to be heated or cooled to a temperature suitable for comfort, and over the year this adds significantly to the total space-conditioning fuel bill.

In practice, occupancy in many premises is variable and is often significantly below the maximum design capacity of the building. If high rates of mechanical ventilation are maintained during periods of low occupancy, the building can be over-ventilated with consequential waste of warm air. It is therefore possible to effect considerable energy savings by reducing ventilation rates at times of low occupancy, either by recirculating extract air or, on sites where this is not practicable, by reducing the total volume of air circulated through the building.

Early in 1982, the Rank Organisation decided to test a variable ventilation system controlled by an infra-red carbon dioxide (CO_2) sensor. The sensor continuously monitors the concentration of CO_2 in the building, and adjusts the flow of fresh air accordingly so that set levels are not exceeded. The potential savings were estimated at approximately £4,600/year or 25% of the space heating load, for an initial cost of £10,400. The Rank Organisation operates 75 cinemas, 61 social clubs and a number of other catering and leisure establishments, with a total fuel consumption of approximately 3,900,000 therms/year (409,500 GJ) and the potential savings of such a system, if replicated, are therefore clearly significant.

The two test sites chosen were the Rank Bingo and Social Club at Hounslow (London) and the Odeon Film Centre at Leicester.

Aim of the project

The aim of the project was to demonstrate that energy consumption could be reduced by:

- the use of a CO_2 sensor to adjust the rate of building ventilation to suit varying levels of occupancy;
- the use of an air temperature controller to reduce air heating at times of low ventilation flow rates.

Assistance under the Energy Efficiency Demonstration Scheme

In 1982 the Rank Organisation made an application for some of the cost associated with the installation of the CO_2 sensor-controlled ventilation system to be met by a grant under the Energy Efficiency Demonstration Scheme on the basis of the energy savings expected. The scheme is administered by the Energy Efficiency Office (EEO) and is intended to stimulate investment in new methods of using energy more efficiently. Organisations putting forward suitable proposals can obtain grants of up to 25% of the cost of installing a new piece of equipment or a process under normal working conditions, providing they allow the EEO to monitor the project independently to assess what energy savings have actually been achieved. The EEO meets all the costs associated with such monitoring and publicises the results of the project in order to encourage replication.

The Rank Organisation application for financial support was approved and the EEO contributed £2,700 towards the total capital and installation cost of the equipment. The ECD Partnership were contracted to monitor independently the overall performance and energy consumption characteristics of the two modified ventilation systems.

National energy saving potential

In the United Kingdom there are approximately 2,940 public entertainment buildings with a combined total energy consumption for space heating estimated at 250,000 tce/year. Approximately 80% of these buildings are mechanically ventilated.

If 80% of the mechanically-ventilated buildings were suitable on other considerations for the installation of CO_2-controlled ventilation systems, and if it were possible to achieve in each of them energy savings similar to those made in the social club, the national energy saving would be 27,800 tce each year.

2. DESCRIPTION OF THE PROJECT

People produce CO_2 as part of their normal breathing process (typically 12.6 to 72 litres/hour/person depending on the level of activity) and, for a given activity level, the amount of CO_2 generated in a building depends directly on the number of people present. In the bingo and social club and the cinema this CO_2 is removed continuously by mechanical ventilation and natural air infiltration.

In the CO_2 sensor-controlled variable ventilation system, the supply and extract flow rates are adjusted to maintain pre-set levels of residual CO_2 within the building. When the amount of fresh air supplied to the building by the ventilation system is reduced by the CO_2 sensor, the heating load is also reduced and fuel is thus saved.

The two buildings chosen for testing the variable ventilation system were The Top Rank Club at Hounslow, London, and the Odeon Cinema, Leicester. Both buildings are similar, the club being a converted cinema, and both heating systems use warmed fresh air and radiators, ie 'split' systems.

The Top Rank Club

The club (Fig 1) has a seating capacity of approximately 1,500, distributed between front stalls, rear stalls and circle. It remains open nearly every day of the year for approximately 11 hours each day, although most people attend only the main afternoon (1400 to 1500 hrs) or evening (1800 to 2200 hrs) games. Occupancy is therefore highly variable.

The club has a full fresh air ventilation system provided by supply and extract fans located at opposite ends of the building; these fans are switched on and off manually. Heating is by two 292 kW boilers, converted to natural gas. Most of the heating load is covered by a heater battery in the fresh air ductwork, although radiators, originally designed to counter fabric losses, provide background heating. The annual gas consumption of the club prior to conversion to variable ventilation was approximately 3,040,000 cu.ft. Assuming a net calorific value of 0.3036 kWh/cu.ft., the total calorific value of the gas consumed was approximately 923,500 kWh (3,300 GJ).

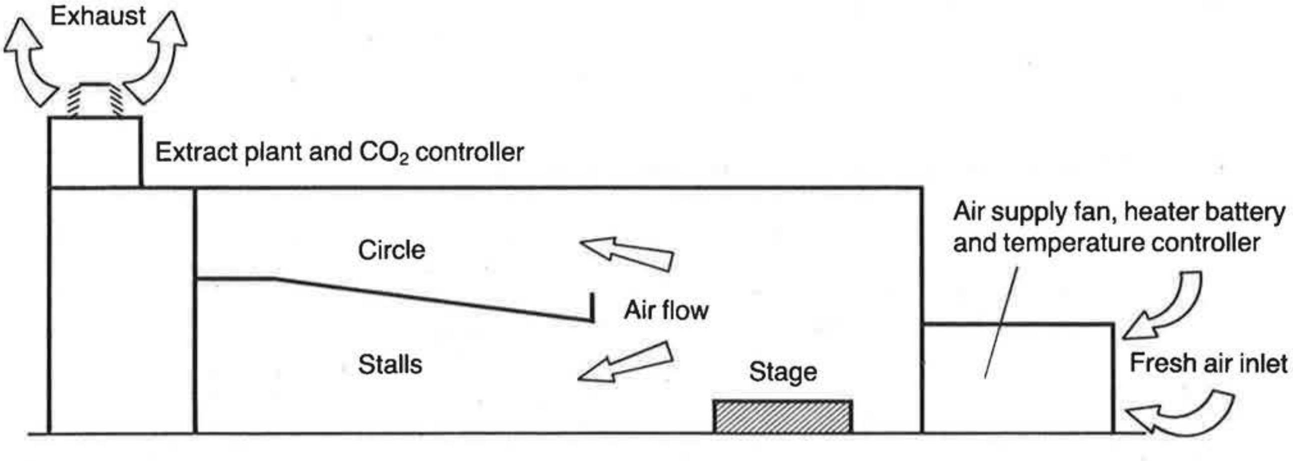

Fig 1 Schematic section through bingo and social club

The Odeon Cinema

The cinema (Fig 2) is divided internally into one large auditorium comprising the old circle and front stalls, seating approximately 1,200 people, and two small auditoria, of approximately 110 seats each, which originally were the rear stalls of the old main auditorium. Programmes run almost continuously (1300 to 2230 hrs) each day of the week, although occupancy is variable depending on the films showing and the day of the week.

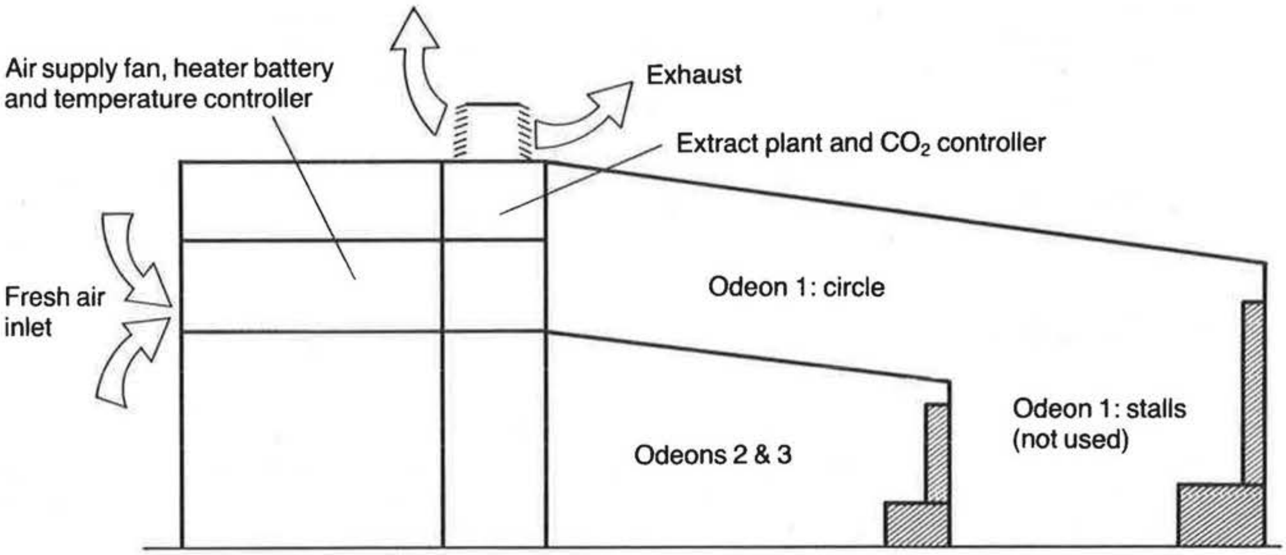

Fig 2 Schematic section through cinema

Heating at the cinema is provided by two 440 kW oil-fired boilers with a split system of a similar design to the one at the club. A radiator circuit provides background heating and a heater battery in the full fresh air ventilation system provides most of the space heating load. In practice the heater battery was found to be undersized, and this changed the relative heating contributions of the two heating circuits. As at the club, the ventilation fans are switched on and off manually.

The annual oil consumption of the cinema prior to conversion to variable ventilation was approximately 58,900 litres. Assuming a net calorific value of 9.9 kWh/litre, the total calorific value of the oil consumed was approximately 583,000 kWh (2,100 GJ).

The variable fresh air ventilation system and CO_2 sensor

The system (Fig 3) at both sites was installed by Information Transmission Ltd (ITL) and consists of variable ventilation plant controlled by a CO_2 sensor. The sensor continuously samples air in the extract duct (or directly from the auditorium) and measures the concentration of CO_2. If the concentration exceeds a pre-set value, usually 700 to 1,000 parts per million (ppm), dampers in the supply and extract ducts open to increase the ventilation air throughput. By comparison with this pre-set level of CO_2 concentration, the recommended upper limit value is 5,000 ppm and the normal external concentration of CO_2 in the atmosphere is 300 to 350 ppm. During periods of low occupancy (and therefore low CO_2 concentration) the dampers close to reduce the total flow of air through the building.

There are four sets of dampers in the exhaust and supply ducts. Three are controlled by the CO_2 sensor and the fourth opens fully, immediately the fans are switched on, to prevent damage to the ducts and to provide a minimum amount of fresh air irrespective of the number of people in the building. At night all dampers are fully closed to prevent heat losses through convective ventilation and also to provide some frost protection to the heater batteries.

The installation of an air recirculation system, which could have reduced costs, was not practicable at either the club or cinema due to the large distance between the supply and extract ducts.

The temperature control system

When the amount of fresh air drawn into the building is reduced, the heating load is also reduced and fuel is thus saved. However, if the temperature within the building is allowed to rise, fuel savings will not be achieved. Effective temperature control is therefore essential.

At both sites, the temperature of the fresh air supply is thermostatically controlled by a separate temperature controller that monitors the temperature within the auditoria: if the internal temperature drops, eg as a result of increased heat losses, the set point temperature of the fresh air supply is increased. Typically, the controller is set to provide air at 22°C when the auditoria are at 20°C, and 42°C when the temperature in the auditoria falls to 17°C.

The radiator circuits were uncontrolled however, and this reduced the overall effectiveness of temperature control and contributed to the low fuel savings in the first year of operation.

Installation of equipment

The conversion of the existing system to a CO_2-controlled variable fresh air ventilation involved the following main items of work:

- installation of dampers in the fresh air and exhaust ducts;
- installation of a motorised diverting valve and by-pass in the heater battery circuit;
- installation of a temperature controller near the heater battery;
- installation of a CO_2 sensor and controller near the extract fan;
- installation of temperature and CO_2 sensors;
- wiring of the controllers to the sensors and damper actuators.

Only the first two items represented a significant amount of work and possible disturbance. In practice all the equipment was installed and commissioned in approximately one month with only minor difficulties and disturbance, although space heating was interrupted for approximately one week to install the by-pass and heater battery.

Although, ideally, work on heating systems should be carried out during the summer, thereby avoiding interruptions to space heating, such arrangements were not possible in this particular instance because the necessary financial approval for the project was received at the start of the heating season.

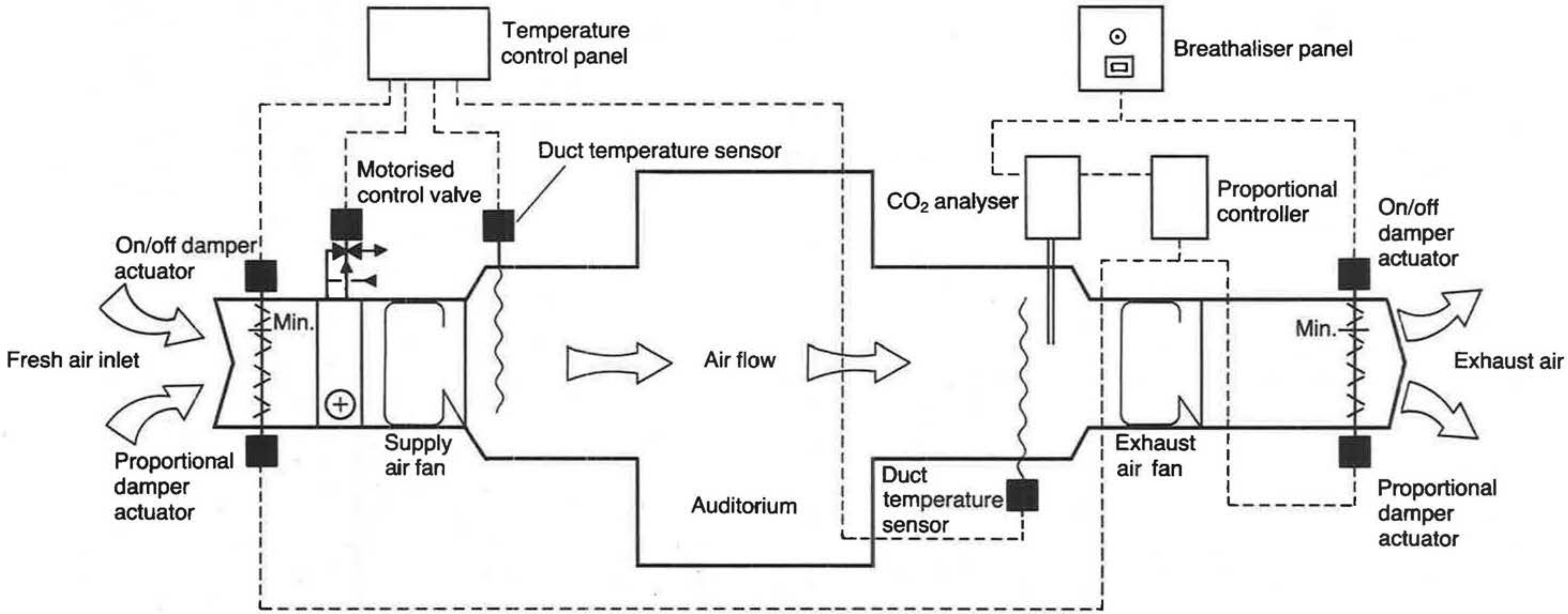

Fig. 3 Diagrammatic layout of ventilation plant and controls

Installation costs were higher at the cinema than at the club because, while the bypass was being installed, the isolating valves of the heater battery failed and had to be replaced. Space and access to the pipework and to the exhaust duct was also more restricted. This required additional modifications to the pipework and made the work more difficult.

The actual installation and commissioning costs and the approximate timetable are given in Table 1.

Table 1 Installed costs and timetable

Location	Cost (£)	Installation	Commissioning
Bingo and social club	4,734	Nov 1983	Dec 1983
Cinema	6,073	Dec 1983	Jan 1984

Specification of the variable ventilation equipment

The variable ventilation and building breathaliser equipment consists of:

- the Horiba indoor CO_2 monitor model APBA 200E (0 to 2,000 ppm) with duct probe supplied by ITL;
- the CO_2 controller interface module type 100E supplied by ITL;
- the proportional damper actuators type AUH 250 by Staefa (one in the exhaust duct and another in the fresh air supply duct);
- the on/off damper actuators type A2H 250 by Staefa (one in the exhaust duct and another in the fresh air supply duct);
- the control dampers by Johnson Controls D8 series; four dampers in the extract duct and another four in the supply duct.

The temperature control equipment, all by Staefa Controls, consists of:

- one ventilation and air conditioning controller type RDK9;
- one universal reset transmitter type WSU1;
- one PDPI controller type SRK 3;
- one AID4 motorised valve;
- two temperature sensors (types T30 and T105).

The temperature control equipment was built into a standard sub-rack housing system with hinged front clear panel and power supply.

3. OPERATIONAL EXPERIENCE

Ventilation air quality was consistently maintained during the 18-month monitoring period, and the measurements carried out indicate that the required gas and dust limits were not exceeded. However, problems were experienced with low air temperatures and poor temperature control, chiefly when operating without the variable ventilation system (which was disabled during alternate weeks for monitoring purposes). These problems were compounded by inadequate initial commissioning of the temperature controller and, at the cinema, by an undersized pump in the heater battery circuit.

Carbon dioxide control

The CO_2-controlled variable ventilation system performed well throughout the monitoring period although there was a small amount of random variation (drift) in control sensitivity which, if persistent, will require adjustment during annual maintenance procedures.

It is considered that improvement could be made to the alarm which signals when the set concentration of CO_2 is being exceeded. At present the alarm is integral to the equipment, which is located in a rarely frequented area of the building, and is therefore unlikely to be noticed quickly. A separate alarm in the manager's office is recommended and this is being considered by the equipment manufacturers. Finally, there is no override key to revert to full ventilation, the existing one being fitted for monitoring purposes only. An override facility can, however, be supplied by the equipment manufacturers.

Temperature control

The importance of efficient temperature control is paramount because no fuel savings will be achieved if the internal temperature is allowed to rise when fresh air flow is varied.

The radiator heating circuit was uncontrolled at both sites and this resulted in some loss of performance. During the second year of monitoring it was decided to fit thermostatic radiator valves (TRV's) to all radiators in the auditorium of the club. Fuel savings increased, partly as a consequence of this, from 14.6% to 17.4%.

The initial commissioning of the temperature controller took longer than expected at both sites and resulted occasionally in low internal temperatures. The set points at the cinema had to be altered on several occasions and temperature control was never completely satisfactory. This was largely due to the heater battery being unable to supply sufficient heat during cold spells. The fault was eventually traced to the circulating pump, which was a 1960's replacement of the original 1930's unit, and which was found to be undersized. Although the heater battery was cleaned externally to improve performance, and an unnecessary heating loop was bypassed to increase the water flow, the heater battery remained insufficient to provide adequate heating, particularly when operating under full air flow. A new heater battery and pump were subsequently installed. A minor problem was encountered with a broken damper actuator link at the club. This was discovered during an inspection and was probably due to mechanical weakening during manufacturing. It is unlikely to occur at other sites.

Mode of operation and effect on fuel savings and system design

During the monitoring period it became apparent that the fans at the cinema were not used as much as originally thought. The supply fan tended to be switched on sometime after the beginning of the first performance, and switched off sometime before the end of the last performance: the extract fan was hardly used. In retrospect this is not surprising considering that the fans are operated from manual switches fitted at opposite sides of the building and one of the switches is in a rarely used room.

This mode of fan operation reduced the performance of the system because the amount of fresh air supplied prior to conversion to variable ventilation was effectively reduced and because the system required both fans to be operated.

As a result of experience gained during the monitoring period, the system was re-wired so that it was only necessary to run the supply fan in order to operate the variable ventilation control system.

Frost protection

To reduce standing losses the temperature control system is wired so that when the extract fan is switched off the heater battery is by-passed. However this means that the heater battery is more exposed to frost damage even though the dampers are closed overnight to provide some protection. As a result of this situation, the battery at the club was frozen during a very cold period whilst operating without variable ventilation. At the cinema the heater battery is well protected by the building and, being at higher level, by some reverse air circulation. In view of the potential risks however, it is recommended that future installations are wired to protect the battery, even at the expense of a small increase in the standing heat losses.

Heating-up period

The heating-up period is increased due to the reduced air flows obtained with variable ventilation. The system at the club was modified during the second year to provide an early-morning boost mode to overcome this problem.

4. MONITORING PROGRAMME

Data monitoring

The data needed to calculate the energy savings was measured within the following main parameters:

- total fuel use;
- total heat provided by the heater battery;
- total electricity consumption of the fresh air fan;
- internal temperatures.

Additionally, gas and dust contents were measured during some site visits.

Fresh air supply and concentration of CO_2

The air flow and electricity consumption of the fresh air fan were regularly measured. The concentration of CO_2 and the position of the dampers were monitored for 26 days using a two-channel chart recorder connected to the control panel of the CO_2 controller (Hounslow).

These measurements were used to obtain total fresh air supply rates by calculating the total internal generation of CO_2 (based on the number of occupants and average metabolic rates). The infiltration rate was obtained by subtracting the fan contribution from the total fresh air supply rate.

Gas concentration and dust levels

The concentration of CO_2 and CO and $NO+NO_2$ were regularly measured.

Internal temperature

Hourly measured internal temperatures were used to compare conditions with and without variable ventilation, and to calculate actual degree days.

Method of data collection

Data was collected by:

- weekly forms containing meter readings, status of the CO_2 controller, occupancy levels and a qualitative assessment of comfort. The forms were completed weekly by the site engineer, the manager and the ticket office;

- temperature recorders installed in the premises to record hourly internal temperatures for up to six weeks. The data was transferred onto floppy disks prior to subsequent analysis;

- monthly weather reports from the nearest Meteorological Office station. Daily maximum and minimum temperatures were used to compute daily average temperatures and degree days;

- site visits, during which the concentration of gases were measured using Draeger tubes (CO, CO_2 and $NO+NO_2$) and dust levels using a Casella pump and filter. Other quantities measured during site visits were: air flows and electricity consumption of the fresh air fan (with shutters open and closed), water flow through the heater battery and various temperatures.

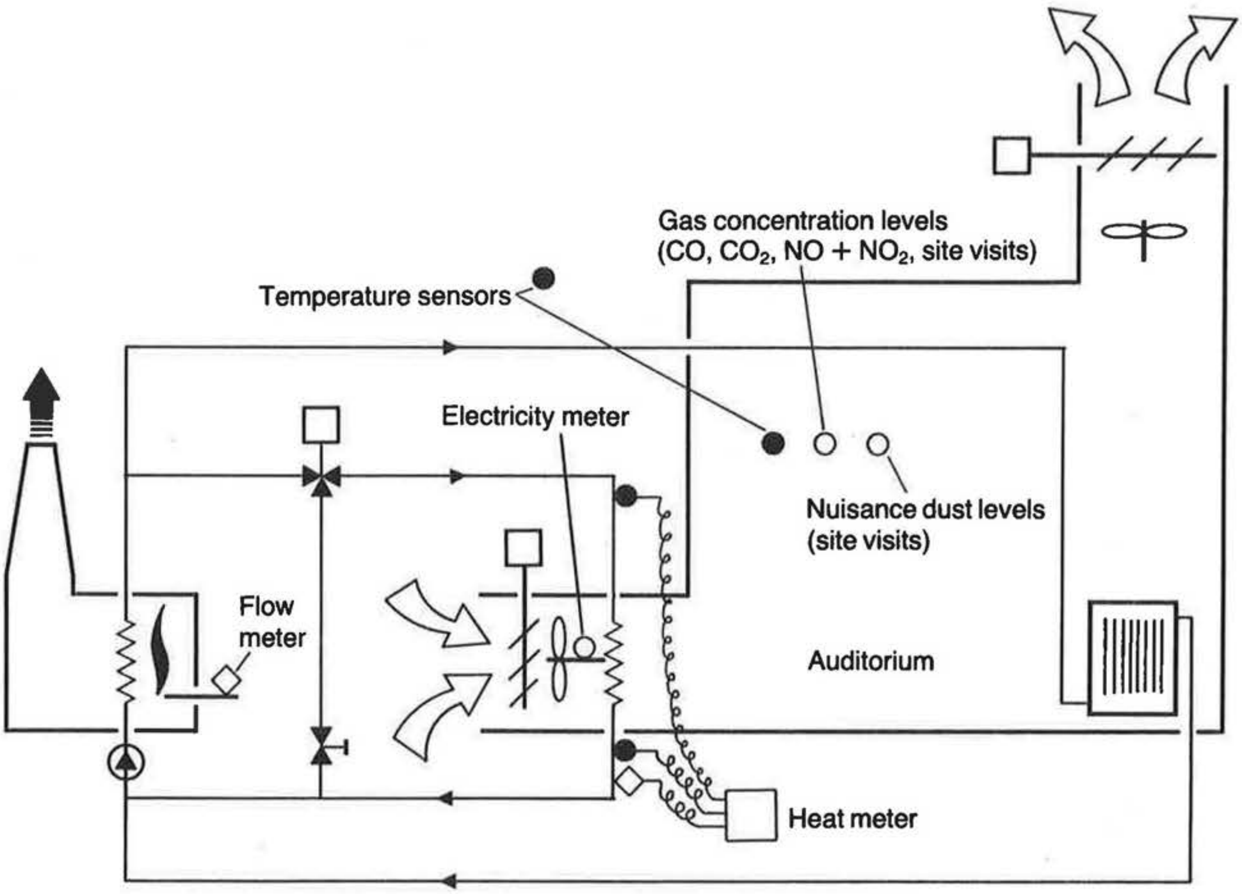

Fig 4 Schematic layout of data collection equipment

5. MEASURED RESULTS

The amount of fresh air supplied mechanically to the heated spaces is determined by the design and position of the dampers. At the club and cinema it was possible to reduce the air flow by up to 25% and 35% respectively (Table 2). The flow could not be reduced further, however, as this would have significantly reduced the heating capacity of the air heater battery.

Table 2 Measured mechanical fresh air supply rates

	Club	Cinema
Full fresh air (m^3/s):	5.02	9.38
Minimum fresh air (m^3/s):	3.77	6.08
Fresh air reduction (%):	25	35

In practice the average reduction in fresh air was smaller. With a CO_2 set point of 1,000 ppm (which corresponds to a fresh air supply rate of approximately 28 m^3/hour/person) fresh air ventilation increased when the audience exceeded approximately 485 at the club and 782 at the cinema until the dampers opened fully and the fresh air ventilation was at its maximum. With the occupancy rates recorded during the monitoring period, this meant that the club operated mostly at minimum ventilation except for peak evening and weekend game sessions. The cinema often operated at minimum ventilation.

Measurements of CO, CO_2, $NO+NO_2$ and nuisance dust never exceeded the recommended threshold limit values (Table 3), although during the monitoring period occupancy was low.

Table 3 Fresh air supply, gas and dust concentration table (club)

	No of people(a)			Limit(b)
	679	1,000	1,500	
Fresh air supply:				
fan (m^3/h)	18,072	18,072	18,072	-
infiltration (m^3/h)	4,428	9,600	9,600	-
total (m^3/h/person)	33.1	27.7	18.5	18/28.8
Gas consumption:				
Co_2 (ppm)	910	1,010	1,320	5,000
CO (ppm)	4.9	5.8	7.3	50
$NO+NO_2$ (ppm)	0.3	0.4	0.7	5
Nuisance dust (mg/m^3)	2.0	2.2	2.6	5

(a) 679, during measurements; 1,000 max recorded (approx) 1,500 nominal sitting capacity

(b) Ventilation: CIBS Guide A1, minimum/recommended gas and nuisance dust: threshold limit value

However, extrapolation from the measurements indicates that limits would not be exceeded even during the days of highest recorded occupancy, the maximum concentrations being determined by the size of the ventilation system. Nevertheless, during low occupancy there was a significant reduction in the fresh air supply, compared to the original full fresh air system, and a consequent increase in gas and dust levels. These increased concentrations did not appear to cause problems and there were no complaints reported from the occupants.

Table 4 shows the internal air temperatures achieved and indicates that the cinema was occasionally below comfort temperature. This was due to the under-capacity of the heater battery and was particularly significant when operating under full fresh air conditions, (as required during alternate weeks by the disablement monitoring).

Table 4 Summary of measured internal air temperatures

Temperatures (°C)	Club	Cinema (Odeon 1)
Night minimum temperature (Christmas closed period not included)	13.8	9.0
Typical minimum night temperature	14	10
Average recorded temperature	19.1	17.2
Typical maximum temperature	24	23
Maximum recorded temperature	26.9	24.8

Data period: club: 30 November 1984 - 7 March 1985
cinema: 23 November 1984 - 7 March 1985

At both the club and the cinema the temperatures fluctuated in accordance with the timing of the heating periods and with occupancy. As a result the temperature profiles show a daily and a weekly cycle: the air temperature varies daily by approximately 5°C to 7°C as a result of the heating cycle. The bias of attendances towards Fridays and Saturdays is shown by a gradual increase in average temperature towards the end of the week, followed by a reduction towards the beginning of the following week (Fig 5).

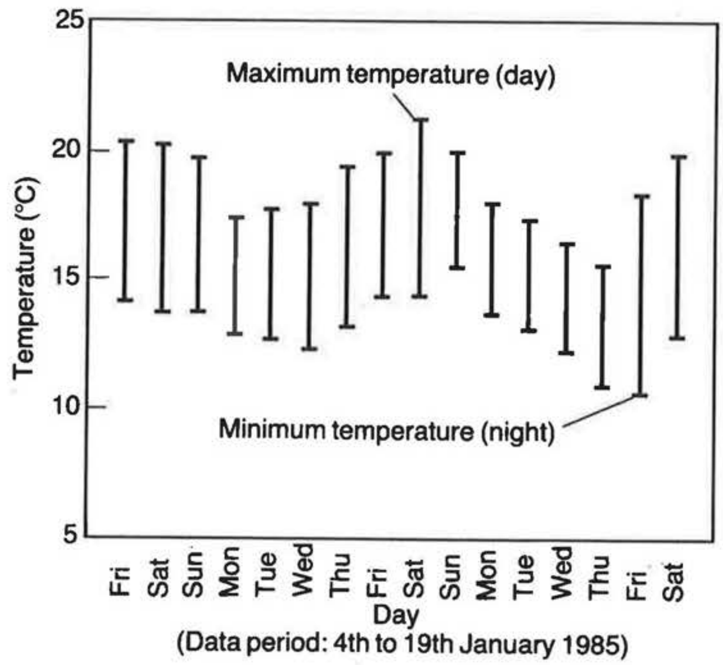

Fig 5 Daily maximum and minimum temperatures: cinema

Table 5 shows the performance of the heater batteries for the period November 1984 to May 1985. The figures show that at the cinema only approximately 17% of the gross calorific value of the fuel used was absorbed by the heater battery, compared with approximately 40% at the club. The figures show that this was because:

- the air supply fan was used for 40% fewer hours;
- the water flow through the heater battery was 70% lower at the cinema than at the club.

Table 5 Summary of main measurements

Variable	Club Manual (%)	Club Auto (%)	Club Total	Cinema Manual (%)	Cinema Auto (%)	Cinema Total
Fuel use (kWh input)						
Measured	37.0	63.0	607,018	57.2	42.8	489,654
*Long-term	-	-	966,063	-	-	617,828
Degree days (15.5°C base)						
Measured	34.6	65.4	1,553	55.3	44.7	2,081
Average long-term	-	-	2,137	-	-	2,527
Heater battery						
Output (kWh output)	37.7	62.3	241,240	49.1	50.9	91,820
% of auxiliary input	40.6	39.3	39.7	16.6	22.6	18.8
Water flow (m^3)	45.3	54.7	33,310	53.7	46.3	10,076
Inlet fan						
Electricity use (kWh)	42.3	57.7	4,980	58.2	41.8	2,860
Hours run	39.2	60.8	1,642	52.8	47.2	991
Data Period						
From	19 November 1984			2 November 1984		
To	30 May 1985			30 May 1984		

* Adjusted to long-term average degree days

6. ENERGY SAVINGS AND ECONOMIC ANALYSIS

Table 6 shows that during the period November 1984 to May 1985 the variable ventilation system saved 17.4% of the fuel costs at the club and 11.4% at the cinema. After making allowance for annual maintenance costs these fuel savings give simple payback periods of 2.4 years at the club and 4.8 years at the cinema. (3.6 years payback for the project as a whole). If the error margins in the calculated savings are taken into account, the range of payback periods is 1.8 to 3.0 years at the club and 3.3 to 6.3 years at the cinema.

NB: Total installed costs can vary significantly with the type of application.

Table 6 Annual fuel savings and cost effectiveness

	Club	Cinema
Calculated fuel savings (%)	17.4	11.4
Long-term average reference load (kWh input/year)	966,063	617,828
Long-term average fuel savings (kWh input/year)	168,095	70,432
Fuel price (p/kWh)	1.26 (gas)	2.12 (oil)
Long-term average fuel cost savings (£/year)	2,118	1,493
System costs		
Initial cost (£)	4,734.00	6,073.00
Maintenance (£/year)	171.80	231.00
Simple payback period (years)	2.4	4.8
Net present value (Over 10-year period)	£13,876	£ 5,930

Energy savings calculated using linear regression analysis techniques.

Fuel prices excluding boiler losses: Gas = 37 p/therm (1984/85);
Oil = 21 p/litre (1984/85 av)

Net present value: Actual prices used for November 1983 to May 1985

Assumptions for future: Interest rate 4%; Fuel inflation rate 2%. (These figures are expressed in real terms and include an allowance for an annual inflation rate of 5%)

The initial predictions by ITL and Rank were 25% fuel savings and associated payback periods of 1.4 and 2.0 years respectively. The longer payback periods are due to the following factors:

- the total system costs include the temperature control equipment but savings relate only to the effect of the variable ventilation control system;

- undersized heater battery (cinema only): during very cold weather the net effect of variable ventilation was to increase internal temperatures in the cinema rather than to save fuel. It is estimated that without this improvement in comfort conditions the annual fuel savings would have increased to 15.7% and the payback period reduced to 3.3 years;

- poor temperature control (cinema only): poor temperature control resulted in an increase in air flow temperatures and a reduction of fuel savings;

- larger than expected installation costs (both sites): the initial predicted costs were exceeded by 2.8% at the club and by 4.3% at the cinema.

Calculations for payback periods ignore the net financial gains that continue throughout the lifetime of the equipment, after the investment has been paid. Table 6 shows that in the first ten years of operation the installations at the club and cinema will provide a net financial gain (net present value) of £19,800. These figures are derived from actual costs for the monitoring period and assume interest and fuel inflation rates of respectively 4% and 2% in real terms for the rest of the 10 year period.

During the second year of monitoring (1984/1985) there were no significant detectable variations in temperature caused by the systematic changes between variable fresh air and full ventilation modes required for monitoring purposes. A systematic increase in internal temperatures, due to poor temperature control under reduced ventilation, would have reduced fuel savings.

7. DISCUSSION

The three main criteria for the cost-effectiveness of variable ventilation are that:

- mechanical fresh air ventilation represents a significant space heating demand for the building;
- the occupancy of the building is variable;
- there is adequate temperature control.

The fuel savings measured at the club were 17.4%. This is a realistic savings target for potential replicators and, if the criteria for cost-effectiveness are satisfied (Appendix 1), similar or greater savings could reasonably be expected, particularly if there is better temperature control.

In installations where the internal temperature is not controlled automatically to set comfort levels, it may be cost-effective to install a controller, as even relatively small increases in internal temperature above the set levels increase the heating load significantly. Temperature control can be achieved by varying the water flow rate or temperature of the heat emitters, as a function of indoor and/or outdoor temperature, using:

- thermostatic radiator valves;
- thermostatically controlled three-way valves, which can be either mixing or diverting (in flow or in return).

Costs (Based on 1985 prices)

The current cost of the CO_2 sensor and controller is £1,200. However a new unit currently being developed is likely to cost approximately £500-£600. Another manufacturer is also offering equipment based on the same operating principle for £625. Such reductions in capital costs will clearly result in shortened payback periods.

The demonstration projects included an extra £3,530-£4,870 for the supply and installation of a temperature controller and dampers to achieve the variable ventilation. Installed costs could be under £1,000 in new installations or in retrofit applications with existing recirculation and temperature control. However, savings achieved in such circumstances may be relatively smaller because ventilation losses are likely to be less.

In retrofit applications where no temperature and air flow control system exists, the installed costs are likely to be in the region of £4,000-£5,000. Savings are likely to be significant however and there are few other options available to reduce ventilation heat losses.

The decision flow diagram (Fig 6) summarises the main criteria for likely cost-effectiveness. The diagram also helps to identify potential sources of difficulties such as air quality or temperature control and other factors that may affect cost-effectiveness.

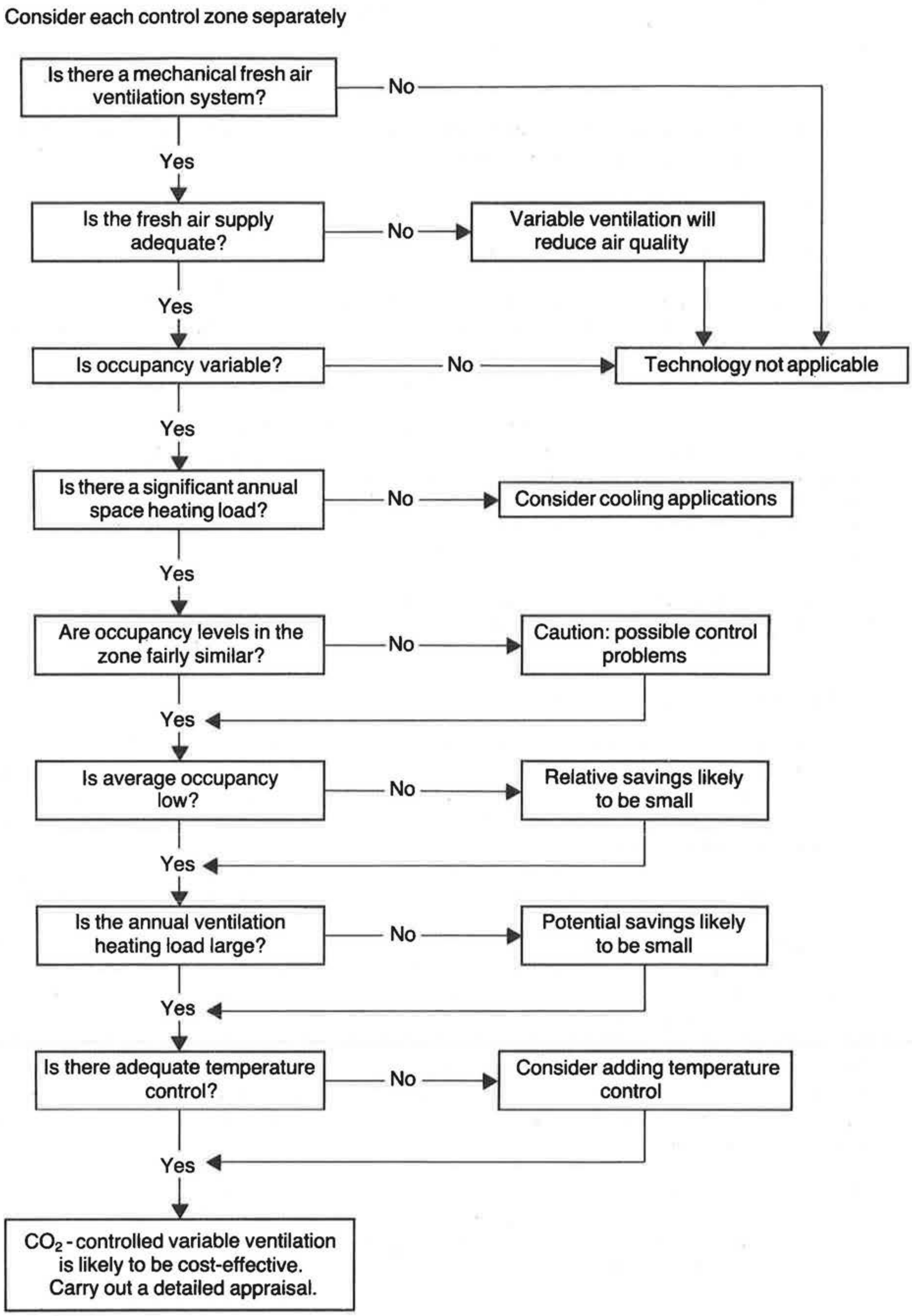

Fig 6 Decision diagram for suitability of CO_2 controlled variable ventilation

The following points are of particular importance to those considering the installation of similar ventilation control systems:

- the CO_2 controller and display unit tested is a high precision sensor. The unit incorporates a sampling (suction) pump and filters which require maintenance and eventual replacement; the proportional operation of the dampers appear to have little advantage over a simpler (and perhaps cheaper) on/off control in this type of application;

- the unit tested incorporates an integral alarm which is triggered by excessive CO_2 levels. However, if units are mounted in rarely frequented locations (as was the case at both demonstration sites) the alarm is unlikely to be noticed. It is therefore recommended that a separate alarm is fitted in such a position that it will be readily noticed if it is triggered;

- the unit tested did not incorporate an override facility. Because of this it was not possible to quickly revert to full ventilation in the event of, for instance, unusually high summer temperatures. It is therefore recommended that an override facility is fitted in a suitably accessible location;

- the controller is only sensitive to the CO_2 level. This is a good indicator of the number of occupants. However, tobacco smoke in the auditoria will vary according to the proportion of smokers and non-smokers. Where this proportion is likely to vary significantly, the set point in the CO_2 controller may have to be adjusted to a lower value;

- if a single controller adjusts the ventilation rate to a number of separate spaces, it would be possible for one space to reach high CO_2 concentrations before the average concentration detected by the sensor was sufficient to increase ventilation. Should this be the case the set point on the CO_2 controller would need to be adjusted to a lower value;

- in variable ventilation systems the supply fan must be operated continuously whenever the building is occupied. If previous practice has been to operate the extract fan only when conditions warrant, ie when occupancy is high, the advantages of a variable ventilation systems will be reduced;

- in full fresh air systems, the reduced ventilation rates achieved under ventilation control increases the heating-up period and therefore decreases potential fuel savings. The installation at the cinema was modified to provide a boost period, but this increased the capital costs;

- in a full fresh air ventilation system, fresh air is circulated only once through the heater battery and building before being extracted. Variations in air flow are therefore only possible by reducing the total volume of air handled by the fans;

- in a recirculatory ventilation system, extracted air is recycled and mixed with the fresh air supply in proportions which vary according to the amount of fresh air required. The distribution and mixing of air in the building spaces and the air heating capacity of the ventilation system remain unaffected by the variations in the fresh air supply;

- dampers are usually the cheapest means of modulating air flow in a ventilation system. They do not significantly reduce the load on the fans but, compared with other methods, they reduce infiltration losses at night;

- variable inlet vanes reduce the load on fans, but do not close at night and are usually more expensive than dampers;

- variable fan speed systems can be achieved by using either eddy current coupling or inverter control. Such systems, although being energy efficient, require expensive controls. However, if existing fan motors are to be replaced anyway, for instance as part of an overall refurbishment scheme, the reduced installation costs may substantially off-set the extra cost of the control system.

Building regulations

Current ventilation practice for places of public entertainment is based on a fresh air requirement of approximately 28 m^3/hour/person. This can be achieved in CO_2-controlled variable ventilation systems by a control setting of approximately 1,000 ppm.

Details of all conversions of existing installations (and new installations) have to be submitted to the relevant authorities for approval.

For this project all the appropriate authorities were contacted prior to the conversions. These included local representatives from Licensing, Health and Safety, Fire, and Architects Departments: no objections were raised.

8. CONCLUSIONS

This demonstration has shown that CO_2-controlled variable ventilation is a cost-effective investment which can save a significant amount of heating fuel. The measured annual fuel savings were £2,118 at the club and £1,493 at the cinema. At current fuel prices and after making allowance for annual maintenance costs, the associated payback periods are 2.4 and 4.8 years respectively. The net present value of the project is estimated as being £19,800 over a ten year period.

The equipment was installed in one month, with only minor difficulties and disturbance, at a total cost of £4,734 for the club and £6,073 for the cinema. Of this total, the cost of the CO_2 controller accounts for approximately £1,200 and the remainder is the temperature control equipment installation cost. Future installations may be cheaper.

The main conclusions which can be drawn from this demonstration are:

- the CO_2 variable ventilation controller was reliable and worked as expected, but needed minor annual servicing;
- temperature control was unaffected by the CO_2 controller and was adequate at the club although it was never totally satisfactory at the cinema. This was due to the combined effects of:
  - o the monitoring technique, which required weekly changes between full ventilation and controlled ventilation;
  - o insufficient time allowance for the commissioning of the equipment, which was due in part to the late start of the project, ie at the start of the heating season;
  - o an undersized heater battery (cinema only);
  - o an uncontrolled radiator circuit;
- fresh air ventilation control was acceptable in both the club and cinema. The minimum statutory air quality standards were maintained throughout the demonstration and there were no complaints from people using the buildings. However, because the fresh air supply is also used for space heating, the maximum potential fuel savings were not achieved because:
  - o the minimum air flow rate could not be reduced below approximately 35% of full flow. This was necessary to maintain acceptable inlet fan pressures and to provide adequate warm air distribution;
  - o the heating-up period was increased at low ventilation rates;

- minor changes were required to the control wiring because:
  - o initially the variable ventilation system at the cinema could not operate without running the extract fan. During monitoring it was found that the extract fan was rarely used and conseqently the wiring between the controllers was changed to allow independent operation of the CO_2 controller.

APPENDIX 1

TYPICAL METHOD OF CALCULATING THE POTENTIAL ANNUAL FUEL COST SAVINGS RESULTING FROM THE IMPLEMENTATION OF A CO_2 CONTROLLED VARIABLE FRESH AIR VENTILATION SYSTEM

Fabric losses (sum (U-value x areas)): ..... W/°C (1)

Fresh air ventilation
mechanical ventilation (fan duty): ..... m^3/hr (2')
infiltration: air changes x building volume: ... ach x ...m^3 (2")

total (mechanical + infiltration): ..... m^3/hr (2)

Ventilation losses:
Mechanical ventilation 0.33 x ...(2') = ... W/°C (3')
total (mech + inf): 0.33 x ....(2) = ... W/°C (3)

Percentage mechanical ventilation losses:
100 x .....(3') (.....(3)+ .....(1)) = ... % (4)

Space heating costs (fuel bills): ..... £/year) (5)

Mechanical ventilation costs:
0.01 x .....(4) x .....(5) = ... £/year (6)

Maximum design occupancy capacity ..... no of people (7)

Average actual occupancy: ..... no of people (8)

Percentage average occupancy:
100 x ..... (8) ..... (7) = ... % (9)

Adequacy of fresh air ventilations systems:
Design: .....(2) ..... (7) = ... m^3/hr/person (10)
Average:.....(2) ..... (8) = ... m^3/hr/person (11)

IF (10) is greater than 28 - **Continue**
IF (10) is less than 28 - **Plant undersized, continue with caution**
IF (11) is less than 28 - **Plant too small NOT SUITABLE**

Initial estimate of annual heating savings:
(100 - ..... (9)) x ..... (6) 100 = ... £/year (12)

Initial estimate of installed costs:
CO_2 control: £600 - £1,300: .....

(Cost additional items only if required):
Temperature control: £400 - £600: .....
Variable ventilation system £1,000 - £2,000: .....

TOTAL BUDGET COST: ..... (13)

Conclusions: preliminary estimate of likely payback period

IF ...... (12) greater than 0.5 x ..... (13): **less than 2 years**
IF 0.25 x.... (13) less than .... (12)
and less than 0.5 x .... (13): **2 to 4 years**
IF ..... (12) less than 0.25 x .... (13): **greater than 4 years**