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PAPER 10

DEVELOPMENT OF OCCUPANCY-RELATED VENTILATION CONTROL FOR BRUNEL UNIVERSITY LIBRARY

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SYNOPSIS

A microprocessor system is being developed for occupancy related ventilation control of mechanical ventilation in Brunel University Library. The objective is to reduce space-heating costs by decreasing the input of (cold) fresh-air to the building below existing (heating-season) levels, when the number of occupants in the building is sufficiently small to allow this. The occupancy levels can be measured in terms of CO_2 level in the exhaust duct.

The microprocessor control system is operational when linked to a CO_2 monitor. The control system senses the CO_2 level and the computer sends an appropriate signal to reset the fresh air, exhaust and recirculation dampers, to maintain a preset CO_2 level.

A previous study has indicated fuel cost savings of about £1500 per annum.

1. INTRODUCTION: THE PROBLEM

Previous studies (Windsor[1] and Buchanan[2]) led to the concept of ventilation control related to occupancy of the library at Brunel University. The objective is to reduce space-heating costs by decreasing the input of (cold) fresh-air to the building below existing (heating season) levels when the number of occupants in the building is sufficiently small to allow this. The library is a 4 storey building with a total floor area of approximately 6,400 m^2. It has a mechanical ventilation system which, during the heating season, ejects warm air to the atmosphere at the equivalent of about 16 kW per ^oC temperature difference between the interior and exterior of the building.

Buchanan's study[2] of heat recovery systems indicated that improved ventilation control was likely to have a shorter pay-back time (6.3 years) than various 'run-around coils' (6.6 to 8.9 years) designed to recover heat from exhaust air. It compared even more favourably with cavity wall insulation (14.7 years pay-back time) installed where possible. Present worth and internal rate of return analyses yielded similar comparisons. Actual fuel cost savings were estimated at about £1,500 per annum for the occupancy related control system. Other studies by Ogasawara et al[3] and Warren[4] have also given estimates of substantial fuel savings which should be possible (e.g. in departmental stores) by using similar systems.) The system under development has been designed to be flexible e.g. with more computer memory and input/output channels than required for ventilation control as such. The authors are aware of commercial systems based on the detection of CO_2 or O_2 levels which are already available.

2. EXISTING HEATING SYSTEM AND CONTROL IN BRUNEL UNIVERSITY LIBRARY

The overall Brunel heating system is of the district heating type with a centralised boiler and heat distribution to buildings via high pressure hot water mains (at $\sim 160^\circ C$, 10 bar pressure). Heat exchangers transfer heat to 'low pressure' heating systems in buildings. Warm air is the main heat distribution medium in the library building. There are fans ($\sim$ 3kW rating) to drive the fresh air and exhaust air-streams with provision for recirculation of air extracted from the library. (The fresh-air rate and percentage recirculation being set by the intake, exhaust and recirculation dampers indicated on Fig. 1). Typical operating conditions in the spring are 17 $m^3 s^{-1}$ of fresh air and 8 $m^3 s^{-1}$ of recirculated air with an exhaust rate of 16 $m^3 s^{-1}$. The exhaust rate is slightly lower than the intake rate to maintain a small positive pressure in the library and so to minimise air infiltration through doors and windows. There are two heater batteries in the fresh air stream. The hot water supply rate to the heater batteries is modulated to achieve the desired set temperature of air input to the library. The above system is duplicated in East and West plant rooms located on the library roof. (There are also some additional 'booster' heater batteries located at various points in library duct work to the ceiling warm-air diffusers.) The existing (Honeywell) control system works in two regimes, i.e.'heating season' and 'non-heating season'. The proposed modifications will only be effective during the heating season. During this time the system is at present run on what is termed 'minimum fresh-air'. This corresponds to fixed damper settings giving a fixed proportion of recirculated air.

Excessive fresh air input rates to the library can occur with the dampers fixed, e.g. taking a rate of 17 $m^3 s^{-1}$ of fresh air to the library with say 300 people in the library yields an average rate of 57 ls^{-1} (per person) which is 7 times the rate recommended by CIBS[5] for open-plan offices. There is therefore scope for reducing the fresh-air input and exhaust rate of warm air to the atmosphere. Conversely surveys have shown that some users complain of 'stuffiness' in reading areas in the afternoon.

3. SYSTEM UNDER DEVELOPMENT FOR OCCUPANCY RELATED VENTILATION CONTROL

3.1 General Considerations

The original proposal was to use turnstile counters (in and out) to provide a measure of the number of occupants in the library. Turn stiles are already installed with a counter on the exit only. However, this system has now been rejected in favour of using CO_2 level in the exhaust duct to provide a signal related to library occupancy. (This is based on an average CO_2 exhalation rate per person of about $4.7 \times 10^{-6} m^3 s^{-1}$.) Reasons for choosing this system are:

(a) more compact equipment - though the cost of CO_2 monitor (at least £1,000) is an additional cost balancing reduced wiring costs;

(b) wider applicability for retrofit to existing buildings which in general do not have turnstiles.

There are no standards for CO_2 levels in UK buildings and CIBS[5] indicates 0.5% as acceptable. However, some continental countries specify 0.1% by volume as an upper limit. (Ventilation rates to remove body odours are in any case often higher than those required to provide acceptable CO_2 levels).

3.2 Ventilation Control System

A schematic diagram of the control system under development is shown in Fig. 1. A Horiba CO_2 analyser is connected to the library exhaust duct air via a plastic tube. The analog signal from the CO_2 analyser is connected to the controller/logger equipment (see appendix for details) which registers the CO_2 level and gives a print out of this together with the time. A servo motor adjusts a potentiometer connected to the Honeywell control system to give the necessary setting of damper angle.

Software has been written such that the fresh-air intake (FAI) and exhaust dampers are nominally fully closed if the CO_2 concentration in the exhaust air is less than 500ppm. (In practice there would still be sufficient air flow for sampling purposes). The recirculation dampers would be fully open in this mode. The FAI dampers are effectively fully opened if the CO_2 concentration rises to 1000ppm. A linear relation between damper angle and CO_2 concentration is assumed.

4. MEASUREMENT OF CO_2 CONCENTRATIONS IN EXHAUST AIR

CO_2 concentrations in the library exhaust duct have been monitored by Hunt[6] on a number of days (as shown in table 1). On February 7th 1983 the recorded peak CO_2 concentration was 600ppm. This is relatively low compared with an acceptable value of 1000 ppm even though recorded at a time when the use of the library is usually fairly intensive. On April 26th (when only final year and postgraduate students are on the campus) CO_2 concentrations are even lower. The occupancy numbers generally show reasonable correlation with the CO_2 concentrations. Assuming a fresh air input rate of $17m^3/s$ the CO_2 concentrations are consistent with a CO_2 exhalation rate per person of about $6 \times 10^{-6} m^3/s$ per person.

Table 1 Library CO_2 Concentrations

Time	7 February	26 April	
	CO_2	CO_2	Occupancy
Hours	ppm	ppm	
09.00	420	300	35
10.00	430	315	82
11.00	490	320	92
12.00	520	335	122
13.00	580	325	98
14.00	600	320	110
15.00	510	315	108
16.00	480	315	94

5. SYSTEM TESTS

In a qualitative sense it has been shown that increase of CO_2 level in the exhaust duct will lead to increased opening of the fresh air dampers in the library building. However long term tests have not yet been made. The existing dampers and damper motors together with mechanical linkages are more suited to occasional manual readjustment rather than continuous modulation. These need upgrading before long term tests can be made in this particular building.

6. CONCLUSIONS

Observations suggest that the Brunel library is overventilated as the CO_2 levels which exist in the exhaust air are well below 1000ppm. However the problem of underventilation of certain areas reported by some users suggests that CO_2 analysers should be installed on every floor of the library.

The logger controller could then be programmed to respond to the maximum CO_2 level. An alternative transducer would be air quality monitors based on O_2 content of the air which are cheaper than CO_2 analysers and can also detect smoke.

It would also be desirable to monitor energy savings by heat metering of the hot water supply of the fresh-air heater battery. This could either be done by a separate heat meter or by using spare capacity of the controller logger together with suitable transducers. It is known that a number of installations of commercial equipment have led to substantial savings[7].

APPENDIX

VENTILATION LOGGER CONTROLLER

The ventilation controller is constructed in a box with commercially available microprocessor and analog input cards, plus memory and clock cards. The controller is thus versatile and can be readily re-programmed during development. It can indeed be used for other applications. The programs were developed using Motorola's version of Basic. This is particularly suited to hardware control applications, and allows future development by workers who could not be expected to work with low-level assembler programs.

Fig. A1 shows the components of the controller. The blocks make up a powerful general purpose computer with analog input and provision for an analog output card to be included. CO_2 levels are read in at pre-defined intervals, typically 10 minutes, and used to update the potentiometer position to set the dampers. This is achieved with timer chip programmed to provide variable length pulses to a rotating servo unit. A pulse of 0.8m sec sets the servo to fully anti-clockwise. A pulse of 1.4m sec rotates it clockwise to 90^{o}. The pulse length depends on the CO_2 reading. The servo is mechanically linked to the shaft of the potentiometer in the damper drive circuit.

The CO_2 level is logged using a printer which can be switched off. Alternatively, the printed message may be transmitted to a remote computer for further analysis and recording on disc.

The clock is used to initiate the CO_2 read operations, and is used also to print the date and time alongside CO_2 values. It can also be used to initiate different control regimes at different times of the day or year.

The control program is outlined in Fig. A2. Each block in the flow chart represents a call to an appropriate sub-routine. The program was developed in modular form both for clarity and to allow ease of future development.

Development of a specialised compact controller is possible by replacing the program and its sub-routines with equivalent assembler-code routines. The structure of the software remains the same but uses much less memory. A single chip microcomputer would thus support input/output channels using a single card, possibly installed in the CO_2 analyser box itself.

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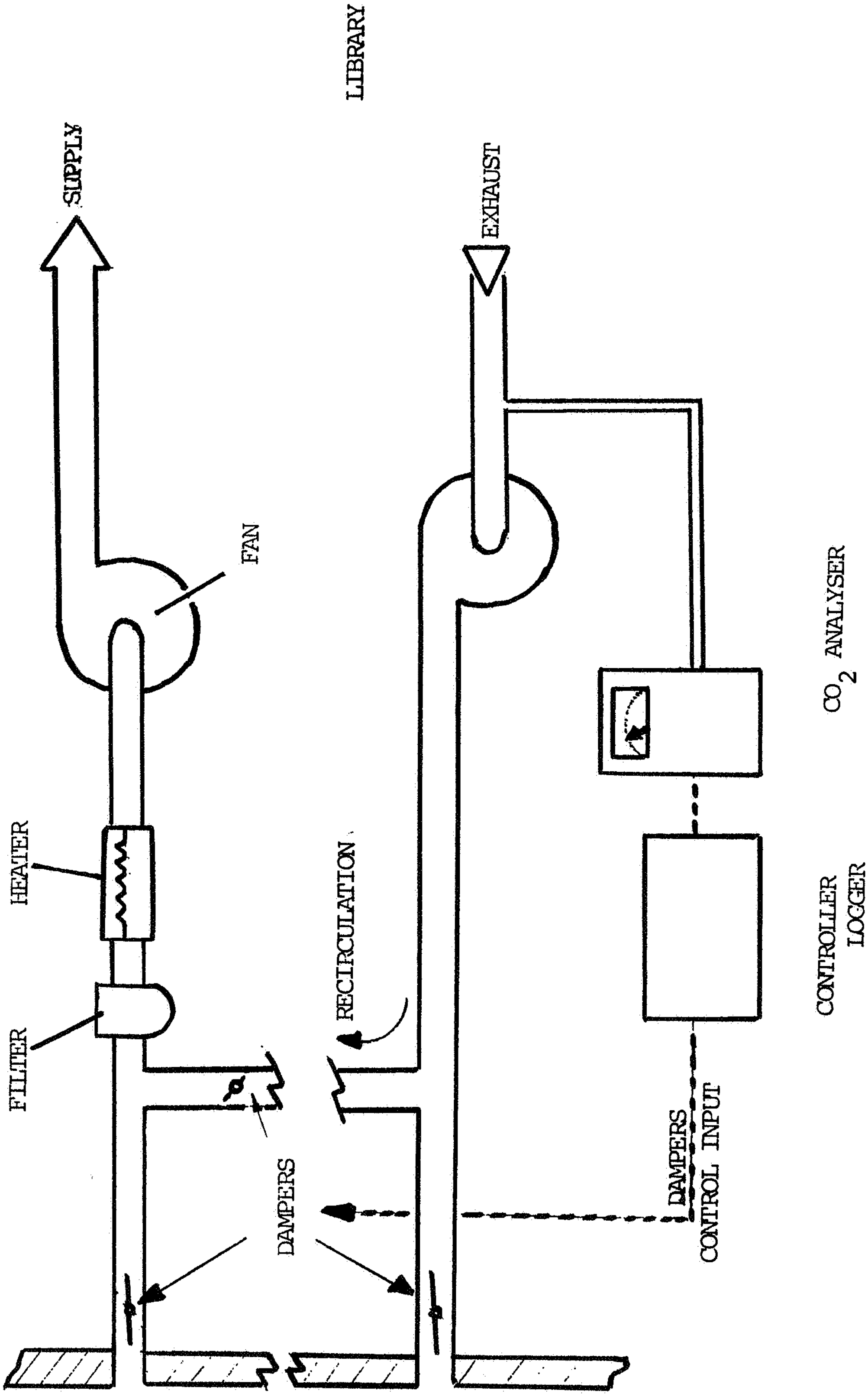

FIG 1 Ventilation control system

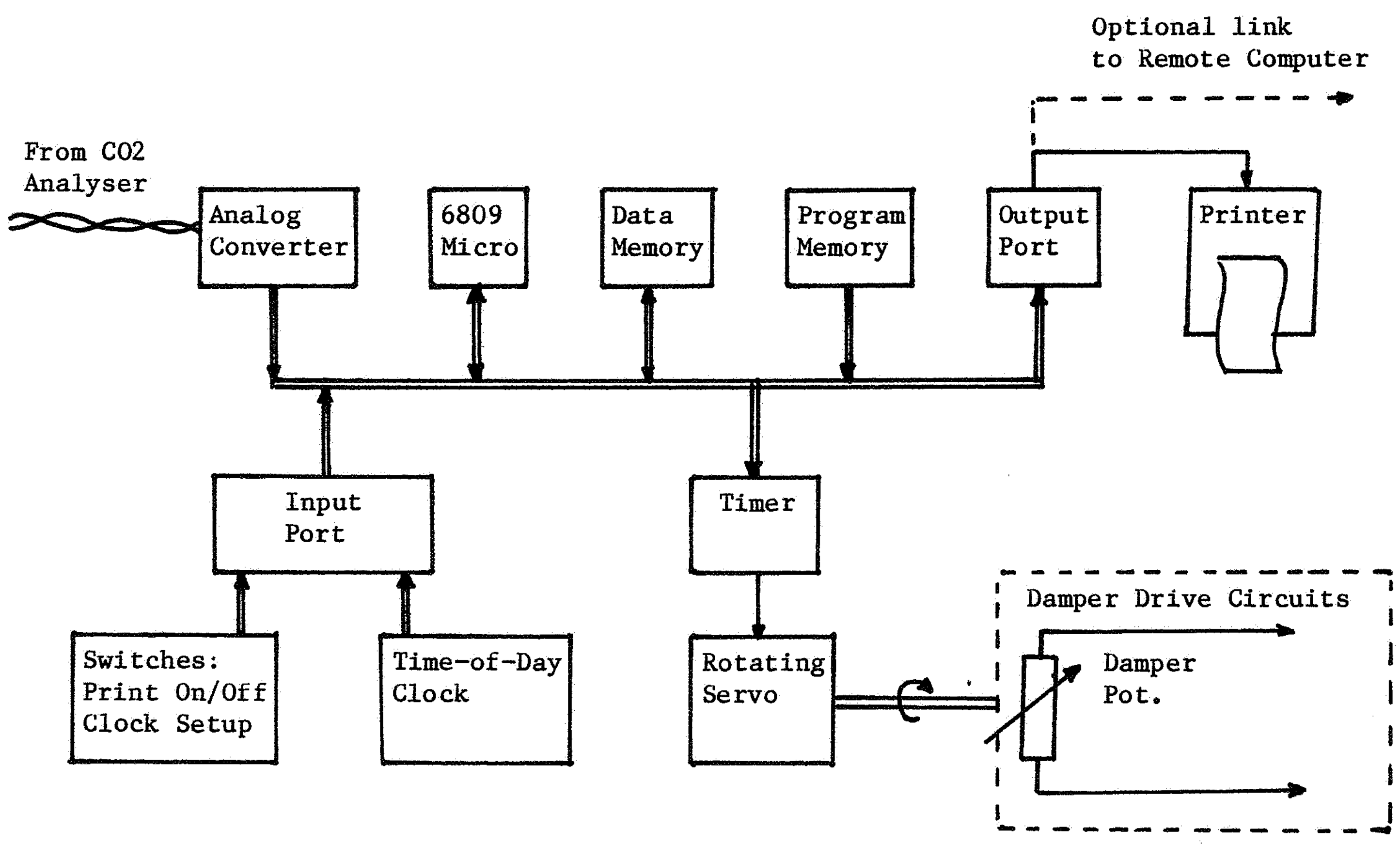

Fig A1: Ventilation Controller Hardware

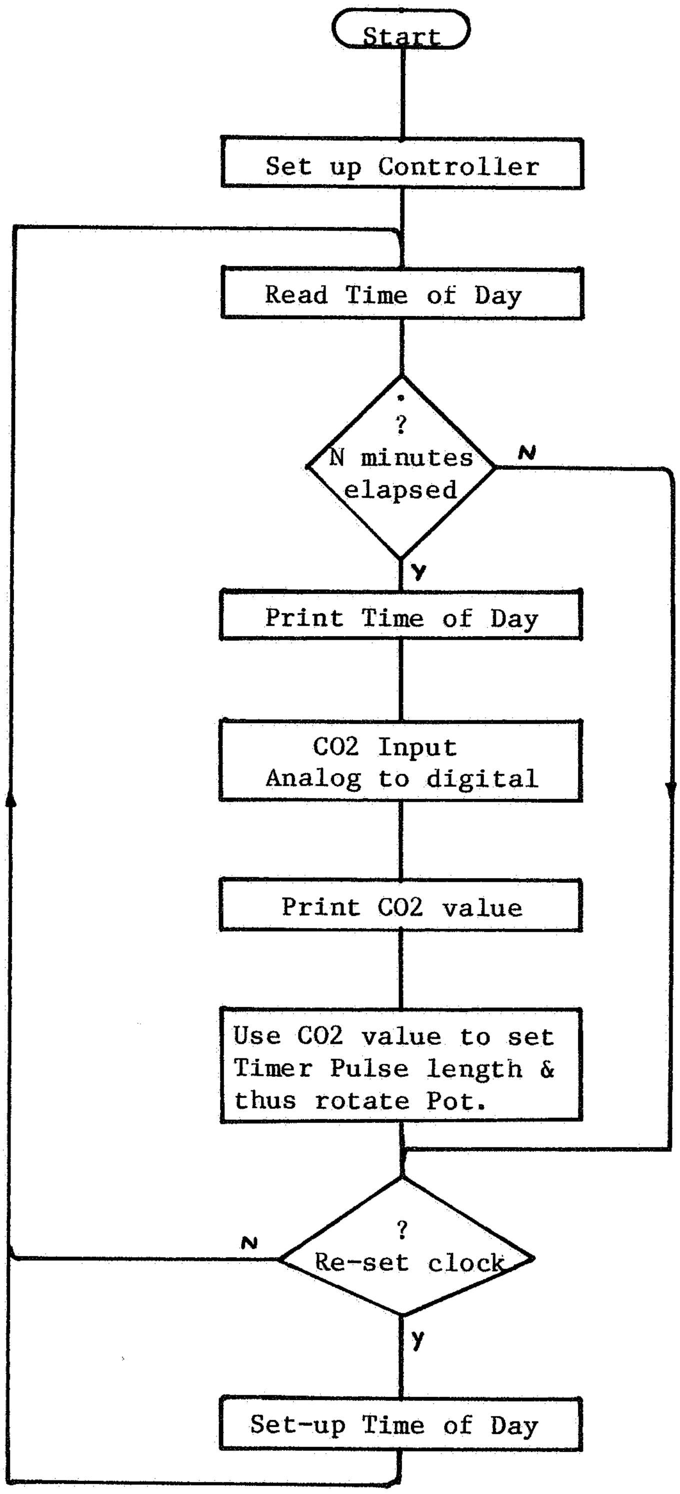

Fig A2. Outline Flowchart