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A Low Cost Technique for the Measurement of High Ventilation Rates

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Synopsis
A recent investigation into the thermal environment of tropical housing required a low cost method for the measurement of high ventilation rates. As a result a simple measurement system, using the detection of the decay of smoke density, was developed. The sensor, based on an infrared LED emitter and a silicon diode receiver, was easily portable, highly robust and could be constructed for less than £50. It was found to be suitable for the measurement of decay rates in excess of 20 air changes per hour. The visible smoke tracer required for the system was easily generated by a number of methods, including smouldering coir matting, smoke bombs and theatrical smoke generators.

1 Introduction
In support of a recent investigation into the thermal comfort of tropical housing [1], the need arose to measure the ventilation rates occurring in those buildings. In tropical climates the building envelope can be highly porous, and the large leakage areas have the potential to produce very high ventilation rates under windy conditions. Thermal modelling of the conditions in these types of houses indicated that comfort conditions could change significantly between different assumed ventilation rates, even at the levels of 50 - 100 air changes per hour [2].

Little information was found to be available as to the actual ventilation rates to be encountered in such dwellings; few field trials had been made where ventilation was a measured parameter. Within the scope of a doctoral investigation is was decided to attempt to measure the ventilation rates of such dwellings, to determine if the large rates assumed in the thermal modelling actually occurred in practice.

2 Traditional Methods
In developing the methodology for these measurements, it was considered that tracer decay techniques were the most appropriate. However there appeared to be three key drawbacks in the equipment then available, which were based on the measurement of the commonly used tracer gases N_20, SF_6, and CO_2;

- the ventilation rates were expected to be high, for instance >20 ac/h. It was considered that the lower cost gas analysers had long time constants, and that this could affect their ability to accurately measure large ventilation rates.
- gas analysis equipment with low time constants were too costly for the funding available. There were none available to commit to a long term project abroad, it was not feasible to transport regularly from the U.K. to S.E. Asia, and it was not within the project budget to purchase new equipment at that scale.
- the reliable and regular supply of tracer gas in large amounts to remote rural locations would be difficult or impossible to achieve.

3 The effect of instrument time constant
The time constant of a gas analyser can theoretically have a significant effect on the accuracy of the estimation of high ventilation rates. This instrument time constant will depend largely on the flow rate and purging effectiveness through the detecting equipment. In Infrared Gas Analysers (IRGAs) this time constant can be short (on the order of seconds) but is apparently inversely proportional to the equipment cost. High quality fast IRGAs may cost in excess of £10000, while simpler lower cost instruments in the range of £1000 can have response time in

the order of 10's of seconds. Gas chromatography equipment have significantly longer response times than that.

Figure 1 shows the calculated effect of instrument time constant on the estimate of ventilation rates by measured tracer decay. Imposed "true" ventilation rates of 50 and 100 air changes per hour were used. It can be seen that significant errors may be made for time constants >30 sec for the very high rates assumed. Note that 100 ac/h in a dwelling room may seem extraordinary but equates to a mean air flow across a typical room of only 0.3 m/s or less. High air velocities in rooms or tropical housing are in fact desirable for achieving comfort conditions, and recent field measurements by Rahman [3] have confirmed that air movements of this order are common.

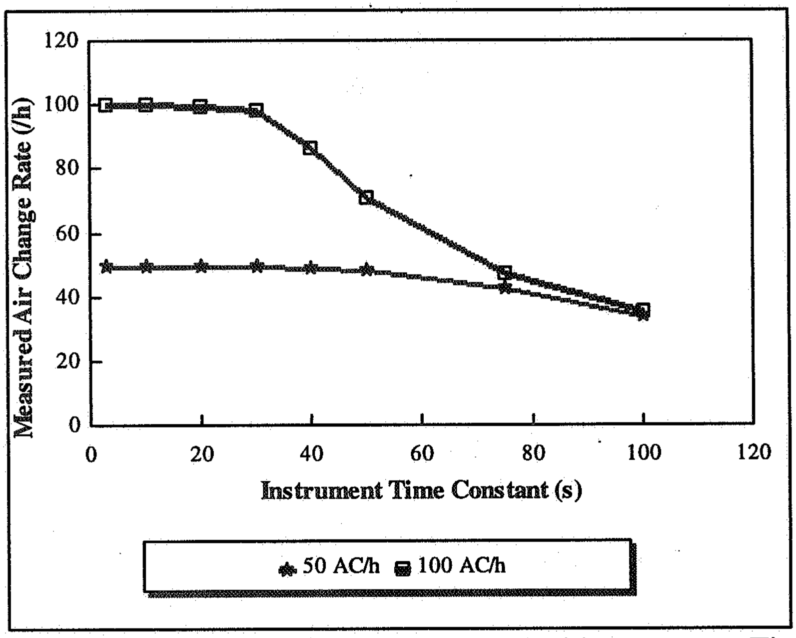

Figure 1 Theoretical Measurement Errors Associated with Instrument Time Constants

3 The smoke detector

To circumvent the cost and time constant restrictions discussed above, an alternative instrument or technique was sought. Etheridge and Nolan [4] described the measurement of ventilation in wind tunnel models using smoke as a tracer substance and an optical detector. We considered that this approach was appropriate to adapt for use in full scale buildings, as it was potentially fast, cheap, portable and robust.

The decay of smoke, as long as the condensation of the smoke matter was not significant, should be commensurate with the decay of a tracer gas, and so could be used to estimate ventilation rates. Since large ventilation rates were expected in our applications, condensation was not felt to be a problem. Smoke of various forms have been used widely in building science to visualise air movement, detecting leaks, and as a qualitative indication of ventilation. We are not aware of previous use in a quantitative measure of ventilation in full scale buildings.

The instrument described by Etheridge and Nolan is based on the optical detection of smoke in air, using an infrared LED emitter and silicon diode detector pair. The detection of smoke is by optical scattering caused by the particles present in the smoke. In a properly aligned system, figure 2, the detector will be illuminated only by the light scatter off the smoke. Etheridge and Nolan determined that the response of such a system was linear to smoke concentration. Since ventilation measurement by tracer decay relies on the differences in concentration over time, linearity of the measurement system is a crucial requirement. Fortunately for a low cost system, the ability to produce an absolute calibration is not a requirement for the analysis of the decay data.

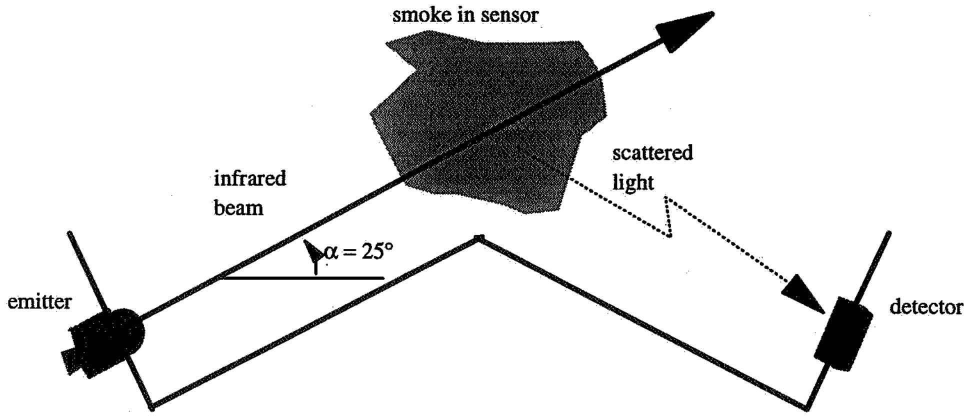

Figure 2 Optical Smoke Sensor Geometry

The sensor head produced by us is shown in figure 3. The emitter/detector pair are enclosed in a small opaque box, through which room air is drawn by a small fan. The box is highly baffled to exclude light, and its interior is painted matt black. Using the parts listed in table 1, the instrument costs less than £50 in 1995, and produces a signal of between 5 and 75 mV dc output according to the density and type of smoke to which it is subjected. The higher output quoted corresponds to a distinct, but not unacceptable (for short periods) haze in room air, equivalent to a visibility of approximately 50m. The dark signal of 5 mV has been found to be stable over long periods and changing light conditions. The response time of the sensor is virtually instantaneous (τ <1 s).

Component	Description	R.S. number	Approximate Cost , £
LED emitter	High power Infrared, Narrow Beam	195-344	1
Detector	5mm^2 silicon diode with integral amplifier.	308-067	16
Fan	miniature 5 V.dc fan, 40x40x12 mm	498-126	20
Case	ABS box, 150x80x50mm	508-936	2
Miscellaneous	Brackets, paint etc.		5

Table 1 Components of Sensor Head

The voltage signal produced by the sensor head is intended to be recorded by a portable data logger or chart recorder. We have used logging equipment produced by Grant and by Campbell. These data recorders are not inexpensive (in the region £500-£1000) but are general purpose and multi-channel. Simpler single input data recorders are now readily available in the region of £100 each. The entire system, sensor and recorder, could potentially be powered by rechargeable battery, making it suited for use in remote areas.

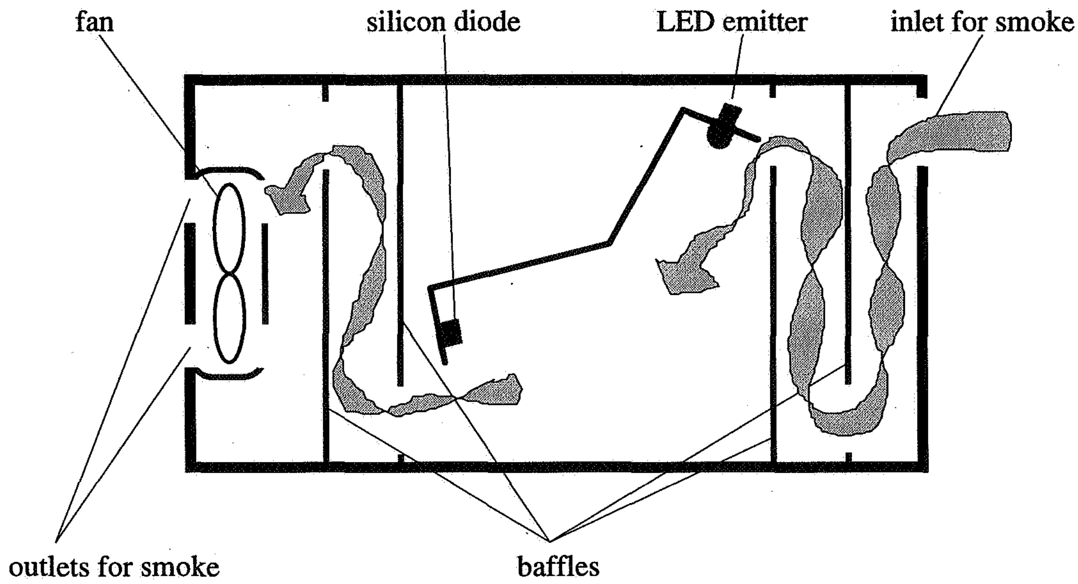

Figure 3 Drawing of Sensor Head

4 Testing in Laboratory Conditions

Tests were made to compare the results achieved with this instrument against known flow rates and against more traditional tracer gas methods. These tests were made in a room of approximately 60 m^3. A controlled, known ventilation flow was produced by a large fan installed in the door way of the test room; external windows across the room from the door were open. Several mixing fans were introduced into the room, but at the flows imposed by the door fan, these were probably unnecessary. The door fan, a building envelope pressurisation fan ("blower door"), was capable of generating between 0.1 - 2.5 m^3/s flows through the room, equivalent to air change rates of 5 to 150 air changes per hour; the fan flow rate was measured by orifice pressure drop during each test. In some trials, CO_2 was injected in the test room, as well as smoke and CO_2 levels measured by a Horiba IRGA.

Figure 4 shows a comparison of the decays of both smoke and CO_2 concentration during a single test. Figure 5 shows comparisons of the measurement method against the "known" rates as determined from the fan flow rate.

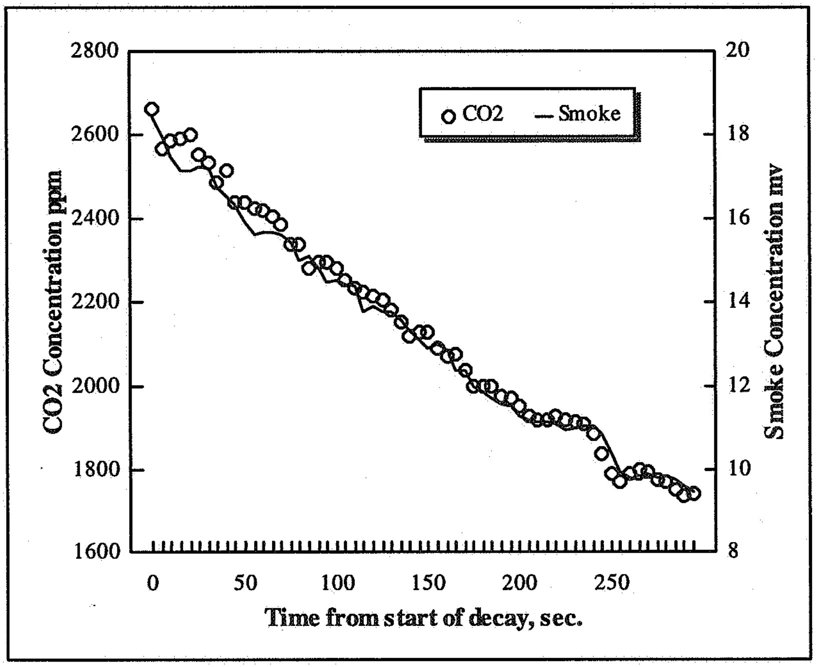

Figure 4 Example of Recorded CO_2 and Smoke Decay Curves

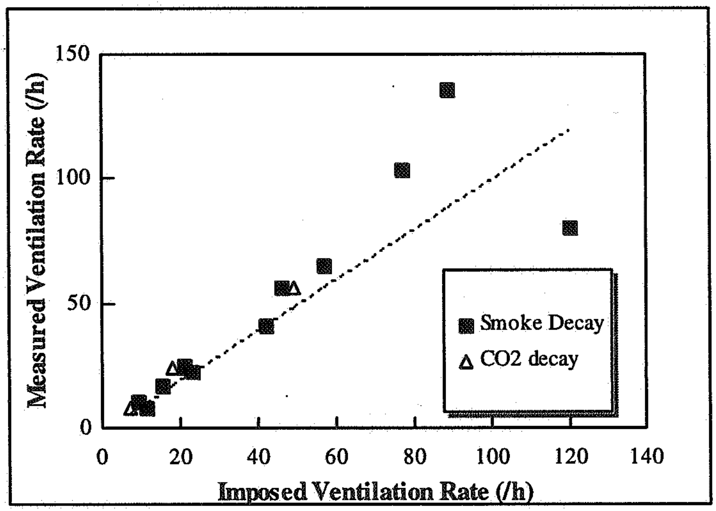

Figure 5 Comparison of Smoke Decay Results

The smoke and CO_2 methods were felt to be comparable, agreeing to within 12% for rates under 50 air changes per hour. The agreement at high rates (~100 ac/h) was not as satisfactory, but it is not at this time known if this was a characteristic of the smoke decay, the smoke sensor, or of the errors associated in calculating a ventilation rate from a (very high) flow rate. For the latter a ventilation effectiveness must be assumed and this may been in error. Thus at the higher flow rates, the estimate of the "true" ventilation rate could equally be in error as the measurement method. Additional work is planned to test the sensor further.

Given that CO_2 is itself not an ideal tracer gas to use for ventilation measurements, due to the naturally present background level, it can be concluded that the smoke decay method is at least as accurate as the CO_2 decay method, and potentially more accurate at high flows due to its' faster response time. For a low cost instrument this level of accuracy is felt to be suitable for its intended purpose. Potentially, accuracy and sensitivity could be increased by further development, but undoubtedly this would come only as a result of higher costs.

In the development of the system other smoke detector systems were also investigated. Notably, those found in fire detection systems are considerably more sensitive to low concentrations of smoke than the sensor described here. Unfortunately the component sensors of such systems are optimised for that particular use and provide only a binary output; e.g. above or below a threshold concentration. As such they are not directly suited for ventilation measurements, nor can they be modified for such.

Smoke from various sources were also tested for suitability. The tests described were made with a commercial oil based smoke generator; this smoke could be objectionable after exposure for a long time. Other sources of smoke have been tried; all were detectable by the instrument, though some were more pleasant than others to use. Those that have been tested are theatrical smoke generators (more acceptable to occupants, pleasantly scented, but low dispersion fluid should be used), joke shop smoke bombs (foul persistent smell), sewer leak-detection smoke pellets (copious coloured smoke but strong smell), cigarettes (socially unacceptable in many locations), incense (powerful odour if enough density of smoke produced), and even smouldering coir matting (a readily available local source for the target application).

It is accepted that this smoke decay technique is not a method readily applicable to buildings in use, due to the rather alarming appearance during the tests. However, there are equally many claims made about the acceptability of many of the tracer gases commonly used in ventilation research. The advantage of the system described here is that due to its' low cost, it may be usable in situations were other techniques would not be available or appropriate, and therefore may provide hard data where otherwise there would be none. It is notable and paradoxical that a secondary advantage of the system lies in the visibility of the tracer gas used; air flow visualisation may be done concurrently with the ventilation tests, supplementing the information gained.

A further advantage to be gained from the low cost of the instrument is that multiple monitoring points may be easily used in large spaces, without the need for pneumatic multiplexing. This can decrease the need for artificial mixing during measurements and lead to more natural measurement results, and possible greater accuracy at higher ventilation rates.

5 Testing in Field Conditions

The use of the instrument in the field went well, ventilation rates from 10 to 30 ac/h were measured in examples of modern housing in rural areas of Malaysia [3]. Measurement in examples of the traditional, very porous, housing was however less successful, in that there was an inability to generate sufficient initial smoke density, due to the high rates encountered. To account for this, it is considered that rates greatly in excess of 30 were being encountered. A more energetic smoke generator may have been able to overcome this problem, and provide more robust data.

6 Conclusion

To summarise, a smoke sensor has been developed to allow the measurement of ventilation rates in buildings, using smoke as a tracer. The sensor is low cost, and of comparable accuracy to the use of CO_2 as a tracer gas. The sensor is small and robust, suitable for sustained field work, and capable of monitoring high ventilation rates. The smoke may be generated by local materials or simple equipment. It is hoped that such an instrument may provide measurements where more traditional methods may unavailable or inappropriate.

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