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The Great Escape

There is little information available on ventilation rates in factories, even though they could account for a large proportion of total heat losses. David Etheridge describes how equipment developed for ventilation research in housing has been used in small factories.

Compared to ventilation of dwellings, very little is known about the natural ventilation of factories and it is only fairly recently that much research has been done on this topic. One such project is the Factories Research Programme of the Welsh School of Architecture. This project sets out to provide, among other things, information on designing and constructing factories to have lower air infiltration rates. This reduces energy consumption while at the same time maintains adequate ventilation rates for the occupants. The term 'infiltration' refers to air flow through openings which are not purpose-provided; however, no distinction will be made here, ie infiltration will be included in the term 'ventilation'.

Part of the project required investigating the ventilation of two factories and Watson House was asked to assist. Factory 1 is typical of current design. Factory 2 was designed to be more energy efficient, it has increased levels of insulation and a tighter method of construction was specified with the aim of preventing excessive ventilation. Apart from this the factories are similar. They are both open-plan and fairly small compared with some factories; their volumes are 1300 m³ and 810 m³ respectively. These volumes are, however, very large compared to dwellings and this point was of particular interest because the intention was to make use of experimental techniques specifically developed for dwellings. Fig. 1 shows the relative positions of the factories on the site. The site itself is operated by the Welsh Development Agency which was also responsible for the design of the factories.

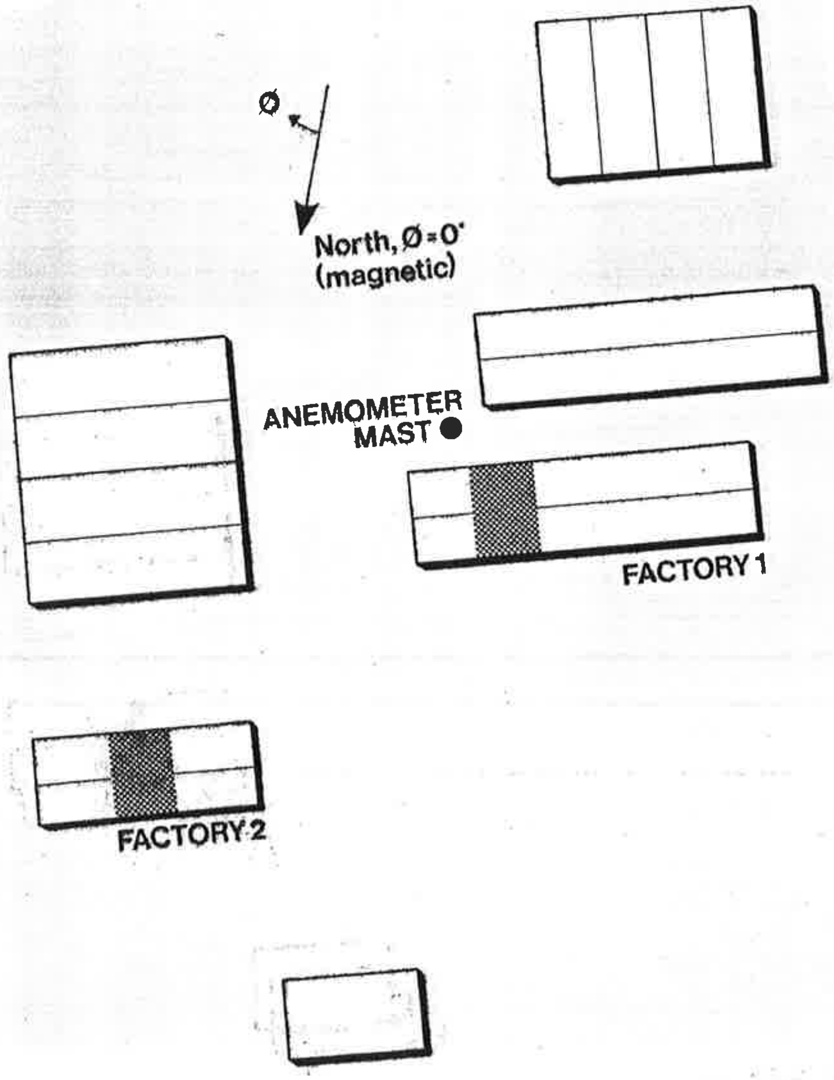
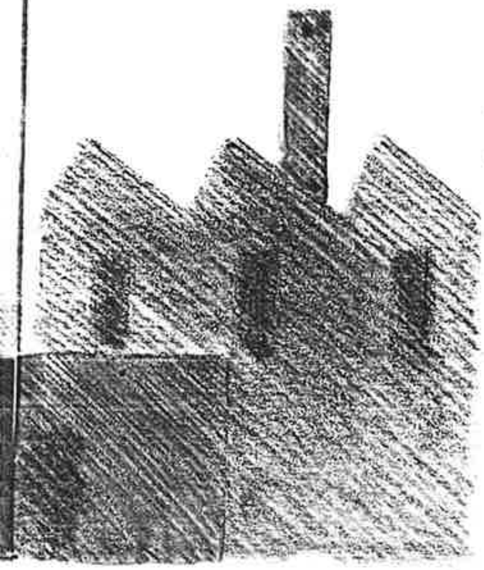


Fig. 1: Plan of site.

Experimental objectives

The primary aim of the experiments was to find out the ventilation rates which could be expected in each factory and at the same time determine whether the design objective of reduced infiltration for Factory 2 had been achieved.

The first question to be asked when investigating natural ventilation is whether actual measurements of ventilation rates are necessary or will air leakage measurements be sufficient. This question is asked because it is generally much easier and quicker to measure air leakage than it is to measure ventilation rate, at least for small buildings such as houses. The air leakage gives an indication of the total open area of the openings in the envelope of a building. It is



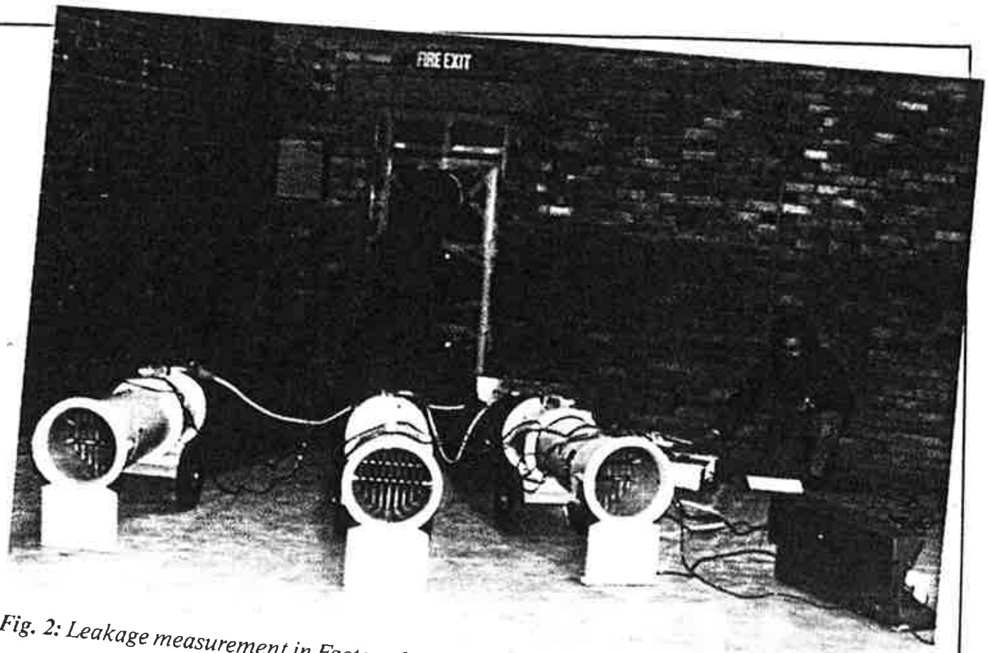


Fig. 2: Leakage measurement in Factory 2.

measured by pressurising the building to a specified level using a large fan. The flow rate through the fan is the air leakage at the specified pressure. The problem with air leakage is that it is not simply related to ventilation rate which depends on other factors (notably weather conditions, building shape and position) in addition to the total area of openings. For this reason, air leakage measurements are best used for comparative purposes. For example, when two similar buildings are on the same site the major cause of any differences in their ventilation rates is likely to be differences in their leakages. This, of course, is the situation for the two factories. So it could be argued that it was only necessary to measure ventilation rates in one factory because the rates in the second could be estimated from a comparison of their leakages; and this was what was done. However, it must be stressed that air leakage measurements are generally a poor substitute for accurate ventilation measurements. Even for comparative purposes, air leakages can give misleading results. The underlying reason for this is that air leakages are measured at pressures which are much greater than those occurring with natural ventilation.

Experimental equipment

Air Leakage

Air leakage rates were measured using the Watson House Leakage Tester. Each unit consists of a cylindrical duct mounted on large wheels for manoeuvrability. The entrance to the duct is a bellmouth inlet followed in the downstream direction by a 'Wilson' flow grid, a honeycomb flow straightener and a variable-speed axial fan. One advantage of the flow grid is that it is relatively insensitive to upstream conditions, and has a large pressure output and a low pressure loss. The flow rate through the unit is obtained from a calibration curve supplied by the manufacturers. A maximum flow rate of $1.0\,m^3/s$ can generally be achieved, depending on the resistance of the flexible duct used to connect the unit to the opening in the building.

Ventilation Rates

The Watson House Autovent system was used to monitor ventilation rates by the constant concentration technique. Artificial mixing was provided by 17 desk fans, six of which were placed at high level. Temporary electric fan heaters also enhanced the mixing. Most measurements were made with N_2O as the primary tracer gas, but in some cases SF_6 was used, although with less accuracy.

As its name implies, the constant concentration technique relies on maintaining the concentration of a tracer gas at a specified value. This is achieved with a computer control system which periodically injects tracer gas in calculated amounts at up to 12 points in the building. The ventilation rate over a given period (eg half an hour) is simply equal to the total amount of gas injected over that period, multiplied by a known factor.

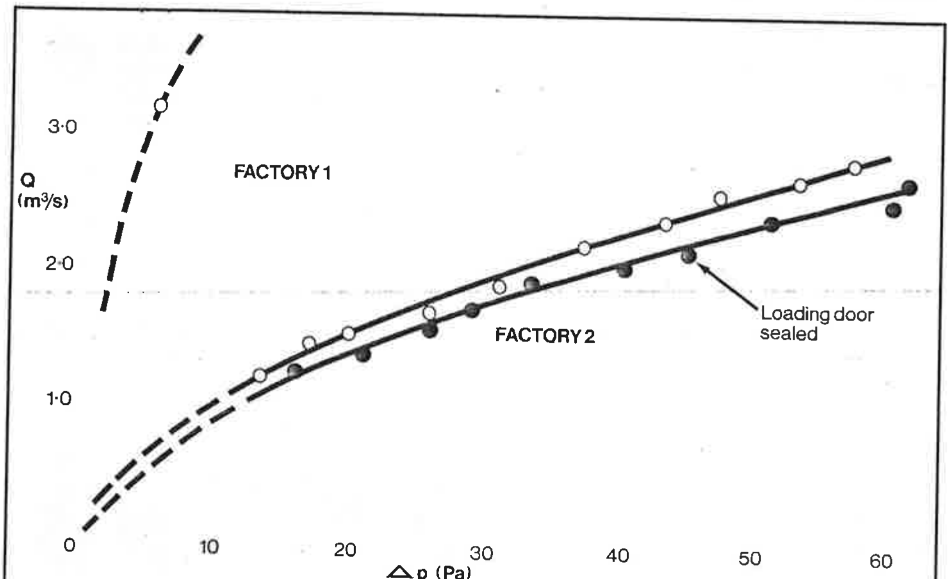


Fig. 3: Air leakage of Factories 1 and 2.

Using the techniques

Although using the air leakage equipment in a factory presents no fundamental problems, one is faced with the simple problem of scale. Roughly speaking, the larger the building the larger its air leakage. Consequently, at the outset it was accepted that one leakage tester would almost certainly be insufficient to generate a significant pressure in the factories. Therefore, three units were used in parallel, giving a maximum flow rate of $3.0\,m^3/s$ (see Fig. 2). This was adequate for Factory 2 but not for Factory 1.

Application of the Autovent system to large open-plan buildings presents rather more fundamental problems. The simple problem of scale (higher ventilation rates) still exists, but can be overcome by using higher flow rates of tracer gases. In addition, though, adequate mixing must be ensured because it is essential for the constant concentration technique to work properly. This is important because the number of injection points is limited to a maximum of 12 in the current Autovent system and each point would be coping with a much larger volume. Also, unlike rooms in a dwelling, the individual volumes are not separated by internal walls. In view of this, special tests were carried out to check that acceptable control of the tracer gas could be achieved simply by using a larger number of mixing fans. Adequate control was possible, and it transpired that the biggest problem was shortage of tracer gas supplies, resulting from the unexpectedly high ventilation rates found in Factory 1.

Results

Air Leakage

It is common practice to quote the air leakages of buildings at a pressure of 50 Pa (ie the fan flow rate required to pressurise the building to 50 Pa). However, Factory 1 was much too leaky and only a low level of pressure could be obtained with the three fans. Factory 2 was much tighter and 50 PA was achieved; this can be seen in Fig. 3 which shows flow rates plotted against pressure. The comparison between the two buildings, however, has to be made at the low pressures, where measurement errors are likely to be at their largest. Nevertheless, it is obvious that Factory 2 is much tighter, with a leakage approximately one quarter that of Factory 1.

A visual inspection of Factory 1 revealed that the loading bay door was a large source of leakage, whereas in Factory 2 the door was much better sealed. The effect of sealing the door on Factory 2's leakage is shown in Fig. 3; the effect of sealing the door on Factory 1's ventilation rate is described below. Fig. 4 shows the temporary sealing being applied.

Fig. 4: Sealing the loading door of Factory 1.

Ventilation Rates

The results of the measurements in Factory 1 are shown in Fig. 5 as air change rate plotted against wind speed. Above about 3 m/s wind becomes the determining factor of the ventilation rate. Below this speed, temperature difference (the so-called 'stack effect') becomes more important. On the basis of these results, and knowing the weather conditions over a heating season, an 'average' value for the air change rate was estimated to be approximately $1.4\,h^{-1}$. When the heating for Factory 1 had been sized an air change rate of $2.0\,h^{-1}$ was chosen. Although not known at the time, the measurements suggest this was a reasonable choice as they indicate that $2.0\,h^{-1}$ would be exceeded approximately 10 per cent of the time.

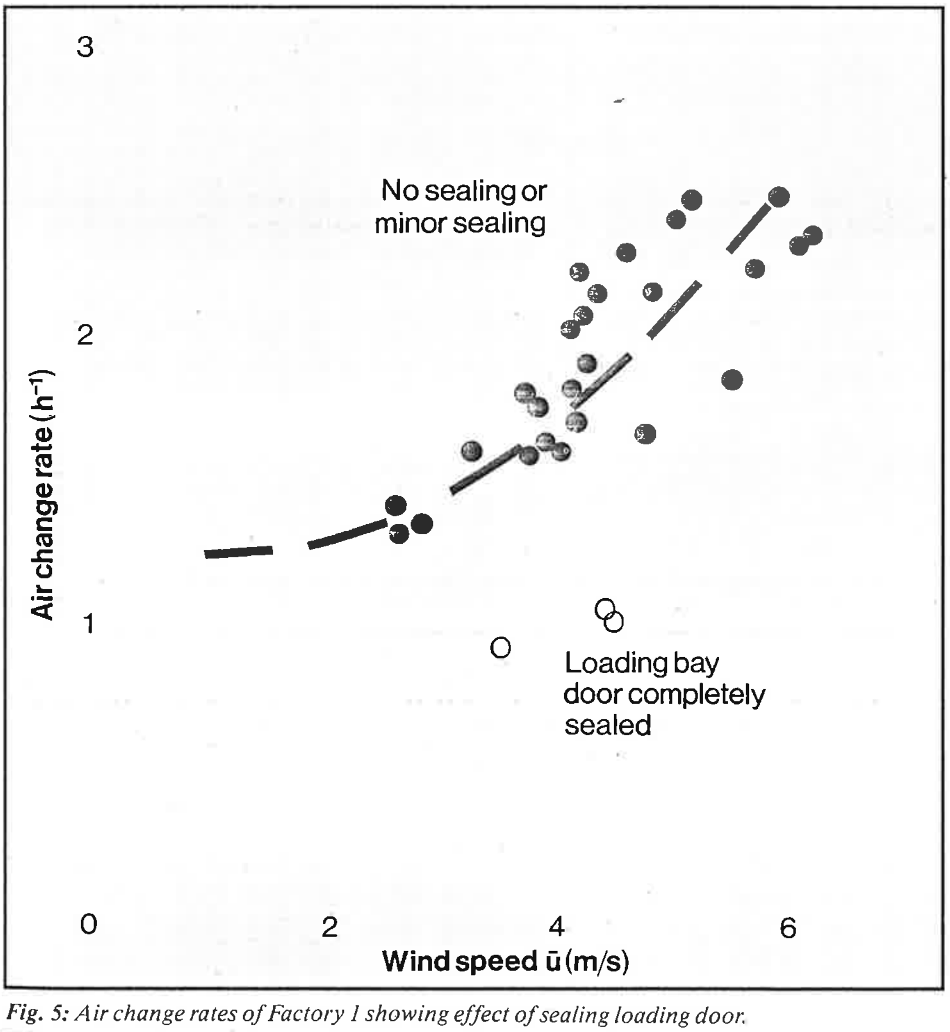


Fig. 5: Air change rates of Factory 1 showing effect of sealing loading door.

When the system for Factory 2 was sized an air change rate of $1.0\,h^{-1}$ was chosen to reflect the anticipated reduction in leakage. On the basis of the comparative leakages of the two factories, and taking into account their different volumes, the 'average' ventilation rate of Factory 2 was estimated to be $0.6\,h^{-1}$. Again this suggests that the design rate is reasonable.

Returning to Factory 1 and the results in Fig. 5, one can see the effect on the air change rate of sealing the loading bay door. The reduction is quite dramatic (approximately 45 per cent) and it appears that this is potentially a very cost-effective measure.

Conclusions

Experimental techniques for investigating ventilation in dwellings can be applied to larger open-plan buildings such as the two factories considered here. Problems of scale do arise but with the present buildings they were not too serious and some very useful results were obtained. In particular, the ventilation rate of Factory 1 and its dependence on weather conditions was determined and it was shown that sealing the loading bay door is a potentially cost-effective means of reducing energy consumption. The leakage tests have shown that the design objective of obtaining a tighter construction for Factory 2 has been successful.