BRE Information Paper

Latest research information and how to apply it

IP 21/89

December 1989

(57)

Passive stack ventilation in dwellings

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Passive stack ventilation (psv) is a means of providing simple extract ventilation in the 'wet' rooms (eg kitchens and bathrooms) of dwellings. Comprehensive guidance on the performance of psv systems is not yet available, and research continues. This paper gives interim advice, based on current knowledge, on the design and installation of psv systems in single- or two-storey dwellings, and discusses the key factors affecting performance. It is intended to assist designers of psv systems, such as housing architects and services engineers, in making decisions.

INTRODUCTION

All dwellings need a supply of fresh air, for the health and comfort of the occupants, for the control of condensation and to ensure the safe and efficient operation of combustion appliances. At present, the vast majority of dwellings in the United Kingdom are ventilated by natural means and, although whole dwelling mechanical ventilation systems and room extract fans are becoming more common, in most situations natural ventilation is the preferred option.

In recent years, changes in construction practices and the declining use of open fires have resulted in houses with fewer ventilation openings, leading in many cases to problems associated with inadequate ventilation. One of the major difficulties when relying on natural ventilation alone is that of ensuring that the moisture generated by normal household activities is removed efficiently from the dwelling, preferably at source.

One solution is to provide an easy escape route for the moisture generated in kitchens and bathrooms, by making effective use of the forces which drive natural ventilation. Passive stack ventilation (psv) has become the accepted name for systems of vertical or near-vertical ducts running from the ceiling of the kitchen and bathroom to terminals on the roof. They are suitable for single- or two-storey dwellings with pitched roofs.

The opportunity for dwelling owners and designers to specify psv systems is somewhat restricted by the lack of published information on system design and performance. Research on psv is in hand, and this paper gives interim guidance on duct selection and layout, inlet and outlet terminals and fan assistance, and advice on the main pitfalls, such as noise and fire, associated with such installations.

OPERATING PRINCIPLES

Passive stack ventilation systems work by a combination of the stack effect, ie the movement of air due to differences in temperature between inside and outside, and the effect of wind moving over the roof of the house. During the heating season and under normal UK weather conditions, the ducts

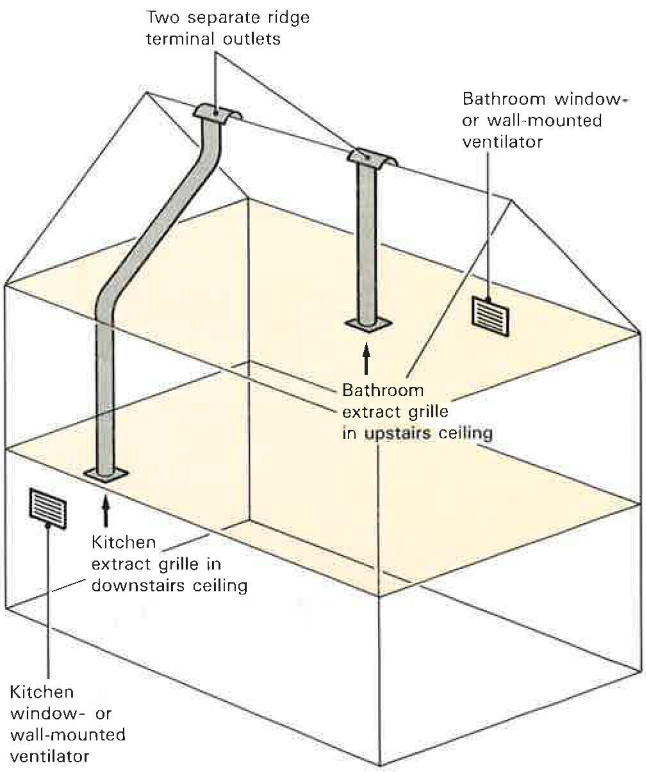

Figure 1 Typical kitchen and bathroom passive stack ventilation systems

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serve to extract warm, moist air from the 'wet' rooms of the dwelling, venting it directly to outdoors. The rate of air flow within the duct depends on a number of factors but in general, flow rate increases as the difference between indoor and outdoor temperatures increases. The system should thus be most effective when it is most needed, ie during the colder parts of the heating season. Wind speed and direction also influence the rate of air flow but in a relatively complex way, depending on the interaction between factors such as the airtightness of the dwelling, the type and position of air leakage paths and the type and position of the duct outlet terminal.

DESIGN OF PSV SYSTEMS

Because a psv system is similar in operation to a chimney, equally careful attention needs to be paid to design if it is to be effective in improving the ventilation of the dwelling. To date, few studies have been made in the UK of how psv systems operate in practice and several field studies are currently in hand to improve understanding. A number of design points have however already been established in work by BRE and other organisations[1,2]. The following guidelines are based on this current knowledge.

System layout

The layout shown in Figure 1 is considered to be suitable for the majority of two-storey dwellings. Separate ducts are taken from the ceilings of the kitchen and the bathroom to terminals on or near the ridge of the roof.

In order to maximise the stack effect, ducts should be as near vertical as possible and must be well supported. However, if the ducts are to terminate on the roof ridge (the preferred option — see later), some bends in the system are inevitable. These introduce resistance to the flow of air and so should be as few as possible and should be of the 'sweep' rather than the 'sharp' type. In addition, no section of duct should be at an angle of more than 45° to the vertical.

The positioning of the duct which runs from the kitchen ceiling is usually constrained by the layout of the room(s) above, since the duct needs to run either in a corner, where it can be boxed in, or within a cupboard. Where there is a choice, the inlet of the kitchen duct should be positioned above the cooker.

The two ducts should *not* be joined together because there will be isolated occasions, usually associated with high wind speed, when reverse air flow, ie *down* the duct, may occur. Although reverse air flow is believed to be a relatively rare occurrence, a common outlet terminal could result in air from bathrooms being routed into kitchens.

The positioning of the outlet terminals is constrained by the need to ensure, as far as possible, that air flow in the ducts is not unduly affected by the prevailing wind speed and direction, or sudden changes in these. The preferred solution is for the ducts to terminate at outlets on the roof ridge. This inevitably introduces bends into the duct but has the advantage that wind gusts and certain wind directions are less likely to affect performance adversely.

If the ducts run vertically, penetrating the roof away from the ridge, it is good practice to extend the duct above roof level to at least ridge height, in order to ensure that the duct outlet is in the negative pressure region above the roof[3]. If this is not done the outlet may often be subject to positive pressure, leading to possible reverse flow down the duct. There are disadvantages in extending the duct above roof level — the considerable visual impact and the likelihood of moisture condensing in the external part of the duct and running back into the dwelling.

Outlet terminals

For duct systems which terminate on the ridge of the roof, standard ridge terminals with appropriate adaptors are suitable. Gas-flue ridge terminals may offer less resistance to air flow up the duct than other types. If for some reason the ducts do not terminate on the ridge, the need to extend the duct above the roof rules out the use of standard tile ventilators — flue or soil-pipe terminals should be used instead. The design of the outlet terminal should be such that rain is not likely to enter the duct and run down into the dwelling, but should offer the minimum of resistance to air flow (ie open area greater than that of the duct).

Internal grilles

Grilles or terminals on the inlet ends of the ducts do not serve any useful purpose in relation to the operation of the psv system; they are required for aesthetic purposes only. The grilles should present the least possible resistance to the flow of air and should be easy to clean. Most concentric-ring and egg-crate types are suitable, though other types should not be ruled out.

Duct size and materials

To achieve an adequate but not excessive flow rate of air, the diameter of the ducting should normally be between 100 and 150 mm. 'Off-the-shelf' upvc pipes and fittings, of the type used for drain-pipes, are suitable and have the advantages of being smooth-walled, inexpensive, widely available and, to some extent, self-supporting. Flexible ducting is more expensive but has the advantage of being easy to install, particularly in the roof space where access may be restricted. It is also available in pre-insulated form (see later). There are however the disadvantages of increased resistance to the flow of air, because of the corrugations in the duct wall, and the need to support bends in a smooth curve. The effect of the increased resistance has not yet been quantified, not least because psv duct velocities are usually below those for which pressure-loss data are available from manufacturers. Work in hand at BRE will provide further information.

Duct insulation

The duct should be insulated to a thickness of at least 25 mm wherever it is run outside the heated volume of the dwelling (the roof space is not usually part of the heated volume). This helps to maintain the stack effect and reduces the risk of condensation forming inside the duct and running back down into the dwelling. It may be difficult to insulate that part of a duct which projects above the pitch of the roof but the consequences of not doing so are not yet known.

Air inlet to the dwelling

If the psv system is to work as an extract system, there must be a way of supplying air to the rooms it serves. This may be by means of the chance entry of air through gaps and cracks in the fabric of the dwelling, but the preferred option, which is essential in a relatively airtight dwelling, is to use controllable, purpose-provided ventilators. In airtight houses there is some evidence[2] that occupants can exercise a degree of control over the air flow rates in the passive stack system by adjusting the air inlets. Obviously in a system which is driven by natural forces only, there is no way of guaranteeing that inlets will not for some of the time act as air extract points.

Clearly the airtightness of a given dwelling is not usually known and so some guidance is needed. Research by BRE and others has shown that airtightness varies widely in the UK, even in nominally identical dwellings. Furthermore, airtightness cannot be assessed purely by visual inspection; some form of measurement is required.

Airtightness can be measured quickly and easily using the technique known as fan pressurisation, as described in reference 4. This yields the air leakage rate under an artificially applied pressure difference, which is a measure of the airtightness of the dwelling. In the UK a relatively airtight dwelling will have an air leakage rate, at an applied pressure difference of 50 pascals, of about 10 or less air changes per hour (ach). This compares with an average of 14.8 ach measured by BRE in 282 dwellings of many different types throughout the UK. (Note that although ventilation rates and air leakage rates are often expressed in the same units of air changes per hour, they have completely separate meanings because of the different pressure conditions under which they are measured.)

Type of construction usually has an influence on airtightness. For example, modern timber-framed dwellings incorporating a carefully fitted polyethylene vapour barrier during construction can be very airtight indeed (less than 4 ach at 50 pascals pressure difference) but tears and other penetrations of the barrier greatly affect the final airtightness. It is usually very difficult to make an existing leaky dwelling into a very airtight one, whatever type of construction is used. Fitting draughtproofing materials to windows and doors will rarely be sufficient so attention should also be given to sealing all service entries, wall/floor junctions, suspended timber floors, boxed-in pipe runs, etc.

The fan-pressurisation technique is relatively new in the UK and is not yet widely available as a service, but it does promise to be a useful tool in a range of domestic ventilation applications, including psv system installation.

Preventing excessive heat loss

Unless the dwelling has a reasonable standard of airtightness, the combination of the passive stack system and adventitious air leakage paths may, under certain weather conditions, lead to ventilation rates which are higher than required. Simple control mechanisms are being developed, such as sprung flaps in the duct, which are activated when air flow rates in the duct are greater than some pre-set value. If however the dwelling is relatively airtight, control of the air flow rates may be possible to some extent using controllable air inlets, as described in reference 2.

FIRE PRECAUTIONS

A duct from the kitchen could, in the event of a fire, act as an easy path for the transfer of smoke and fire to the first-floor living space. This aspect of psv systems is currently under investigation. As an interim measure, it is recommended that a quick-acting fire damper, such as a fusible link type, should be properly fitted close to the inlet of the kitchen duct. Other types of fire damper, such as intumescent collars, are available and will also be investigated.

PERFORMANCE IN PRACTICE

From the limited amount of monitoring that has been carried out on psv systems in the UK, it is not yet clear if there is a simple way of predicting how effective the psv system will be in enhancing the ventilation of the dwelling. In addition to the design of the psv system, other factors affect performance, including: the air leakage characteristics of the dwelling, the location of the dwelling and its proximity to other buildings, interaction with other ventilation systems such as extract fans and, of course, the prevailing weather conditions.

BRE is conducting a series of field trials to assess the performance of various designs of psv system. Results have been obtained so far from two systems serving a ground-floor kitchen in a two-storey dwelling. For a system consisting of a 153 mm bore upvc duct with two 45° bends and a gas-flue ridge terminal, the average air flow rate through the duct (over a range of weather conditions) was of the order of 55 m^3/h. For another system using the same upvc duct but with no bends, terminating above the roof pitch and with a 'Chinese hat' flue terminal, the average air flow rate was of the order of 80 m^3/h. Neither system had an intake grille fitted.

The BRE data confirm the results of research by Johnson *et al*[2] which showed that in a system very similar to the BRE ridge-terminated system, the long-term average air flow rate was of the order of 50 m^3/h. A similar duct of 103 mm bore, but serving a first-floor bathroom, was found to give a mean flow rate of around 20 m^3/h under the same conditions.

Johnson *et al*[2] also examined air flow rates in a dwelling fitted with a 103 mm bore plastic duct running straight from the ground-floor kitchen to just below the ridge and another similar duct with two bends from the bathroom to just below the ridge. The mean air flow rates measured were about 27 m^3/h for the kitchen duct and 18 m^3/h for the bathroom duct.

Interestingly, all three psv systems serving the kitchen (in two-storey houses) and terminating at or beside the roof ridge had mean air velocities in the centre of the duct of about 0.9 m/s, even though one duct was of a smaller diameter. This would seem to be consistent with Dutch practice[5] for sizing psv ducts which is simply based on a maximum average air velocity in the duct of 1 m/s. The lower velocities measured in the ducts serving bathrooms are presumably due to the shorter vertical length of the ducts.

The use of an extract fan serving the same room as a psv system is generally not recommended because, at least with internal doors shut, such fans can generate sufficient reduction in pressure in the room to cause reverse flow in the psv system. For short periods this may be acceptable to occupants from a comfort point of view but the psv duct will become cooled and it is not yet known how quickly proper operation of the psv system is re-established. A better alternative might be a fan-assisted psv system.

FAN-ASSISTED PSV SYSTEMS

One way of enhancing the performance of a psv system during periods of cooking or bathing is to use fan assistance. A fan is incorporated in the psv duct so that, when required, higher air flow rates can be created in the duct than those which occur under natural forces.

The fan can of course be fitted with humidistat control, but the humidity sensor should not generally be fitted in the duct because it will rapidly become fouled with household dust, fluff and grease, and may be inaccessible for cleaning. The problem of cleaning also applies to the fan impeller, although this might be made partially self-cleaning by careful design. Unfortunately the fan also presents a resistance to air flow up the duct when the psv system is working under natural forces, so careful selection of the fan is needed to minimise this effect.

A further selection criterion is the environment in which the fan will be usd. The fan may be switched off for much of the time and could suffer damage in a warm humid air flow. Condensation may occur when duct air temperature and humidity suddenly rise because of, for example, an occupant turning on a hot shower.

NOISE

When a simple psv system was installed in the kitchen of a test house at BRE it was noticed that the duct admitted noise from traffic on a motorway situated about 250 metres away, and from aircraft. There did not appear to be a noise nuisance in the bedroom through which the duct passed completely exposed.

Clearly, in situations where external noise is likely to be intrusive, eg near busy roads and airports, some sound attenuation in the duct is desirable. However, the degree of attenuation required is uncertain because it depends upon a number of factors, including the attenuation provided by the duct system itself. Until research has been carried out on the acoustic properties of psv systems it is suggested that, where external noise is intrusive, the fitting of an 'off-the-shelf' sound attenuator (essentially a straight length of highly perforated duct wrapped with mineral wool) where the psv duct passes through the roof space is likely to be effective.

CLEANING

It is not yet known how often psv systems will need cleaning, but without filters, which would restrict the air flow, they are likely to need regular attention, particularly to the inlet grilles. During field trials of psv system performance in occupied dwellings[2], fluff was occasionally found on measuring probes projecting into the duct, and a thin layer of dry dust was observed inside a kitchen duct after some months of use. Whilst frequent cleaning of the ducts themselves will not be required, this observation does show that quantities of matter are drawn up the ducts, and so some cleaning will be necessary.

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Printed in the UK for HMSO. Dd.8245026, 11/89, C95, 38938.