ENERGY EFFICIENT DOMESTIC VENTILATION SYSTEMS FOR ACHIEVING
ACCEPTABLE INDOOR AIR QUALITY

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USER EXPERIENCE OF MECHANICAL VENTILATION IN HOUSES

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SYNOPSIS

Four 'low energy' electrically heated houses incorporating extra thermal insulation and heat recovery mechanical ventilation systems, were built for sale by two national builders.

Their standard house designs were modified to accommodate the extra features; air tightness was made an objective so that the ventilation system would provide as much of the required fresh air as possible.

Instrumentation was installed during construction to monitor the performance of the houses, with the co-operation of the eventual purchasers.

The houses were leak tested and sealed where necessary. Ventilation rate calibrations were carried out to provide data for estimating the ventilation rate when the houses were occupied.

The mechanical ventilation systems were found to provide good internal conditions without opening windows and freedom from condensation. The total ventilation heat loss was less than one quarter of the total heat loss from the house.

1. INTRODUCTION

When the U-value of the walls of a house has been reduced to 0.3 $Wm^{-2}K^{-1}$ and the ventilation rate is one air change per hour, the transmission and ventilation heat losses are approximately equal, each of the order of 4000 kWh per heating season for a $200m^3$ house at a mean internal temperature of 18°C. It is therefore necessary, for minimum heating costs that this ventilation rate should not be exceeded without good cause; if it can be reduced, significant savings in heating energy will result.

Provided moisture from clothes drying and moisture and smells from cooking can be prevented from entering the house air circulation, then 0.5 to 1 air change per hour (whole house) satisfies accepted ventilation criteria[1] for the average family in the average house. This low ventilation rate would minimise heat losses and could be improved upon only by dehumidification or heat recovery.

An essential component of the Electricity Council Research Centre (ECRC) low energy house programme was to ascertain how far this ideal could be realised by existing builders constructing speculative electrically heated housing for the owner-occupier market.

Two national builders modified one of their popular designs of three bedroom, brick and tile detached houses according to guidelines worked out at ECRC. The philosophy was to achieve the best that conventional building techniques could achieve without using revolutionary or untried procedures which would result in confusion on the building site, and also might not work. The houses, two per builder, were sold on the open market to private individuals who agreed to allow ECRC to monitor the thermal performance of the houses for a limited period (i.e. one or two heating seasons).

2. VENTILATION STRATEGY

Methods of improving the thermal performance of a house envelope are relatively straightforward, whereas the best way to achieve a low and predictable ventilation heat loss is less clear.

While openable windows are virtually essential for summer cooling, they can result in very high heat losses, or low internal temperatures, if used much in winter.[2] On the other hand, inadequate ventilation will result in stuffiness, odours and condensation.

Local extract fans in kitchens and bathrooms offer a marked improvement in internal environment but there is still a high probability that living rooms and bedrooms will be poorly ventilated. Provision of a ducted fresh air distribution system ensures that all rooms are adequately ventilated, and while this more than doubles the cost and complexity of the ventilation system, the available option of recovering heat from the exhaust air to preheat the fresh air is an extra bonus.

3. VENTILATION SYSTEM

Since these houses were for sale in the market place, a commercially available heat recovery ventilation system was chosen. A cooker hood type unit was chosen since it seemed desirable to have those parts requiring maintenance or cleaning to be readily accessible in the kitchen rather than forgotten in the loft. The kitchen unit includes two fans, heat exchanger and controls. A pair of 125mm diameter ducts pass from this unit through the wall to the outside 'balanced flue' type terminal. These are the fresh air supply and exhaust air ducts. A similar pair of ducts on the other side of the kitchen unit convey fresh air to the living room and bedrooms and collect air extracted from the bathroom and W.C. The whole system is shown schematically in Figure 1.

There are three fan speeds designated Low, Normal and Boost, together with a damper on the kitchen hood to increase the extraction rate above the cooker at the expense of the other points. The system is designed for continuous running.

All inlet and outlet registers were located at or near the ceiling following the manufacturer's recommendation. Ducting to the first floor rooms passes through the airing cupboard and into the loft. Access for ducting to the ground floor ceiling depends on the floor joist direction being suitable for laying the ducts in between them. There was an extract point in the bathroom and downstairs W.C. (one of the house designs only). Fresh air was supplied to all the bedrooms and to both ends of the combined lounge/dining room. The internal doors were considered sufficiently leaky to permit return air flow without any modifications.

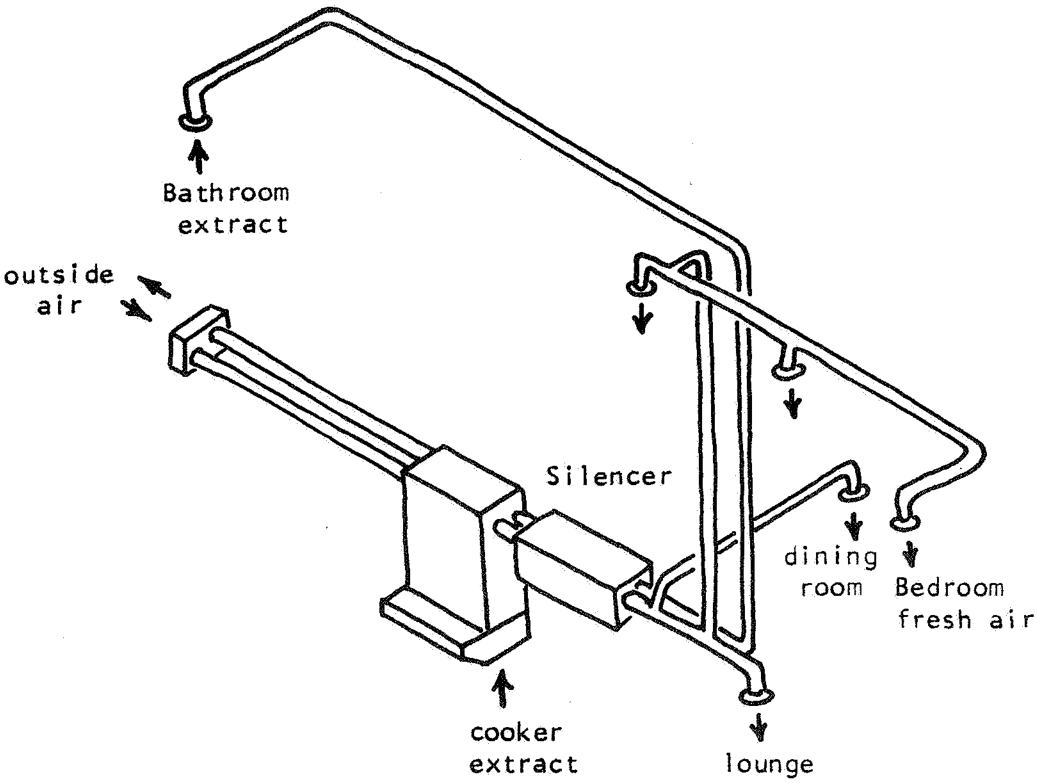


Fig. 1 Schematic view of complete ventilation system

4. VENTILATION RATE

Previous tests have shown that for a balanced ventilation system the mechanical and natural ventilation rates are virtually additive. The mechanical rate was set at 0.5 air changes per hour (100 m^3h^{-1}) at the Normal setting on the assumption that the background natural leakage could probably be reduced to about 0.3 air changes per hour, giving a total rate of about 0.8 ach^{-1}. The flow was divided equally among the various registers.

5. HOUSE STRUCTURE

The houses were built with sufficient extra thermal insulation in the walls, roof and floor to give a transmission heat loss of about 120 WK^{-1}, corresponding to a wall U-value of 0.35 $Wm^{-2}K^{-1}$. To minimise uncontrolled ventilation the structure had to be less leaky than traditional housing in the U.K. Most of the leakage in conventional brick houses occurs where masonry and timber abut because the timber shrinks on drying out and gaps appear at joints and corners. Air tightness has never been a design criterion before.

A first step was to specify 'high performance' door and window frames with integral weatherstripping. Ideally the frames should be sealed into the brick wall with a flexible gasket but no practical solution could be found so, reluctantly, mastic was used after construction in the usual way.

Wet plaster finish rather than dry lining was specified because it seals the myriad of small leakages in the wall. Dry lined walls are prone to unpredictable and unsealable leakage unless very carefully installed with air tightness in mind.

Even a wet plaster finish does not seal the wall surface between the ground floor ceiling and the first floor. Joists set into holes in the inner leaf provide leakage holes through the wall which can be avoided by using joist hangers.

The other main source of leakage is where services penetrate the envelope. Unfortunately the mechanical ventilation system itself adds to the number of penetrations. The boxing-in of services can provide leaky 'chimneys' from floor to floor and usually into the loft space unless the holes are made good at each floor penetration.

Incorporation of the ventilation system also influences house design. To achieve low pressure drops and low noise levels the main distribution ducting has to be 125mm diameter and the branch ducts to individual rooms must be 80mm diameter. With ducting of this size it is not possible to notch floor joists and so the main problem in system design is how to travel at right angles to the joist direction. Modification of joist layout may be necessary.

It was hoped at first to avoid taking the ducting into the loft because, although this is very convenient for distribution, the ducting must then be thermally insulated and also the penetrations of the ceiling are likely sources of leakage unless carefully sealed. However, the use of ceiling mounted air registers makes ducting in the loft inevitable.

The type of ventilation unit chosen influences, and may severely limit, the kitchen layout because:

(i) there must be a suitable route through an outside wall for the main supply and extract ducting.

(ii) a large silencer on the house side of the kitchen unit determines the minimum distance between the unit and the kitchen wall on that side.

Difficulties also occur on site because the ventilation unit has to be in place at an early stage in the construction so that the ducting can be installed prior to ceiling and floor boards.

6. WORKMANSHIP

A low-leakage house is a new concept which is not understood on

British building sites. Although potential leaks should be anticipated and 'designed out' this is almost impossible. The experience of these two projects showed that a satisfactory house is unlikely to be built by subcontract labour because the supervision, motivation and commitment are lacking. It is essential that the men on the job understand that any hole through the envelope is undesirable whether it can be seen or not. For example, square holes around circular ducting going up into the loft will not be made good if the part inside the house is boxed in and the hole in the loft is concealed under a thick blanket of glass fibre insulation.

7. LEAKAGE TESTING

The houses were tested by a conventional pressurisation test using a fan installed in an external doorway. The outside terminal of the ventilation system was blocked off during tests. A smoke puffer was used for locating leaks while the door fan was running at constant maximum speed.

However, sealing after leak testing is no substitute for tight construction as it is very laborious to seal leaks at this stage and not very effective because only the surfaces of the cracks are accessible. Identified cracks and openings were sealed with mastic and polyurethane foam with insulating board spanning large openings. Additional draughtstripping was necessary on some of the external doors. This whole operation was surprisingly difficult and time-consuming, and showed that sealing a house 'after the event' is not a practical proposition even if a pressurisation fan is available to identify the leaks.

The leakage values measured were in the range 5 to 7 air changes per hour at a pressure differential of 50 Pa. The houses, even after careful construction, leaked at all the 'usual' places such as corners (especially at wood/masonry joints), outside doors and window frames, at service penetrations, loft hatches. Two of the houses had particularly bad leaks around the 'balanced flue' ventilation terminal where no attempt had been made to minimise the size of the hole in the wall or to fill in the hole after fixing. A first floor bay window proved to be a leaky type of structure. Loft hatches tended to leak even when draughtstripped, showing the need for positive closure rather than just relying on the weight of the hatch.

Leakage increased by about 20% during drying out but was reduced again by sealing up visible shrinkage cracks.

8. VENTILATION MEASUREMENTS

So that future ventilation rates could be predicted from weather records, ventilation system usage and open windows, the house was calibrated by tracer measurements using both decay and continuous (equilibrium concentration) methods. In winds up to 7 ms^{-1} and temperature difference of 10°C to 20°C rates of 0.25 to 0.5 air changes per hour were measured (figure 2). With open windows rates up to 10 h^{-1} were measured (figure 3). Measurements with the ventilation system running, and windows closed, confirmed that natural and mechanical ventilation was additive.

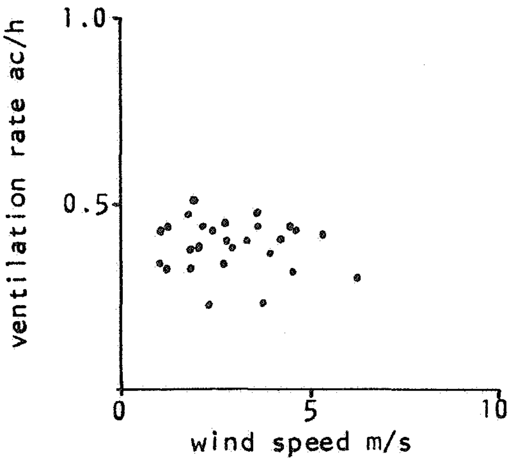


Fig. 2 Measured ventilation rates (one house): ventilation system off and windows closed

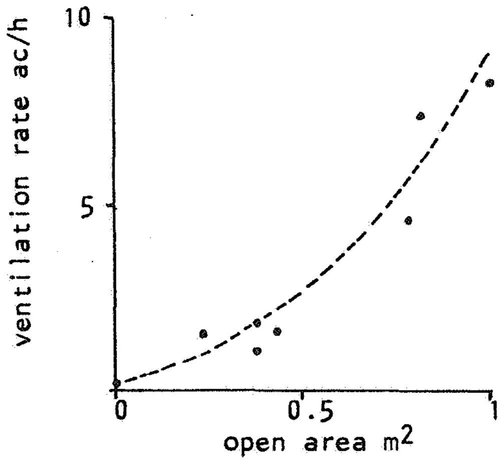


Fig. 3 Measured ventilation rates with open windows

9. INSTRUMENTATION

The house was provided with thermocouples for monitoring room temperatures and recording kWh meters; also the ventilation system was instrumented to measure inlet and outlet air temperatures and dewpoints. The fan speed and damper settings were also monitored on event recorders. An intruder alarm indicated whether a window or door was open. The data-logger recorded the actual duration of window and door opening and whether a particular switch setting on the ventilation system had been used within the previous half hour.

10. USER EXPERIENCE

10.1 Use of controls

In all four houses the occupants chose to use the Low setting of the ventilation system for more than 80% of the time. This corresponds to a mechanical ventilation rate of 65 m^3h^{-1}. They switch up to Normal (105 m^3h^{-1}) or more commonly to Boost (150 m^3h^{-1}) for periods of half to two hours around meal times. At these times the kitchen damper would also be open; it was seldom opened at other times.

Apart from a preference for the Low setting, the ventilation systems were used as intended. They were operated continuously and there was no significant window opening until the end of April, and very little until mid-May. Up to mid-April the total (i.e. mechanical + natural) fresh air ventilation was in the range 0.6 to 0.8 air changes per hour (figure 4) for all four houses, with 50 to 55% of this being mechanical.

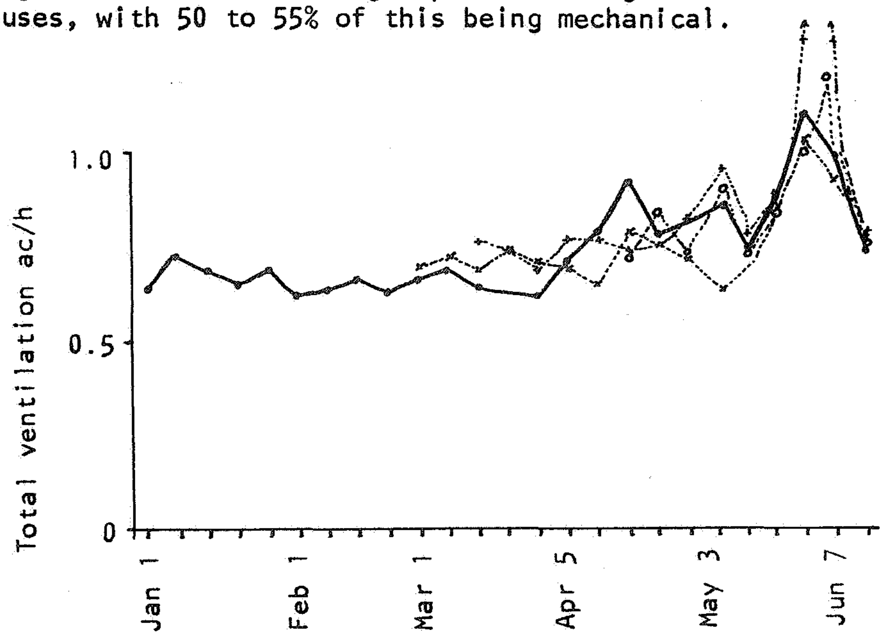


Fig. 4 Weekly mean ventilation rates Jan-June (all 4 houses)

A typical usage pattern for a week in November is shown in figure 5.

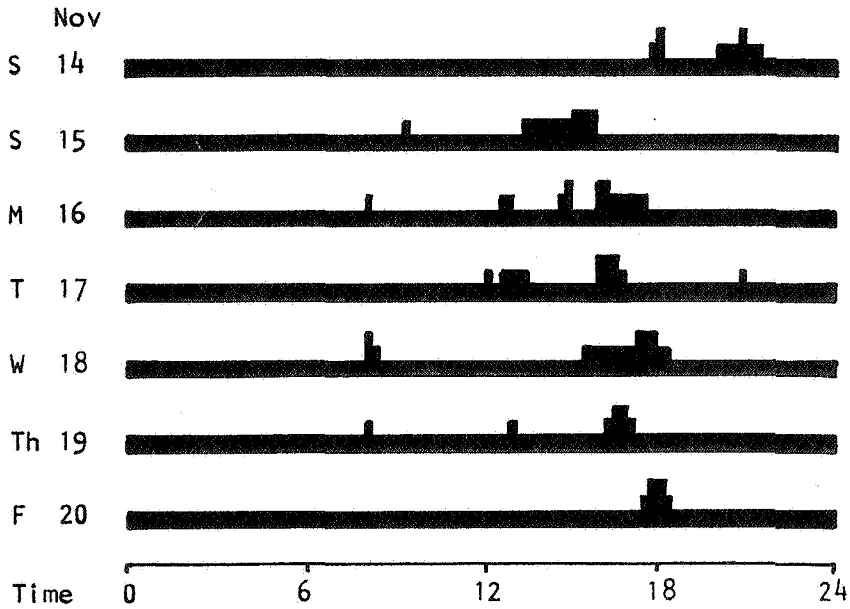
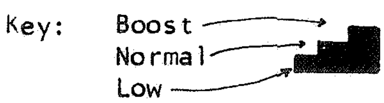


Fig. 5 Ventilation system usage for 1 week in November



10.2 Subjective assessment

Only one of four houses was occupied in time for monitoring a full heating season. Records for the other three commence in March. However, operation through choice on the Low setting and the lack of window opening until the beginning of May (when the mean outside temperature reached 12°C) suggests that the ventilation obtained has been satisfactory in all the houses.

There has been no condensation and this is seen as a major advantage of the systems. It also seems that window opening is not indulged in when internal conditions are acceptable.

10.3 Internal environment

Twenty-four hour dew point profiles for one of the houses averaged over the period November to March are shown in figure 6. The internal dew point is about 4.5 degrees above external dew point corresponding to an extra moisture load of 0.0015 kg water per kg air. At a ventilation rate of 160 m^3h^{-1} this corresponds to a moisture production rate of 1.2 x 160 x 0.0015 x 24 = 7 kg per day.

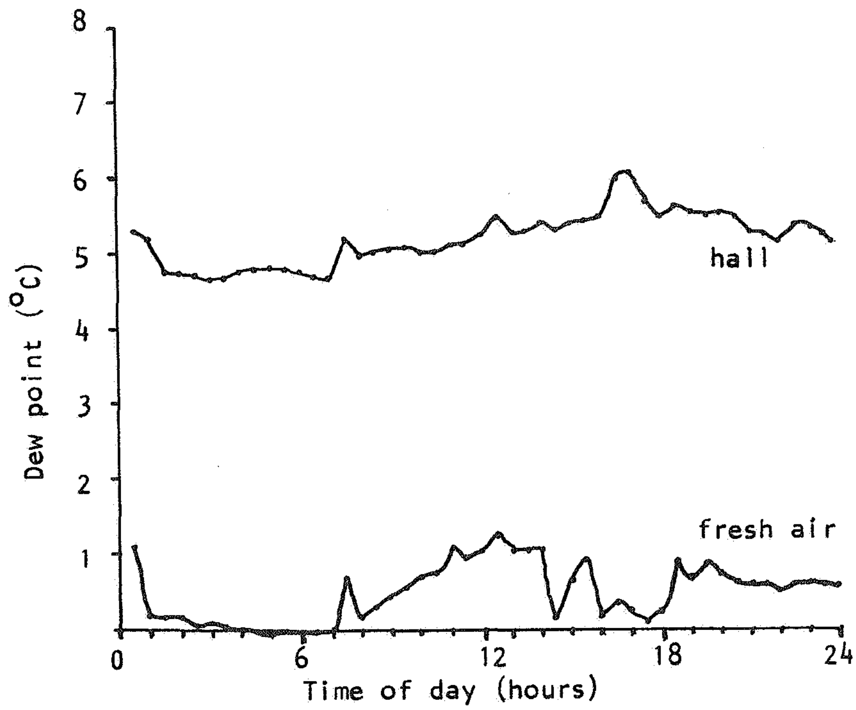


Fig. 6 24 hour dew point profile (November to March)

The dew point sensor in the exhaust duct of the ventilation system was not working until April. Dew point profiles for April are given in figure 7. It is seen that the dew points in the ventilation duct are very similar to those in the hall with moderate increases at cooking times as would be expected.

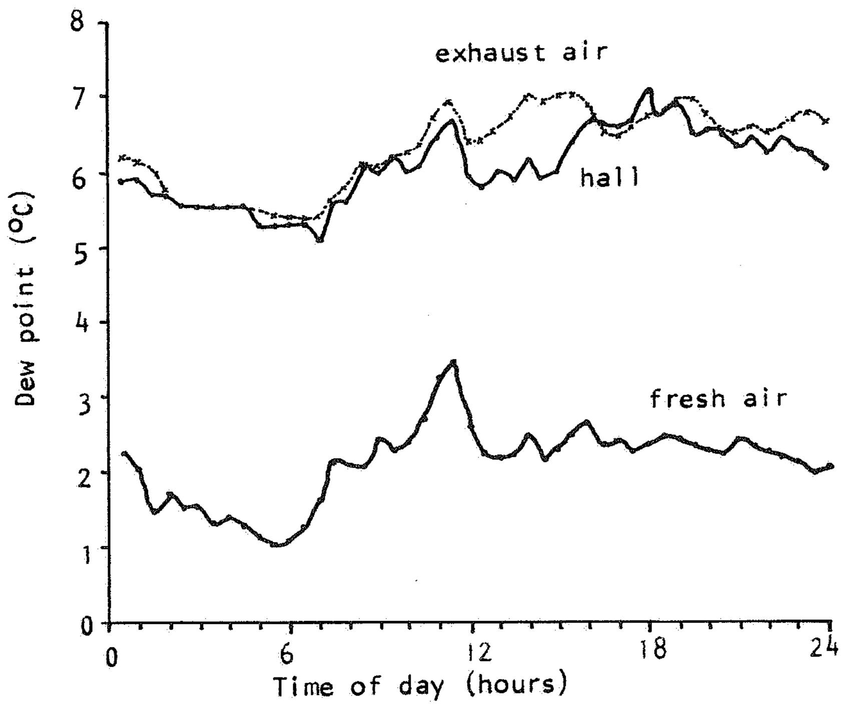


Fig. 7 Dew point profiles (April) including ventilation system exhaust

Individual records show intermittent dew point peaks to 10°C or 12°C but at internal temperatures of 18 to 20°C condensation would not be expected under these conditions, even on the window surfaces (double glazed), which will be at a temperature of approximately inside temperature minus 40% of the inside to outside temperature difference.

10.4 Energy implications

The reason for installing a mechanical ventilation system was to give a low, predictable, ventilation heat loss and an environment which was sufficiently 'fresh' to make window opening unnecessary and undesired during the heating season.

The heat loss data for November to March is given in figure 8. It is seen that the ventilation heat loss is always between a third and a quarter of the transmission heat loss.

The air leaving the house has a greater specific enthalpy than the incoming fresh air because of its higher moisture content. Some of this is recovered in the heat exchanger since the exhaust air is cooled to nearly the outside air temperature as dew point. This gives the heat exchanger an apparently higher efficiency than it would have in dry air.

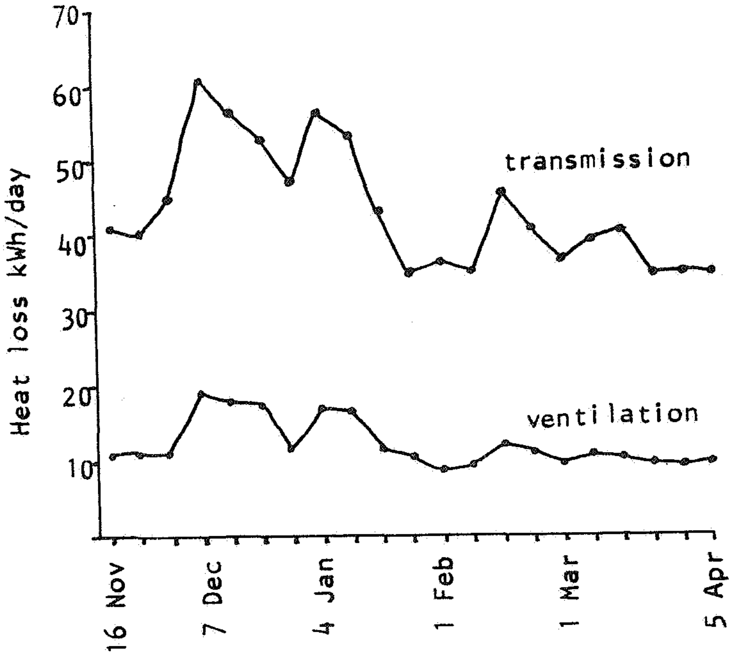


Fig. 8 Transmission and ventilation heat losses - daily average for each week 16 Nov to 5 April

If fresh air enters the heat exchanger at the outside temperature T_o, is supplied to the rooms at a temperature T_1, and exhaust air leaves the rooms at the mean internal temperature T_h the apparent efficiency of the heat exchanger is $(T_1-T_o)/(T_h-T_o)$ which has values of about 0.8. This means that the energy cost of the extra mechanically provided ventilation is only 20% of what it would be if provided by the usual routes, apart from the net fan power loss which is less than 2 kWh/day.

11. CONCLUSIONS

Heat recovery mechanical ventilation systems can be successfully built into conventional electrically heated British housing with only minor modifications. However, to obtain the full benefit much more care than is customary must be taken to build a house which is as leak-tight as possible.

Air tightness is a new criterion for houses both on the drawing board and on site. A learning period is to be expected at the end of which it should be possible to construct a house which does not have to be sealed as a separate exercise after completion.

However, even with half of the ventilation supplied by accidental leakage, it is possible to provide a comfortable environment with no condensation and low running costs.

User reaction is favourable. Systems are used as they were intended to be and there has been no window opening during the heating season.

12. ACKNOWLEDGEMENTS

The co-operation of the Building Site Agents and of the owner-occupiers in these four houses has been essential to the success of the project and is gratefully acknowledged.

13. REFERENCES

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2. Dickson, D.J.
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