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The Energy Efficiency and Environmental Impact of Domestic Mechanical Ventilation Systems in the United Kingdom

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ABSTRACT

Balanced mechanical ventilation with heat recovery (MVHR) offers, in principle, a way of reducing carbon dioxide emissions from dwellings. In order for such systems to produce a clear reduction in CO_2 it is necessary for the emissions from the low temperature heat saved to exceed those from the electricity used to drive them. This condition places a lower limit on the coefficient of performance (CoP) of MVHR systems, which in the UK is around 3.

The major variable in system performance is the electrical input to the fans. The electrical input required to drive MVHR systems available in the UK, based on manufacturers' literature, varies between 60 and 170 Watts. The lower end of this range implies a coefficient of performance just above 5, while the upper end of the range implies a CoP below 3. It therefore appears that a number of systems currently on the market in the UK may fall below this limit, while the best are only just above. In contrast, theoretical calculations suggest that an electrical input as little as 10 Watts might be sufficient for a carefully designed system, giving a CoP of 30.

A three year project has been established in which detailed measurements of electricity use and energy dissipation in six domestic MVHR systems will be made, followed by the design and construction of a system with a significantly higher CoP.

TERMINOLOGY

CO_2	Carbon dioxide.
MVHR	Mechanical Ventilation Heat Recovery.
UK	United Kingdom of Britain and Ireland.

NOTATION

CoP		Coefficient of Performance.
ΔC	$kgC.s^{-1}$	Net rate of addition to carbon emissions as a result of installing a MVHR system in a dwelling.
C_e	$kgC.s^{-1}$	Rate of carbon emission ascribable to electricity used by MVHR system.
ΔC_h	$kgC.s^{-1}$	The fall in rate of carbon emissions from space heating, resulting from heat recovery.
C_p	$J.kg^{-1}.K^{-1}$	Specific heat capacity of air at constant pressure.
c_e	$kgC.J^{-1}$	UK carbon emission coefficient for electricity.
c_g	$kgC.J^{-1}$	UK carbon emission coefficient of gas.
η_b		Thermal efficiency of boiler.
η_x		Thermal efficiency of heat exchanger.
ρ	$kg.m^{-3}$	Mean density of air.
F	$m^3.s^{-1}$	Specific volume flow rate of air supplied & extracted from a dwelling using a balanced MVHR system.
ΔT	K	Temperature difference between room and outside air.
W_e	W	Electrical power requirement of the MVHR system.
ΔW_h	W	Reduction in space heating power requirement, resulting from heat recovery.

INTRODUCTION

Balanced mechanical ventilation with heat recovery offers, in principle, a way of reducing carbon dioxide emissions from dwellings. Such systems essentially consume electricity to reduce low temperature heat demand. In order to demonstrate a clear saving of CO_2 for MVHR systems, it is necessary to account for the carbon intensities of low temperature heat and electricity. It is clear that these intensities depend on details of the systems used to produce each. In the UK more than two thirds of the UK domestic space heating demand is met by natural gas (Evans, 1990), while the electricity system is based predominantly on fossil fired generators with a modest nuclear component (fig 1). Thus for the majority of dwellings, the carbon intensity of low temperature heat is approximately one third that of delivered electricity.

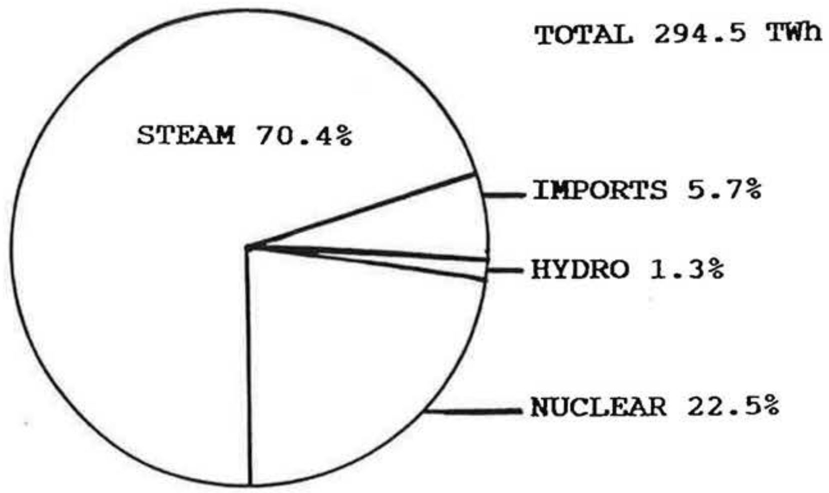

Fig.1 Net electricity supplied by type of plant to UK public supply in 1992

The ratio of heat saved by the MVHR system, to the electrical energy required to power it, is termed the Coefficient of Performance (CoP) of the ventilation system. Literature from six UK suppliers of MVHR systems suggests that the maximum electrical power required by a system is between 70 and 180 Watts. The lower end of this range implies a CoP just above 5, while the upper end of the range implies a CoP below 3.

If one assumes that the heat recovered by an MVHR system displaces heat that would otherwise be supplied by an efficient natural gas boiler, then these systems require a CoP of 3 or more if they are to reduce the total amount of carbon dioxide attributable to space heating in the UK. It appears that a number of systems currently on the UK market may fall below this limit, while the best are only just above.

A three year project has been established at Leeds in which detailed measurements of electricity use and energy dissipation in six UK domestic MVHR systems will be made, followed by the design and construction of a system with a significantly higher CoP. The electrical power required for mechanical whole house ventilation depends on several factors, some of which are determined by the dwelling and its occupants, and others determined by the MVHR system. This study concentrates on reducing energy consumption through technological improvements to the MVHR system itself. Those factors that depend on the dwelling have been fixed, by considering a notional UK dwelling, representative of a late 1970's house design (fig. 2).

A simple attempt to account for the influence of the occupants is made, by establishing energy use, for a range of specific flow rates, over different time periods. Best and worst case duty cycles are used to represent the limits of operating conditions established by occupants. An assessment will be made of the environmental impact of installing MVHR systems in UK dwellings as an energy efficiency measure that provides carbon dioxide abatement.

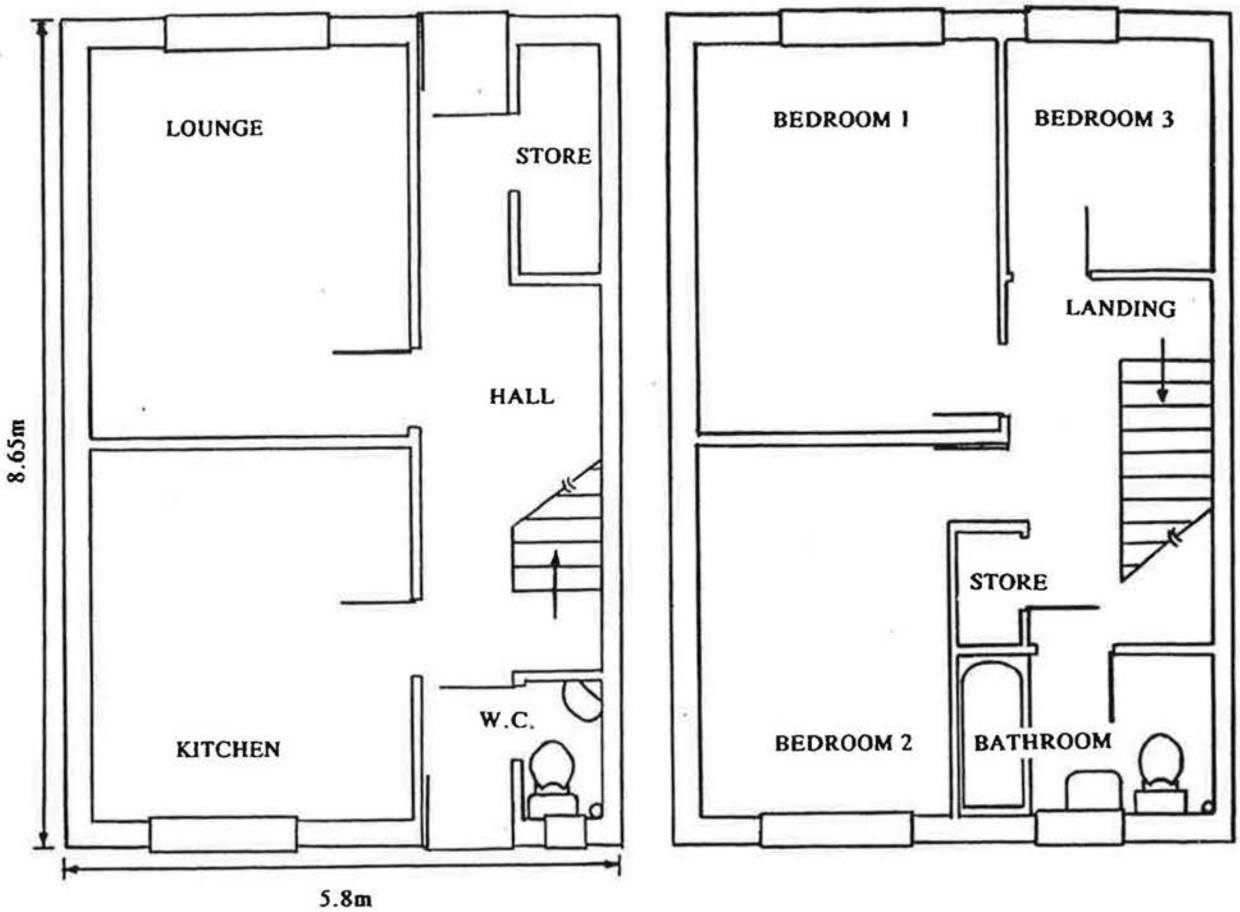

Fig.2 Notional two storey UK dwelling for MVHR study

ANALYSIS OF CARBON EMISSIONS.

The net addition to carbon emissions, as a result of installing an MVHR system is

$$\Delta C = C_e - \Delta C_h \qquad \text{eqn(1)}$$

where Ce is the carbon emission ascribable to electricity used by the MVHR system and ΔC_h is the reduction in carbon emissions resulting from heat recovered. For an MVHR system to produce a net reduction in carbon emissions, ΔC must be less than zero. An MVHR system with a value of ΔC greater than zero generates a net increase in emissions. The limiting condition may be rewritten

$$\Delta C_h / C_e \geq 1 \qquad \text{eqn(2)}$$

If this low temperature heat is supplied by a gas boiler with an efficiency η_b, then the reduction in carbon emissions from reducing the heating power requirement is given by

$$\Delta C_h = \Delta W_h . c_g / \eta_b \ (\text{kgC.s}^{-1}) \qquad \text{eqn(3)}$$

where ΔW_h is the low temperature heat recovered by the MVHR systems, and c_g is the carbon intensity ($kg.J^{-1}$) for natural gas. The carbon emissions (C_e) resulting from the electrical power requirement of the MVHR system is given by

$$C_e = W_e.c_e \ (kgC.s^{-1}) \qquad \text{eqn(4)}$$

where W_e (Watts) is the electrical power requirement of the MVHR system and c_e is the carbon intensity ($kg.J^{-1}$) for electricity.

The limiting condition shown in equation 2 can therefore be written

$$\frac{\Delta W_h.c_g}{\eta_b.W_e.c_e} \geq 1 \qquad \text{eqn(5)}$$

If we note that $\Delta W_h/W_e = CoP$, then

$$CoP \geq \eta_b.c_e/c_g \qquad \text{eqn(6)}$$

The ratio of carbon intensities for electricity and gas in the UK is approximately 3.3 and the most efficient gas boilers available have efficiencies of approximately 0.9 giving a limiting CoP of about 3.

The low temperature heat recovered by a continuously running balanced MVHR system is given by:

$$\Delta W_h = \eta_x.F.\rho.C_p.\Delta T \ (Watts) \qquad \text{eqn(7)}$$

where ΔT is the temperature difference across the thermal envelope of the dwelling. If we substitute the latter form into equation 5, we get the following:

$$\frac{\eta_x.F.\rho.C_p.\Delta T.c_g}{\eta_b.W_e.c_e} \geq 1 \qquad \text{eqn(8)}$$

This can be rearranged to give a limit on the electricity consumption of MVHR systems as follows:

$$W_e/F \leq \frac{\eta_x.\rho.C_p.\Delta T.c_g}{\eta_b.c_e} \qquad \text{eqn(9)}$$

We will refer to the ratio W_e/F as the specific electricity consumption of an MVHR system. For a given climate and in the context of a given energy supply infrastructure, there is relatively little uncertainty in the terms on the right hand side of the above inequality. Our conclusion is therefore that there is a rather clear limit on the specific electricity consumption for MVHR systems.

In the UK the mean outside temperature during the heating season is 6°C. Quoted heat recovery efficiencies for MVHR systems are in the range 0.7 - 0.8. Taking mean air density as $1.22 \ kg.m^{-3}$ and the specific heat capacity of air at constant pressure as $1015 \ J.kg^{-1}.K^{-1}$, then the limiting specific electricity consumption for MVHR systems in the UK is approximately

$$W_e/F \geq 4045 \ (J.m^{-3}) \qquad \text{eqn(10)}$$

LIMITS TO THE ANALYSIS.

UK emission coefficients for gas and even more so electricity are not constants. A full analysis should distinguish between average and marginal coefficients, and the effects of load factor should be taken into account. In the analysis presented above, the average emission coefficients have been used (DOE, 1992). These are derived by dividing energy delivered to final consumers in the UK by the current annual emissions of CO_2 for each industry (not including the effects of energy embodied in the infrastructures of the electricity and gas industries).

The difference between marginal and average emission coefficients for the gas industry is not great - the primary fuel input to the gas system in the UK is overwhelmingly methane, with small amounts of higher alkanes (mainly propane) used to tailor burning characteristics of the gas supplied to consumers. The enthalpy of combustion of methane is approximately 44 $MJ.kg^{-1}$, giving an emission coefficient of just over 1.67×10^{-8} $kg.J^{-1}$. In the long term natural gas will be replaced by other sources of low temperature heat, with a potentially wide range of emission coefficients - coal derived substitute natural gas is likely to have an emission coefficient twice as high as that of natural gas, coal fired combined heat and power may be similar to natural gas, while solar heat will be significantly less.

The picture in the UK electricity industry is much more complex (DTI, 1993). Electricity is generated by a combination of nuclear stations operated continuously, coal fired plant operated in continuous and load following modes, and oil and gas stations. Although nuclear generated electricity has an emission coefficient close to zero, short run marginal generation is all fossil fired. Thus the emission coefficient of short run marginal electricity is roughly 30% higher than the average emission coefficient for the industry.

For an industry in long term equilibrium, the long run marginal emission coefficient will equate to the instantaneous average. This is a justification for using average emission coefficients rather than marginal ones in the analysis above. The UK electricity industry is not however in equilibrium, having recently embarked upon a programme of replacing coal fired generation with relatively more efficient gas fired plant. This policy is not likely to be sustainable in the long term due to the limited availability of natural gas, but at least for the next two decades, the UK can look forward to a reduced emission coefficient for electricity.

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