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CONTROL OF CONDENSATION IN DWELLINGS WITH MECHANICAL VENTILATION

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1. Introduction

Recent building practices with improved insulation and construction methods are contributing towards more energy efficient dwellings by reducing fabric transmission losses and ventilation losses. The increase in energy cost and national energy efficiency drives are also influencing peoples' attitudes towards more energy efficient dwellings. Measures such as wall insulation, draught proofing, removing chimneys and stacks and even modern furnishing materials and living habits have all contributed towards an increase in the indoor air pollution and moisture levels. In many modern dwellings, natural air infiltration has been reduced to such a low level that it is no longer sufficient to maintain an acceptable indoor air quality. As a result, an increase in the concentration of pollutant gases (eg CO_2, formualdelyde, radon, odour, smoke etc) and water vapour is being experienced. This has prompted building standards organisations in some countries (1) to specify minimum ventilation rates for each room of a dwelling. To achieve these requirements mechanical ventilation is needed, either as an extract only system or a combined supply and extract system.

In this paper, some results obtained from a test house ventilated using a supply and extract system with a heat recovery unit are presented. This represents part of an ongoing project to assess the potential of mechanical ventilation in reducing condensation-related problems in Scottish dwellings. The study of other pollutants does not constitute a part of this work. The investigation has been carried out in an unoccupied test house with the moisture-related aspect of occupancy being simulated.

2. Test House

2.1 The House

The dwelling selected for this investigation is an end-terraced, two storey, three-bedroom house situated in Penicuik near Edinburgh. The house was constructed in 1973 with concrete external walls dry lined with a plaster board finish, timber ground and first floor and a pitched tiled roof. Figure 1 is a plan of the house which has a total floor area of $87m^2$. The house was furnished to simulate the hygroscopic characteristics of furniture.

An all-electric heating system was installed as follows:-

(i) an off-peak, night storage heating system in the lounge, livingroom, kitchen, downstairs hall and upstairs hall connected to a weather watch sensor;

(ii) panel radiators thermostatically controlled on time clocks in all bedrooms;

(iii) panel radiator thermostatically controlled in the bathroom.

Pressurisation and depressurisation tests were carried out before ventilation tests were performed to determine the house air tightness characteristics as this influences the mechanical ventilation rate and the effectiveness of the heat recovery system as will be discussed later. Initially, the air leakage rate with carpeted floors and draught proofed windows was 20 ach at 25 Pa. A comparison with BRE pressurisation tests carried out on 100 U K dwellings (2) showed this to be an unacceptably high leakage. The BRE distribution curve showed air change rates ranging from 4 to 25 ach with a mean value at 11.5 ach. Further draught proofing measures were undertaken to reach a target value close to the mean air leakage rate of 11.5 ach. The major leakage paths were identified, using infra-red thermography , as the floor, skirting and eaves levels. As a result, the floors were covered with polythene sheets and the skirting and eaves were sealed. These measures drastically improved the house air tightness and finally an air change rate of 9.5 ach at 50 Pa was achieved.

2.2 Moisture Generation

Since the primary objective was the control of condensation, the moisture generation due to household activities, ie. cooking, washing, cleaning, bathing etc as well as moisture generation due to the occupants' physiological activites were simulated. The moisture due to household activites was produced by an electric immersion heater in a small tank. One such unit was situated in the kitchen and another in the bathroom. These humidifiers were controlled by time clocks and the tanks were automatically replenished with water from a larger header tank. The moisture due to people was simulated by four wet wheel humidifiers distributed in the lounge and bedrooms under time clock control. The nominal moisture generated in each room per day is shown in Table 1 giving a total of 12 kg per day for the house which represent typical rates for a 4-person dwelling (3, 4).

2.3 Ventilation System

The ventilation system installed in the test house was of the air supply and extract type through a plate heat exchanger type Rexovent RDAA situated in the loft. Flakt supply diffusers type CTVA-3 were installed on the ceiling, in the kitchen, dining-room, lounge and each of the three bedrooms. Extract-grilles type KGEA-1 were fitted on the ceiling in the W C, bathroom and each bedroom. A cooker hood type CPAD with electrically-controlled damper provided large extract rates during cooking periods and a small background extract at other times. Figure 1 shows the positions of the supply and extract points in the rooms.

2.4 Data Collection

Measurements of air temperature and relative humidity throughout the test house were required for different ventilation strategies. For this purpose, Freeman Enercon temperature recorders type TM1 were set up in each room and programmed to record the temperature at 15 minute intervals. Thermohygrographs were also installed in the rooms which were provided with humidifiers. Four Freeman Enercon humidity and temperature recorders type TM1H were also installed across the heat exchanger unit to measure the air temperature and relative humidity every 30 minutes.

In addition to the temperature and humidity measurements, the electricity consumption for the house and the water consumption of the humidifiers were recorded over each weekly monitoring period.

3. Ventilation Modes

A theoretical investigation to predict the ventilation rate for a dwelling, which was based on field data of 97 occupied flats (apartments) in Scotland, was reported in reference (5). It was shown that the total ventilation rate Q (ie. natural plus mechanical) is related to the natural air infiltration rate Q_n by

$$Q = Q_n \left(\frac{P_{in} - P_a}{P_{im} - P_o} \right)$$

where P_i and P_0 are the inside and outside water vapour pressures and subscripts n and m refer to natural and mechanical ventilation respectively.

The values of P_{in} and P_0 where obtained from the field data and P_{im} is the desired maximum vapour pressure in the dwelling. Assuming a natural air infiltration rate for the test house of 0.5 ach, which is typical for draught-proofed U K dwellings (6), and a P_{im} corresponding to a maximum of 60% relative humidity, a total ventilation rate of 1 ach is obtained. For the test house, this represents 240 m^3/h of fresh air, half of which is supplied by the ventilation system (ie. Q_s = 120 m^3/h). To maintain an acceptable air supply temperature a larger air extract rate Q_e was used. Values of extract to supply ratio Q_e/Q_s of 1.2 and 1.7 were investigated with two extract modes:

(i) extract from kitchen, bathroom and W C reminiscent of present practice (7);

(ii) extract from kitchen, bathroom, W C and bedrooms, as bedrooms have been identified to maintain large humidity levels particularly at night (5, 8), hence condensation risk zones.

In addition, tests were also carried out without mechanical ventilation but with similar moisture generation rates as in the two ventilation modes.

4. Discussion of Test Results

The results of seven tests are given in Tables 2 and 3 where each test represents the data collected over a six-day period. Figure 2 shows the variation of mean outside vapour pressure with mean outside temperature over the monitoring period. As previously observed (5), the vapour pressure increases linearly with temperature.

Table 2 gives the average external and internal temperatures and relative humidities as well as the rate of daily electricity consumption and moisture generation during each test. The internal values were obtained by averaging the temperature and humidity results from the thermohygrographs in the kitchen, lounge, bathroom and one bedroom. These rooms represent different thermal zones in the house. Although average internal temperatures and RHs were also obtained from the extract air when the mechanical ventilator was operating, it was decided to use the thermohygrograph records so that comparison may be made with the results from the natural ventilation tests.

Table 3 gives the results for the four thermal zones in the house. The table also gives the average RH peaks over the monitoring period for each zone. The normalised internal RH represents the average RH which would be present in the house for outside conditions of 0°C and 80% RH, average internal temperature of 15.5°C and 12 kg/day moisture generation rate.

As would be expected, the results show that the average humidity levels are higher when the house was naturally ventilated than when it was mechanically ventilated. The normalised mean RH in the house ranges between 55% with mechanical ventilation and bedroom extract to about 70% with natural ventilation. With persistance 70% RH in the house, it is likely that condensation and mould growth will form on cold surfaces, such as windows, external walls and "thermal bridges".

Tests 2, 3 and 6 are for an air extract to supply ratio of about 1.7 and tests 8 and 9 are for a ratio of about 1.2. No significant change in the normalised RH was observed with the lower extract ratios, or in the mean inside temperature and the electricity consumption. Generally, with mechanical ventilation, the relative humidity levels were slightly lower when air was extracted from the three bedrooms. Although higher moisture 'swings' were recorded in the kitchen and bathroom, similar but smaller 'swings' were also measured in all the other zones. This suggests that moisture migration occured even with mechanical ventilation and the fact that a large extract rate was introduced in the kitchen by an electrically controlled damper during moisture generation there.

There was no substantial increase in the energy consumption when mechanically ventilating the house because a moderate ventilation rate was used and also because heat (sensible and latent) was removed from the exhaust air which would have been lost through air infiltration when the house was naturally ventilated. An average effectiveness ε for the heat exchanger of about 80% was measured during five tests. This is defined as:

$$\varepsilon = (t_s - t_o) / (t_e - t_o)$$

where t_s is the air supply temperature to the rooms, t_e the air extract temperature and t_o is the outside air temperature.

Because the house was uniformally heated with an average daily temperature of about 17°C and because there were only small temperature differences between the various zones, no condensation was detected except on the windows during the natural ventilation tests. However, if lower temperatures were maintained in the house or in some zones like bedrooms and bathroom, then it can be expected that higher RH levels will be present and possibly more extensive condensation. This case will be investigated in a future test programme.

5. Conclusions

The test results show that with a uniformally and well heated house there is little risk of condensation even when the house is moderately air tight. However, if some zones, like bedrooms and bathrooms, were not well heated it is probable that condensation and possibly mould growth will occur unless mechanical ventilation is used. Although the relative humidity was reduced when the house was mechanically ventilated, it does not appear to be necessary to distribute the air extract points around the various zones in the house. With a uniformally heated house it would be sufficient to locate the extract points at the high moisture producing zones such as the kitchen and bathroom. No significant increase in energy consumption was detected as a result of mechanically ventilating the house due to the high effectiveness of the heat recovery unit being used.

Acknowledgement

This project was supported by the Scottish Development Department through the Scottish Energy Centre, Edinburgh.

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Table 1. Nominal moisture generation rates for each room

Room	Moisture Generation (kg/day)	Duration (h/day)	Humidifier
Kitchen	6.5	2.0	Steam
Bathroom	1.5	1.5	Steam
Lounge	2.0	10	Wet Wheel
Bedrooms (2)	2.0	9	Wet Wheel
Total	12.0		

Table 2 Mean temperatures and relative humidities for test house

Test No	Ventilation mode	Mean Outside temp (°C)	Mean Outside RH (%)	Mean Inside temp (°C)	Mean Inside RH (%)	Normalised inside RH (%)	Moisture generation kg/day	Electricity consum-ption kWh/day	Heat Exchanger Effectiveness (ε)
1	Natural	9.5	74	18.7	73	69	11.3	110	-
2	Mechanical	1.9	78	17.5	62	61	14.3	110	76
3	Mechanical *	-0.1	76	16.1	61	55	15.9	107	83
6	Mechanical *	-0.1	79	16.2	59	60	12.6	112	83
7	Natural	-3.0	75	14.0	63	65	12.1	118	-
8	Mechanical	0.9	77	16.3	58	60	12.2	107	84
9	Mechanical *	1.5	71	17.3	56	58	13.7	105	78

* with bedroom extract

Table 3 Temperatures and relative humidities for different rooms

Test No	Kitchen			Bathroom			Lounge			Bedroom		
	Mean temp (°C)	Mean RH (%)	Mean RH peaks (%)	Mean temp (°C)	Mean RH (%)	Mean RH peaks (%)	Mean temp (°C)	Mean RH (%)	Mean RH peaks (%)	Mean temp (°C)	Mean RH (%)	Mean RH peaks (%)
1	19.0	63	70	17.8	79	87	19.0	83	90	18.5	65	74
2	17.1	52	59	16.7	67	72	17.0	74	84	19.0	56	61
3	14.9	50	61	15.6	67	79	16.3	73	82	17.7	53	61
6	15.3	49	59	15.7	61	80	15.7	72	75	17.9	52	58
7	11.9	58	71	14.3	71	86	13.0	70	78	16.7	53	59
8	15.4	51	61	15.2	61	75	16.1	68	70	18.3	52	57
9	16.3	48	65	16.9	62	86	16.9	65	69	18.9	50	56

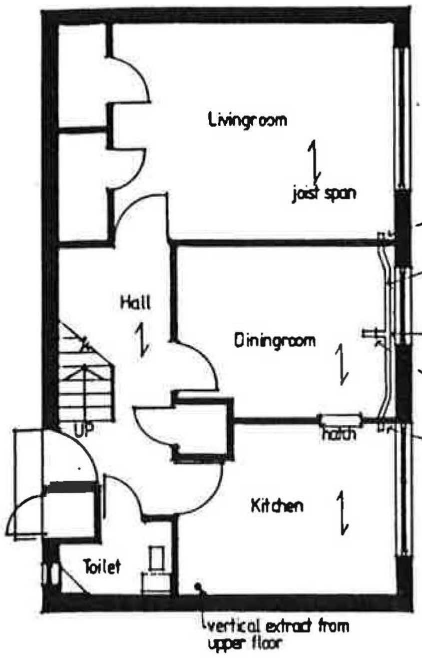

FIG. A-GROUND FLOOR PLAN

Supply ══
Extract ──

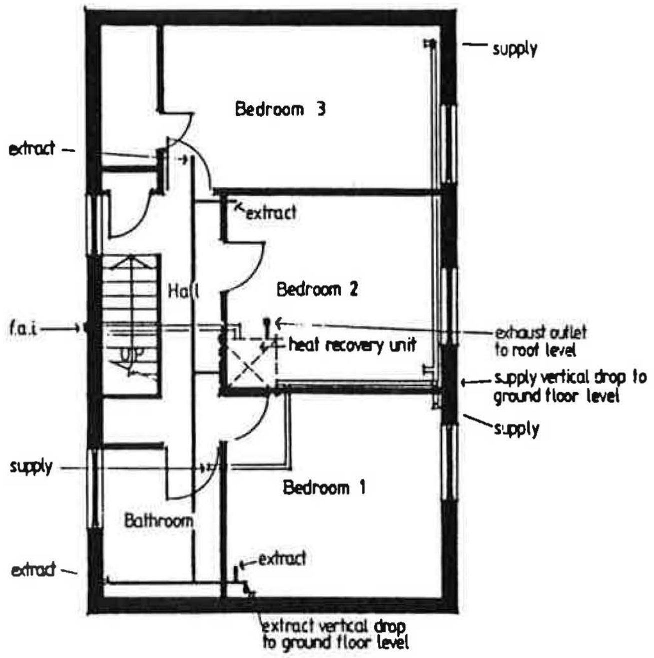

FIG.B-UPPER FLOOR PLAN

Supply ══
Extract ──

FIGURE 1 POSITIONS OF SUPPLY AND EXTRACT REGISTERS

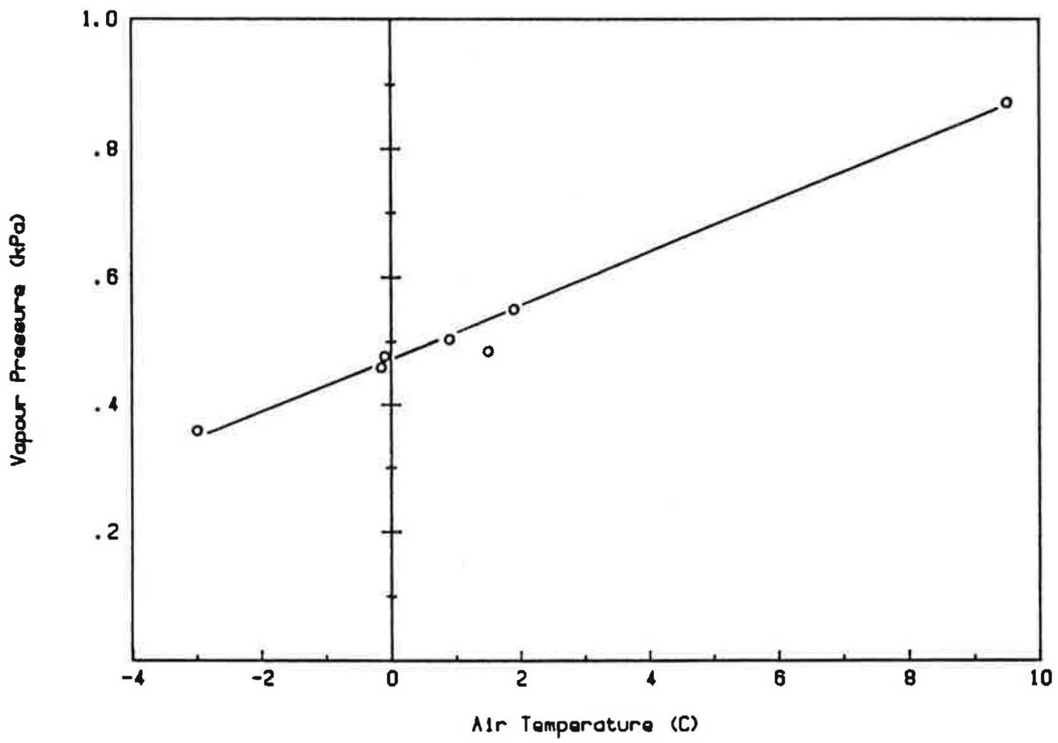

Fig 2 Variation of mean outside vapour pressure with mean outside temperature over monitorin period