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Summary The paper describes a design tool for assessing condensation risk in dwellings and the effect of remedial measures thereon. The BREDEM energy model is augmented by a moisture model to determine mean internal relative humidity (MIRH). This measure of condensation risk is calculated for two zones in a dwelling from mean internal temperatures, moisture generation and ventilation rates. Primary input data relate to occupancy (fuel expenditure and moisture production) and dwelling characteristics (thermal and ventilation). MIRH results are presented as a function of space heating input in example dwellings with remedial measures applied (insulation, draught stripping and extract fans). The constraints imposed by household income and the implications for condensation risk are discussed.

Condensation risk prediction: Addition of a condensation model to BREDEM

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1 Introduction

Condensation is a major problem in many dwellings in the UK, causing an estimated 1.5 million cases of severe dampness[1]. Many of the homes affected are in post-war local authority blocks of flats. A large amount of money is being spent on refurbishing these buildings. At present some of this input is misdirected, as mistakes are made in the design and installation of remedial measures. One reason for error is the lack of adequate tools for making decisions on the best means of remedying condensation and mould growth in particular dwellings.

Recent increased emphasis on energy efficiency in both new and existing buildings, as recommended in BS 8207[2], has led to greater insulation levels and reduced ventilation rates. In many cases the latter have increased condensation related problems. Local authorities do not benefit directly from reducing the energy consumption in buildings since the tenants usually pay the fuel bills. However, if tenants cannot afford to heat their dwellings adequately then the building fabric deteriorates through condensation and mould damage. The cost falls on the local authority through increased maintenance.

Research by the Building Research Establishment (BRE) and other institutions is now leading to a better understanding of the mechanisms causing condensation and mould growth in local authority housing. However, few comprehensive design tools are available which contain the most up-to-date thinking on remedial measure design. Most of the condensation and energy models so far developed (e.g. References 3 and 4) have been far too complicated to be useful in design, and require a level of detail in the input not normally available.

This paper outlines one way of addressing these problems through a combined energy and condensation model. The BREDEM energy model[5] has been enhanced by incorporating Loudon's condensation model[6]. The final objective of this work is to produce a computer package for local authorities. This would calculate the risk of condensation within dwellings using two main parameter inputs; dwelling characteristics and type of occupant (e.g. pensioners, unemployed families, single persons, etc.) as illustrated in Figure 1. Remedial measures (e.g. draught stripping, central heating, etc.) could then be compared for their effect on condensation risk.

The authors' names appear in alphabetical order.

Condensation risk is here taken to mean both the risk of surface condensation and the risk of mould growth due to high humidity conditions on a surface without liquid water present. The paper does not deal with interstitial condensation or rising damp/water penetration which are other common causes of mould growth.

2 Model selection

A condensation risk prediction model which can analyse the effects of changes to building design, moisture control and fuel expenditure requires components which determine the temperature and moisture content of the air inside the dwelling. In practice two integrated models are required; a thermal model and a moisture model.

Current thermal models which deal with energy consumption and internal temperatures in buildings range in complexity from those based on steady-state heat loss for hand calculation to large dynamic simulation models requiring mainframe computers. The latter are all complex and are unsuitable for use as design tools. However, several simple but sophisticated models have been developed to predict annual energy consumption. The BRE have designed the core of such a model, called BREDEM[5], which the present authors considered to be the best vehicle for a condensation risk model. A major advantage is the availability of a very 'user friendly' implementation of version BREDEM-5, which is commercially available as the 'Energy Auditor' computer package[7]. The latter is already widely used as a design tool on local authority refurbishment projects.

BREDEM is a two-zone modified degree–day model which accounts for casual and solar gains, and the efficiency and responsiveness of a variety of heating systems. 'Energy Audi-

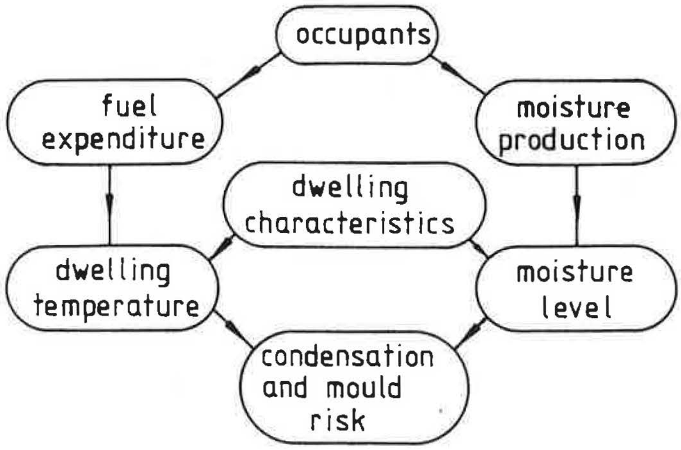

Figure 1 Model for condensation risk prediction

tor' was specifically designed for examining the energy savings associated with improvements to the building fabric and heating systems of existing buildings. The accuracy of 'Energy Auditor' has been tested and reported by Henderson and Shorrock[8].

Much less work has been done on moisture and condensation models than on thermal models, since energy has been far more of a national issue than condensation during the past two decades. The most generally accepted model for prediction of surface condensation and mould growth risk is that due to Loudon[6]. This model uses just two steady-state equations to determine mean internal relative humidity (MIRH); one for energy balance and one for moisture balance in a dwelling or zone. Condensation risk is considered to be unacceptably high if the MIRH in the space exceeds 70%. This work has helped to improve understanding of the interactions between the many factors involved in condensation; it has recently been introduced into a draft revision of BS 5250[9] as a simple design tool. The present authors have therefore chosen to incorporate a moisture balance equation into BREDEM.

3 Interaction of thermal and moisture models

The dwelling is treated as two separate zones as set out in BREDEM: the 'living area' taken as Zone 1 and the 'rest of the house' as Zone 2. The kitchen may be allocated to Zone 1 or Zone 2 depending on the layout of the particular dwelling. The thermal model calculates the mean internal temperature (MIT) of each zone, whole-house ventilation rate and energy consumption over the heating season. The moisture model calculates mean internal vapour pressure for given moisture generation and ventilation rates in each zone. The division of the dwelling into two zones is an improvement on a whole-house assessment since it allows modelling of different modes of heating and moisture production in different parts of the home. The structure of the model is shown schematically in Figure 2.

3.1 Vapour pressure

The steady-state approach assumes that within a given space the moisture generation rate is equal to the rate of moisture removal by air vented to outside less that returned by the make-up air. Internal vapour pressure, as given in the draft BS 5250[9], is then:

$$P_i = P_e + \frac{W}{0.191\,NV} \tag{1}$$

where P_i and P_e are the mean internal and external vapour pressures (kPa). W is the rate of moisture emission (kg day^{-1}), V is the space volume (m^3) and N is the ventilation rate (h^{-1}). This equation is an approximation since prediction of internal vapour pressure is strictly dependent on the density of internal and external air. However, for the present purposes the errors involved are not significant compared with the uncertainties in other input parameters, e.g. moisture production, ventilation rate, etc.

The moisture generated each day in the dwelling is dependent on occupancy and the appliances used (e.g. gas cooker, tumble drier). BS 5250[10] lists typical moisture generation rates for householder activities and for heating appliances.

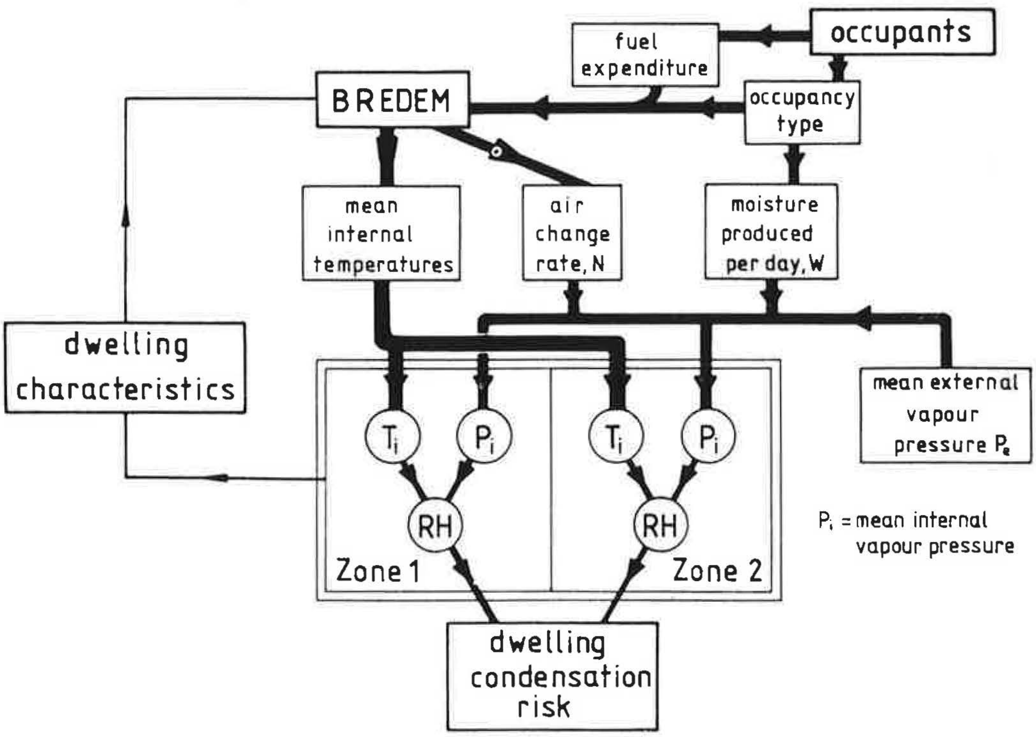

Figure 2 Integration of thermal and moisture models

Table 1 Daily moisture generation for various activities

Origin	Regime	Contribution
Metabolic	Day	½ No. of occupants × Occupancy period × 0.055 kg h^{-1} person^{-1}
	Night	No. of occupants × 7 h × 0.04 kg h^{-1} person^{-1}
Kitchen	Electric cooking	2 kg day^{-1}
	Gas cooking	3 kg day^{-1}
	Dishwashing	0.4 kg day^{-1}
Bathroom	Bathing/washing	No. of occupants × 0.2 kg person^{-1} day^{-1}
	Clothes washing	0.5 kg day^{-1}
Heating	Bottled gas or paraffin only	Total rating × Occupancy period × 0.1 kg kWh^{-1}

These have been combined with occupancy periods to define the daily moisture generation rates shown in Table 1. The way in which this total moisture generation is distributed between the two zones of the dwelling is critical for condensation risk assessment. Rooms in Zone 2 will generally be at most risk since they are usually less well heated than the living room (e.g. bedrooms) and/or contain the areas of greatest moisture generation (e.g. kitchens and bathrooms). Total daytime metabolic moisture generation is calculated assuming that half of the occupants are present in the dwelling for the whole of the heating period. The total is apportioned equally between the two zones.

The algorithm used to determine moisture input to each zone closely follows the recommendations in draft BS 5250 and gives total moisture generation rates comparable to those quoted elsewhere[10,11]. It should be noted that generation rates for activities such as cooking are not related to the number of occupants.

Detailed inter-zone ventilation characteristics of the dwelling are required to determine exactly the moisture transfer from one zone to the other. If a degree of interzone air exchange were to be modelled, then the magnitude of P_e would have to account for make-up air being taken from the adjoining zone as well as from outside. However, this is beyond the scope of currently available input data, and it has been assumed that the two zones are decoupled for moisture migration. The air change rate in each zone is assumed to be equal to the whole-house rate calculated from the thermal model.

Determination of mean internal vapour pressure is very sensitive to the chosen value of P_e. The draft BS 5250 suggests a value for P_e of 0.83 kPa (corresponding to a temperature of 5°C and relative humidity (RH) of 95%, say) which has been used for all calculations presented in this paper. The second term on the right-hand side of equation 1 is small compared with P_e. (From modelling and monitored data it is of the order of 0.3 kPa in occupied dwellings.) Thus relatively small changes in the value of P_e may have large effects on absolute condensation risk. Mean external vapour pressure varies according to the geographical location of the dwelling. However, variations in winter average external vapour pressure between different locations in the UK appear small. Two examples over the period of October to April are Wick, $P_e = 0.74$ kPa, and Kew, $P_e = 0.79$ kPa, derived from monthly averages (1961–70)[12].

3.2 *Mean internal temperatures*

BREDEM determines space heating fuel consumption and cost by utilising the mean internal temperatures (MITs) calculated for Zones 1 and 2. These MITs are then used with vapour pressure to determine mean internal relative humidity (MIRH) for condensation risk assessment. MIT is defined as the 24 h mean temperature averaged over all days in the heating season on which space heating is required.

BREDEM assumes that a suitably large heating system maintains a set temperature in Zone 1 at fixed times. There are three heating demand patterns: (*a*) all-day heating where the set temperature is maintained for 16 h; (*b*) morning and evening heating, set temperature maintained for 9 h and (*c*) evening-only heating where the set temperature is maintained for 6 h. Recent field studies[13] have provided substantive data on periods of dwelling occupation by various groups and the metabolic activity rates during these periods. In the present study two occupancy periods have been used of nine and sixteen hours per day; these are the times for which the heating system is operated both during the week and at weekends. A nine hour occupancy is assumed for employed families and unemployed families with no children. Old age pensioners and unemployed families with children are assumed to have a sixteen hour occupancy.

There are three ways in which the heating of Zone 2 is treated: (*a*) Zone 2 is heated to the same heating demand pattern as Zone 1 with a set temperature a fixed differential below that in Zone 1; (*b*) only part of Zone 2 is heated as in (*a*), the other part being unheated; (*c*) Zone 2 is unheated. MIT in each zone is also determined by the casual heat gains and the responsiveness of the heating system. The latter refers to the time constant of the decay rate of internal temperature in the dwelling at the end of a heating period.

Several reservations must be attached to the use of the mean internal temperature as derived by BREDEM. For example, it is possible that the MITs calculated by BREDEM have a more critical influence on condensation risk than on the calculation of annual space heating load. Of particular note are the assumptions regarding fixed casual gains, calculation of inter-zone heat transfer coefficients and the use of a fixed outside air temperature for determination of the 'cutoff' temperature[5]. However, these limitations could be easily improved upon in the future. Moreover, BREDEM in its present form is certainly more sophisticated than other time-averaged calculation methods for MITs, since it takes account of heating demand patterns, heating system type, internal heat gains and dwelling occupation.

3.3 *Ventilation rate*

An appropriate value of air change rate in a given dwelling or zone is crucial to the determination of condensation risk since the vapour pressure is strongly dependent on this parameter. 'Energy Auditor' calculates air change rate by using four components of ventilation: (*a*) opening infiltration; (*b*) flues and chimneys; (*c*) suspended timber floors, and (*d*) background due to fabric leaks and deliberate ventilation. Each of these has a set value or requires the use of an algorithm based on the dwelling characteristics. Calculated air change rates are limited so that whole-house ventilation ranges between 0.5 and 2.8 h^{-1}.

The calculation of the long-term ventilation rate of any building is complicated, and seldom accurate even using the most sophisticated and detailed models. The method used in 'Energy Auditor' is heuristic and cannot be improved without compiling much more detailed information on a dwelling and its occupants. It allows the separation of effects of various components which might occur in a refurbishment and which could significantly affect condensation risk.

3.4 Extract fans

Of all the active measures available to reduce condensation risk in a dwelling, extract fans are widely considered the most successful and least expensive. It is thus important to assess the effect of extract fans in kitchens and bathrooms. When natural ventilation is being considered then it is assumed that all moisture generated in the kitchen and bathroom is distributed throughout the zone to which they are allocated. Extract fans have two main effects on this situation: Moisture laden air is removed to the outside immediately it is produced during activities such as cooking and washing, thereby reducing the room vapour pressure; The amount of moist air which migrates from the room to the rest of the dwelling is reduced (since the room is depressurised).

For present purposes it has been assumed that fan operation can be modelled by using the effective reduction in actual daily moisture input from a given activity (W_k) to calculate a reduced moisture generation rate (W_{kfan}). The latter is then used as the effective contribution of the activity to total moisure generation in the zone. W_{kfan} is determined by considering the mean room vapour pressures under natural and mechanically assisted ventilation regimes. First the reduced vapour pressure in a room with the extract fan operating may be found from equation 1:

$$P_{fan} = P_e + \frac{W_k}{0.191\,X} \qquad (2)$$

where P_{fan} is the reduced vapour pressure (kPa), X is the fan extract rate ($m^3\,h^{-1}$) and W_k is the actual moisture released into the room (kg day^{-1}). This reduced vapour pressure would also result from the reduced moisture production rate W_{kfan} under a natural ventilation rate N i.e.:

$$P_{fan} = P_e + \frac{W_{kfan}}{0.191\,NV_k} \qquad (3)$$

where V_k is the volume of the room (m^3). Thus, by combining equations 2 and 3, the effective moisture generation rate is given by:

$$W_{kfan} = \frac{W_k\,NV_k}{X} \qquad (4)$$

The effect of the fan on interzone moisture migration cannot be modelled without a complex infiltration analysis. As a first approximation this paper assumes that the effect of extract fan operation on ventilation heat loss is negligible: this may not be the case in practice.

4 Assessment of condensation risk

4.1 Influence of dwelling characteristics

The model described above calculates the mean internal relative humidity (MIRH) of two zones in a dwelling over a winter period. From this figure an assessment of condensation risk must be made. Within a real occupied dwelling the risk of condensation or mould growth will vary widely due to spatial and temporal effects. BS 5250 asserts that condensation risk will be unacceptably high when MIRH exceeds 70%. The validity of this limit is open to question, however, it seeks to account for differences between conditions in the bulk air of a room and those on the inside of external surfaces and for the fact that mould may grow where surface RH is less than 100% (e.g. mould grows on wood when RH exceeds 85%[14]).

In this paper a value of MIRH = 70% has been taken as critical with regard to condensation risk. However, this may underestimate condensation risk in certain dwellings because it is also dependent on the building layout (e.g. the number of externally exposed walls present in various rooms) and on the elements making up the building envelope (e.g. cold bridges). A generally accepted methodology does not yet exist to relate these building characteristics quantitatively to maximum acceptable MIRH. In producing a tool for use by designers, particularly those working on rehabilitation projects, these factors must be taken into account.

4.2 Influence of occupant income

Condensation risk is critically dependent on dwelling MIT which relates to occupant income through space heating input. For lower income groups the amount of money and thus fuel available for space heating is limited (see section 5.3). Hence, dwelling MITs decrease with decreasing income as confirmed by a number of studies, e.g. References 15 and 16. Dividing the dwelling into two zones, living room and the rest of the dwelling, data from a BRE study (using Figure 18 of Reference 16) are presented in Figure 3 to show how decreasing income leads to a progressive fall in the temperature of Zone 2, while that in Zone 1 remains relatively constant. This implies that people with limited

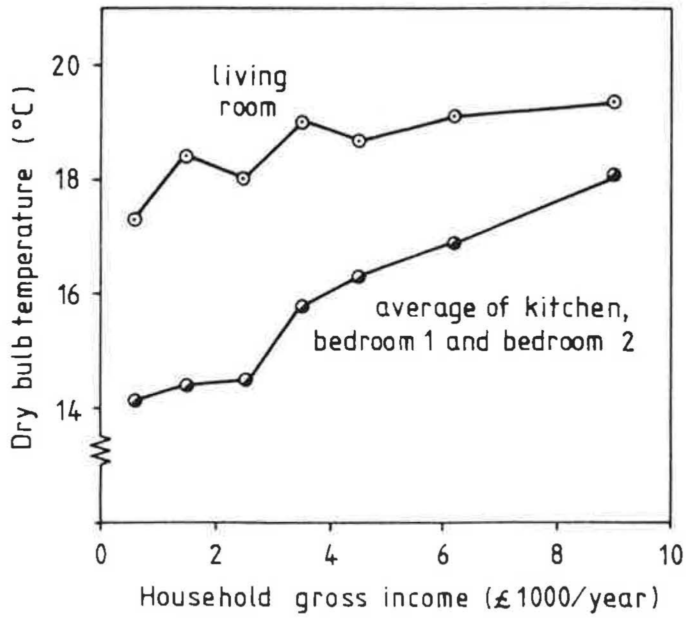

Figure 3 Measured dwelling zone temperatures as functions of household income[16]

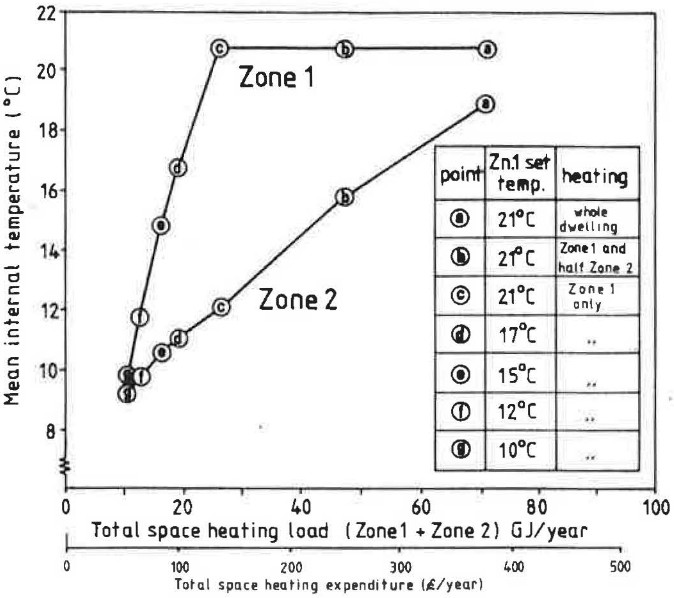

Figure 4 Zone MITs as functions of total dwelling annual space heating load calculated by 'Energy Auditor' for a four-bedroom electrically heated flat

resources maintain a comfortable temperature in their living room while either reducing the heated area in the rest of the dwelling or reducing the temperature at which the latter is maintained.

BREDEM is uniquely structured to model this practice. It allows the calculation of MIT and annual space heating load for the three heating strategies described in section 3.2. The relationship between zone MITs and total dwelling space heating load is assembled for a given dwelling and occupancy. This process is effected by performing a number of BREDEM calculations for different areas of heating in Zone 2 and decreasing demand temperature in Zone 1. The way in which the BREDEM model simulates the findings of Reference 16 is seen by comparison of Figures 3 and 4.

5 Use of the model

The integrated thermal and moisture models have been applied to two specific buildings to illustrate the operation of the condensation prediction method.

5.1 Description of Case 1

The first case concerns a top-floor four-bedroom flat (on a rehabilitated 1940s estate). Constructional and thermal details are given in Table 2. Figure 4 shows mean internal temperatures (MITs) in Zone 1 (living room) and Zone 2 (remainder of dwelling) plotted against total annual space heating load and fuel cost. The heating mode and set-point temperatures for Zone 1, as described above, are shown for each point calculation by 'Energy Auditor'. (Note: All space heating loads discussed below refer to the total space heating load for the dwelling, i.e. the sum of the loads in Zone 1 and Zone 2.)

5.2 Calculation of MIRH for Case 1

The way in which the thermal and moisture calculations are integrated for determination of MIRH is illustrated in Figure 5. The operating points for each zone in the bottom left quadrant set the characteristics of dwelling occupation (i.e. rates of moisture production and fuel/income available for space heating). Zone MITs are then calculated using 'Energy Auditor' for the given building and occupation (bottom right of Figure 5) and zone vapour pressure is calculated using equation 1 (top left quadrant). Thus, mean internal relative humidity (MIRH) may be determined from the psychrometric chart in the top right quadrant.

Table 2 Details of dwellings modelled (Degree-days = 2500)

Building element	U-values and areas	4-bed top floor flat	3-bed 2-storey terrace house
	U-value ($W\ m^{-2}K^{-1}$)	1.8	1.7
External walls	Gross area (m^2)	87.5	41.0
	Zone 1 area (m^2)	12.0	15.0
	U-value ($W\ m^{-2}K^{-1}$)	0.4	1.4
Roof	Gross area (m^2)	100.0	43.0
	Zone 1 area (m^2)	19.7	0.0
	U-value ($W\ m^{-2}K^{-1}$)	NA	0.8
Floor	Gross area (m^2)	NA	43.0
	Zone 1 area (m^2)	NA	19.0
	U-value ($W\ m^{-2}K^{-1}$)	5.8	5.0
Glazing	Gross area (m^2)	13.5	16.0
	Zone 1 area (m^2)	2.3	5.0
Doors	*U*-value ($W\ m^{-2}K^{-1}$)	3.4	2.4
	Gross area (m^2)	1.9	3.0
Volume	Zone 1 (m^3)	47.3	45.6
	Zone 2 (m^3)	192.7	160.8
Heating system		Electric storage radiators	Gas CH
Occupancy		2 adults + 3 children	2 adults + 3 children

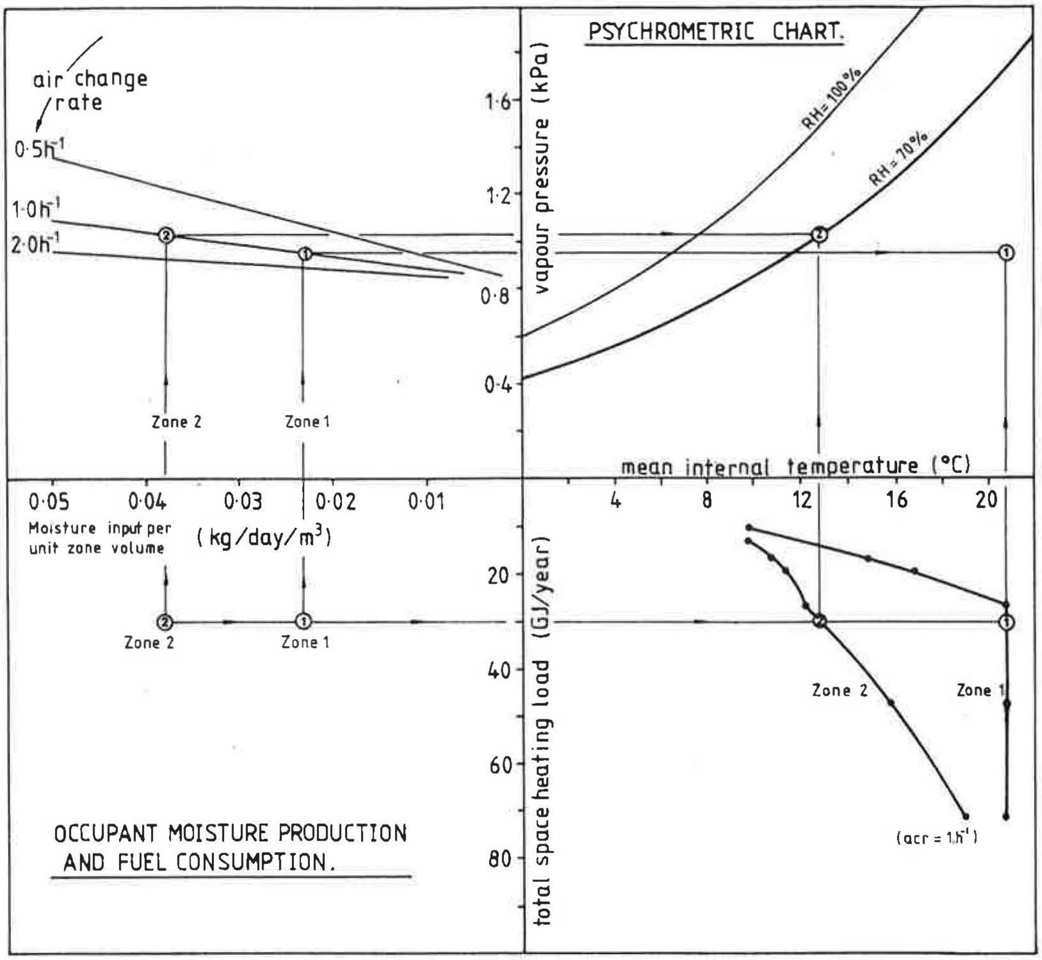

Figure 5 Illustration of the calculation of MIRH by integration of the thermal and moisture models for a four-bedroom flat

A convenient indication of condensation risk is given by plotting MIRH for each zone against total space heating input. An example is shown in Figure 6 for the four-bedroom flat assuming moisture production from a five-person family. The diagram shows that highest condensation risk occurs in Zone 2 where critical humidity conditions (MIRH = 70%) are reached when the occupants supply less than approximately 27 GJ y^{-1} of space heating.

5.3 Remedial measures for Case 1

Zone MITs, vapour pressures, and hence condensation risk, are all influenced by the mean air change rate (ACR) of a

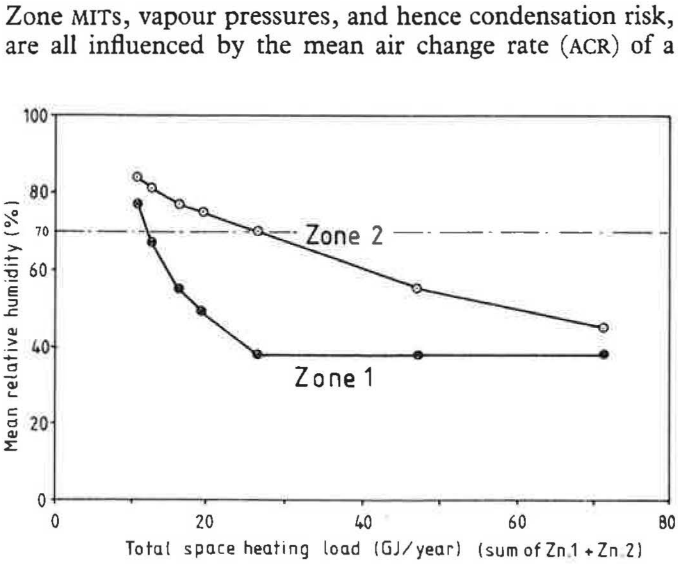

Figure 6 Zone MIRH as a function of dwelling annual space heating load for four-bedroom flat occupied by a five-person family

building. Figure 7 shows MITs plotted against space heating load for the top floor flat with three different ACRs. These results serve to emphasise the importance of taking proper account of the effects on condensation risk of remedial measures such as draught stripping. For a relatively leaky house with a mean ACR of 2.0 h^{-1}, occupants must supply at least 26 GJ y^{-1} total space heating to avoid condensation in Zone 2. If draught stripping were applied and the ACR reduced to 0.5 h^{-1}, MITs would be significantly increased but condensation risk would also increase because of the accompanying rise in internal vapour pressure. To maintain the same risk of condensation occurrence in Zone 2 after draught stripping, heat input must be increased by 7 GJ y^{-1} to a total of 33 GJ y^{-1}. This represents an extra fuel cost for off-peak electrical heating of approximately £37 which occupants may not feel able or inclined to provide.

5.4 Description of Case 2

To facilitate comparison of results with those of earlier studies, a mid-terrace two-storey house with the same construction as the example house used by Loudon[6] was analysed. Constructional and thermal details are given in Table 2.

Two generic types of remedial measure are available for combatting condensation in dwellings: those which increase mean internal temperature and those designed to reduce internal vapour pressure. An example of insulation (i.e. a measure which increases the MIT) is shown in Figure 8, a comparison between the two-storey mid-terrace house built to the Building Regulations in force in 1971 and an insulated version (cavity fill to external walls and 100 mm insulation

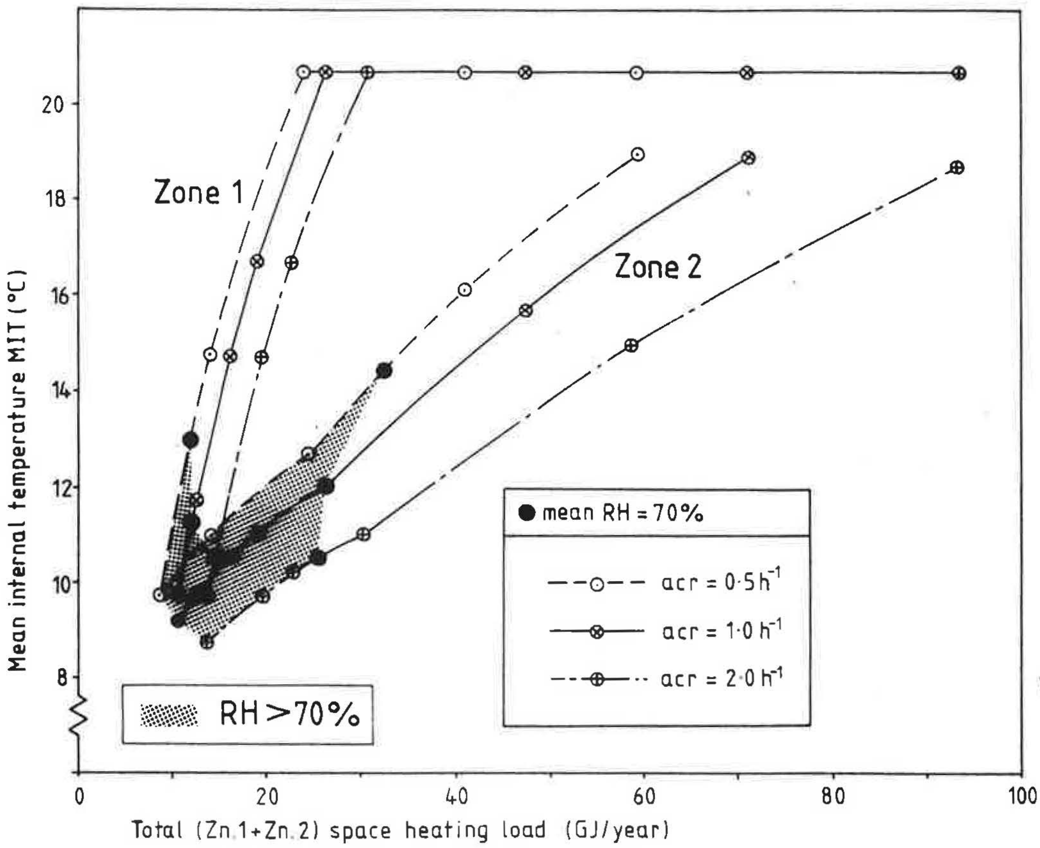

Figure 7 Zone MITs and condensation risk for three dwelling air change rates (four-bed flat occupied by a five-person family)

added to the roof). Moisture production is unaffected by the addition of insulation and condensation risk is therefore reduced for a given annual heat input. Taking the original mid-terrace house to be occupied by two adults and three children producing 8.5 kg day^{-1} of moisture, MIRH of 70% in Zone 2 is maintained for a total space heating load of approximately 52 GJ y^{-1}. The space heating required to maintain the same conditions in the insulated house is reduced by more than half to 25 GJ y^{-1}.

Remedial measures which effectively reduce the input of moisture to the dwelling include the installation of kitchen and bathroom extract fans. Figure 9 illustrates the effect of this in the case of the unmodified mid-terrace house occupied by a five-person family. Using the analysis outlined in section 3.4, extract fans in the kitchen and bathroom were assumed to remove 80% of moisture produced by cooking and

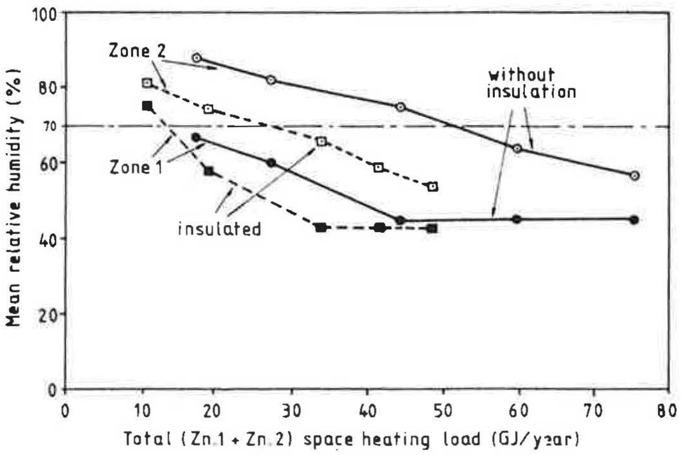

Figure 8 Zone MIRH for standard and insulated versions of a two-storey mid-terrace house (occupied by a five-person family)

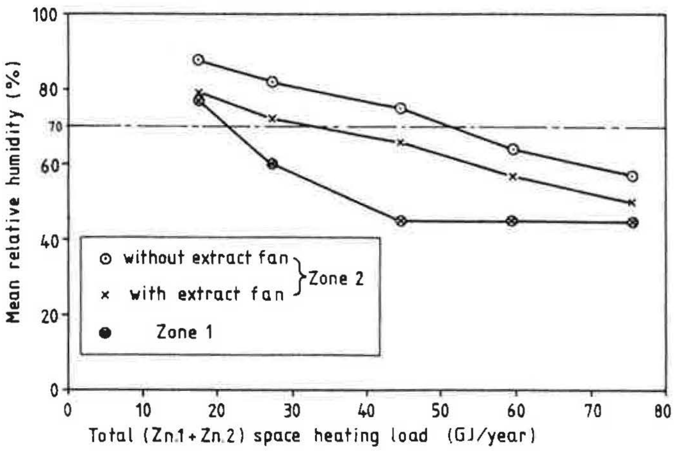

Figure 9 Zone MIRH for a typical two-storey mid-terraced house with and without extract fans in kitchen and bathroom (five-person family)

bathing. The effect of the fans is to reduce the MIRH in Zone 2 by approximately 10% for a given space heating load. The corresponding decrease in the space heating fuel requirement to avoid condensation is 40%.

5.5 Fuel available for space heating

Designers require data on income available for space heating for different types of household. In general terms, low-income households spend proportionately more on fuel than those of higher income, as shown in Table 3[17]. To estimate income available for space heating, one must make some judgement as to how a household apportions its fuel expenditure. As a first step it could be assumed that fuel expenditure for functions other than space heating (i.e. lighting, water heating, appliances, cooking, etc.) is independent of gross income.

Table 3 Percentage of gross weekly income of household spent on fuel, light and power[17]

Income (£ week^{-1})	Proportion spent on fuel, light and power (%)
<40	17.9
40–50	15.3
50–65	14.2
65–80	12.1
80–100	9.5
100–125	8.2
125–150	6.8
150–175	5.8
175–200	5.2
200–225	4.5
225–250	4.1
250–300	3.8
300–350	3.3
350–400	3.2
400–500	2.8
>500	2.8

It is important that local authority designers are aware of how little households have to spend on fuel and how this relates to condensation risk. Consider the mid-terrace house (Case 2) occupied by a five-person family. A recent survey of supplementary benefit payments[18] suggests that a four-person family, with two long-term unemployed adults, paying rent of £18 and rates of £7 per week, presently receives about £102 per week. The addition of a 3 year old child increases this figure to £113 per week (child benefit £10 and heating supplement £2.20). From Table 3 this gives an estimated total fuel expenditure for the five-person family of approximately £9.29 per week or £483 per year. The total cost of hot water heating, cooking, standing charges, lights and appliances as calculated by 'Energy Auditor' is £380 per year, leaving the hypothetical family with £103 per year to spend on space heating. This is equivalent to a heating load of 28.6 GJ y^{-1} (with gas central heating). Reference to Figure 8 shows that this family could not afford to heat their home sufficiently to avoid condensation without the installation of remedial measures such as cavity fill insulation.

6 Discussion

The tool outlined in this paper enables designers to assess the condensation risk which might result from dwelling refurbishment. It enables quantitative comparison of how this risk may be reduced by various remedial measures, e.g. installation of insulation, efficient heating systems and mechanical ventilation. The approach highlights the necessity for dwellings to be appropriate to the needs of occupants; dwelling insulation and heating systems must allow comfort conditions and space heating bills which the occupants can afford. The result of insufficient heating is that people endure reduced temperatures which may lead to mould growth, condensation and building fabric decay. The use of this model will help to identify failures in design (e.g. inappropriate draught-stripping) and so avoid costly maintenance or remedies.

Development of this condensation risk model has been led by demand. The imperative of providing an easy-to-use design tool has resulted in a simplified approach which has several shortcomings and unvalidated assumptions. The approach and the assumptions need to be appraised by others and the model validated against real data and experience. Two main areas of concern are the use of average MIRH and ventilation analysis.

The assessment of condensation risk by using temperature and moisture generation averaged over time and space within a dwelling may not be entirely appropriate. Time averaged MIRH may be sufficiently low to regard a dwelling as theoretically free from condensation, yet condensation may occur at troughs of temperature and at peaks of moisture generation. In addition, thermal capacity of the building fabric is neglected in BREDEM but intermittent heating and occupancy may result in condensation. Similarly, spatial averaging does not account for high condensation risk in specific rooms of a dwelling and at areas of fabric with high local heat loss. These factors could be accommodated through a more sophisticated interpretation of the MIRH value, e.g. by selecting a risk level which depends on layout, building components and occupancy.

Partitioning of the dwelling into two zones, as effected by BREDEM, may not give sufficient resolution for predicting condensation risk. However, analysis of air and moisture exchange between the two zones and to outside is complex. Improving this part of the model will depend on the development of an appropriate ventilation model requiring relatively simple dwelling and occupant data. Similarly, the efficiency of extract fans in reducing internal vapour pressure (under both humidistat and occupant control regimes) needs elucidation.

Validation of this model would take two forms. A great deal of data on monitored humidity levels in occupied dwellings has been gathered (though not assimilated) by a number of research organisations. This data should be used with corresponding site surveys to test this and other models. In addition, many local authorities now record condensation complaints and these could be used more extensively. Results from the condensation enhanced BREDEM model could be compared with those from more sophisticated simulations of condensation in dwellings (e.g. for sensitivity analyses).

The condensation risk prediction model described above is a step towards the development of a more quantitative treatment of dwelling design and redesign which will lead to a greater awareness of the condensation problem and further its ultimate solution.

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