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A steady-state model for predicting hygrothermal conditions in beds in relation to house dust mite requirements

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This paper describes the development, testing and validation of a simple steady-state hygrothermal bed model (BED) which predicts conditions of temperature and relative humidity within the bed core (the occupied space between mattress and covering), given the temperature and relative humidity of the bedroom. BED is the second of three simple steady-state models that in combination allow the impact of modifying bedroom hygrothermal conditions on dust mite populations to be assessed. The first of the trio is Condensation Targeter II, an existing validated model that predicts average monthly conditions of temperature and relative humidity within the bedroom. These conditions are then used as boundary conditions for the BED model which predicts hygrothermal conditions within the bed core. Finally, these outputs are in turn used as inputs to a simple Mite Population Index (MPI) model (to be described elsewhere) that predicts their likely effect on house dust mite population growth in the bed. As reported here, BED has been validated using monitored bedroom and bed data for a full year in three dwellings and the results show that the steady state model predicts monthly bed hygrothermal conditions with a reasonable degree of accuracy. Using Condensation Targeter II and BED in combination, a sensitivity study has been carried out to assess the impact of changes in input parameters of both models on hygrothermal conditions in the bed core. This highlights the importance that the design of the fabric and services of the building has on the hygrothermal conditions in a bed. The impact of climate change has also been assessed using future climate change scenarios.

Practical application: This paper describes in detail a simple steady-state model, (BED) which is used to predict the monthly average temperature and relative humidity within a bed, given the ambient conditions within the bedroon. The input parameters, output parameters and the model formulae are provided so that the model can be easily implemented. BED is the second of three simple models that are used to predict, first the bedroon conditions (Condensation Targeter II), second the bed conditions (BED) and finally the likely effect on house dust mite population growth using a simple Mite Population Index (MPI).

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The Condensation Targeter II and MPI models are described in detail elsewhere. The suite of models allows the testing of the impact of dwelling design and occupant use on likely mite population growth and therefore the health risks of the occupants. It also allows the impact of climate change to be analysed.

List of symbols

A_{body}	surface area of the body (m^2)
A_{head}	surface area of the head (m^2)
C	convective heat losses from the head (W)
d_{cover}	thickness of the bed cover (m)
E_d	latent heat losses by skin diffusion (W)
E_{re}	latent respiration heat losses (W)
h_c	convective heat transfer coefficient for the head (W/m^2 per K)
k_{cover}	thermal conductivity of the bed cover (W/m per K)
L	dry respiration heat losses (W)
M	total metabolic heat gain (W)
Q_{bed}	sensible metabolic heat gains per unit area of body (W/m^2)
R	radiant heat losses from the head (W)
$R_{s.\text{cover}}$	Surface thermal resistance of the cover (m^2/KW)
RH_{bed}	24-h mean relative humidity in the bed core (%)
RH_{unocc}	relative humidity in the unoccupied bed (%)
RH_{occ}	relative humidity in the occupied bed (%)
SVP_{skin}	saturated vapour pressure at skin temperature (Pa)
t_{occ}	number of hours that the bed is occupied each day (h)
T_{bed}	24-h mean bed core temperature (°C)
T_{head}	temperature of the head (°C)
T_{room}	temperature of the room (°C)
U_{mattress}	thermal transmittance of the mattress (W/m^2 per K)
VP_{room}	partial pressure of water vapour in the room air (Pa)
VP_{bed}	partial pressure of water vapour in the bed (Pa)
VR_{body}	vapour resistance of the human body (N/skg)
VR_{mattress}	vapour resistance of the mattress (N/skg)
VR_{cover}	vapour resistance of the cover (N/skg)
ΔT	Temperature difference between the core of the bed (34°C) and the ambient room temperature (°C)

1 Introduction

There is clear evidence that house dust mite faeces are a major causal factor affecting the health of a significant proportion of the population, especially children[1] as well as many adults.[2] There is also clear evidence that the population of mites in dwellings is affected by the conditions of temperature and relative humidity and that mite populations can be controlled by modifying the hygrothermal conditions in dwellings.[3,4] Mites generally favour warm humid conditions. They can survive cool dry periods for short spells but if these become prevalent the mite population declines. Being able to accurately model the conditions in dwellings and beds therefore enables us to look at the impact that changes in the design and use of a dwelling, such as improved ventilation or insulation standards, are likely to have on the size of the population of house dust mites in a bed and hence the health of the occupants.

This paper describes a recently completed multi-disciplinary research council (Engineering and Physical Sciences Research Council) funded project in which two suites of model have been developed to predict hygrothermal conditions within occupied beds and their effects on house dust mite populations. In each case, the suite consists of three models: an existing established model to predict room conditions, a new model to predict bed conditions and a new model to predict the effects on mite population growth. One suite is ‘complex’ in that the models are dynamic, using hourly intervals, and consider the bed habitat as a multi-cell 3D space. These component models, which are seen as more suitable for use in a research context, are described elsewhere.[5] The other suite, described here, and shown in Figure 1, is ‘simple’ in that the models are steady state, using monthly intervals and far fewer variables. This suite is seen as more suitable for use by practitioners such as building designers, energy consultants, environmental health officials and policy makers via its implementation in software which is regularly used for energy consumption and mould risk calculations.[6] As indicated in Figure 1, by bringing the three models together, it is possible to assess the impact on mite populations by modifying any of the input variables at the top of the diagram, either singly or in combination. Thus, for example, one can explore the effect of differences in regional climate, house type (insulation standard, heating provision and air-tightness) and occupant behaviour (thermostat settings, heating cycles, window opening habits and moisture production). In this way the most effective strategy for reducing mite populations can be determined for any given region, house type or occupant behaviour pattern.

2 Modelling hygrothermal conditions in the dwelling

In order to predict the temperature and relative humidity within the bedroom an existing established hygrothermal model is used, Condensation Targeter II. This model incorporates both a thermal model and a moisture model and is described in detail elsewhere.[6] The thermal model used is BREDEM-8, the monthly domestic energy model produced and validated by the Building Research Establishment (BRE).[7] The moisture model used is Loudon’s simple steady-state moisture balance calculation.[8] This moisture calculation assumes that the dwelling is a single zone and

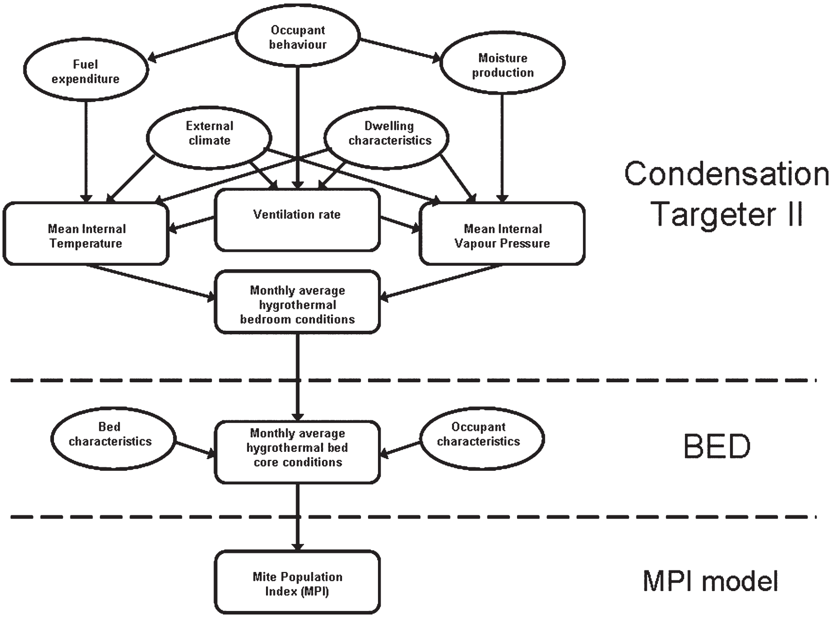

Figure 1 The steady state suite of models

does not account for moisture adsorption or desorption. The Condensation Targeter II model incorporates a sophisticated moisture production rate algorithm, which has been developed following a detailed review of moisture production rates in dwellings.[9] Figure 2 shows the typical range of moisture production rates per person for different activities based upon data found in published literature.[9]

The Condensation Targeter II model has been validated by comparing the measured bedroom conditions in 36 dwellings with those predicted by the model. For the 36 dwellings tested, the mean deviation of the model predictions of relative humidity from the actual relative humidity was just over 5% whilst the mean deviation of the model predictions for temperature from the actual temperature was just under 1°C.[6]

3 Modelling hygrothermal conditions in the bed

This section describes the development of the BED model and the formulae that it uses to determine the monthly average values of bed core temperature and relative humidity, given the room conditions, either as known from monitored data or as predicted by Condensation Targeter II. To avoid confusion, it is emphasized that the bed core is the central space of the bed occupied by the sleeper, not the core of the mattress. The BED model is a simple steady-state model that predicts the monthly averages of temperature and relative humidity at a single specific location in the bed core, directly under the occupant of the bed. It does not predict the average conditions found within the whole mattress. The inputs to the BED model are shown in Table 1.

3.1 Model development

The BED model has undergone significant development since it was first proposed. Many of the assumptions made in early versions of the model were tested and found to be faulty. Early versions of the model assumed constant heat and moisture production rates throughout the year and resulted in very high temperature and relative humidity predictions in the core of the occupied bed.

The BED model overcomes the problems encountered in early versions by adjusting the thickness of the cover so that the bed comfort temperature is maintained at a constant 34°C.

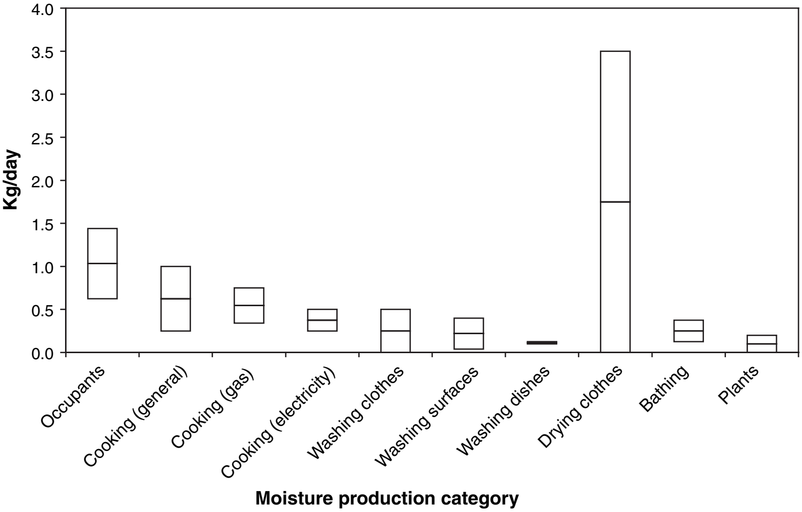

Figure 2 Typical range of moisture production rates for each moisture production category per person (kg/day)

Table 1 Input and output parameters of the BED model

Input parameters	Output parameters
Basic data	
Bed occupant metabolic rate (W/m^2)	
Surface area of occupant (m^2)	
Head radius (m)	
Bed occupant gains	
Number of hours in bed (h)	
Area of mattress exposed to gains (m^2)	
Proportion of gains emitted into bed (%)	
Moisture gains of occupant asleep (kg/h)	
Mattress properties	
Thermal conductivity (W/m per K)	
Vapour resistivity (Ns/kg per m)	
Thickness (m)	
Cover properties	Bed core monthly conditions
Thermal conductivity (W/m per K)	Average temperature (°C)
Vapour resistivity (Ns/kg per m)	Average relative humidity (%)
Occupant properties	
Skin surface temperature (°C)	
Body vapour resistance (Ns/kg)	
Surface resistances	
Cover (m^2/KW)	
Mattress (m^2/KW)	
Bedroom monthly conditions	
Average temperature (°C)	
Average relative humidity (%)	

The moisture calculation then uses the varying monthly cover thickness in the calculation of the moisture in the bed and the bed core relative humidity. In an occupied bed, the human body uses sweating primarily to regulate temperature, not vapour pressure. This has been demonstrated from measurements made in real beds during the development of the complex 3D hygrothermal model.[5] Since the BED model assumes an occupied bed core temperature of 34°C, the impact of sweating has been ignored in this simple model. Although sweating may be important for short periods (and is taken into account in the complex 3D hygrothermal model), BED assumes that the monthly performance is not dominated by this mechanism of moisture transfer but by vapour diffusion through the body.

Comfort within the bed is always assumed when it is occupied. In reality the thickness of the cover on a bed will not vary each month. In most real situations the cover thickness will change only up to twice a year with a winter and summer cover being used, if at all. However, although cover thickness is likely to remain constant for long periods during the year, other factors will tend to maintain a constant internal bed temperature. For example, as an occupant begins to feel too warm in bed they may cover less of their body with the cover, or they may move within the bed. As a result, it is reasonable to assume that the thermal and moisture effect will be similar to having a differing thickness of cover.

The thickness of the bed cover is determined for each month by performing an energy balance calculation for the bed with an assumed constant temperature of 34°C and a fixed sensible metabolic gain into the occupied bed.

Quantifying the sensible metabolic heat gain into the bed is complicated by the fact that, first, it is not the total metabolic heat gain, so radiant heat losses from the head, sensible and latent heat loss through breathing and latent heat loss into the bed due to diffusion of water through the skin has to be accounted for. Second, the metabolic heat gains are a function of the thickness of the cover and so the calculation has to iterate the result.

Figure 3 shows the network diagrams for the thermal and moisture calculations.

The thickness of the cover (d_{cover}) is calculated using the following equation derived from an energy balance assuming fixed internal and external temperatures:

$$d_{\text{cover}} = k_{\text{cover}}\left[\left(\frac{1}{\frac{2Q_{\text{bed}}}{\Delta T} - U_{\text{mattress}}}\right) - R_{s.\text{cover}}\right]$$

The sensible metabolic heat gain into the bed (Q_{bed}) is the key variable, not the total metabolic heat gain (M). For sleeping, the total metabolic heat gain is typically 40 W/m^2 of body surface area.[10] The total metabolic heat gain (M) is the sum of the sensible metabolic heat gains into the bed (Q_{bed}), radiant heat losses from the head (R), convective heat losses from the head (C), latent respiration heat losses (E_{re}), dry respiration heat losses (L) and latent heat losses by skin diffusion (E_d).

Therefore,

$$Q_{\text{bed}} = M - (R + C + E_{re} + L + E_d)$$

Each of these separate components are determined within the BED model using adapted formulae published by Fanger.[10] These adapted formulae have had an appropriate conversion factor (1.163) incorporated to convert from kcal/h to Watts as follows.

For radiant heat losses from the head (R):

$$R = (3.95 \times 10^{-8} \cdot A_{\text{head}}) \times ((T_{\text{head}} + 273)^4 - (T_{\text{room}} + 273)^4)$$

For convective heat losses from the head (assuming that $T_{\text{head}} = T_{\text{bed}}$)(C):

$$C = A_{\text{head}} \cdot h_c \cdot \Delta T$$
$$(\text{where } h_c = 2.38 \cdot (\Delta T)^{0.25})$$

The surface area of the head, A_{head}, is simply calculated using an assumed head radius, which is adjusted to take account of the fact that not all of the head is exposed to the air. The surface temperature of the head, T_{head}, is assumed to be 34°C.

For latent respiration heat losses (E_{re}):

$$E_{re} = 2.67 \times 10^{-3} \cdot M\left(44 - \frac{VP_{\text{room}}}{133}\right)$$

For dry respiration heat losses (L):

$$L = 1.63 \times 10^{-3} \cdot M(\Delta T)$$

For latent heat losses by skin diffusion (E_d):

$$E_d = 3.07 \times 10^{-3} \cdot A_{\text{body}}(SVP_{\text{skin}} - VP_{\text{bed}})$$

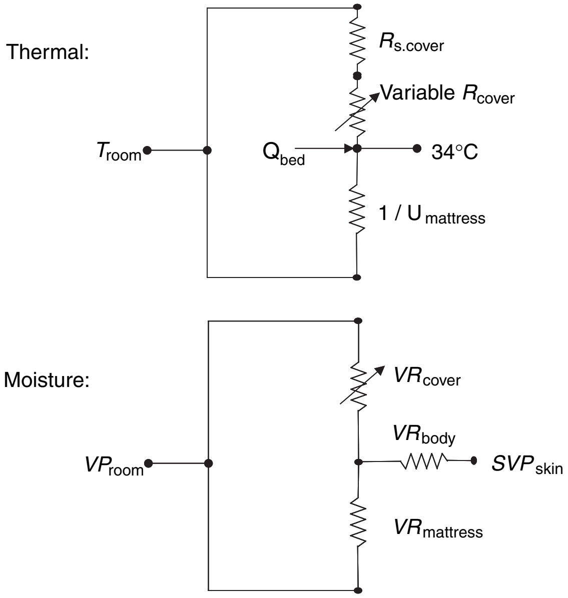

Figure 3 Network diagrams for the thermal and moisture calculations

These formulae are used to determine, by iteration, the thickness of the bed cover for each of the 12 months of the year. Once the thickness of the cover has been determined BED uses a simple thermal and moisture calculation to determine the average temperature and relative humidity in the bed for each month of the year, based upon the flow of heat and moisture upwards through the bed cover and downwards through the mattress.

3.2 Thermal calculation

The thermal calculation is made simple due to the fact that the occupied bed temperature is assumed to be 34°C (the comfort temperature) and the unoccupied bed temperature is assumed to be the ambient room temperature predicted by the Condensation Targeter II model. The number of hours that the bed is occupied (t_{occ}) is required in the calculation, as indicated in the formula below. We normally assume that the bed is occupied for 8 h per night, although other values can be input in the BED model.

$$T_{\mathrm{bed}} = \frac{(34 \cdot t_{\mathrm{occ}}) + (T_{\mathrm{air}} \cdot (24 - t_{\mathrm{occ}}))}{24}$$

3.3 Moisture calculation

The vapour pressure within the core of the occupied bed (VP_{bed}) is calculated using the saturated vapour pressure at skin temperature (SVP_{skin}), the vapour pressure of the air in the room (VP_{room}) and vapour resistance values for the body (VR_{body}), the mattress (VR_{mattress}) and the cover (VR_{cover}) as indicated in the formulae below.

$$VP_{\mathrm{bed}} = \frac{\left(\dfrac{SVP_{\mathrm{skin}}}{VR_{\mathrm{body}}} + \dfrac{VP_{\mathrm{room}}}{VR_{\mathrm{mattress}}} + \dfrac{VP_{\mathrm{room}}}{VR_{\mathrm{cover}}}\right)}{\left(\dfrac{1}{VR_{\mathrm{body}}} + \dfrac{1}{VR_{\mathrm{mattress}}} + \dfrac{1}{VR_{\mathrm{cover}}}\right)}$$

It is important to note that the above equation assumes that the vapour resistivity at the surface of the cover is negligible compared to the vapour resistivity of the cover and so it does not appear in the equation.

As part of the development of the complex 3D hygrothermal model, many measurements have been made in occupied beds, both in real homes and in the laboratory. These measurements show that the lag between occupied bed conditions and unoccupied conditions for both temperature and relative humidity is relatively short in the 24-h cycle. Bed conditions tend to change relatively quickly at the start of human occupation and revert back to room conditions relatively quickly after occupation.[5] Thus while dynamic vapour flow (desorption and absorption) must be accounted for in transient modelling where the timescale of predictions is significantly less than one month, in this model the impact of moisture absorption and desorption will not have a significant effect on the average monthly environmental predictions and so have not been accounted for. Accordingly, when the bed is unoccupied, the vapour pressure within the core of the bed is assumed to be the same as the vapour pressure of the room air ($VP_{\mathrm{bed}} = VP_{\mathrm{room}}$).

Once the occupied and unoccupied vapour pressures have been determined the relative humidity for the occupied bed (RH_{occ}) is determined using the occupied bed temperature (34°C) and vapour pressure (VP_{bed}) and the relative humidity for the unoccupied bed (RH_{unocc}) is determined using the unoccupied bed temperature (T_{room}) and vapour pressure (VP_{room}).

Finally, the 24 h average bed core relative humidity (RH_{bed}) is determined using the number of hours that the bed is occupied (t_{occ}), as indicated in the following formula.

$$RH_{\mathrm{bed}} = \frac{(RH_{\mathrm{occ}} \cdot t_{\mathrm{occ}}) + (RH_{\mathrm{unocc}} \cdot (24 - t_{\mathrm{occ}}))}{24}$$

Figure 4 shows the monthly BED predictions for a typical dwelling in the Thames Valley region of the UK, along with the

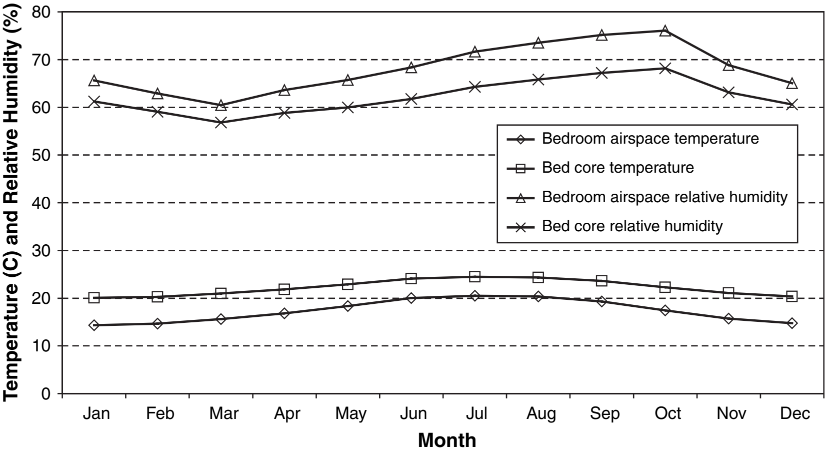

Figure 4 Monthly BED predictions for a typical dwelling in the Thames Valley region of the UK

Condensation Targeter II predictions for the bedroom which have been used as inputs to the BED model in this instance.

4 Validation of the BED model

Long-term monitoring of the environmental conditions in three bedrooms has been carried out using Hobo H8 data loggers manufactured by the Onset Computer Corporation (www.onsetcomputer.com). The accuracy of these data loggers for temperature is ±0.7°C and for relative humidity is ±5.0%. Conditions of temperature and relative humidity in three locations in each bedroom have been measured every 30 min over a period of 2 years. One data logger was positioned in the bedroom away from the bed, one in the bed, with the transducer removed from the logger casing, directly underneath the occupant and one directly underneath the mattress. A fourth data logger was positioned outside of each dwelling collecting simultaneous data for the external climate local to each dwelling.

From the 2 years of monitored data the cleanest and most complete datasets for a full year have been extracted. The monthly averages of monitored temperature and relative humidity have been determined for both the bedroom and the bed core conditions. These have then been compared to bedroom conditions, modelled using Condensation Targeter II, and bed conditions modelled using BED, which itself has used both actual and modelled bedroom conditions as input data.

Figures 5–10 show comparisons between monitored and modelled conditions of

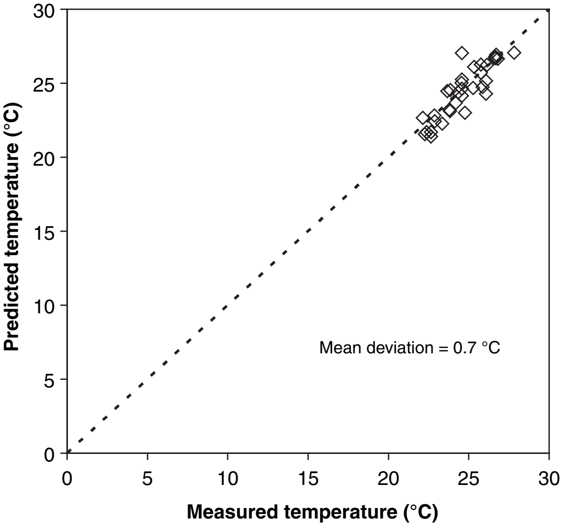

Figure 5 Comparison between monitored and modelled temperature in the bed, using actual bedroom hygrothermal conditions as inputs

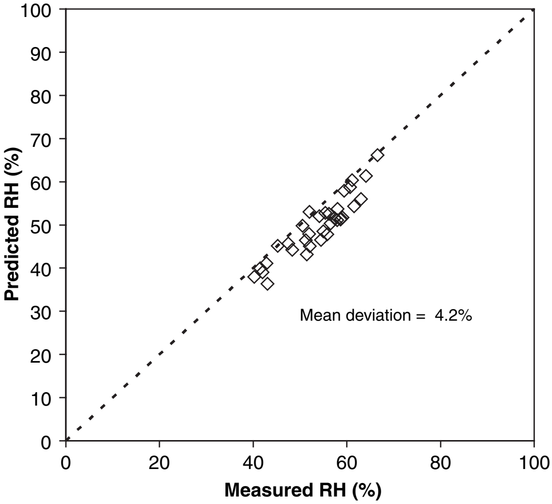

Figure 6 Comparison between monitored and modelled relative humidity in the bed, using actual bedroom hygrothermal conditions as inputs

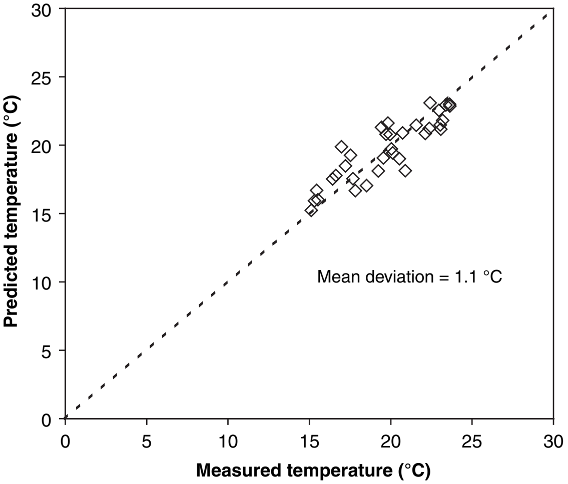

Figure 7 Comparison between monitored and modelled temperature in the bedroom

temperature and relative humidity in the bedroom and in the bed. The dotted lines on these graphs represent perfect agreement between monitored and modelled conditions. Each point represents the result for one bed for one month. The mean deviation of the data from this dotted line is shown on each graph.

Given actual rather than simulated room conditions the results indicate that the BED model predicts the conditions of temperature and relative humidity within the bed core with a reasonable degree of accuracy, given the accuracy of the dataloggers used for monitoring (Figures 5 and 6). The mean deviation between measured and predicted temperatures in the bed is 0.7°C. The mean deviation between the measured and predicted relative humidity in the bed is 4.2%. However, in this case one can see that there is a consistent tendency for BED to slightly underpredict relative humidity. There are a number of reasons why this might be happening, including assumptions relating to material properties of the bedding, comfort, sweating, and heat and moisture transfer, and this is currently being further investigated.

The results for measured and predicted conditions in bedrooms (Figures 7 and 8) show that Condensation Targeter II has again performed well (mean deviation 1.1°C for temperature and 4.5% for relative humidity), although it too slightly under-predicts the average conditions of relative humidity in the bedroom.

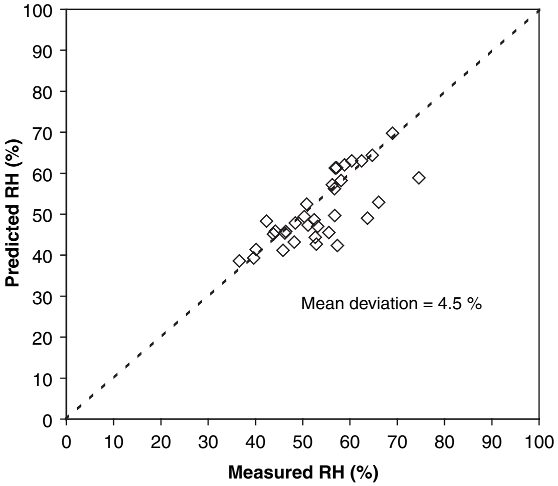

Figure 8 Comparison between monitored and modelled relative humidity in the bedroom

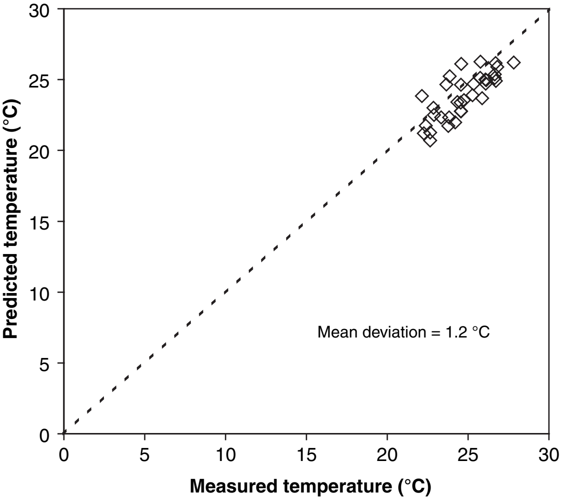

Figure 9 Comparison between monitored and modelled temperature in the bed, using Condensation Targeter II predicted bedroom conditions as inputs

The results for measured and predicted conditions within the bed core, using simulated bedroom conditions provided by Condensation Targeter II, are shown in Figures 9 and 10. The mean deviation is 1.2°C for temperature and 6.2% for relative humidity. Although the latter can still be considered reasonable, the tendency of both models to underpredict average relative humidity requires further investigation.

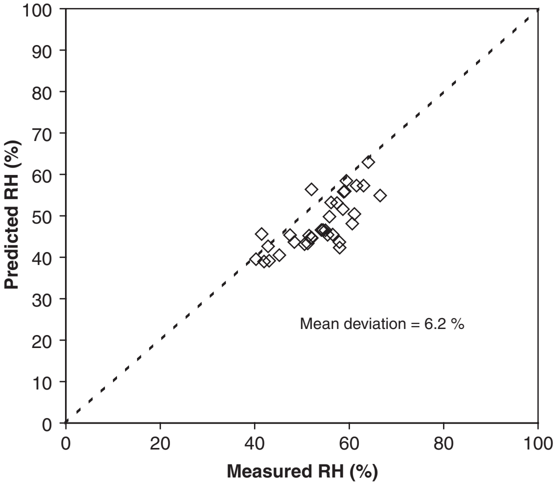

Figure 10 Comparison between monitored and modelled relative humidity in the bed, using Condensation Targeter II predicted bedroom conditions as inputs

It is worth noting that the bed core relative humidity, both measured and modelled, is consistently lower than the bedroom relative humidity, which is counter-intuitive to many people. However, the monitoring of real beds and bedrooms, carried out as part of this research project, has confirmed that relative humidity directly under the occupant does go down when the bed is occupied. This has also been found by other researchers such as Cunningham.[11] The explanation is that although the occupant is producing moisture within the bed, the higher temperature directly under the body more than offsets the increase in vapour pressure at this specific location, thereby reducing the relative humidity in the core of the bed when occupied.

Although house dust mites favour warmth, population growth is adversely affected at temperatures above 30°C. Coupled with the low relative humidity, this means that conditions within the bed core, when occupied, may not favour mite colonization. However, as explained earlier, for almost two thirds of the time, when the bed is not occupied, the conditions are the same as the ambient room conditions. Our detailed measurements show that other positions with the mattress may be more favourable for colonization, provided physical access is achievable at these other locations and food is accessible, although this too is critically dependent on room conditions.[5] Thus although a single point within the bed core may not necessarily be the best location for mite colonization, it can none the less be used as an overall indicator of colonization risk for the mattress as a whole. If average conditions at this point are favourable for mite population growth, then they are likely to be favourable elsewhere in the mattress. And if average conditions are clearly unfavourable at this point, then they are likely to be unfavourable elsewhere within the mattress. The core location also has the practical advantages of accessibility and ease of measurement.

5 Sensitivity of the BED model

The sensitivity of the BED model has been tested by combining it with Condensation Targeter II and modifying the input parameters of both models, in order to assess the impact that these changes have on the predictions of relative humidity in the core of the bed. The input parameters that have been tested thus include both those relating to the occupant and their bed and bedding and also to the fabric and ventilation of the dwelling and occupancy factors such as heating system and controls.

A semi-detached dwelling in the Thames valley region, built to the current Building Regulations, has been used as the base case, and typical occupancy levels and moisture production have been assumed. The base case predictions for relative humidity within the core of the bed is 61.2%.

The sensitivity testing of each input parameter has been carried out separately against the base case scenario. In other words, each input parameter was tested by varying its value within appropriate limits, and once tested the parameter was returned to its base case value before the next input parameter was tested.

The results of the sensitivity testing of the BED model are shown in Figure 11. This shows that the building related input parameters have the greatest impact on the predictions of the bed core relative humidity. Heating pattern, occupancy levels, insulation, ventilation and to a lesser extent demand temperature, all have a significant impact on the predictions of relative humidity ranging between a change of 10% and 15% relative humidity. It is reasonable to expect building related input parameters to have the greatest impact on bed relative humidity, given that it is assumed that the bed is unoccupied for 16 h each day and that it reverts to room conditions during this time.

6 Climate change analysis

Climate change scenarios in the UK have been published by the Climatic Research Unit in Norwich.[12] Using this data the Building Research Establishment (BRE) has published

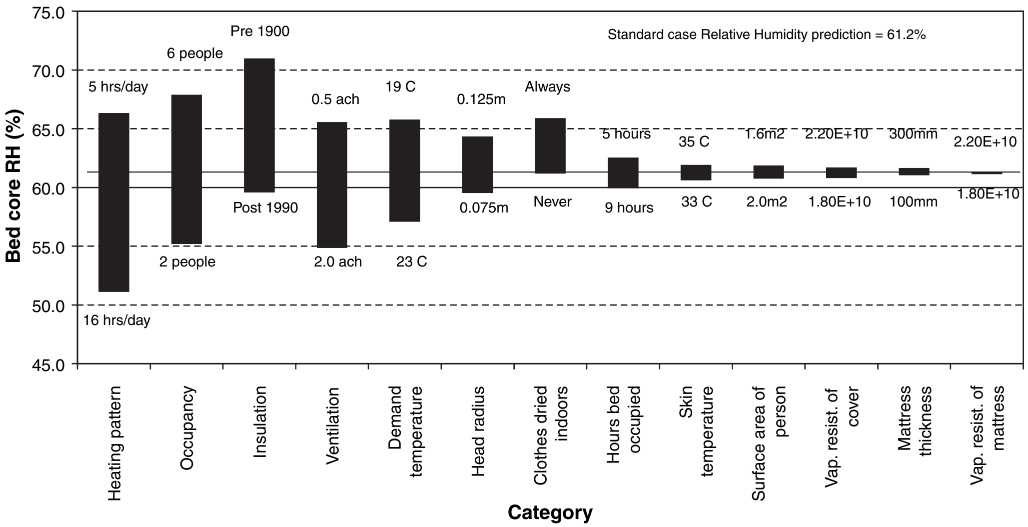

Figure 11 Sensitivity of bed core relative humidity to variations in input parameters of the BED model

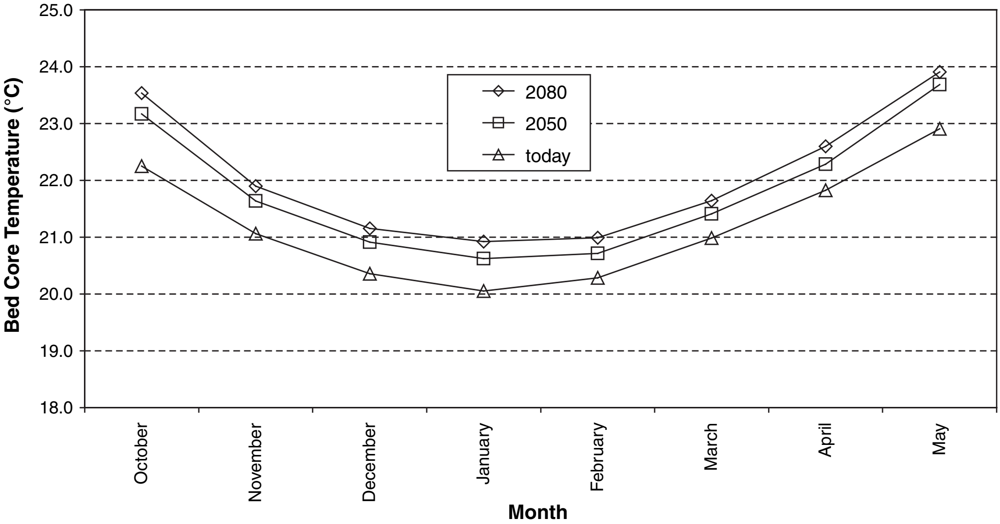

Figure 12 Impact of climate change on bed core temperature

climate change scenarios which give an indication of the likely changes in external temperature and moisture levels in the UK in the years 2050 and 2080.[13]

Using this information, the external climatic data in the Condensation Targeter II/BED model has been adjusted to assess the impact of climate change on the risks associated with the house dust mite in beds.

A typical modern semi-detached dwelling in London has been modelled during the heating season. Figures 12 and 13 show the impact of climate change on bed core temperature and relative humidity respectively.

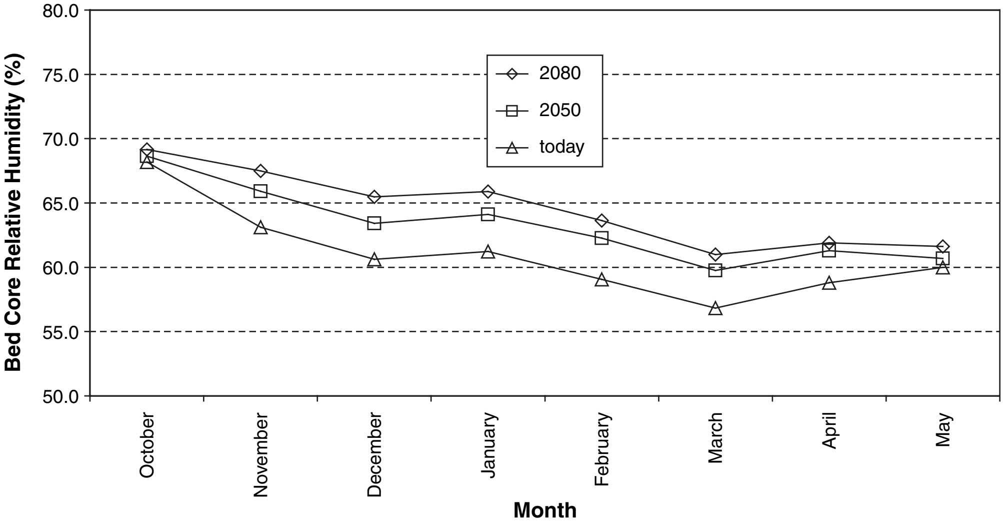

Figure 13 Impact of climate change on bed core relative humidity

The results show that if the published climate change scenaria are accurate then both the temperature and relative humidity in beds are likely to increase. This is not surprising, since climate change predictions suggest that the ambient conditions will be both warmer and more humid. A warmer climate does not necessarily result in reducing levels of relative humidity. Climate change scenarios indicate warmer winters and higher external vapour pressures. The higher external vapour pressures lead to higher internal vapour pressures, which in turn lead to higher bed vapour pressures. On the assumption that the bed core temperature is constant and that we do not sweat any more, this will result in higher bed relative humidities. As a result, the predictions of climate change indicate that the risks associated with house dust mite infestation are going to increase significantly.

7 Conclusions

Both the temperature and relative humidity in a bed are critical factors when determining the population of house dust mites. This is because the temperature impacts on the development time of the house dust mites from the egg to the adult stages of their lifecycle, and the relative humidity impacts on the rate of dehydration and therefore the lifetime of the adult mite. The simple BED model provides a mechanism by which a simple sensitivity study can be undertaken to determine the average conditions that will impact on the population of mites. The BED model predicts the bed core temperature and relative humidity to a reasonable degree of accuracy, albeit that it tends to slightly under-predict the relative humidity. This may be because the model is not sophisticated enough to account for the bed occupant sweating. This requires further investigation.

The sensitivity study presented here highlights the important role that the building environment plays in the bed environment. It demonstrates the potential for controlling house dust mite populations by design modifications to the fabric, ventilation and heating systems.

The BED model has been linked to a simple mite population model, which takes the hygrothermal conditions within the bed to predict the average mite population each month. This work is currently being developed further and will be reported at a later date. In addition, it is clear that house dust mites are exposed to diurnal varying conditions and that the environmental conditions across a bed change from the zone where somebody sleeps to the edge zone where the environment is closer to the room conditions. Mites are able to move to the most favourable environment and ideally this should also be modelled. These factors are taken into account in the more complex hygrothermal and population models that are being developed, in a new EPSRC project (GR/S70678/01). This project involves a major field study involving 36 houses and one of its aims is to further validate the BED model so that it can be used with greater confidence as a predictive tool. The BED model will then be more widely used to determine viable mite control strategies for a range of UK house types.

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