

CONTROLLING HOUSE DUST MITES THROUGH VENTILATION: the development of a model of mite response to varying hygrothermal conditions

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ABSTRACT

There is clear evidence that house dust mite populations in many climatic regions can potentially be controlled by modifying temperature and humidity within dwellings. This paper describes a current multi-disciplinary UK funded research project to develop a predictive model of house dust mite response to varying hygrothermal conditions. The project involves the development of two component models, the first simulating transient hygrothermal conditions in bedding and the second simulating the effect of these conditions on mite populations. The bed model is being developed by adapting existing hygrothermal modelling techniques, starting with a model of conditions within the dwelling and extending it to include the bed environment. It is being tested and validated by comparing predictions with temperatures and humidities measured in a fully instrumented bed in a test laboratory, as well as in normally occupied beds in dwellings. The development of the mite population model is hampered by a lack of available physiological data in certain key areas. Nevertheless the framework for a prototype model has been established, supported by experimental mite studies being carried out in the laboratory. In order to test its output, a series of population growth experiments will be carried out in a computer controlled incubator chamber, where temperature and humidity can be varied to replicate conditions in bedding. Mite samples from field study beds are also being monitored. The aim of the project is to integrate the bed and population models so that one can investigate the impact on mite populations of modifying environment conditions, for example by changes in building insulation, the heating/ventilation regime and occupant behaviour. In this way the most effective and widely applicable measures for reducing mite populations can be determined for a variety of typical house types and climate zones. Similarly, it will enable the likely effect on mite populations of, for example, different climate change scenarios to be assessed. In addition to the complete transient model, a simpler version is being developed for potential use by practitioners, such as building designers, energy consultants, environmental health officials and policy makers.

Key words: House dust mite, hygrothermal, model, bed, population

INTRODUCTION

Allergens derived from house dust mite (HDM) faeces play a major role in allergic disease in many parts of the world, especially in childhood asthma. The number of people affected is rising throughout the world, now impairing the quality of life of a substantial proportion of children (ISAAC 1998) and placing a significant and growing burden on health services. The role that HDM allergen plays in allergic disease has been extensively researched and reported (Platts-Mills and Chapman 1987; Lau *et al.* 1989; Mahmic 1998). The project described in this paper focuses not on the relationship between HDM and health but on the process whereby HDM allergen comes to be in the home. In particular, it investigates the potential for controlling mite populations by environmental means, that is by preventing the hygrothermal conditions they require from occurring. Several studies have indicated that such a strategy can be successful (Harving *et al.* 1991; McIntyre 1992; Raw 1998).

mite physiology

Liquid water is not available to HDM and they generally gain little from food or passive sorption. Instead water intake is achieved by active extraction from unsaturated air via a hygroscopic secretion. Water is simultaneously lost as a result of activity, such as reproduction, defecation and evaporation. The Critical Equilibrium Humidity (CEH) is the RH below which water loss is greater than water intake. As RH rises above CEH, feeding, defecating, mating and egg production all increase (Arlan 1992). Conversely, as RH falls below CEH, all activity reduces in order to minimise water loss. The further RH falls below CEH, the faster mites dehydrate and the quicker they die (the time required varies according to stage of life cycle and species). On the other hand, HDMs can recover quickly from even severe desiccation if short-term (Boer *et al.* 1998). CEH varies with temperature, being lower at low temperatures (Arlan and Vaseline 1981). This is likely in part to be due to the temperature dependence of salt crystallisation which halts the mite's hygroscopic moisture pump.

Since ambient RH increases as temperature falls (for constant vapour pressure), this means that CEH tends to be more easily achieved at low temperatures. However, as temperature falls, egg output slows and egg-to-adult development time increases (Bronswijk 1981). Temperatures have to remain below freezing for some time in order to kill adult mites - indeed they frequently prefer suboptimal temperatures for the sake of higher RH - but mere survival at low temperatures is not necessarily sufficient for population growth. While low temperatures alone tend not to eradicate mites, they do help to reduce proliferation. On the other hand, it is easier to eradicate mites at temperatures above the optimum range, both because RH falls (for constant vapour pressure) and because the CEH rises. Whether mite populations increase thus depends on a) both RH being above CEH and temperature being within the optimum range for a sufficient proportion of time and b) departures from optimum being neither too severe nor too long-lasting.

Mite ecology

HDMs feed on human skin scale and are found in those locations where it collects, in bedding, carpets, padded furniture and soft toys. Since we shed dead skin at a daily rate of 0.5 – 1.0g per person and several thousand mites can survive for months on just 0.25g (Korsgaard 1998), it is possible that HDM populations are not limited by food supply. However, food quality is also a factor, since it needs to be reasonably moist for HDM to digest it. Feeding rates and therefore nutritional uptake and reproduction are thus affected if the moisture content of the food is not high enough. HDM populations tend to flourish in the presence of moulds and one explanation is that mould helps to break down (pre-digest) and soften the skin scale. Another explanation is that mites feed on mould and gain nutritional benefit (Asselt 1999). However, mould activity increases rapidly with rising RH and above about 85% RH mite populations decline as the food supply becomes contaminated by mould toxins.

Climate and population density

At the macro scale, regional differences in HDM numbers can be related to overall climatic conditions (Colloff In Press). Mite densities tend to be highest in warm humid climates, where outdoor humidity and temperature are near ideal for most of the year and indoor conditions tend to be equally ideal. Conversely, mite densities tend to be lowest in cool dry climates, where it is easier to achieve indoor conditions that are too dry for HDMs to survive. However, hygrothermal conditions in the home are affected by several factors other than external climate especially, for example, occupant behaviour in relation to moisture production and ventilation habits. It is thus possible to create conditions favourable to HDMs even in cool dry climates. It is not uncommon to find two identical nearby homes, one with a high number of mites while the other has none, reflecting the different hygrothermal conditions in each case. Such high/low pairs, which are also found in temperate regions such as the UK and the Netherlands, demonstrate the potential for controlling mite populations by environmental means.

Seasonal variations are also important. Even in cool dry climates, the moisture content of outdoor air tends to be high at the beginning of autumn, making it difficult to prevent near-ideal conditions for HDMs. Many studies

have shown that this is when HDM populations tend to be at their peak (e.g. Arlian *et al* 1983). But in winter, the cold outdoor air contains much less moisture, so that a well-heated and well-ventilated house can more easily provide the dry conditions that are inimical to them. Consequently too few survive to take advantage of the following autumn and the population declines. However, if there is inadequate ventilation over winter, humidity may remain high enough for them to survive and prosper. At high latitudes therefore, where cold winters make the provision of warm interiors essential, it is likely that adequate ventilation in winter will be enough to control HDM populations. The Danish experience tends to support this view (Harving *et al* 1991).

In temperate climates, however, the situation is not so clear. Being less cold in winter, outdoor air is less dry and therefore less effective for lowering indoor humidity by means of ventilation. Mild winters also make good insulation and efficient heating less essential, so that bedroom temperatures tend to be lower (as is certainly the case in the UK). This is likely to help HDM survival in winter, because RH will then tend to be higher and CEH will be lower. This may explain why simply improving ventilation alone in such circumstances is not always found to be beneficial (Niven *et al* 1999); a more subtle combination of environmental interventions, possibly including improved insulation, may be required. At the same time, temperate summers may not necessarily be as favourable to mites as generally assumed. In a study of Dutch dwellings, Boer (2000) has found hygrothermal conditions in carpets on some winter days to be more favourable to mites than some summer days. He goes so far as to suggest that a poor summer could be as effective in reducing HDM populations as a cold winter. Achieving the required hygrothermal conditions to control mite populations in temperate climates is therefore a more complex problem than for cool dry climates.

AIMS OF THE RESEARCH PROJECT

The possibility of controlling HDM populations by environmental means has been recognised for some time (eg. Cunningham 1996). However, as indicated above, hygrothermal conditions within dwellings are the result of many interacting factors, many of them constantly changing over time and giving rise to transient effects. This is important because it has been shown that dust mites can survive and even prosper in conditions that are on average hostile, provided there are regular bouts of more favourable conditions (Boer *et al.* 1998). A further complication is that the HDM microenvironment in bedding, carpets and upholstery is distinctly different from room conditions, although affected by them. This is particularly true of bedding, where there are large diurnal variations of both humidity and temperature as a result of human occupation.

Mean room values are thus doubly unreliable in that they take no account of either transient effects or the fact that microenvironments conditions are different. This is unfortunate since they are frequently used in studies investigating the role of environmental variables in determining HDM population and allergen levels (often mean room RH alone is used, ignoring the important effect of temperature on mite growth). In epidemiological surveys, because of the number of dwellings required for statistical significance, measuring mean room values is all that is usually feasible: better indicators of the likelihood of mite proliferation are urgently required.

There is thus evidence that HDM populations could potentially be controlled by environmental means in many parts of the world, but it will be difficult to determine how best to achieve this until we can more accurately simulate hygrothermal conditions in mite micro environments and relate these to mite physiology so that the effect on mite populations can be predicted. This then is the overall aim of the project. If successful, we would be able both to explore the effectiveness of alternative environmental control measures and to investigate better indicators of proliferation. Such a model should provide answers to such questions as:

- How much have past changes in heating and occupant behaviour affected mite populations?
- What impact do energy efficiency improvements have on mite populations?
- What will be the impact of global warming?
- What can I do in my house to control mite populations?

This paper highlights the preliminary findings halfway through a two year research project, covering the results of monitoring environmental conditions and mite populations in laboratory and field study experiments, as well as the development of both a transient hygrothermal model and a corresponding mite population model.

LABORATORY EXPERIMENTS

Environmental monitoring in the laboratory bed

In order to establish the typical environmental conditions within an occupied bed and to validate the transient hygrothermal model being developed, a test bed was set up within an environmental chamber, which had a relatively stable internal temperature and RH compared to a typical bedroom. The first series of test results were carried out using an open cell latex single mattress on a wood slatted base and a synthetic hollow fibre quilt (tog 12). Different mattress types are currently being tested, including open sprung mattresses.

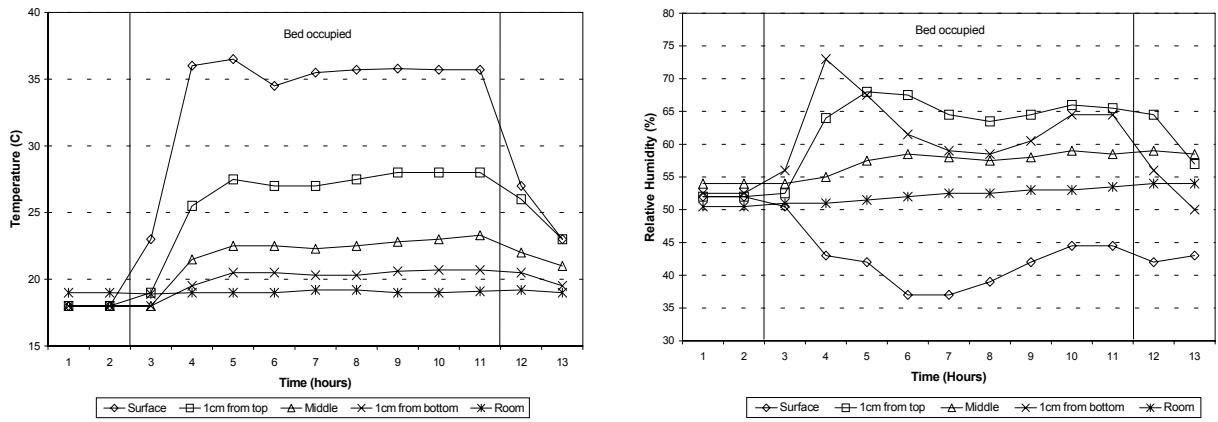


Figure 1: Monitored temperature (left) and relative humidity (right) on the surface and within the mattress

The test bed mattress was monitored for temperature and RH at 75 locations in a grid pattern at the surfaces of the pillow, covers and mattress, and within the mattress depth. Environmental conditions within the room were also monitored. The instrumentation used consisted of two *Campbell Scientific* 23 X micro-loggers with six thermocouple multiplexers. Temperature was measured using Type K thermocouples and RH using miniature *Honeywell* HIH3605A ceramic sensors. Conditions were monitored every second and hourly averages were recorded. Monitoring was continuous, with volunteers being asked to sleep in the bed at night.

The results (eg. Figure 1) show that whilst the bed is occupied the top surface temperature conditions respond very quickly to the skin temperature required for thermal comfort. As a result, the RH at this surface reduces in relation to the RH of the ambient bedroom conditions. The temperatures found within the depth of the mattress are however significantly lower than at the surface. Even at a depth of 0.01m under the top surface the temperatures are typically 8°C below that of the top surface. This significant reduction in temperature, plus the additional moisture diffusing into the bed, results in a RH within the mattress above the RH of the bedroom air. In other words, hygrothermal conditions within the mattress exhibit wide variations both spatially and over time.

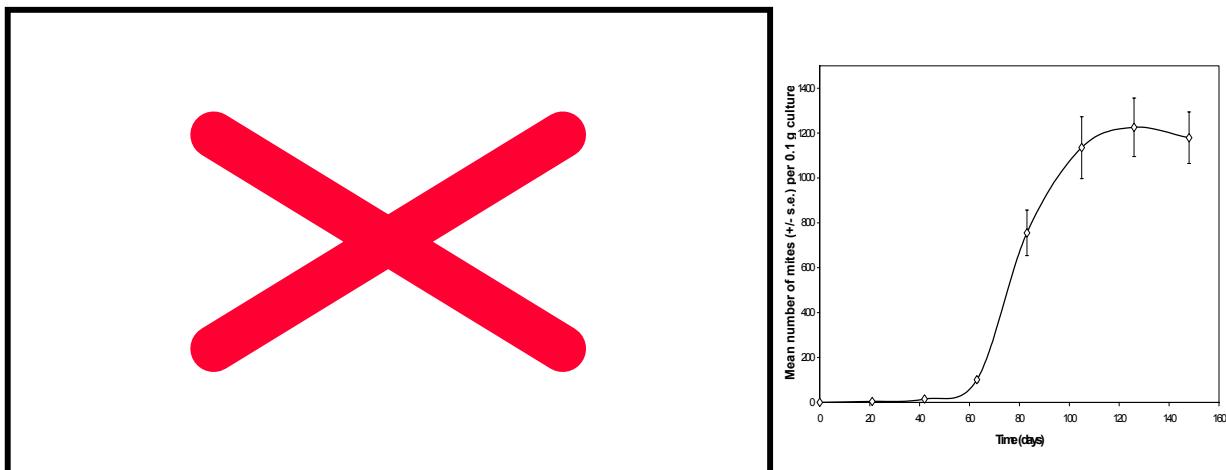
Mite laboratory experiments

By contrast to hygrothermal monitoring, determining the transient distribution of house dust mites within bedding, even in the laboratory, is fraught with difficulty. By cutting a foam mattress into rectangular columns, Boer (1990) has shown, for a particular moment in time, that mites can be found at various depths according to environmental conditions. However, such work is beyond the scope of the current study. Instead, we have focused on finding answers to specific questions that are important for developing the population model.

Mite box experiments

Very little is known about HDM movement or the extent to which mites travel within their microenvironment so as to find the most favourable locations, which the laboratory bed results show are constantly changing. In order to study how mite movement responds to hygrothermal changes, a specially designed mite box has been constructed as shown in Figure 2. Milled out of aluminium alloy with two identical elongated chambers, one instrumented, the other not, the box is surrounded by insulation and has a double glazed lid. A temperature gradient can be established by passing warm water through one end and cool water through the other. A rubber gasket seals the chambers so that vapour pressure is held constant. The temperature gradient thus results in a matching RH gradient along the long axes. It is assumed that the conditions in the two chambers are the same. Live adult mites are placed in the uninstrumented chamber and their movements are observed with a high-resolution digital camera at pre-set time intervals. The digital images are then analysed to quantify the extent and speed of movement according to different temperature and humidity gradients. To date, most of the mite counting has been done by visual inspection, but automated visual processing techniques are being developed.

In the first experiment so far completed, approximately 200 adults were placed in a roughly even distribution within the box. Without a temperature gradient, the distribution remained even (Line 1 in Figure 4). A temperature gradient was then applied, resulting in 18°C and 90% RH at one end and 28°C and 50% RH at the other. After 8 hours the mites had moved such that 7% remained in the driest quarter, with the other quarters containing 21, 34 and 38% respectively, following the humidity gradient (Line 2). A similar distribution was present after 24 hours. When the temperature gradient within the box was reversed, mites began to move in the opposite direction, again towards the end with high humidity, as shown by Lines 3 and 4. In other words, the mites preferred to be in the high humidity regions, despite a lower than ideal temperature. More experimentation



needs to be done before definitive conclusions can be drawn, but these initial results suggest that mites can sense differences in humidity and do move away from dry conditions up a humidity gradient, albeit slowly.

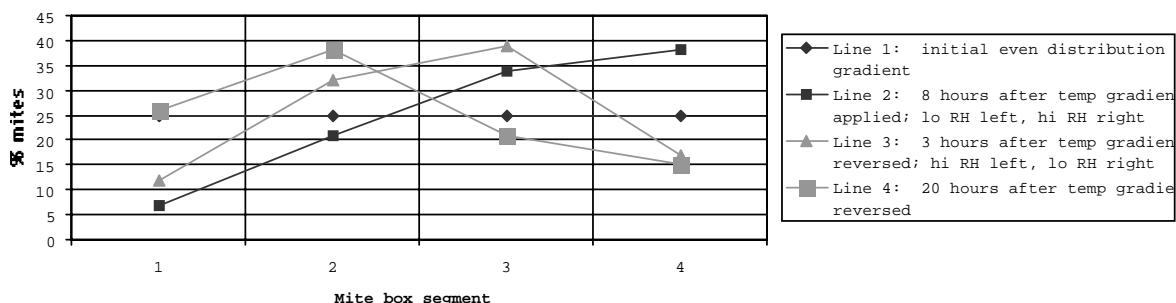


Figure 2: The Mite Box

Figure 3: Population growth for 15 plastic vials of DP at 75% RH & 25°C

Figure 4: Mite movement in the Mite Box in response to temperature and RH gradients (see text)

Population Growth experiments

The house dust mite is unusual in that population growth appears to be relatively free of the normal constraints of food supply and competition from predators. Space or density constraints are also commonly assumed to be absent. However, for population modelling, the maximum density that a population can reach, or carrying capacity, is a fundamental variable that needs to be determined. Since there is surprisingly little data on HDM carrying capacity, the following experiment has been carried out, using *Dermatophagoides pteronyssinus* (DP) mites (the most common species in Europe and many other parts of the world) from laboratory cultures maintained by the Medical Entomology Centre, Cambridge.

Fifteen plastic vials, each containing two pairs of mating males and females with approximately 1.5g of food (50% dried liver, 50% yeast), were kept at 25°C and 75% RH (ideal conditions for DP growth). At regular intervals, weighed samples of culture from randomly selected vials were used to determine population density and, following counting, were returned to the vials. From Figure 3 it can be seen that there was an increase in the mean number of HDMs from the initial 4 mites to a maximum of 1,230 (± 130 standard error) mites per 0.1g culture at day 126. This population growth is sigmoidal and fits closely to what one would expect under the density dependent model, in which case the upper asymptote represents the carrying capacity. This experiment is ongoing, using various volumes of culture and container to determine whether it is space or food which is limiting. In the meantime, it is worth noting that 12,000 mites/g of culture is of approximately the same order as peak values found for mites/g of dust in the field.

Transient condition experiments

Most of the data for mite physiology and population dynamics has been obtained from experiments using steady state hygrothermal conditions, whereas in real life the mite's microenvironment is constantly changing. Andrews et al (In Press) have conducted one of the few studies to investigate transient conditions, albeit over a maximum

of seven days. Using a computer controlled incubator, they subjected mites to the same varying hygrothermal conditions as Cunningham (1998) found in his study of bedding, carpets and upholstery. We intend to carry out similar experiments, using as input data the conditions generated in the laboratory bed experiments described above. In this way we hope to fill in some of the gaps in the data available for developing and testing a population model.

FIELDWORK

The laboratory bed and mite experiments are being supplemented by monitoring the environmental conditions and mite populations in beds in the homes of six of the project participants.

Environmental monitoring in dwellings

Hobo H8 data loggers are being used to record half-hourly values of temperature and RH in three locations in each bedroom: in the room away from the bed, in the bed between the quilt and quilt cover and directly underneath the mattress. A fourth logger is placed outside to collect simultaneous data for the external climate local to each dwelling. This monitoring is similar but less detailed than the laboratory monitoring. On the other hand, it is recording real life seasonal and daily fluctuations in climate over a 12 month period, covering different bedroom conditions, beds and bedding types, as well as a wide age range (10 to 57) of bed occupants.

Although broadly consistent with the laboratory bed results, some interesting variations are emerging. For example, it is noticeable how hygrothermal conditions in the bed are affected by different airing habits, such as replacing the duvet immediately or soon after rising, as against leaving it off for several hours. When the bed occupant is away, on holiday or a business trip, this obviously also affects the monitored values. By the end of the project, we hope to be able to suggest the likely impact of such phenomena on mite populations. Some of the variations in the collected data due to the fact that the beds are monitored at a single point and this is sensitive to the bed occupant moving around (and often away from the sensor) during the night. Since it would clearly be advantageous if future field studies can be carried out without having to use a large number of sensors, this is the kind of practical problem that we hope to resolve.

House dust mite sampling in dwellings

Mite densities in occupied mattresses are normally sampled either by vacuuming the surface and counting the number of mites found in the collected dust, or by leaving 'mite traps', or sticky paper, on the outer surfaces for a period of time and counting the mites stuck to the paper. Unfortunately, neither method is wholly satisfactory since it is difficult to be sure that the sample is representative of the whole mattress, or that all mites in the vicinity are removed. For example, it has been reported that adhesive tape may only recover 8-30% of mites seeded on fabrics (Colloff 1991) whilst vacuuming generally removes dead, rather than live, mites. However, by employing both methods it is hoped that a representative sample of both live and dead mites will be collected. We are also developing a 'caged tube' method, using similar tubes as used for the laboratory population growth experiments, placed at appropriate locations in the mattress. Although mite movement is restricted, they will nonetheless be subjected to real transient conditions, thereby providing data for testing the population model.

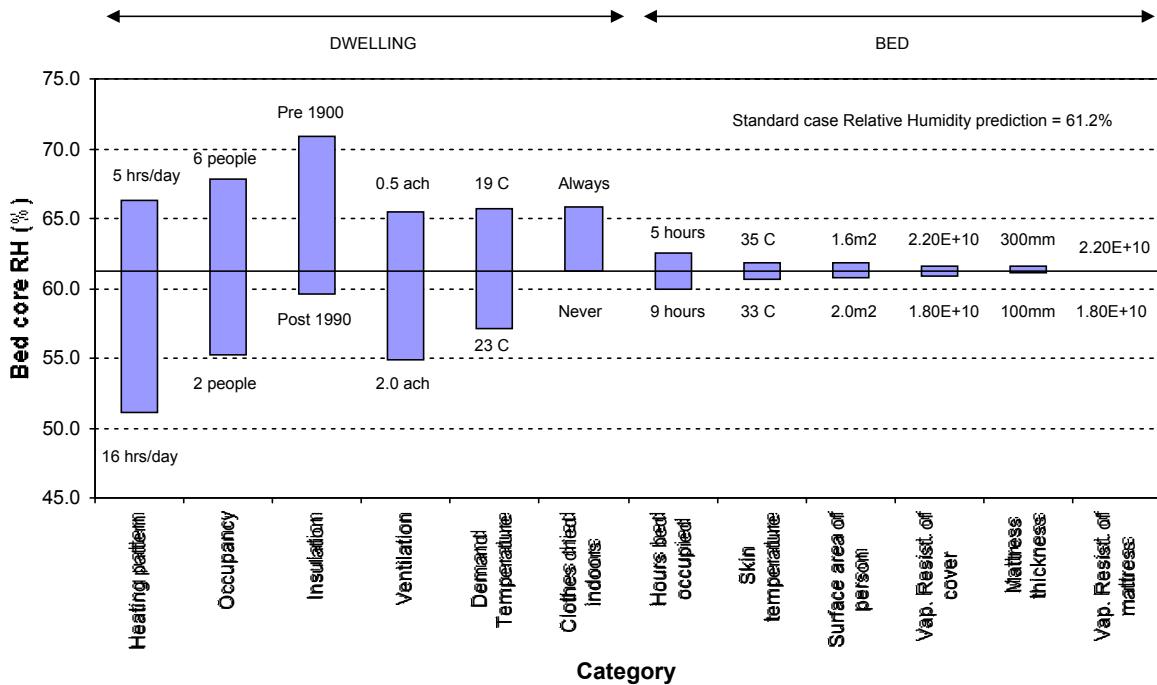
HYGROTHERMAL MODELLING

Steady state modelling of the bedroom and bed

Simple models are inherently valuable for their speed, ease of use and applicability. For this reason, although the focus of the project is to develop transient models, we are also developing simpler versions for general use. A further reason is that such models benefit the project by providing a quick and ready way of investigating overall effects (see below). In the case of hygrothermal modelling, the starting point is *Condensation Targeter II*, a monthly steady state model developed by Oreszczyn and Pretlove (1999). Utilising a modified version of BREDEM-8, this is ideally suited to the prediction of temperature and RH within the airspace of bedrooms. The required data inputs relate to climate, dwelling characteristics, fuel expenditure and moisture production. Despite the simplifying assumptions (in particular that the ventilation rate is constant throughout the year), the model predictions have demonstrated a high degree of accuracy. By extending it to include the bed environment, with input values for vapour resistivities and mattress thickness, the model has been adapted so that it can predict monthly average temperature and RH in the core of bed, ie. between mattress and covering.

Sensitivity analysis has been carried out by modifying the input parameters and assessing the impact that these have on the bed core predictions of RH for the month of January (Fig 5). The base case prediction of bed core RH for January is 61.2%, the central horizontal line. The input parameters tested include those relating to the bed environment (on the right), as well as to the dwelling environment (on the left). It can be seen that the latter have by far the greater impact on the bed core RH predictions. This is a significant finding since it confirms the potential for influencing the mite's microenvironment by modifying these dwelling and occupant characteristics.

A further study has been carried out into the effect of global climate change, using published data for predicted changes in the UK for the years 2050 and 2080 (Graves and Philipson 2000). These indicate that the average external temperature and vapour pressure is likely to increase, whilst the average external RH remains relatively



stable. Inputting these values into the steady state model, the results show that both temperature and RH within the bed are likely to increase as a consequence during winter, becoming more favourable for mite proliferation.

Figure 5: The impact on bed RH as a result of varying the input variables for the steady state model

The TAS/Umidus transient hygrothermal model

A transient hygrothermal model has been developed which predicts hourly values of temperature and RH at a given Cartesian co-ordinate location within the mattress using input data for external climate, building fabric, heating and ventilation schedules, moisture production, hours of bed occupancy, etc. The transient model works in two stages; it models first the hygrothermal conditions within the bedroom and then the microenvironment within the bed. Existing software packages were used in each case.

For the bedroom environment, the model used is *TAS*, produced by EDSL. This is a response factor model which has been tested as part of an IEA thermal model validation study (IEA 1994). *TAS* can predict both passive wind and buoyancy driven building ventilation once the flow characteristics of openings and air leakage paths have been specified. The internal RH is determined using a simple mass balance calculation from the zone temperature, external moisture content and ventilation rate. The main limitation of *TAS* is that it assumes zero building hygroscopicity; other models are currently being investigated that do not have this limitation. For the bed microenvironment, the model used is *Umidus*, a coupled heat and moisture movement model developed by Mendes *et al* (1999). *Umidus* accounts for both diffusion and capillary regimes, that is, the transfer of water in the vapour and liquid phases through the material can be analysed for any kind of climate. The model predicts moisture and temperature profiles within multi-layer elements for any time step and calculates heat and mass transfer. The following properties of the mattress need to be known: thickness and density, thermal conductivity, sorption isotherm and vapour diffusivity.

The transient modelling of the mattress is carried out in a number of steps. Firstly the *TAS* model predicts the hourly average temperature and RH conditions in the bedroom for a full year. These conditions are assumed to be the boundary conditions at the base of the mattress, which has been shown empirically to be the case where the mattress is not sitting directly on the floor. The boundary conditions at the top of the mattress are determined using a spreadsheet calculation called *PreUmidus* which uses the output data from *TAS* and estimates the hourly values of the bed surface temperature and RH for five different zones on the mattress surface. The values of the temperature and RH within each of these zones are based on experimentally observed conditions during occupation of the laboratory bed. Once the occupant has left the bed, the boundary conditions start to change

until they reach equilibrium with the ambient conditions in the bedroom. Experimentation has shown that each of these zones maintains a vapour pressure excess when compared to the vapour pressure of the room. *TAS* and *PreUmidus* therefore provide the boundary conditions at the top and bottom of the mattress and this data is then used by *Umidus* to determine the micro-environmental conditions of temperature and RH within it.

The model has been initially tested by comparing its output with the monitored values for the top of the mattress in one of the project participant's bed (see Figure 6). For this purpose the monitored external climate data was used as a model input, together with surveyed dwelling characteristics. The results show that the average hourly difference between predicted and monitored temperatures is 3.0°C and the average hourly difference between predicted and monitored relative humidities is 5.2%. The main discrepancies are the peaks in the monitored RH recorded during the bed occupation periods. It is possible that moisture production is highest in the first few hours of occupation and there is also the variability noted above due to the occupant moving away from the single sensor. Alternatively this may be a sensor phenomenon and is currently being investigated. The model also assumes that the bed was occupied each night between 10pm and 7am and in reality this is variable.

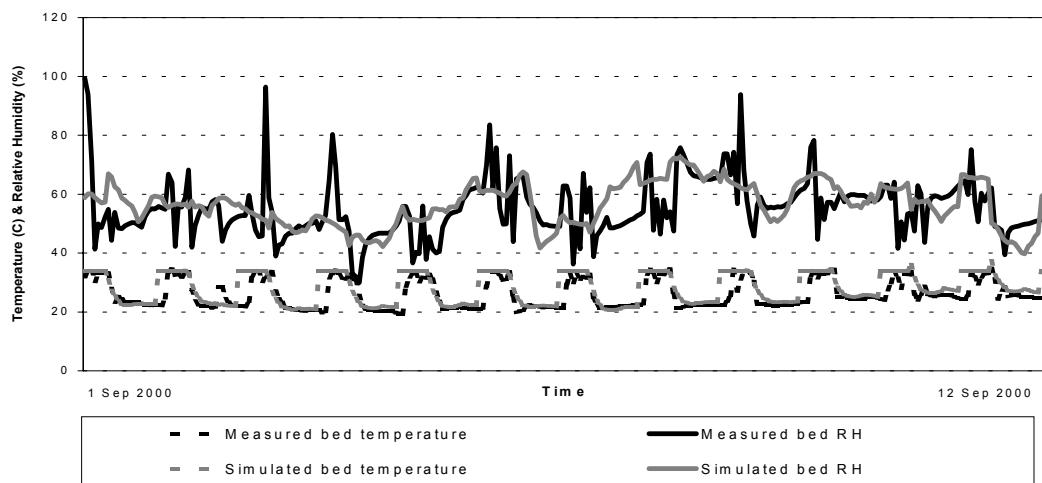


Figure 6: Comparison of *TAS/Umidus* simulation and monitored real bed conditions 1st - 12th September 2000

POPULATION MODELLING

The Mite Index

The simplest form of population model is to relate overall population size to mean hygrothermal conditions. However, as explained above, mean conditions are unlikely to be a reliable indicator for mite growth and it may be better to use a concept similar to the degree-day. Mites for which the CEH is 70% will dehydrate more quickly at 50% RH than at 60% RH and this can be taken into account by calculating the total number of RH-hours below CEH. Similarly, to take account of the fact that egg to adult time significantly lengthens below 25°C, the total number of degree-hours below 25°C can also be calculated. Each of these measures can then be normalised to obtain a number between 1 (ideal conditions for eliminating mites) and 0 (ideal conditions for mite growth). An overall Mite Index can thus be obtained by multiplying them together on an hourly basis and summing over a given time period. The resultant number can be calculated for each spatial zone of the bed. If the Index for all zones is high, this clearly suggests a mite free bed. On the other hand, even a single zone with a low score suggests the likelihood of mite infestation and this likelihood will rise the higher the number of such zones and the lower their scores. Different ways of summarising the overall risk are being investigated.

It remains to be seen whether the Mite Index will prove useful. Being based on simple physics, it has the virtue of transparency and can potentially be used to calculate the risk factor for a large number of combinations of climate zone, building characteristics and occupant behaviour. However, more sophisticated population models, providing a full understanding of mite infestation, are required to test the validity simple indices of this kind.

The Cunningham model

Unfortunately, since complex models of house dust mite population dynamics do not yet exist, it is difficult to determine a priori the optimum level of complexity required. A valuable step forward has recently been made by Cunningham (2000). Using the limited mite physiology data available, he has curve fitted two separate equations, one for population growth rate when RH is above CEH and the other for population decline when RH

is below it. The effect of temperature is also included in the equations. For any time interval for which temperature and RH are known, the model can thus predict the effect on mite populations. Cunningham has applied the model to monitored hourly hygrothermal data at particular locations in bedding, carpets and upholstery, showing the predicted cumulative effect on mite population in each case.

Although able to simulate transient effects, the Cunningham model is not a multi-zonal model. The aggregate mite population in a mattress as a whole can only be predicted by considering it as a single homogenous zone. In view of the significant spatial variations reported above, and the mite's ability to move in response to them, this is a major limitation. It also takes no account of population structure, which is likely to be relevant, since each stage in the mite's life cycle from egg to adult is affected differently by temperature and humidity.

The new population model

A new more detailed population model has therefore been developed that:

- is multi-zonal, the study volume being divided into a 3-D grid of cells as chosen by the user,
- takes account of mite movement in response to hygrothermal conditions (using the results of the ongoing mite box experiments previously described) and
- considers the effect of hygrothermal conditions for each stage of the mite's life cycle.

The data requirements for such a model are considerable. For all relevant combinations of temperature and humidity found in bedding, we require values for: egg production rates, egg-to-larva and larva-to-adult development times, mortality rates for eggs, juveniles and adults (male and female), and mite movement rates. Unfortunately, despite the efforts of experimental acarologists, there are serious deficiencies in the available data. Nevertheless, there is enough at least to make a start in developing the new model and establishing a framework, which is enabling us to specify the areas where further entomological research is most urgently required. As reported more fully in a later paper, the incomplete matrices are being filled using simplifying assumptions. These then form the basis for curve-fitting equations and the derivation of rate functions. As better data sets become available, it will be a relatively simple matter to adjust the controlling parameters accordingly.

The model takes as inputs either the outputs of the hygrothermal model or real monitored values. An initial starting population of young adult mites is assumed, distributed as the user chooses. The model then calculates the effect of the hygrothermal conditions for each cell and time interval, for each life cycle stage. Thus new eggs are laid, previously laid eggs hatch, juveniles mature and adults age and die. Juveniles and adults also travel to an adjacent zone if conditions are more favourable. Having run the model for a specified number of days, the output is the number of eggs, juveniles and adults in each cell and for the mattress as a whole.

By matching the level of detail now possible with hygrothermal modelling, the new population model allows for a comprehensive examination of how mite population dynamics are affected by transient environmental conditions. How the latter can be manipulated to minimise mite infestation will then become evident. Future developments will allow for the inclusion of carpets and upholstery, allergen production and the immigration (eg. brought in on clothes) and emigration (eg. by vacuuming) of mites to and from each microenvironment.

DISCUSSION

The house dust mite appears to be exquisitely sensitive to hygrothermal conditions in its microclimate, which in turn are the net result of interacting variables, many of which are potentially controllable. The aim of this project is to contribute towards unravelling this complex process. Progress is being made in developing both the hygrothermal and the population sub-models. On the hygrothermal side, we have been able to build on existing modelling techniques and we are already achieving results of reasonable accuracy at a fine level of spatial detail. Data for the hygroscopicity of bedding materials is in short supply, but we hope soon to make good this deficiency. For population modelling, the lack of data is a more serious problem, requiring extensive further experimental research on mite physiology. Better methods of sampling mite colonies in dwellings will also be required for validating the model predictions. Nevertheless, we have developed a modelling framework which can be fine tuned and validated with increasing accuracy as more data become available.

In the past, much environmental mite research has focused on mean RH or absolute humidity alone as a proxy for mite infestation (ie. ignoring the important effect of temperature). Some countries have even set mean RH or absolute humidity as a recommended value in order to control mite populations (Becher *et al* 1999; Platts-Mills and Weck 1987). One of the aims of this project is to use the transient model to test the validity of such mean values and if found inappropriate, as expected, to develop new indicators, such as the Mite Index.

We envisage the transient model as being essentially a research tool. However we are very much aware of the need for simpler models which are easier to use and have a wider applicability. It is anticipated that once the transient model has been successfully developed, some of its complexity will be found to be unnecessary. By eliminating, or summarising this excess complexity, we thus hope to develop and test the validity of a simpler version, based on the steady state model described above, that can be more easily used by those involved in the design, construction, management and use of dwellings for determining effective mite control strategies.

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Acknowledgement

This research project is funded by the Engineering and Physical Sciences Research Council (EPSRC) of the UK.