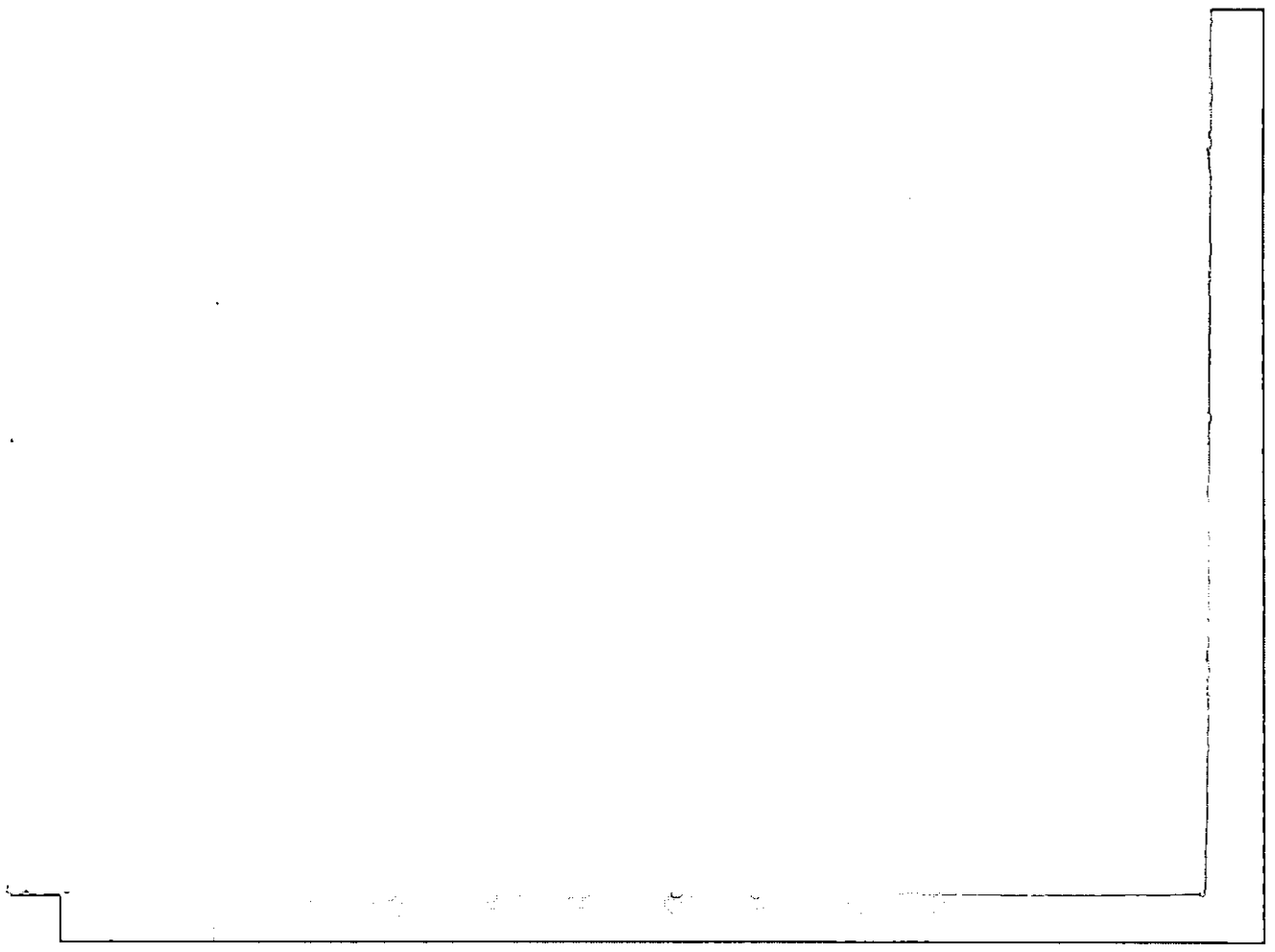

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Controlling Dust Mites Psychrometrically - A Review for Building Scientists and Engineers

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Controlling Dust Mites Psychrometrically – a Review for Building Scientists and Engineers

M. J. CUNNINGHAM

Abstract The literature for the control of dust mites by modification of the psychrometric conditions of the environment is reviewed from the standpoint of a building scientist or engineer, both to present to building science workers an envelope of microenvironment psychrometric conditions to use as control, and to highlight those areas of dust mite biology that require further research to complete the knowledge of the psychrometric envelope for dust mite viability. Some important data to allow tight specification of psychrometric control conditions are missing, viz.: the temperature dependence of critical equilibrium activity for *Dermatophagoides pteronyssinus* and *Euroglyphus maynei;* behaviour of dust mite populations under a fluctuating climate; and the difference between wild and laboratory populations. The widely quoted figure for dust mite control of 7 g/mg absolute humidity should be used with caution.

Key words Dust mites, Biocontaminants, Critical equilibrium humidity, Asthma

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Introduction

This paper reviews the literature for dust mite water balance from the point of view of, and in the language of, a building scientist or HVAC engineer, to establish more clearly the extent of knowledge of the range of psychrometric conditions that are effective in controlling dust mites, particularly conditions in the microenvironment.

House-dust mites are widespread in temperate and humid climates throughout the world. They are associated with serious, widespread diseases (Platts-Mills and Chapman, 1987). In particular, there is good evidence showing them to be a major aggravating factor for asthma and related respiratory allergies (Platts-Mills and Chapman, 1987; Dubinina, 1985; Ford and Platts-Mills, 1987; Carswell, 1988; Chapman, 1990; Arlian, 1991). They are closely associated with other disorders including atopic dermatitis (Norris et al., 1988; Beck and Korsgaard, 1989), chronic or perennial rhinitis (Freudenberger et al., 1988), and keratoconjunctivitis (Mumcuoglu et al., 1988).

In the UK, 80% of asthmatics are dust mite allergic (Sporik et al., 1990, 1991). Studies in other countries have shown comparable levels of dust mite allergic asthmatics, e.g. Denmark (Korsgaard, 1983a, 1983b), Sweden (Wickman et al., 1991), New Zealand (Warner and Boner, 1988), coastal Australia (Peat et al., 1987), and coastal Canada (Murray et al., 1985). Studies also show correlation in Europe, North and South America, China, India, Korea, Brunei and New Guinea (Platts-Mills and Chapman, 1987). Many (but not all) studies have shown that there is often marked improvements in asthma symptoms when dust mite avoidance measures are implemented (Wright, 1963; Heller-Haupt and Busvine, 1974; Sarsfield et al., 1974; Burr et al., 1976; Dutau et al., 1979; Burr, et al., 1980a, 1980b; Mitchell and Elliot, 1980; Platts-Mills et al., 1982; van der Maele, 1983; Murray & Ferguson, 1983; Korsgaard, 1983a, 1983b; Bowler et al., 1985; Sly et al., 1985; Walshaw and Evans, 1986; Gillies et al., 1987; Harving et al., 1988; Kersten et al., 1988; Mosbech et al., 1988; Arlian, 1989; Beck and Korsgaard, 1989; Dybendal et al., 1989; Schober, 1989; De Boer and van der Geest, 1990; Colloff, 1990; Denman and Cornthwaite, 1990; Hart and Whitehead, 1990; Howarth et al., 1990; Owen et al., 1990; Rieser et al., 1990; Reisman et al., 1990; Sporik et al., 1990; Walshaw and Evans, 1990; Harving et al., 1991; Vervloet et al., 1991; Kneist et al., 1991; Harving et al., 1992; Sooltangos et al., 1992.)

There are many dust mite allergens that both sensitize the individual and provoke asthma attacks. A major allergen is known as Der p 1 which Tovey, Chapman and Platts-Mills (1981) first showed was present in fae-

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cal pellets. However, there are many other allergens present in the dust mites faeces, body and gut – at least seven groups have been recognized by the WHO/IUS Allergen Nomenclature Subcommittee (Stewart, 1994). Stewart (1994) has collated these allergens and presented a bibliography of primary references. Der p 1 is now thought of as a marker to the presence of these other allergens (Crane, private communication).

Controlling Dust Mites Psychrometrically

A number of dust mite control measures have been tested, including:

1. Chemical control (Heller-Haupt and Busvine, 1974; Dutau et al., 1979; Kersten et al., 1988; Beck and Korsgaard, 1989; Colloff, 1990; Rieser et al., 1990; Kneist et al., 1991; Sooltangos et al., 1992).
2. Cleaning and vacuuming (Sarsfield et al., 1974; Burr et al., 1976; Burr et al., 1980a; Burr et al., 1980b; Sly et al., 1985; Gillies et al., 1987; Van Bronswijk et al., 1987; Wassenaar, 1988; Fell et al., 1992).
3. Use of electric blankets (Mosbech et al., 1988; De Boer and van der Geest, 1990).
4. Covering of mattresses (Sarsfield et al., 1974; Burr et al., 1976; Burr et al., 1980b; Murray & Ferguson, 1983; Bowler et al., 1985; Walshaw and Evans, 1986; Gillies et al., 1987; Denman and Cornthwaite, 1990; Howarth et al., 1990; Owen et al., 1990).
5. Removal of carpets, soft furnishings and soft toys (Walshaw and Evans, 1990).
6. Indoor humidity control (Korsgaard, 1983b; Walshaw and Evans, 1986; Harving et al., 1988; Schober, 1988; Dybendal et al., 1989; Schober, 1989; Hart and Whitehead, 1990; Vervloet et al., 1991; Harving et al., 1991; Harving et al., 1992).
7. Other physical control methods e.g. freezing (Colloff, 1986 and Dorward et al., 1988).

This paper is concerned with the control of dust mite populations through humidity modification. Higher humidities not only provide conditions suitable for mite population survival and growth but also result in greater faecal production per mite, resulting in higher allergen levels (Arlian, 1992). Several studies have correlated mite abundance with estimations of indoor humidity (Schober, 1988; Dybendal et al., 1989; Schober, 1989; Hart and Whitehead, 1990; Brenner et al., 1991; Vervloet et al., 1991; Harving et al., 1991; Harving et al., 1992). Modern, better insulated and more airtight homes tend to have higher indoor humidities than in the past and can be more prone to dust mites (Furusho, 1988; Korsgaard, 1988; Nordvall et al., 1988; Tilak and Jogdand, 1989). The same can probably be said of older homes that have been air tightened as a result of retrofitting.

Controlling room relative humidity has been shown to be effective in controlling mites, allergen levels, and asthma. For example, in the UK, McIntyre (1992) has shown significant reduction of dust-mite population with room humidity control; Harving, Korsgaard and Dahl (1988) in Denmark showed a mite population reduction of 60% with mechanical ventilation, and significant improvements in asthma symptoms amongst sensitive individuals when the indoor humidity was reduced.

However, in general, it will be difficult to repeat the experience of Korsgaard, who was working in Denmark, because of climatic and housing differences, and social, cultural, and economic differences. Furthermore, the upper bound of absolute humidity of 7 g/kg used by Korsgaard (1988) is regarded as valid at best at 21°C only (Arlian, 1992); conditions for dust mite viability are more likely to be a function of relative humidity or saturation deficit, defined below (Maelzer, 1993). Moreover, it is local rather than room or global conditions that must be controlled; the importance of microclimates has been stressed by Colloff (1991) and is covered in detail later in this work. In many mild and humid climates, ventilation alone as a dust mite reduction strategy either will not be appropriate or will be ineffective.

Hence, to achieve some measure of dust mite control by altering the ambient psychrometric conditions requires a more detailed understanding of the microclimate of the dust mites' habitat, and how this affects dust mite population dynamics.

This knowledge is far from complete, and is scattered through the biological and health literature, in a form and a language not familiar to building scientists and engineers. This paper reviews the literature of dust mite water balance in the language of building science – both to present to building science workers an envelope of microenvironment psychrometric conditions to use as control, and to highlight those areas of dust mite biology that require further research to complete the knowledge of the psychrometric envelope for dust mite viability.

Terminology

Critical Equilibrium Activity (CEA) – the water activity in the microenvironmental air below which dust mites are unable to regulate their water balance and consequently lose water and die. 100% relative humidity is defined as having a CEA of 1, so

CEA=(moles of water vapour present in the air of the mite environment)/(moles of water vapour in saturated air)
=(relative humidity)/100

Critical Equilibrium Humidity (CEH) – the relative hu-

midity corresponding to the CEA, e.g. if the CEA is 0.73, then the CEH is 73%.

This term is used only rarely in the biological literature, but it will be used almost exclusively here, in keeping with the aim of writing an article whose language is understood and used by building scientists.

Saturation deficit (SD) – the difference between saturation and actual vapour pressure of air at the temperature under consideration, e.g. saturated vapour pressure at 23°C is 2808 Pa, and at 73% it is 2050 Pa, so SD=758 Pa. Sometimes this is called vapour pressure deficit (VPD). This quantity is important biologically because it is a measure of how quickly water will evaporate from living plants and animals.

Other terms such as absolute humidity (in literature universally measured as grams of water vapour per kilogram of air), relative humidity etc. are used with their usual meaning, although the author occasionally detects some confusion in the dust mite literature of how these psychrometric concepts relate to each other, particularly the role of temperature.

The Importance of the Microenvironment

The sites where mites live include carpeting, furniture and bedding. These locations are called the microenvironment in this paper, and the local psychrometric conditions in the microenvironment constitute the microclimate. Although the microclimate is influenced by ambient conditions, it may differ substantially from them.

Temperatures in the microenvironment are influenced by nearby heat sources and sinks.

Heat sinks exist at thermal bridges, locations in the building envelope where building detail is such that heat flows more readily there than in adjacent parts of the envelope. Such thermal bridges will exist where, for example, structural elements such as studs connect indoor lining to outdoor cladding without intervening insulation, or where convective air currents can be set up in building cavities that by-pass installed insulation.

Heat sources are present wherever people or animals are sitting or sleeping, e.g. beds or furniture, or where local heating is being supplied, e.g. electric blankets or underfloor heating.

Humidities in the microenvironment are influenced by nearby moisture sources and sinks.

Possibly the most important moisture source influencing dust mite viability is people. A person releases about one-and-a-half to two litres of moisture a day in respiration and perspiration (Lstiburek and Carmody, 1991). This represents a considerable moisture load in the immediate vicinity of sitting or lying people. Other moisture sources, such as washing, showering, cooking etc., influence the ambient humidity and so influence the microenvironment indirectly.

Hygroscopic materials, such as wall linings, furniture, and most importantly, carpets and bedding, become moisture sinks when they are not in moisture equilibrium with their surroundings and need to gain moisture to be so. Conversely, they become moisture sources when they need to release moisture to equilibrate with their environment.

Each of the factors above will contribute significantly to bedding, carpeting and furniture microclimates and thus influence dust mite viability. Some of the microenvironment conditions that will affect mite viability include:

- damping of humidity fluctuations in the presence of hygroscopic materials. This implies that mites in these locations, such as carpets and furniture, will not be exposed to extremes of relative humidities, which should be favourable for local dust mite population provided the mean humidity is high enough.
- higher humidities at cold spots. These enhanced humidities occur because, for the same vapour pressure, lower temperatures imply higher humidities. Provided temperatures are not too low, the higher humidities will encourage mite growth.
- higher absolute humidities in occupied beds. The bed occupant is both a heat and moisture source, and hence the bed microclimate is significantly different from the ambient microclimate, and often independent of it (Yellen, 1995). Generally, the temperature and relative humidity conditions created in beds have been found favourable to mites (Koekkoek and van Bronswijk, 1972 and Yellen, 1995).

Dust Mite Water Balance

The most common and widespread dust mites are *Dermatophagoides pteronyssinus, Dermatophagoides farinae* and *E. maynei.* These house-dust mites go through five stages in their life-cycle, viz. egg, larva, protonymph, tritonymph and adult. For *D. pteronyssinus* at 23°C and 75% relative humidity each pre-adult stage takes approximately 8 days, 10 days, 7 days and 8 days respectively (Arlian et al., 1990). Total development times at a range of temperatures as found by Arlian, Rapp and Ahmed (1990) appear in Table 1. Between each stage for *D. farinae* there is a resting or quiescent phase which can be prolonged to many months (Ellingsen, 1974, 1975, 1978; Arlian et al., 1983).

There exists a critical equilibrium relative humidity (CEH) below which mites become unviable and die. The critical relative humidity for *D. pteronyssinus* at 25°C is 73% (Arlian, 1975); it has not been measured for *E. may-*

Table 1 Total development time for *Dermatophagoides pteronyssinus* as a function of temperature (Arlian, Rapp and Ahmed, 1990)

Temperature (at 75% rh)	16°C	23°C	30°C	35°C
Egg to adult development time (±one SD)	122.8±14.5	34.0±5.9	19.3±2.5	15.0±2.0

Table 2 Critical equilibrium humidity for *Dermatophagoides farinae* as a function of temperature (Arian and Veselica, 1981a, 1981b)

Temperature	15°C	25°C	30°C	35°C
CEH	52%	58%	63%	69%

nei but is less than 75% since the species can be cultured at 75% relative humidity (Arlian, 1992). The CEH for *D. farinae is* dependent on temperature (Arlian and Veselica, 1981a, 1981b), rising as temperature rises as shown in Table 2. (An older figure of 70% at 25°C, due to Larson (1969), has been superseded by this data.) The temperature dependence of CEH for *D. pteronyssinus* and *E. maynei* has not been measured.

This temperature dependence for the CEH has a small but important effect when considering the microclimate of a habitat with a temperature lower than room temperature, e.g. a thermal bridge or other thermal anomaly. If the CEH were constant at all temperatures at say 58%, and if ambient conditions were say 22°C, 35%, and the microenvironmental temperature was 15°C, then the relative humidity at the cold bridge would be 55%, which is below the supposed constant CEH – i.e. the mite population will die. However, because the CEH is temperature-dependent, its correct value at 15°C is 52%, i.e. the population is viable. To render this population unviable, an ambient relative humidity of 33% or less would have to be maintained.

Mites lose moisture by evaporation, egg production, body secretions and defecation. They have no respiratory system so some active mechanism is required to replace this lost moisture. This is achieved by a hygroscopic mixture, containing sodium and potassium chloride amongst other constituents, flowing externally from a gland at the base of the first pair of legs, to the mouth. This mixture absorbs moisture hygroscopically if the relative humidity is greater than the CEH (Arlian, 1992). Below the CEH the hygroscopic salts crystallize and block the excreting gland, thus helping to waterproof the mite (Wharton et al., 1979).

As a consequence of this, in temperate climates dust mite populations rise and fall seasonally, reflecting the seasonal changes in ambient relative humidity (Spieksma and Spieksma-Boezeman, 1967; Domrow, 1970; van Bronswijk et al., 1971; Hughes and Maunsell, 1973; Miyamoto and Ouchi, 1976; Lang and Mulla, 1978; Murray and Zuk, 1979; Arlian et al., 1982; Arlian et al., 1983; Arlian 1989).

This immediately suggests the possibility of controlling dust mite populations by lowering the microenvironment relative humidity below the CEH, achievable by lowering the room relative humidity to some appropriate level. Korsgaard (1990 and 1993), working out of Denmark, settled on a figure for control of dust mites of 7g/kg ambient absolute humidity as a maximum, at which level he claimed an improvement in lung function amongst asthmatics (Harving et al., 1988). This criterion should be treated with caution as it holds only in the temperature range of 20–22°C. Arlian (1992) has shown experimentally convincing evidence that this figure should not be used for other temperature ranges. Relative humidity, or perhaps saturation deficit (Maelzer, 1993), is the appropriate controlling quantity.

Since 7 g/kg at 21°C corresponds to 45% relative humidity, then the next obvious control level to specify is 45% relative humidity, independent of temperature. This, however, does not allow for the known rise in CEA as temperature rises, at least for *D. farinae*, (from 52% at 15°C to 69% at 35°C) (see Table 2), representing a change of just under 1% rh/°C. Using 1% rh/°C as an adjustment to the ambient conditions driving the microclimate, ambient relative humidity should be kept below 40% at 16°C, 45% at 21°C and 50% at 26°C.

Desiccation-Resistant Mechanisms

Dust mites have a number of mechanisms that allow survival when conditions become unfavourable, especially when the humidity falls below the CEH.

1. The quiescent protonymph stage of *D. farinae is* able to survive many months under desiccating conditions which destroy all active life stages. Quiescent protonymphs thus form a nucleus of a new population when conditions once again become favourable (Ellingsen, 1974, 1975, 1978; Arlian et al., 1983).
2. Eggs of *D. pteronyssinus* can hatch after 7 months at 10°C, 60% relative humidity, implying that they can over-winter at these lower temperatures (Colloff, 1987).
3. Under desiccating conditions, at least in laboratory observations, mites aggregate to decrease evaporation (Fain et al., 1988).
4. Wild populations appear more resistant to desiccation than laboratory populations, but it is from laboratory populations that most of the CEH and population growth and decline data have been derived (Colloff, 1987).

In all, it appears that to obtain useful control of dust mite populations with relative humidity modification, the lower relative humidity must be maintained continuously, on both a daily and yearly basis. It must also be accepted that this may not kill the dust mite population entirely but only keep it in a quiescent or low activity state, ready to multiply again if conditions become more favourable.

This suggests that relative humidity control should be supplemented with other control messages as advocated by Colloff (1994), such as vacuuming or washing of bedding, to remove or denature allergens, to remove mites that have been killed by lowering humidity, and to reduce numbers in the component of the population that is little affected by relative humidity control.

Dust Mites' Response to a Fluctuating Climate

To use psychrometric conditions to help control dust mite populations in a more sophisticated manner than has been used until now, a knowledge of how dust mite populations respond to a varying climate is required. To date, very little information exists on how dust mite populations respond to say periodic changes in psychrometric conditions, as happens in beds and indeed in all microenvironments. Such knowledge is urgently needed.

At least three approaches suggest themselves:

1. Use of existing steady-state data on the growth and decline of dust mite populations.
2. Use of correlations established between measured room ambient psychrometric conditions and associated dust mite counts.
3. Application of the "Time of Wetness" concept, that has been found useful in understanding mould growth (Adan, 1994).

1. Using existing data to infer response to a fluctuating climate

If daily mean temperatures and relative humidities within the dust mites' environment were known, then it might be possible to use population growth and decline statistics to predict the population the next day from the previous day's psychrometric conditions, and hence predict the effectiveness of microenvironmental climate changes. If, as a simple illustration, an exponential population growth or decline curve were assumed, with the population never becoming dense enough for regulating factors to come into action, then under this model

$$N_t = N_0 \exp(rt) \qquad (1)$$

where N_t is the population at time t

N_0 is the population at time zero

r is the rate of population increase

implying

$$r = \ln 2 / t_d \qquad (2)$$

where t_d is the time for the population to double. Knowing r, equation (1) can be used to calculate the population at each day given the population on the previous day.

Unfortunately, data are not yet complete enough over a wide range of psychrometric conditions and species to make this approach fully viable.

Table 3 shows data on population growth or decline collected from four sources: Koekkoek and Bronswijk, 1972; Arlian, 1975; Brandt and Arlian, 1976; and Colloff, 1992. The doubling times attributed to Koekkoek and Bronswijk were obtained by calculation from data shown in Figure 1 of that reference. Arlian et al. found the time in days to kill 50% of a test population which is taken as the halving time. Where Colloff presented two results, the geometric mean appears in this Table.

Table 3 Mite population doubling or halving times from various sources

Temperature °C	Relative humidity %	Species	Doubling time (days)	Halving time (days)	Reference
15	75	DP	274	–	K[1]
20	65	DP	18	–	CA[2]
20	65	DF	27	–	CA
20	75	DP	22	–	K
23	75	DP	13	–	C[3]
25	75	DP	12	–	K
25	40	DF	–	3.7	A[4]
25	50	DF	–	4.0	A
25	60	EM	76	–	C
25	75	EM	25	–	C
25	80	EM	57	–	C
28	40	DF	–	2.7	A
28	50	DF	–	3.2	A
28	50	DP	–	3.3	B[5]
30	75	DP	9	–	K
30	75	EM	18	–	C
30	80	EM	31	–	C
31	40	DF	–	2.3	A
31	50	DF	–	2.6	A
31	50	DP	–	2.9	B
34	40	DF	–	2.1	A
34	40	DP	–	2.1	B
34	50	DF	–	2.3	A
34	50	DP	–	2.2	B

1. Koekkoek and Bronswijk, 1972 – calculated from graphed data.
2. Confer and Arlian. 1995 – extrapolated from weekly growth figures.
3. Colloff, 1992 – where two results exist, the geometric mean has been taken.
4. Arlian, 1975 – time required to kill 50% of population taken as halving time.
5. Brandt and Arlian, 1976 – time required to kill 50% of population taken as halving time.

2. Correlation between ambient conditions and dust mite population

Another problem with the approach above is that it requires a direct knowledge of the psychrometric conditions in the microenvironment. Using the room conditions instead, Maelzer (1993) has derived correlations which describe the population dynamics, from data reworked from other authors (van Bronswijk et al., 1971; Arlian et al., 1982; Arlian et al., 1983). This description takes the form of correlations of the sort

$$\ln(N_t)=a_0+a_1\ln(N_{t-1})+a_2X_2+a_3X_3 \qquad (3)$$

where the independent variables X_i are temperature, relative humidity, absolute humidity or saturation deficit for the room ambient air. Maezler's unit of time is a week. The coefficients a_i are derived by fitting the changes of dust mite count to the independent variables. His fits, particularly when using saturation deficit, are very good. Using these correlations one could, in principle, predict the population of dust mites at each week, given the population in the previous week and the new psychrometric conditions.

The problem with this method is that it is case-specific – a correlation that holds for one house does not necessarily hold for another. This is so because the link between the room ambient conditions and the microenvironment will be different for different houses. Nevertheless, this approach could be useful. If accurate microclimate control of dust mite population is sought, the room ambient conditions and dust mite counts could be monitored for a period long enough to establish a reliable correlation, then room psychrometric conditions adjusted to conditions that the correlation shows will cause a population decline.

3. Time of Wetness concept

The concept of "time of wetness" TOW, (Adan, 1994), has been introduced in the study of the viability of mould growth in buildings. It has been defined as the proportion of time the microenvironmental relative humidity is above a defined critical limit, often taken as 80% for mould growth (Adan, 1994). For example, if the humidity in a mattress is 80% for 8 hours when being slept upon, and is 60% for the remaining 16 hours of the day, then TOW=8/24=0.33 if the critical limit is defined as 75%, but zero if it is defined as 85%. For periodic relative humidity fluctuations, Adan found that the growth curves for mould correlate well with time of wetness, nearly independently of the frequency of the fluctuating relative humidity.

It is plausible that dust mite TOW figures could also be independent of relative humidity frequency. The natural critical relative humidity would be the relative humidity corresponding to the CEA of the dust mite species in question. This suggests that when experiments on dust mite population dynamics are undertaken, the possibility that the results could be explained succinctly by use of the TOW concept should be investigated.

Further Research

1. Ambient and microclimate differences

Unanswered is the question of why dust mite populations thrive in rooms when the room relative humidity is considerably below the critical relative humidity of 70–73%, e.g. Korsgaard in his studies recommended an AH of 7g/kg which is 45% RH at 20–22°C (Korsgaard, 1993).

There may be several reasons, each of which would require careful investigation, to explain this phenomenon.

- The mite population might depend upon bursts of higher humidity to replenish body water and allow survival through the next period of lower humidity, particularly since rates of water absorption above CEA are faster than rates of loss below CEA (Arlian, 1972). This fluctuating relative humidity environment would be seen particularly in bedding where optimum conditions will be established each night (Koekkoek and van Bronswijk, 1972, Yellen, 1994).
- As mentioned previously, the microclimate of the mite habitat may differ significantly from ambient room conditions. Any cold spots caused, for example, by thermal bridging will have temperatures colder than ambient and hence higher relative humidities (Cunningham and Trethowen, 1993). Building science research is required here, addressing additional issues such as hygroscopic storage and damping, and then suggesting appropriate control strategies.
- The mite population may have a temperature dependent CEH, as does *D. farinae;* if so, the mite population may be surviving at lower humidities in cold localities than that anticipated by simple considerations using a nontemperature-dependent CEH (see above).
- Wild populations of mites may have different tolerances to humidity conditions than laboratory specimens (Colloff, 1987) on which most measurements have been made.

These questions can only be settled by close monitoring of both room conditions and the microclimate conditions at known dust mite sites, together with frequent dust mite counts to assess population levels.

2. Fluctuating psychrometric conditions
There is a vital need for laboratory data on mite population response to cyclic and transient conditions, particularly 24-hour cycles.

In an uncontrolled living space there is typically a 24-hour humidity cycle, and a 24-hour temperature cycle. Superimposed upon this are short transients of high humidity in response to specific occupant behaviour, either in the room or in another room connected to the room under study. These transients arise from cooking, showering, dish and laundry washing etc. These cyclic and transient relative humidity values will drive the microclimate which will follow them, possibly with a lag, with a reduced amplitude and an offset.

Much more information is needed on dust mite population dynamics under fluctuating conditions before relative humidity control of the microenvironment can be usefully applied.

3. Time of wetness and dust mite viability
In research on the effects of transient relative humidities on mould growth, Adan (1994) has introduced the concept of Time of Wetness, (TOW) defined above. He has shown that this is a useful concept in that it correlates well with mould growth independently of frequency (except for the highest frequencies greater than $1^1/_2\ h^{-1}$, which do not occur in practice). It would be useful to discover whether a similar relationship holds for dust mites.

4. Temperature dependence of the CEH
Data exist on the temperature dependence of the CEH for *D. farinae* (Arlian and Veselica, 1981a, 1981b), but not for *D. pteronyssinus* or *E. maynei.*

5. Population growth and decline rates
A wider range of population growth and decline rates under various psychrometric conditions is needed, particularly at lower temperatures and humidities (see Table 3).

7. Other factors
There may be other factors that affect the CEH, for example diet (de Saint Georges-Gridelet, 1982).

Interim Recommendations

Once the necessary research has been completed, ideally it would be possible to state:

1. The connection between the indoor climate and the microclimate in the habitat of the dust mites;
2. The pyschrometric envelope outside of which the wild dust mite population in question would be unviable.

Neither of these facts is known at the moment so, for the time being, building scientists are forced back on empirical solutions that have been shown to work, at least partially (Wickman et al., 1991; Korsgaard, 1993).

As temperatures fall, population growth rates fall dramatically (see Table 3). Indeed, there has been speculation that one of the reasons for the increased incidence of asthma is that indoor temperatures, particularly in bedrooms, are not as low as they used to be, as house-wide heating has become common in developed countries.

Clearly, a return to cold indoor temperatures is unlikely to be acceptable. Indeed, arguments can be made for maintaining higher temperatures all year round, perhaps above 18°C, as follows:

1. At lower temperatures the CEH is lower, at least for *D. farinae* but possibly for all dust mites. Achieving the required lower relative humidity at these lower temperatures is a difficult technical task for air-conditioning equipment.
2. At lower temperatures, life-cycle stages of the dust mites survive longer at marginal conditions (Colloff, 1987; Furumizo, 1973; Arlian et al., 1990) and can form the basis for a population increase once temperatures and humidities rise again.

In using these relative humidity control conditions it is essential that the building envelope has sufficient thermal integrity to avoid spots that are excessively cold, and therefore have a local relative humidity well in excess of the room ambient relative humidity.

It seems necessary to maintain these psychrometric conditions all year round, because the protonymph form of *D. farinae* is capable of many months' survival under desiccating conditions, and so forms the basis for population regrowth once conditions are more favourable. It must be accepted that while this kind of measure controls the population, it does not exterminate it.

It is not likely to be sufficient to keep just the daily mean relative humidity below the CEH. If the fluctuations about the mean are such that there is a significant proportion of time when the relative humidity is above the CEH, then the population may remain viable (e.g. in beds).

Indeed, there is a growing consensus that effective dust mite control will not be realized by one method alone (Colloff, 1994). To supplement relative humidity control one can add:

1. vacuuming with a fine filter;
2. use of acaricides;
3. freezing of bedding either with liquid nitrogen or by placing bedding in the freezer;

4. steam cleaning;
5. use of mattress covers;
6. removal of carpets.

Conclusions

The literature shows that relative humidity control can have a significant effect on dust mite population densities and allergen concentrations. There is, however, a growing consensus that other complementary measures might also be needed. Building scientists must aim relative humidity control towards keeping the humidity of the mites' microenvironment below the critical equilibrium relative humidity. Conditions in the microenvironment may differ significantly from the room conditions. To measure this, instrumentation needs to be developed capable of measuring psychrometric conditions, particularly relative humidity, in the microenvironment. There is a well established temperature dependence in the critical equilibrium humidity for *D. farinae*, but less is known about the temperature dependence for other important species. A number of approaches have been suggested in this work for deciding what humidity levels, at what duration, will discourage mite growth when the climate is fluctuating, but all are hampered by lack of fundamental knowledge in this area. There is also very little data on how wild populations differ from laboratory populations. It is clear, however, that control measures need to be continuous to prevent the re-emergence of the dust mites from quiescent or slow developing life-cycle stages.

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