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The Effects of Micro-Environmental Factors on the House Dust Mite

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Abstract

The proliferation of the House Dust Mite(HDM) is affected by temperature, humidity, ventilation, etc. Measuring temperature and humidity was performed at the very location where dust samplings take place and where they live in reality together with temperature and humidity of the ambient of the room. There has been discussion over the key environment factor of HDM survival; absolute humidity or relative humidity. It seems that relative humidity is the more important determinant for the mite's survival through the analysis of previous studies. Temperature, humidity, ventilation rate and Der P1 were measured in 4 flats in London. Mite allergen was detected in every house. Levels of Der P1 varied between <100ng/g and 22,778ng/g. Flats with high relative humidity(>50%) and poor ventilation(<0.5ach) showed higher levels of mite allergen than flats with lower humidity and adequate air change rate. Questionnaire survey was conducted and the result helped to confirm the findings from monitoring of environmental factors and the dust sampling.

Keywords : Humidity, Temperature, Ventilation, House Dust Mite(HDM), Allergen Level(Der p 1)

1. INTRODUCTION

1.1. Background

Indoor air quality (IAQ) of Building has become worse since the energy crisis in the 1970's. This phenomenon has been caused by various sources. One of the main reasons is decreased ventilation rate than before and the other reasons are building materials, furniture, microbes, etc. Moreover the fact that people stays longer time in the building than past times brings out sick building syndrome (SBS). IAQ of houses especially is very important because children and elderly people spend most of their time in their houses.

Many studies have been doing in order to solve the IAQ problem of the house but most of them are focused on chemical pollutants caused by building materials, furniture and household goods recently in Korea. Of course chemical pollutants are toxic and should be controlled but some substances from microbes are more harmful to the human health which is a question of long standing in some climate regions such as England. The most common creature in the house which might cause health disorder is house dust mite (HDM).

Doctors knew as early as 1923 that it caused occupational asthma and in 1928 one doctor noticed an improvement in his asthmatic patients after the 'bed-mite' was removed from their environment(Whitrow, 1995). Despite these discoveries, for nearly 40 years people were not interested in the dust mite and twenty-five or thirty years ago, just a few researchers knew about the mite present in house dust. Today doctors, patients and even manufacturers of vacuum cleaner, air filters and mattress covers talk about them. In the UK around 3 million adults and one in very seven children have asthma(Smith, 1996).

HDM are found everywhere in the world, throughout the year, even in clean homes; in bedding, mattress, pillows, cushions (especially feather filled), carpets and condensation on the surface of structure or materials. Many measures have been recommended for allergen reduction in houses and many trials have taken place. However measures are not executed generally before HDM proliferation is found and it is not easy task for a house owner to perform those measures regularly. Furthermore once HDM proliferate, reducing the number of HDM is difficult because so far no universally recognized method has been found.

Environmental control such as temperature, humidity, and ventilation might prevent HDM from proliferating in dwellings fundamentally if buildings are designed properly from the first stage. Architectural approaches are needed to solve HDM problems. Monitoring exact temperature, humidity and ventilation rate of HDM's habitat and understanding the correlation between environmental parameters and dust mite allergen would enable the architectural strategies.

1.2. Objective and Methodology

House Dust Mites are influenced by environmental factors such as temperature and humidity. The microclimate of the mite habitat may differ from ambient room conditions and Cunningham(1996) proposed close monitoring of both room conditions and the mite habitat conditions. Other factors can affect HDM population. Dwelling characteristics, ventilation rate, occupant characteristics, etc are related to the microclimate, the mite habitat indirectly(Cunningham, 1996). But data concerning the above factors are still not enough to explain, understand and predict HDM survival and population. The reason is that a proper and accurate measuring instrument and logger are necessary for monitoring temperature, humidity of microclimate and ventilation rate, especially the instrument for ventilation rate is not commonly used besides building scientists. Building science can control temperature, humidity and ventilation inside the buildings if it is carefully designed from the start. It could be said that temperature, humidity and ventilation are most important factors in the building science approach. Therefore this study focused on temperature, humidity and ventilation rate among factors with HDM population, allergen. Methods were carried out in four phases as follows,

Phases 1 – Literature review

Biological characteristics and the health effect of HDM were investigated and the most critical environmental factor for HDM survival was surveyed though previous studies review.

Phases 2 – Pilot Test

Many previous researchers measured the ambient(indoor) temperature and humidity, although HDM do not exist in the air. Even though monitoring both of ambient and microclimate is recommended (Cunningham, 1996), microclimate has not been measured often because monitoring instrument for microclimate are not common and HDM live at various places. Therefore the pilot test was done to know the temperature and humidity differences between ambient and microclimate and find out where temperature and humidity measuring should be done.

Phases 3 – Test

4 houses were designated in London in order to make collections of dust, and measure temperature and humidity. Allergen, Der P1(Dermatophagoides pteronyssinus) was extracted from the dust sampling. In addition, in order to find a correlation between the air change rate and HDM population, ventilation test was performed.

Phases 4 – Questionnaire survey

The questionnaire survey was performed to find relationships between HDM proliferation and type of family, house characteristics, diseases related to HDM, etc.

2. LITERATURE REVIEW

2.1. Biological review and health effect

Dust mites are just visible to the naked eye, being about a third of a millimetre in length and can be felt with the fingertips. They appear as a white dot on a dark background, but can be seen clearly under the low power of the microscope. They are sightless, have eight legs and their bodies are covered by a colorless cuticle, which is permeable to oxygen and carbon dioxide. The mite has an ingenious mechanism of water balance. A small gland by the first pair of legs leads to the mouth through a shallow groove or gutter. This gland secretes a salt solution. In damp condition the salt solution, which is hygroscopic, absorbs water from the air. The solution pours down the gutter and into the mouth of the mite. In dry conditions, water evaporates from the solution so that slows down water loss. But in prolonged dry atmospheres the mite eventually dries out and dies. So the amount of water present in the air, that is the level of humidity, is crucial for mite multiplication. The early stages in the life cycle of mites are much more resistant to extremes of climate, enabling them to survive dry periods and to re-emerge when favorable conditions return i.e. a resting or quiescent phase(Ellingsen, 1978). About 60% of the growth period takes place in stages when the mite does not move, does not take nourishment, and when there is only minimum of metabolism and very little shedding of water. The absence of these responses surely gives house dust mites some survivor advantages. The non-active stages are suitable, for example, passive transport(spreading) or survival at temporary unfavourable conditions in their habitat(Hallas, 1991).

Eleven species are found in house dust. Dermatophagoides pteronyssinus(DP) is commonly found in Europe and another smaller species called Euroglyphus is the second most abundant species in Europe while Dermatophagoides farinae is the most abundant species and Dermatophagoides pteronyssinus is the second one in Korea.

Mating takes place once or twice during adult life and is followed by the production of twenty to forty eggs, laid one at a time. These are small oval and cream coloured. The eggs develop at a rate that is determined by the temperature and humidity of the immediate environment. In ideal conditions, the development period from egg to adult is about twenty-five days. They produce 2000 droppings in their lifetime of three months, which contain a number of medically important allergens. Their life cycles overlap so that adults, eggs and nymphs can be found at all seasons.

They feed on skin scales which are constantly shed from our bodies. People cast off about 1 gram of skin in bed each week and those with eczema shed even more. This is a huge amount of food as far as mites are concerned. In addition, mites have a varied diet of pollen grains, fungal spores, bacteria and plant material, although recently researchers have shown that mites also thrive on semen(Whitrow, 1995).

2.2. The critical environmental factor for HDM survival

Temperature below 15 ℃ and above 35 ℃ slow their development and they are killed quickly in temperatures above 55 ℃ and about -18 ℃(Whitrow, 1995). Values with the same relative humidity and species in [Table 1] were extracted from Cunningham's data(Cunningham, 1996) in order to find out a correlation between temperature and the HDM proliferation. This table shows that HDM do not multiply quickly below 15 ℃ and keeping our bedrooms just below this temperature might be one of dust mite control ways. However this temperature will create discomfort to people at homes therefore other measures are needed to reduce the mite population keeping the temperature within the comfort zone.

An early study in 50 Danish dwellings showed that there is a correlation between the dust mite number and humidity, that the absolute humidity should be kept below 7 g/kg for reducing dust mites population growth(Korsgaard, 1983). In 1993 Harving et al(1993)

Table 1. Mite population doubling or having times in accordance with temperature

Temperature (℃)	Relative Humidity (%)	Doubling Time (days)	Halving Time (days)	Species	Source
15	75	274	-	DP	K
20	75	22	-	DP	K
23	75	13	-	DP	C
25	75	12	-	DP	K
30	75	9	-	DP	K

K : Koekkoek, H H M and van Bronswijk, J E M H, "Temperature requirements of a house dust mite Dermatophagoides pteronyssinus compared with the climate in different habitats of houses", Experimental and Applied Entomology, 1972,15,438

C : Colloff, M J, "Age structure and dynamics of house dust mite populations", Experimental and Applied Acarology, 1992, 16, 29

Table 2. Mite population doubling or halving times in accordance with absolute humidity

Absolute humidity (g/kg)	Relative humidity (%)	Temperature (℃)	Doubling Time (days)	Halving time (days)	Source
20	75	30	9	-	K
19.5	65	20	18	-	CA
17.4	50	34	-	2.2	B
15	75	25	12	-	K
14.6	50	31	-	2.9	B
13.8	40	34	-	2.1	B
13.5	75	23	13	-	C
11.7	50	28	-	3.3	B
11	75	20	22	-	K
8	75	15	274	-	K

K : Koekkoek, H H M and van Bronswijk, J E M H, "Temperature requirements of a house dust mite Dermatophagoides pteronyssinus compared with the climate in different habitats of houses", Experimental and Applied Entomology, 1972,15,438

CA : Confer, P D and Arlian, L G, "Influence of climate factors on dust mite growth:, Journal of Allergy and Clinical Immunology, 1995, 95(1),part 2, 261

B : Brandt R L and Arlian L G, "Mortality of house-dust mites, Dermatophagoides farinae and D. ptetonyssinus, exposed to dehydrating conditions or selected pesticides", Journal of Medical Entomology, 1976, 13, 327-331

C : Colloff, M J, "Age structure and dynamics of house dust mite populations", Experimental and Applied Acarology, 1992, 16, 29

found that HDM are especially abundant in houses with absolute humidity(AH) above 7 g/kg which is the proposed threshold limit value(TLV). Munir(1995) revealed that houses with AH greater than 7 g/kg or relative humidity(RH) greater than 45 % suffered from high concentrations of dust mites. The widely quoted upper bound of AH of 7 g/kg used by Korsgaard, Harving et al and Munir is however, regarded as valid at best at 21 ℃ only(Arlian, 1992) which might implies that HDM viability might be also influenced by RH. In order to find out which RH have an influence on dust mite proliferation Cunningham's data was used. In the data there are only relative humidities, they were, therefore, converted into absolute humidities.

[Table 2] shows that dust mite population in not proportional to RH but environment over RH 65 % provides a good condition to dust mite while environment below 50 % does not. There is another factor, temperature, which might affect dust mite proliferation more than humidity. Previous studies have not considered humidity and temperature at the same time. Thus it is necessary to study the relationship between dust and humidity-temperature together in the near future.

Korsgaard(1991) found that mechanical ventilation with heat recovery(MVHR) which established a basic ventilation rate of 0.5 ACH(air change rate per hour) significantly reduced dust mite populations in dwellings and others have also found that ventilation control as an indirect method is associated with dust mite population[7] because ventilation plays an important role in varying the internal temperature and humidity levels. However it should be noticed that the excessive air change rates lead to a rise of humidity level under certain conditions. For example in winter draughty houses may have air change rate, over 1 ACH. Although outdoor air contains smaller amount of moisture than indoor air has. This rate is high enough to lower the internal temperature level and in turn, the humidity level will increase even with the same amount of water vapour.

On the other hand, a study of 638 children showed no building factors such as size of the home, heating, type of foundation, dampness, wall to wall carpets, significantly correlated with symptoms reported by children(Gustafsson, 1996).

2.3. Importance of the micro-environment

Some recent studies have been interested in the micro-environment and concerned the outdoor climate, room condition and the micro-climate but the majority of previous researchers measured the ambient (indoor) temperature and humidity, although HDM do not exist in the air and there might be some temperature and humidity differences between ambient (indoor) air and where HDM live. For HDM reduction the micro-environment where HDM live such as the carpet must be controlled rather than the room conditions. Thus in order to achieve some measures for dust mite control by altering the ambient psychrometric conditions, a more detailed understanding of the micro climate of the dust mites' habitat is required, and it is necessary to present an envelope of the micro environment psychrometric conditions. A comparison is shown below between two conditions i.e. when considering the ambient air temperature and the micro-environment where the HDM live practically assuming that there is a temperature difference of 2 ℃(the micro-environment temperature is lower that of the ambient air) between two conditions and no absolute humidity difference. The values for the humidity also were input at discretion. From the [Table 3] it could be thought that with

Table 3. Ambient & practical relative humidity

Temperature	15 ℃	25 ℃	30 ℃	35 ℃
Ambient RH	52 %	58 %	63 %	69 %
Practical RH	60 %	65 %	70 %	78 %

Table 4. Test Houses

House	**Test Period**			
	Pilot	**Main**	**Infiltration**	**Questionnaire**
A	-	16^{th} ~ 30^{th}, July	19^{th}, July	19^{th} ~ 20^{th}, July
B	-	16^{th} ~ 30^{th}, July	19^{th}, July	19^{th} ~ 20^{th}, July
C	-	16^{th} ~ 30^{th}, July	19^{th}, July	19^{th} ~ 20^{th}, July

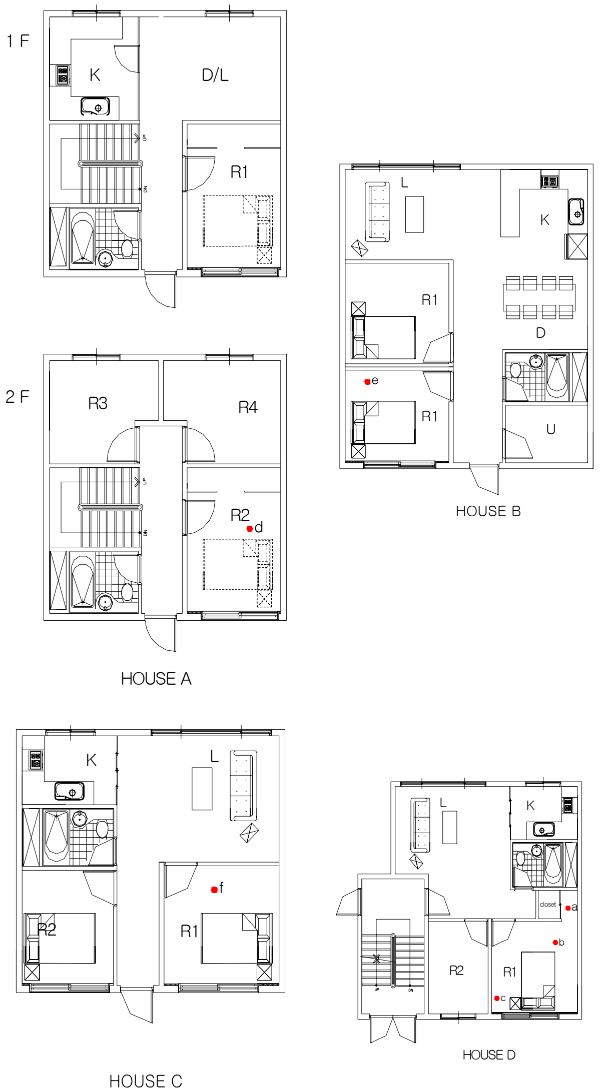

Figure 1. Unit plans of test houses

the same amount of water in the air, relative humidity of the ambient might prevent the HDM from growing, whereas relative humidity of micro-environment(practical) might let the HDM survive assuming the mites' environment is 2K lower. For example, if with relative humidity of the ambient air is 52 % at 15 ℃, relative humidity of micro-environment will be 60 % due to the temperature difference. If 52 % is the critical humidity below which mites die, this ambient condition will not allow HDM to survive. But HDM will live well practically under 60 %, a fairy good humidity condition.

3. MEASUREMENT OF INDOOR FACTORS AND HDM ALLERGENS

3.1. The outline of measurement

Four dwellings were designated in London for collection of dust and measuring temperature, humidity and ventilation rate. Designated test houses are located in London and have carpets in the bedrooms and living rooms like other western houses. Der P1 was extracted from the dust sampling. house 'D' among 4 houses as the core house for the pilot test was selected for investigating the micro-environmental conditions at four places, collecting samples at three different locations in the bedroom and monitoring the temperatures and humilities of the ambient air as well of each location [Figure 1]. As mentioned above, the pilot test was done to know the temperature and humidity differences between ambient and microclimate and find out where temperature and humidity measuring should be done. The rest three dwellings are named "typical houses" in this study. A, B, C, and D represent these four houses afterward[Table 4]. House D was tested in the pilot test and house A, B, C, and D were tested in the main test. House D was thus tested two times.

The selecting criteria of houses were the following; similar characteristics such as type of ventilation(particularly the bedroom in question which should be without any mechanical systems), type of house, type of window and so on. Most of temperature measurements were spot measurement and measured in the ambient in previous studies. In addition, the spot measurement of the temperature and humidity is not reasonable because they are changing continuously so that they can not represent practical values which vary with the time, the moisture input and so on. Thus continuous data loggers recording environmental conditions every six minutes were used. Initially both bedrooms and living rooms were to be monitored however only bedrooms were monitored because it is known that the concentration of mites is higher in dust samples from the floor in bedrooms than from the floor in living room(Sesay, 1972) and people usually stay more in bedroom than in the living room except infants and house wives.In relation to obtaining the consistent and analysable HDM sampling results, there are four important points; 1) The equipment used, 2) The time at which vacuuming is done, 3) The area vacuumed, 4) The time spent in vacuuming. There fore sampling was performed with the same vacuum cleaner, within the same area for 3 minutes as near to the same time as possible and the procedure of the sampling is below,

Table 5. ACH calculation procedure

Procedure	Calculation	Unit	Pressure
1	Air flow amount	ft^3/min	50 Pa
2	X 60	ft^3/hr	
3	÷ 37	m^3/hr	
4	÷ vol.(m^3)	ACH	50 Pa
5	÷ 20	ACH	Background

Table 6 Equipment and method of monitoring

Object	Equipment	Method
Temperature	Temperature/Humidity Sensor(UCL)	Data logger
Humidity	Temperature/Humidity Sensor(UCL)	Data logger
Ventilation	Retrotec Blower Door	-
Allergen (Der P1)	MEDIVAC(Medical Dust Sampler)	Elias

Table 7. Temperature and humidity of house 'D'

Point	a	b	c
Temperature	22.6 ℃	23.0 ℃	22.2 ℃
Predicted RH	65.7 %	64.2 %	67.3 %
Measured RH	65.7 %	53.3 %	73.5 %

① The plastic dish were weighed using PRECISA 125A balance at the Chemical Engineering Department, UCL before monitoring took place.

② Samples were collected from the bedroom carpets and once in a week by using a MEDIVAC(Medical Dust Sampler). It is recommended that standard machines have an 800 - 1200W motor. MEDIVAC has a 1000W motor and the airflow of 2.7 m3/min. There are 3 types of filters ; 1000 µm_nylon mesh(56 mm diameter) filter arrests extraneous matter ≥ 1 mm, 300 µm_stainless steel mesh(50 mm diameter) filter arrests extraneous matter ≥ 300 µm_and nylon mesh 5 or 10 µm_filter, "Mob Cap" design arrests particulate matter ≥ 5 or 10 µm which is adequate for collecting mites faeces 10 - 40 µm(mean 24 µm)(Platts-Mills, 1983) in diameter.

③ For the core house three samples were collected in which the surface temperatures might be different from the ambient temperature but one sample was taken in each of the 3 other houses(typical houses)

④ The filter holder should be cleaned and completely dry before being reused

⑤ Samples were weighed again so that the weight of dust could be calculated. They were stored in the freezer at - 3 to - 5°C on the ground that mites might produce faeces over 0°C

⑥ Samples were labelled and sent to the Wythenshawe Hospital for analysis

In order to find out a relationship between air change rate and the HDM population, infiltration tests were performed for all houses. Infiltration rate of all houses were tested using the 'Retrotec Blower Door' which utilizes the depressurization and pressurization methods. Values from the equipment were calibrated by 'Retrotec Blower Door Infiltrometer(RBDI)'. RBDI gives the values as a air low amount(ft^3/min) at 50 Pa. In order to have air change rate it needs to be multiplied by 60(minutes), divided by 37(ft^3 → m^3) and divided the volume of the house(m^3). Finally it is air change rate at 50 Pa and background air change rate can be obtained by dividing this value by 20[Table 5]. And [Table 6] shows the equipment and method for monitoring.

3.2.The results of measurement

1) Pilot test

From the pilot test, it was found that temperature and humidity differences exist between the carpet and the ambient air in the room of the core house. There was a temperature difference of 2.0 ℃ when windows were open and there was a temperature difference of 2.5 ℃ when the room was heated by the electronic heater on the wall. There was also a humidity difference between the ambient air and the floor. The relative humidity of the floor was 20 % higher than that of ambient air. For the main measurement, monitoring temperature and humidity of the floor, where the house dust mites live actually, is need because there were temperature and humidity differences between the ambient and the floor and relative humidity especially is regarded as the critical factor for HDM survival.

1) Main test

Among 4 houses 1 house, 'D' as the core house was selected for measuring the micro-environmental conditions and collecting samples at different points(a,b,c), in the bedroom of the core house and monitoring the temperatures and humilities of the ambient air. [Table 7] shows the result of temperature and humidity measurement. If the amount of water vapor in the air is constant, the relative humidity is dependent only on temperature changes. When the humidity, 65.7 %, measured at point 'a' is regarded as the standard on the grounds that humidity of position 'a' is closest to the mean relative humidity of 'a', 'b', and 'c'. Relative humidities of position 'b' and 'c' should be 64.2 % and 67.3 % which are calculated by the Buck formulae, however there are differences. They were 53.3 % of 'b' and 73.5 % of 'c' which are much lower and higher than the calculated ones. This implies that the amount of water vapour in the air is not constant in the room and there might be different water vapour sources from out side the room.

These temperature and humidity variations in the same surface imply that the monitoring result could be different according to the location where the measurement takes place. In fact, many previous studies have measured the ambient air temperature and humidity. The present study shows that temperature and humidity measured in the ambient air is not adequate for HDM study and it is recommended that measurements of temperature and humidity be performed at the very location where dust sampling take place and where they live in reality or at least at the location which could represent the surface conditions.

As mentioned previously there was a controversy about

Table 8. Comparison of temperature, humidity and CEH

	Temperature	Humidity	CEH
Ambient	24.1 ℃	52.2 %	58.6 %
Carpet(Floor)	23.0 ℃	64.2 %	56.8 %

Table 9. The result of Der P1 samplings

Type	RH (%)	Sample No.	Sample Weight (g)	Extract Weight (g)	Der P1 (ng/g)
'A'	-	4	0.0680	0.0443	< 100
		9	0.0240	0.0102	< 100
		7	0.0030	0.0020	< 100
'B'	46.0	2	0.3000	0.1000	< 100
		15	0.1040	0.0894	4,000
		12	0.1240	0.1000	4,250
'C'	-	1	0.5440	0.1000	< 100
		16	0.3460	0.1000	< 100
		5	0.0850	0.0674	< 100
'D'	65.77	a-3	0.0760	0.0499	19,500
		a-13	0.0630	0.0494	21,250
		a-17	0.1010	0.0826	25,500
		b-11	0.2450	0.1000	25,500
	53.30	b-14	0.1570	0.1000	23,500
		b-18	0.1280	0.1000	14,750
		c-6	0.0570	0.0495	> 25,000
		c-10	0.1070	0.0987	> 25,000
	73.56	c-19	0.0810	0.666	> 25,000

Table 10. Der P1 level and ventilation rate

Type	Ventilation (ACH)	Mean Der P1 (ng/g)
'A'	0.45	<100
'B'	0.75	2,750
'C'	0.53	<100
'D'	0.36	22,778

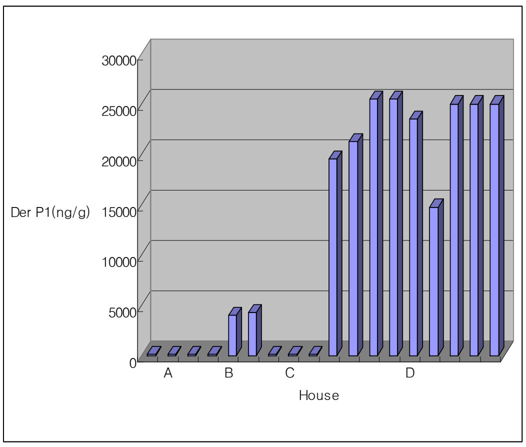

Figure 2. Der P1, Allergen level

the critical factor on HDM survival; absolute humidity or relative humidity. From the literature review, it was found that relative humidity is more critical factor. In order to understand the overall all HDM survival situation, relative humidity and critical equilibrium humidity(CEH) under which HDM could not survive, were compared. The mean humidity and temperature of the ambient air was 52.2 % and 24.1 ℃ respectively while the mean humidity of the carpet was 64.2 % at the mean temperature of 23 ℃. The critical equilibrium humidity, 56.8 %, at 23 ℃ was extrapolated. It appears that this relative humidity level, 64.2 % in the micro-environment exceeding CEH of 56.8 % have provided the viable condition to HDM. On the contrary,[Table 8] provided temperature, 24.1 ℃ and humidity, 52.2 % of the ambient air is regarded as the condition for the HDM control, the result will be totally different that relative humidity should be keep below 58.6 % however the relative humidity of air was 52.2 %. It might, therefore, be misunderstood that relative humidity(below CEH; 56.8 %), 52.2 % could prevent the mite from proliferating if temperature and humidity of the ambient air are considered for the HDM control, but in fact humidity(above CEH; 56.8 %), 64.2 % of the micro-environment where the mites lives in practice, provides a good condition for HDM proliferation.

[Table 9] shows that fairly low allergen levels were detected in 'A', 'B', and 'C' house. Every sampling of house 'A' and house 'C' has a very low Der P1 level, below 100 ng/g. However, house 'B' showed allergen levels of two samples were high compared to samples from house 'A' and 'C'. WHO suggested 2 ㎍/g as the hygiene standard. The allergen level, Der P1, of the core house was found to be very high that is more than 20 times the standard which may be a crucial level to residents especially to children's health. There was a fivefold increase in asthma among children of atopic parents in southern England who were exposed to more than 10 ㎍/g, Der P1, since infants spend most of their time indoors in the first year of life. The allergen levels of point 'c' in house 'D' was beyond 25,000 ng/g which is the highest. The second level was found at the point 'a' and the lowest at the point 'b' in House 'D', but still high. In order to find if there is a relationship between the allergen level and the relative humidity, the correlation and P-value were analysed by t-test. The result was that correlation coefficient is 0.855 and P-value 0.02. This confirms previous studies[8, 14] which have revealed that proliferation of HDM is associated with relative humidity. On the other hand, collected dust amount was not the same and the amount of dust in House 'C' was the most, however the allergen level was the lowest that is less than 100 ng/g. The correlation analysis assuming that the allergen levels of House 'A' and 'C' are 100 ng/g shows that the correlation coefficient is -0.423 which means the sample weight is not associated with Der P1 level which seems that dust amount or the frequency of room cleaning is not directly related to HDM survival.

The ventilation test[Table 10] shows that the highest ventilation rate was found in House 'B', 0.75 ACH, while the lowest rate in the core house, house 'D', 0.36 ACH. Generally speaking as the ventilation rate increases the Der P1

Table 11. Survey summary of family and house characteristics

Question \ House	A	B	C	D
A. Family				
A1. Location	London	London	London	London
A2. Sex(Age)	M(35) F(34)	M(40), M(40)	M(35) F(31)	M(32) F(29)
	F(6)	Yes	M(1 1/2)	M(2)
A3. Smoking	No	No	No	Yes
A4. Disease	No		No	Age32 - Rhinitis
				Age28 – Atopic
B. House				
B1. Room(No.)	6	9	5	5
B2. Heating 1	Electric	Electric	Underfloor	Electric
B3. Heating 2	No	No	No	No
B4. Temperature	Slightly warm	Slightly warm	warm	Slightly cool
B5. Comfort	Comfortable	Comfortable	Comfortable	Stuffy(winter)
C. Ventilation				
C1. System	Cooker hood	Don't know	Extract fan	Cooker hood,
C2. Trickle vent.	NA	NA	NA	trickle vent
C3.Window open	Summer	9 AM ~ 11	Summer	Never open
	(always)	AM	(1hr)	Summer
	Winter-1hr		Winter	(always)
	Other-2hrs		(No)	Winter-20min
			Other(No)	Other-1hrs
D. Condensation				
D1 Condensation	Yes(MR)	No	Yes	Yes(MR)
D2.Steam When cooking	Yes	No	-	Yes
D2. Hanging out wash indoor	Yes-except Summer	Yes	Yes	Yes
D3. Mould	No	No	-	Yes (wall corner)

● MR : Master Room L; Living room, B; Bedroom, D; Dinning room, K; Kitchen, B; Bathroom

level of each house decreases. However house 'B' which has the highest ventilation rate shows the second highest Der P1 level. The statistical correlation between the ventilation rate and Der P1 concentration showed that the correlation coefficient was -0.711 and the P-value was 0.031. It would appear that the correlation coefficient of -0.711 is not very high, however, P-value of 0.031 shows that these two factors are associated with each other. It might be said, there fore, that a low ventilation rate reduces HDM concentration in dwellings.

Although there are many values of environmental factor and dust sampling(Der P1), there are only 4 houses. 4 questionnaires are not enough for any kind of statistical analysis or generalization of the results, however, they might help to identify existing problems in the test houses, to correlate them with possible causes and to confirm or disprove findings of the monitoring or sampling. The results of questionnaire survey[Table 11] are blow,

House 'A'

Two adults and a child live in House 'A', a tree bedroom flat. Nobody smokes and has suffered from asthma, eczema, chronic, rhinitis or any other respiratory diseases. This is in accord with the findings of the monitoring study, which showed a low allergen(Der P1) level. i.e. <100 ng/g. There is only one ventilation system, a cooker hood in the kitchen besides windows but it has not been working. Therefore they have only used windows for ventilation, opening them almost all day in summer, for average 2 hours in spring and autumn and for 1 hour in winter which may be considered to be an adequate time to keep the indoor humidity level in a proper range. This house has no mould problem in any season but condensation is present on windows in the master bedroom in winter. The overall tenants' assessment of the humidity condition in the houses is 'too draughty' in winter is not in accord with the finding of ventilation test i.e. 0.45 ACH which could be fairly adequate level to lower the indoor humidity level and not create a draught.

House 'B'

This house is a four bedroom shared flat. Two people stayed in this house. One of them smokes and nobody suffered from any diseases described in the questionnaire. In fact, the person who answered the questionnaire had not lived in house 'B' in winter and spring & autumn and thus answered questions related to summer season only. Windows in the monitored bedroom were kept open for 2 hours from 9 am till 11 am and the overall assessment for the house is 'Comfortable'. Windows of this house were closed almost all day unlike windows in the other houses in summer. This could be explained by the way a comparatively high air change rate might compensate the short window opening time.

House 'C'

This flat has two bedrooms, a living room, a kitchen and a bathroom. Two adults and an one and a half year-old boy live in this house. Nobody smokes and has suffered from any of the diseases described in the questionnaire. There is an interesting fact that they open windows in bedrooms for one hour only when cleaning rooms in summer, moreover, they never open windows in bedrooms in spring & fall and winter. Nevertheless the allergen level of this house was much less than the recommended standard, 2 ㎍/g, by WHO. The underfloor heating of this house might have played a key role in reducing the HDM allergen(Der P1) level as low as <100 ng/g. The higher temperature on the floor than the ambient air temperature will have lower relative humidity. The overall tenant's assessment with the regard to the thermal conditions revealed that the central underfloor heating may not a flexible heating system. Temperature in winter was described as 'Warm', in spring & autumn "Slightly cool", and in summer "Neutral", however, with the regard to the humidity level in the dwelling, they described their house as "Comfortable" despite the short window opening period and having no particular ventilation system.

House 'D'

There are two bedrooms, a kitchen, a living room and a bathroom in this flat. Two adults and a two and a half year-old boy live. One of tenants smokes but not often. They described their house as "Stuffy" in winter which is consistent with the low infiltration rate, 0.36 ACH and there was an interesting fact that they have not used trickle ventilators in windows which in turn, might have made indoor air quality worse. In this house there were two people who have suffered from diseases possibly related to HDM. One has been suffering from a rhinitis for four years and the other from an atopic dermatitis from birth. It could be a coincidence that there are only two people suffering from HDM related diseases among all tenants in the monitoring houses and both of them have lived in the same house in which the HDM allergen level is the highest, 22,778 ng/g i.e. more than 2 times the Der P1 threshold. However, the person who is suffering from a rhinitis had a relapse of it some months after they moved into this house, accordingly it may be quite within the realms of possibility that the high Der P1 level might have triggered the rhinitis again.

4. DISCUSSION

Many scientists, engineering and designers have aimed at controlling indoor environment to prevent HDM from proliferation. In practice, it is not an easy task to keep the indoor temperature and humidity at the proper range always. Furthermore keeping the humidity and temperature level properly might conflict with human comfort. For example, provided the average ambient air temperature in a heated room is 18 ℃, the floor temperature may be around 4 °K lower, i.e. 14 ℃. Keeping relative humidity below CEH(51.4 % at 14 ℃) will result in relative humidity of nearly 40 % at most at the air temperature of 18 ℃ assuming that the amount of moisture is constant in the room. This relative humidity, 40 %, is the boundary of the human comfort zone(40 – 70 %) in buildings recommended by CIBSE and moreover humidity is not constant within a year, a season, and even a day and always fluctuates in accordance with environmental changes.

Accordingly some other measures have been recommended which are vacuuming with a fine filter, use of acaricides, freezing of bedding either with liquid nitrogen or by placing bedding in the freezer, steam cleaning, use of mattress covers and removal of carpets.

Therefore it is needed to study the micro-environment and develop architectural based HDM control strategies because other measures mentioned above are not performed generally before the HDM proliferation is found and it is not an easy task for a house owner to perform those measures regularly. Furthermore once HDM proliferate, reducing the number of HDM is difficult because so far no universally recognized method has been found. On the other hand, the micro-environmental control might prevent HDM from proliferating in dwellings fundamentally if buildings are designed properly from the first stage. An adequate design will remove the temperature variations in a house, in fact, the temperature variation always exists even in spring or autumn when the inside and outside temperatures are similar and the building fabric can not absolutely block the heat transfer from outside to inside or vice versa.

However it should be possible to remove cold bridges and reduce temperature variations in surfaces and temperature differences between the surface and the ambient air if buildings are well designed and constructed. It is also believed that well designed and constructed buildings might have less damp and mould problems and in turn, have lower HDM population on the basis that mites and fungi depend on each other for food. The mites feed on fungal spores and HMD droppings in turn provide nourishment for the fungi(Whitrow, 1995). Thus fungi in house support the growth of mites by providing them with spores as food.

Besides temperature and humidity, the ventilation rate as an indirect method has been found to play an important role in reducing HDM concentration as in the present study as in other studies. However it should be kept in mind, of course, that the ventilation rate should meet requirements for the human comfort and indoor air quality as for HDM control.

The type of heating might have an effect on vertical temperatures gradient in dwellings. ISO 7730 and ASHRAE standard recommends a maximum air temperature gradient of 3 °K between 1.1 and 0.1 m above the floor. As discussed above temperature difference will result in high relative humidity on the floor and, in turn, high HDM concentration. Provided this mechanism is taken advantage of by contrary with another heating system such as an underfloor heating, the floor temperature will be higher i.e. 6-7 °K higher usually than that of the air and in turn, automatically relative humidity of floor will be lower. Therefore, relative humidity of floor where HDM live in practice might be remained below CEH all the time without any other measures when heated.

5. CONCLUSION

The present study began with the hypothesis that the surface temperature and humidity would different from the ambient air temperature and, in turn, the surface humidity would be different from the ambient air and, furthermore, there might be temperature and humidity variation on the same surface. In fact, many previous studies measured temperature and humidity of the room ambient air, however temperatures and humidities were monitored at several points in the present study. Test result shows that there were temperature and humidity differences between the carpet and the ambient air in the test monitoring, which showed the necessity of detailed monitoring at the main monitoring stage, and moreover there were temperature and humidity variations on the same carpet. In addition, it was an interesting thing that the vapour pressure was not constant in the core room. These findings imply that the result from the monitoring might be different according to the location where monitoring takes place and measurements of temperature and humidity of the ambient air may not be suitable for a HDM study. Therefore it could be recommended that measurements of temperature and humidity be performed at the very point where dust sampling take place and where they live in reality or at least at the location which could represent the surface condition. But the monitoring micro climate of mite's habitat at a few points is not enough to represent the total mite's real survival environment in a room or house as discussed above.

The result of this study shows that high relative humidity and poor ventilation result in high Der P1 levels. Mite allergen was detected in every house. Homes with high relative humidity(>50 %) and poor ventilation(< 0.5 ACH) showed higher levels of mite allergen than homes with lower humidity and better ventilation. The allergen level was related to relative humidity and air change rate, however was not related to the collected weight. The result support the concept that reduced ventilation in homes involves a risk of increased house-dust mite exposures.

Data from the questionnaire survey are not enough number for the statistical analysis or generalization of the results, however, the survey helped to confirm the findings of the monitoring and samplings, comparing Der P1, humidity level and ventilation rate with the window opening period, illness related to HDM, etc.

As the recommendation for the further research, advanced equipment in building science field such as thermal infrared camera might be useful for precise monitoring in consideration of time(fluctuation). And it is needed to analyse the influence of heating system; especially underfloor heating and the other system. There might be interesting finding from the monitoring micro-climate and sampling dust allergens of underfloor heating and the other system.

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