Research Paper

The Nottingham energy, health and housing study: reducing relative humidity, dust mites and asthma

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Abstract

This paper describes the Nottingham energy, health and housing study, a project where seven Nottingham City Council households subject to either fuel poverty or heat poverty have been refurbished to improve the internal environmental conditions and therefore the health of the occupants. The main aim was to provide improvements in ventilation, insulation, draughtproofing and heating control in the dwellings. An intervention study was carried out in the seven dwellings where temperature, relative humidity, health, dust mite numbers and ventilation were measured before the introduction of a range of heating, ventilation and insulation improvements. These were then monitored again a year later. The results of the study indicate that with a limited budget, significant improvements have been realised in the comfort levels of the occupants and in their health. Modelling of the environmental conditions and energy consumption in each dwelling has been carried out using the steady-state Condensation Targeter II model. Comparisons between the model predictions and the measured data show that Condensation Targeter II can be used as an effective tool for selecting the most appropriate design modifications for an individual dwelling and can assess the impact that these modifications will have on the energy efficiency of the dwelling and the health of the occupants.

1 Introduction

The primary aim of the Nottingham energy, housing and health project was to reduce asthmatic symptoms and improve the health of seven Nottingham City Council households subject to either fuel poverty, heat poverty or both. Given the limited resources the project was seen as a pilot study that would reveal the key problems associated with providing well ventilated and energy efficient dwellings.

The project was originally devised by NEA Nottingham who were successful in securing funding from the Nottingham Health Authority Health Initiatives Budget. The main aim was to provide improvements in ventilation, insulation, draughtproofing and heating control in the seven dwellings. Nottingham City Council was also a partner in the project and provided new or improved heating systems through their health priority scheme. Additional theoretical and practical advice was provided by the Health and Housing Group, funded by a grant provided by EAGA Charitable Trust, and The Bartlett School of Graduate Studies also provided monitoring support.

The aims of the project were:

- To improve the energy efficiency of the seven dwellings
- To enable the dwelling occupants to maintain warmer homes at the same or lower costs
- To reduce the average internal relative humidity
- To reduce house dust mite populations

- To obtain noticeable improvements in the health of the occupants
- To explore the advantages and disadvantages of different ventilation systems in terms of cost, installation and maintenance
- To examine practical lessons from the installation of space heating systems and controls

This paper describes briefly the critical factors that affect the health of dwelling occupants, the method of selection of the seven houses, the range of improvements chosen for each of the dwellings and their installation.

Each dwelling was extensively monitored before and after improvements were installed. Data was collected relating to occupant living patterns and their energy usage, internal temperature and relative humidity, ventilation rates, house dust mite counts and health monitoring.

Finally, the average temperature, relative humidity and energy consumption in each of the dwellings has been predicted using Condensation Targeter II, a monthly temperature and relative humidity prediction model which has been described in detail previously(10) and comparisons with the measured data have been carried out.

This project provides both interesting results and demonstrates a methodology that may be appropriate for further large scale studies. For more details of the project the reader is referred to the project report(7).

2 House dust mites, housing and health

Reducing the cost of space heating and improving thermal comfort is a careful balance between using insulation and controlled ventilation to reduce heat loss while maintaining appropriate indoor air quality.

Sources of internal air pollution are widespread and include tobacco smoke, carbon monoxide, volatile organic compounds, mould spores, oxides of nitrogen, sulphur dioxide, animal dander, radon and house dust mites. In four levels of health hazard risks the Building Research Establishment has categorised both hygrothermal conditions and house dust mites within the highest level of risk(16).

The most common species of mite found in UK dwellings is *Dermatophagoides pteronyssinus* (the house dust mite). In many UK dwellings the *Euroglyphus Maynei* mite is also found, and in rare situations the *Dermatophagoides farinae* (the storage mite) which is more usually found in continental Europe and North America. Dust mite populations vary seasonally and concentrations vary considerably between different dwellings although the seasonal pattern is common in all Northern Hemisphere countries. Mite populations are highest during the months of August, September and October and lowest in the months of February, March and April(5).

Dust mites measure only 250 to 350 microns in length and are translucent implying that they are not easily seen with the naked eye. They feed on dust that accumulates in carpets, bedding, fabrics and furniture.

The development time of dust mites from egg to adult depends upon both temperature and relative humidity. At a constant 75% relative humidity and 16°C it takes an average of 123 days for the *Dermatophagoides pteronyssinus* mite to develop from egg to adult whilst at the same relative humidity and 35°C it takes an average of only 15 days.

The main environmental control factor for dust mites is relative humidity. This is because dust mites can not drink liquid water to keep themselves hydrated. The main mechanism for hydration is a duct at the side of their head that carries a salt solution towards the mite's mouth. This salt solution absorbs moisture from the surrounding environment if the ambient relative humidity is sufficiently high.

The Critical Equilibrium Humidity (CEH) is defined as the relative humidity below which the mites are unable to regulate their water balance, due to salt crystallisation, and consequently begin to lose water and eventually die. The CEH for *Dermatophagoides pteronyssinus* at 25°C is 73%[(2)]. However the CEH is also dependent upon temperature such that as the temperature increases so does the CEH. This has been measured for the *Dermatophagoides farinae* but not directly for *Dermatophagoides pteronyssinus*. If we make the assumption that the same phenomenon occurs for both species of mite then we can specify limiting environmental conditions for the growth and proliferation of the house dust mite. Cunningham[(8)] has suggested that the ambient relative humidity should be kept below 40% at 16°C, 45% at 21°C and 50% at 26°C.

It must be pointed out that dust mites have been known to thrive in situations where the average relative humidity is kept below these critical levels and there may be several reasons for this:

- The dust mites may depend upon short-term bursts of high relative humidity to replenish body water and allow survival through low relative humidity periods.
- The micro-environmental conditions within which they exist may differ significantly from the ambient conditions.
- The dust mites may have a temperature dependent CEH and so may be surviving at lower relative humidities in colder locations.
- Under desiccating conditions mites tend to aggregate together so that moisture losses from the group are reduced to a minimum.

The house dust mite is associated with widespread illness, particularly allergic reactions. Antigens derived largely from the mite faeces are one of the major causes of allergic sensitisation in the UK(10). Dust mite are closely associated with asthma, dermatitis, rhinitis and keratoconjunctivitis(8). There is clear evidence of causal relationships between the indoor environment and mite infestation, between mite infestation and allergen exposure and between allergy and respiratory disease(18). Allergy to mite allergens is fairly common in the atopic population and reported prevalence amongst asthmatics varies between 45% and 85%(19). The house dust mite allergen has been said to contribute to the 2,000 asthma related deaths that occur in the UK every year(20).

3 Practical methods of controlling dust mite populations

There are a number of control measures available for reducing dust mite populations:

- Chemical control
- Cleaning and vacuuming
- Use of electric blankets
- Covering mattresses and pillows
- Removal of carpets, soft furnishings and soft toys
- Indoor humidity control
- Freezing and steam cleaning

A number of studies have examined the use of acaracides to reduce mite levels. Some have indicated significant lowering of mite numbers[6] whilst others have found no significant change in mite numbers[3]. No clear correlation has yet been found between frequency and thoroughness of vacuuming and mite numbers although in experiments carried out to determine the effectiveness of washing it was found that all mites were killed by water temperatures over 55°C[11]. Colder washing removed all mite allergens but left live mites. The use of electric blankets has been found in most cases to decrease mite populations since temperatures in the bed are increased therefore lowering the relative humidity. However these experiments were carried out with blankets kept on for 12 hours a day throughout the year[12]. The removal of carpets and the covering of mattresses with semi-permeable covers have been found to significantly reduce the levels of house dust mite allergens in dwellings[17].

Indoor relative humidity control is one of the most effective long-term mite control measures. There are many ways in which the internal relative humidity can be controlled including the use of appropriate ventilation, the reduction of internal moisture production and the maintenance of adequate internal temperatures through the use of efficient heating and insulation. It has been shown that Mechanical Ventilation with Heat Recovery (MVHR) systems can significantly reduce internal relative humidities within rooms and mattresses[10] leading to a healthier internal environment.

The main emphasis of the Nottingham study was to improve the energy efficiency, to improve internal environmental conditions, to reduce dust mite populations and thereby improve the health of the occupants in seven dwellings.

4 Research methodology

The Nottingham project set out to improve the energy efficiency and ventilation of a small group of houses where it had already been decided to improve the space heating system. Nottingham City Council operates a special medical priority budget, which can provide central heating systems for a limited number of tenants with special medical needs. This project was an intervention study where monitoring was carried out before the dwelling improvements were installed and then again a year later after the interventions. It was not possible to maintain a control group because of the limited project finances.

Installing central heating alone can lead to other problems, if, for example, the occupants can not afford to heat the dwellings to adequate internal temperatures, it may result in environmental conditions which encourage the population of dust mites. As a result, this project, with a limited total budget of £8,500, intervened in seven houses with a range of additional energy efficiency and ventilation measures designed to improve the environmental conditions and hence to improve the health of the occupants.

The seven houses chosen for the study were selected from a list of houses included in the City Council's scheme, which had yet to have their heating installed. The criteria used for selecting the houses were divided into two groups: essential and desirable, and are indicated below.

Essential:

- Occupants intended to remain in the dwelling for at least two winters
- Occupants were keen and prepared for the required level of interference
- Occupants had a low income or were classified as living in fuel poverty (where the fuel costs exceed 10% of the disposable income of the occupants)
- Occupants had one or more children with asthma who are known to be allergic to house dust mites

- Dwelling had no full space heating installed
- Occupants had no pets which would produce animal dander

Desirable:

- A range of different dwellings in terms of age and construction
- No smoking in the house

It was not possible to achieve all of these objectives. In one dwelling there was almost full central heating prior to the interventions, in three of the dwellings there were dogs and it was not possible to eliminate smokers.

The monitoring of environmental conditions, measurement, sampling and testing in each dwelling was carried out in February 1998 and repeated in February 1999 when the interventions had been completed. The monitoring included the following:

- The infiltration rate in each dwelling was determined using a blower door manufactured by Retrotec (Europe) Ltd.
- Energy Audits were carried out, each house being modelled using the National Home Energy Rating (NHER) scheme[13].
- Temperature and relative humidity was monitored in each bedroom using TinyTalk electronic dataloggers manufactured by Gemini Data Loggers Ltd. Simultaneous external conditions were also monitored.

- House dust mite samples were collected from carpets using a Medivac vacuum cleaner, in one bedroom and the living room in each home and the number of mites per gram of dust was determined. A $1m^2$ area of carpet was chosen in the centre of the living room and beside the bed in each dwelling and these areas were vacuumed for 1 minute in one direction and then a further minute at right angles to this direction.
- Occupants who were asthmatic were asked to record their daytime and nighttime use of inhalers and any general comments on their wheezing, coughing and respiratory system. The peak air-flow was also monitored for each asthmatic to test his or her breathing.
- A simple diary was provided for each household to be completed during the monitoring periods, recording heating patterns, the use of baths and showers, the number of meals cooked, frequency of washing clothes, window opening behaviour and the use of ventilation systems.

5 The improvements

Given the restricted budget available to this project, the improvements carried out in each dwelling, over and above the improvements carried out by Nottingham City Council, were limited. Table 1 indicates the improvements and the *total* costs of improvement in each of the seven dwellings.

6 Energy efficiency, fuel usage and environmental conditions

The NHER rating of each of the seven dwellings has been determined before and after the improvements had been installed. Although the NHER involves additional factors to the Standard Assessment Procedure (SAP rating), a very approximate equivalent is the NHER is a tenth of the value of the SAP rating.

The total predicted running costs to achieve comfort levels have also been determined, together with an estimate of the running costs as a percentage of the occupant income. The predicted running costs assume that the heating system is switched on for 2 hours in the morning and 7 hours in the evening during weekdays and 16 hours per day at the weekends. It also assumes a demand temperature in the living room (zone 1) of 21°C. This data is shown in Table 2.

The improvements in NHER ratings and the total predicted costs to achieve comfort are significant as Table 2 indicates. Whilst in some houses there has been a substantial increase in energy efficiency in others there is very little or no change. On average, the total predicted running costs have reduced by over 30% although this figure varies considerably between each dwelling. The widely acknowledged definition of fuel poverty in a dwelling is where the cost of fuel exceeds 10% of the disposable income of the occupants(15). In this case it can be seen that before the interventions, six of the dwellings would be described as suffering from fuel poverty. After the improvements it can be seen that this has reduced to three dwellings, and although this is a positive result it is still of some concern. This highlights the poor condition of some UK properties. Even after the expenditure of £3,000, the Bilborough house still has a comfort fuel bill which equates to 15% of the occupants disposable income.

Blower door tests were carried out in each dwelling before and after the interventions. The results obtained relate to the air change rate at a pressure difference of 50 Pa. The results have also been converted to air changes per hour under average external conditions.

The consumption of energy was also measured in each of the seven dwellings, although a certain level of uncertainty has to be attached to this data. This is due to the fact that fuel meter readings were taken when the dataloggers were collected and delivered. The periods of environmental monitoring were slightly shorter than this.

The blower door test results and the average energy consumption in each dwelling, before and after improvements, is shown in Table 3.

The measured ventilation rates in the seven houses generally fall within the expected limits apart from Bilborough where excess ventilation existed and where numerous air bricks and other sources of air leakage were found. The data presented in Table 3 shows the wide variation of dwelling volume between these seven houses.

The results also show that although the energy efficiency of the dwellings has been improved the measured energy consumption increased after the intervention. This slight rise in average energy consumption can not be explained by differing external conditions since after the interventions the outside temperature was warmer by 1°C. Further analysis of the results shows that although the measured temperatures in the living room are relatively similar before and after improvements were carried out the bedroom temperatures significantly increased during this period by up to 5.4°C. This suggests that following the interventions the occupants tended to heat their dwellings, or parts of their dwellings, to higher comfort temperatures. Measured temperatures and relative humidity are shown in Table 4.

A target relative humidity of 50% was set on the basis that at this level the risk of dust mite proliferation is limited. Before improvements were carried out the average bedroom relative humidity exceeded this figure significantly, although in two of these dwellings the relative humidity was just below this figure due to elevated internal temperatures. Following improvements the average bedroom relative humidity was reduced significantly although remained just above the 50% target. The living room relative humidity was found to be below 50%, both before and after improvements were carried out. Living room temperatures rose slightly after the improvements which is not surprising since this area of the house is usually the warmest both in energy efficient and poorly heated homes. The average bedroom temperatures increased by an average of 2.2°C.

7 House dust mites and health monitoring

House dust mite samples were collected before and after the improvements were made to each dwelling and were extracted and counted using the flotation method of Thind and Wallace using kerosene water mixtures. *Dermatophagoides pteronyssinus* accounted for 66% of the mites found, *Euroglyphagus maynei* made up 12%, *Glychagus domesticus* made up 10% and the remainder included three other types of mite and some that were not identified. The number of mites per gram of dust before and after improvements were carried out are shown in Table 5.

The results show a clear divide between bedrooms and living rooms with all bedrooms having higher levels of mites. The 1999 results show that in four bedrooms the mite counts have reduced to zero and in other dwellings the counts have reduced significantly. In the Broxtowe house where the installations of fans had been faulty and where the tenant had hardly used the bedroom fan or the heating, there was some improvement in total mite numbers although the mite count in the living room had increased. The World Health Organisation (WHO) categorises mite counts under 100 per gram of dust as low, between 100 and 500 per gram of dust as intermediate and counts exceeding 500 per gram of dust as a high health risk. Using their definitions there was originally one bedroom in the high-risk category and three in the intermediate-risk category. After interventions this has reduced to one bedroom on the low to intermediate risk boundary.

Two measures of health were taken during the survey including the SF-36 self-completion questionnaire[(4)], a widely used self-assessment research tool that scores between 100 (very good) and 0 (very poor). The results of the SF-36 survey were positive in five of the dwellings, indicating an improvement in perceived health of up to 40%, neutral in one dwelling and negative in the other dwelling. The average improvement in perceived health of all seven dwellings was just under 10%.

The second measure of health was the recording of peak expiratory flow readings. This is a measure of the effectiveness of the lungs and is achieved by blowing into a small tube which records the pressure exerted by the lungs. Only a limited number of measurements were made as indicated in Table 6.

The results of the health monitoring show some significant improvements in the health of the dwelling occupants following the improvements carried out. However, the sample size is too small to lead to conclusive health predictions.

8 Modelling environmental conditions and energy consumption

The temperature, relative humidity and energy consumption in each of the seven dwellings has been modelled using Condensation Targeter II, a steady-state model that has previously been described in detail[(14)]. The modelling has been carried out to assess the ability of Condensation Targeter II to be used as a tool to assess the impact of changes in dwelling design on the dwelling energy efficiency and the health of the dwelling occupants.

Basic dwelling and occupancy data was collected as part of the original survey of each dwelling, and from the diaries, and this was incorporated into the Condensation Targeter II model. One of the key input parameters required by Condensation Targeter II is the dwelling demand temperature. A demand temperature of 21°C is normally assumed in the living room (zone 1) area under standard occupancy patterns although, in reality, it varies considerably. For each dwelling an estimate of the zone 1 demand temperature has been made which reflects the average conditions measured. Predictions of the average temperature and relative humidity in the living room and bedrooms, both for the original dwelling configuration and for the refurbished dwellings have been determined and these have been compared to the measured conditions. Energy consumption predictions have also been determined for each dwelling and compared with the measured consumption. For each set of data a chart has been produced comparing the monitored and predicted data. On each chart the dashed line indicates perfect agreement between monitored and predicted data (x=y), the solid line represents the linear trend line of the data points and the straight-line equation ($y = mx + c$) and the R^2 correlation coefficient of this trend line is indicated. Figure 1 shows the comparison of predicted and measured temperatures and Figure 2 shows the same results for the relative humidity.

The predicted and monitored temperatures in each dwelling, before and after refurbishment, are in good agreement with each other. This is to be expected since the demand temperatures in each dwelling were determined by examination of the average measured temperatures. The mean deviation between predicted and measured temperature is 0.6°C. There is also good agreement between the predicted and measured relative humidity with a mean deviation of only 6.1% relative humidity. The results show that although there were some limitations in the moisture production input data in each of the dwellings, the moisture calculation in Condensation Targeter II predicts relative humidity with a reasonable level of accuracy.

The results of the comparison between predicted and measured energy consumption is shown in Figure 3. Each of the seven dwellings has been identified on the chart and the arrow joining each of the two data points indicates the difference in energy consumption before and after refurbishment.

The results show that there is a significant variation between the energy consumed in each dwelling and the predictions of Condensation Targeter II, before and after the refurbishment process. The results show a mean deviation between predicted and measured energy consumption of 35 kWh/day. Interestingly, measured energy consumption has not always reduced after refurbishment, as might be expected following an increase in dwelling energy efficiency. However, the changes in measured energy consumption are inconsistent, with three of the dwellings showing reductions in measured energy consumption and four showing an increase. The predictions of energy consumption are also variable, with five of the dwellings indicating an increase in predicted energy consumption and two of the dwellings showing a reduction. For four of the dwellings the predicted energy consumption trend follows the measured consumption trend including three dwellings where there is an increase and one where there is a reduction. For the other three dwellings the predicted energy consumption trend is in conflict with the measured energy consumption.

9 Discussion

The primary aim of this project was to improve the health of seven Nottingham City Council households subject to either fuel poverty, heat poverty or both. The project aimed at reducing relative humidities and increasing the affordability of heating and the internal temperatures within the seven dwellings.

The number of properties modified, the type of modification and the degree of monitoring was severely constrained by the available funding. The results should therefore be seen as indicative only since the sample size is too small to provide statistically significant results. However, some very interesting results were obtained from this small sample of dwellings. In addition, the methodology developed is appropriate to larger scale studies. A similar study is now being undertaken as part of the Government HEES scheme in 200 properties with a control group.

Significant improvements occurred in the environmental conditions in all of the dwellings. On average, the NHER ratings in the dwellings increased by an average of 2.1 on a ten-point scale and predictions of energy consumption reduced. As a result, the perceived number of households suffering fuel poverty has reduced. The fact that the measured average energy consumption increased during the two monitoring periods can be partly accounted for by the increased comfort levels, as is demonstrated by the increase in measured internal temperatures. However, when this is taken into account in the NHER modelling there are still significant variations between predicted and measured energy consumption. This suggests that the core algorithm behind the NHER calculation, BREDEM-12[(1)], may need further development to account for energy consumption in the fuel poverty sector of housing. It is also interesting to note that several of the properties, which were classified as 'fuel poor' prior to the interventions, had an increase in energy consumption after the interventions.

Given the limited amount of data available in this project, the Condensation Targeter II model has demonstrated that it can be used to assess the internal environmental conditions in dwellings and can assess the likely impact of changes in dwelling design and occupancy on the health of the occupants. The accuracy of the predictions of energy consumption in the seven dwellings is variable. However, in the majority of the dwellings modelled the changes in the predicted energy consumption have followed the trend in the measured energy consumption. The results highlight the fact that it is very difficult to model what actually happens in an individual dwelling.

The Condensation Targeter II model is currently being further developed under a Government funded research project. This project is examining the link between the ambient environmental conditions in bedrooms and the micro-environmental conditions in the mattress and bedding, the environment where the house dust mites live. The ultimate aim of this project is the development of a hygrothermal model of house dust mite response to environmental conditions in dwellings.

Monitored internal temperatures increased by an average 2.2°C in the bedrooms and by 0.7°C in the living rooms. However, whilst the average temperatures in five bedrooms were below 18.0°C before the modifications, three were still below 18.0°C after the refurbishment was completed.

Monitored relative humidity in the bedrooms and the living rooms reduced during the monitoring periods, most significantly in the bedrooms where the average relative humidity reduced by almost 10%, even though the external relative humidity increased by 7% over the same period. This can be explained, in part, by the significant increase in the average bedroom temperatures, and in part by the reductions in vapour pressure excess.

A substantial reduction in the number of dust mites collected in the living room and bedroom occurred after the intervention. The number of mites found in the bedroom was significantly more than in the living room and following the interventions reduced from an average value of 377 mites per gram of dust to only 18. In all but one of the dwellings the number of mites found in the bedroom reduced to below 10 mites per gram of dust; an insignificant level as far as the health of the occupants is concerned. However, in the living room of one dwelling the number of mites found increased from 11 mites per gram of dust to 167, the reason for which is unknown.

The perceived health of the occupants as measured by the SF-36 questionnaire improved by an average 10% and the effectiveness of the lungs of the four asthmatics tested improved by an average of over 20% as measured by the peak flow readings.

8 Acknowledgements

Various organisations have assisted in this project and the authors would like particularly to thank the tenants of the seven dwellings, EAGA Charitable Trust, Nottingham Health Authority, National Energy Action (NEA) and Nottingham City

Council. The authors are also grateful for the assistance provided by Brynmor Evans and Craig Milliken in the data collection.

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