Quantifying ventilation needs in Local Authority Housing - A case study

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Synopsis

A Tool Kit was developed to assess indoor air quality. The Tool Kit was designed to be robust, reliable, universal and to provide data that could be linked with other studies assessing health, social factors and building conditions for any given locality. A case study using the Tool Kit to assess 116 Local Authority houses is described.

Introduction

Overview

A community survey was carried out in 1997, by the Tenants of a Local Authority owned housing estate, after the Tenants had voiced concerns about the state of their housing conditions and whether these conditions were affecting their health. An initial survey of 96 households revealed that 64% of the households suffered damp conditions and that there was at least one occupant with a respiratory illness in 60% of the houses. The population participating in the survey, had a normal social and age distribution representative of any housing estate population in the UK.

Following the community survey a decision was made by the Local Authority to fully investigate any links between physical conditions in the houses and the Tenants' health. Although the houses were of the same size, age and construction, they had different combinations of ventilation, insulation and personal household management. Therefore, the investigation needed to be multi-disciplinary, taking into consideration the existing building conditions, socio-economic factors, health factors and the indoor air quality (IAQ) in each individual house. The survey also led to a commitment from the Local Authority to renovate the properties to meet the latest UK Government recommended standards for housing. The commitment to upgrade the housing stock over a two year period opened up a unique opportunity to conduct a comprehensive study.

A 'randomised to waiting list' controlled trial was initiated (with the estate stratified into streets, with one house equalling one unit and a population of 509 people), based on five parallel studies, over two years:

1. An environmental assessment of the IAQ, outdoor air quality and rates ventilation for individual houses concentrating on major parameters linked to ill health. This study would register any changes in IAQ, ventilation rates and how the Tenants managed their properties, before and after the renovations.
2. Personal health checks conducted through face to face private interviews between Tenants and a community nurse.

3. A prevalence study of illnesses (mainly respiratory), including the recording of the number of people and pets per household, the number of smokers per household and the type of cooking and heating systems installed.
4. The recording of personal social details.
5. Details of the physical attributes of the property as assessed by SAP ratings (DETR, 1998 a).

All the parameters recorded in each study were carefully chosen to look for confounding factors associated with certain illnesses.

Theory behind a 'Tool Kit' for measuring IAQ and ventilation

In order to fulfil the requirement for an environmental assessment of the air quality and ventilation rates in the houses (parallel study no 1), a method of monitoring had to be designed which was reliable and robust. The method required a 'Tool Kit' to monitor the chosen parameters. The design of the Tool Kit had to be universally functional and easy to handle. There was no prior agreement with the Local Authority before the investigation began, as to which parameters would be recorded, indeed there are no UK Government guidelines as to which IAQ parameters are the most important in relation to human health (COMEAP, 1997). Therefore the parameters measured were based on extensive studies of scientific literature and chosen to be representative of IAQ, ventilation rates and factors generally related to poor health. The parameters chosen and their measurement had to be readily understandable by all the other groups involved in the parallel studies and compatible with the methodology used in these studies.

To allow for analysis of the results collected by the Tool Kit, together with the results from the parallel-studies, the measurements needed to be quantitative rather than qualitative. Although the data collected by the Tool Kit could not be the basis of a judgement about 'good or bad' IAQ and ventilation rates, the quality of the indoor environment could be assessed in conjunction with results from other parallel studies in a holistic analysis.

The Tool Kit was designed originally to take a 'snap shot' of the air quality in the Local Authority houses. It reflected how the Tenants managed ventilation, heating, the reduction of aerosolised contaminants, relative humidity and any other indoor air pollutants. The Tool Kit had to be easy to operate in a limited time period, as 116 houses were to be assessed, which logistically did not allow for extensive studies of each house. When the 'snap shots' of the air quality are compared before and after the renovation programme for the houses, an assessment can be made as to whether the IAQ and or ventilation regimes/ rates have changed. The 'snap shot' will also show whether the Tenants have changed their management of indoor air/ ventilation. Assessing changes in the Tenant's health throughout the renovation programme might allow links to be made between changes in physical parameters and health.

This paper describes the science and methodology behind the Tool Kit and describes a case study undertaken in the Local Authority housing.

Methodology

Background

The composition of indoor air in general is characterised by a number of factors:

- Outdoor air borne pollutants - 60 -70% of fine (< 2.5 μm) and coarse (> 2.5 μm) particles penetrate into buildings (Dockery et al, 1981; Thatcher et al, 1995). The sources of these

particles can be defined as bio-aerosols (bioload), mineral, combustion, home/ personal care and radioactive aerosols (Owen and Ensor, 1992).
- Outdoor weather conditions - The weather, location and orientation of the dwelling are important factors affecting IAQ and ventilation rates.
- Human and larger animals' (pets) physical activities - These activities create fresh particles through abrasion and 'old' particles are re-suspended (Ekberg, 1994). These activities are normally associated with coarse particles, together with exhaled water molecules (which also lead to increases in relative humidity).
- Tobacco smoking and food preparation - Smoke and the emissions from cooking, create a very large number of fine particles, along with gaseous compounds such as nitrous oxides and particles with adsorbed poly aromatic hydrocarbons (Abt et al, 2000).
- Specific contaminants - Some sources and activities release specific contaminants such as formaldehyde or lead. However these are relatively unusual and were therefore not included in the Tool Kit. An exception was made for the measurement of the house dust mite (HDM) allergen, Der p 1 as it is implicated as a factor in respiratory disorders (ENDS, 1996).

Previous work (Rosén and Richardson, 1999) demonstrated the variation of fine and coarse particle numbers over time, in localities where intense changes in activity levels occur and how this might be linked to breathing related illnesses or problems. Strong links have been found between outdoor levels of particulates and human health problems (COMEAP, 1997; DETR, 1998b), therefore by implication, indoor air should also be assessed for similar links. Consequently this work focuses on the design of a Tool Kit capable of assessing IAQ and rates of ventilation in a given locality, during one visit, lasting 1 hour, with particular emphasis on particulate concentrations. An array of scientific instruments were used to measure the various parameters.

Description of the universal Tool Kit

A Tool Kit was required, to sample and record data for further research on the quality of indoor air and ventilation rates, meeting the following criteria:
- The ability to record robust data without any prior preparations in a locality. All measurements were made in triplicate.
- The equipment had to be easy to set up and run in the limited time available. For example, measurement of coarse particles was carried out within 15 minutes of arrival in each location to equalise any settling effects after any initial disturbance.[1]
- The Tool Kit had to be portable by one person and completely functional without causing disruption in the locality. All test methods had to be non-destructive and intrinsically safe, especially since some units of the Tool Kit had to be left running unsupervised for up to one hour.
- The data had to be collected and recorded in a manner that was easily computerised. The resultant data spread sheets had to be compatible with statistical packages such as Microsoft Excel and SPSS 9.0 for Windows.
- Data collection had to be unobtrusive, therefore every attempt was made to use low noise equipment powered by batteries and no structural changes were required.

1 Unlike coarse particles, fine particles have settling rates << 1 m/ h, therefore the number of fine particles are not affected over the short measuring period in the house (Thatcher, 1995).

Parameters recorded by the Tool Kit

The following table lists the main parameters recorded by the Tool Kit. In the majority of cases parallel measurements were taken outdoors, to allow an assessment of the level of infiltration of outdoor pollutants.

Main parameters	Units	Outdoors	Indoors
RH (Relative Humidity)	%	X	X
Temperature	^{O}C	X	X
PM_3 (fine particles) & PM_7 (coarse particles)	No./ l air/ 30 sec.	X	X
Wall/ wall surface dampness	WME %		X
CO, CO_2, Volatile Organic Compounds, NO_x	ppm/ppb	X	X
House Dust Mites (HDM allergen Der p 1)	µg* & µg/ g dust		X
Small -/+ charged air ions	No.'s/ cm^3 of air	X	X
Mould counts	no.'s/ slide		X
Wind speed and direction	m/ sec	X	

* total µg per sample.

The total data set available from each visit comprised 34 parameters.

Details such as study number, time and date of data entry were used to locate data sets from each visit, allowing a seamless integration of data between the parallel studies, which also used the same data locators.

The equipment and methodology used by the Tool Kit

- PM_3 (fine particles 0.3 to 3.0 µm) and PM_7 (coarse particles 3.0 to 7.0 µm) were measured using a laser beam particle counter, equipped with a temperature (°C)/ relative humidity (RH %) probe, (Met One model 227B, Oregon, USA). Particles were counted per litre of air, continuously over a 30 second period, both in and out of doors (5 % coincidence error at 70,671 particles/ litre). The characteristics of the counter defined the particle size ranges used. All measurements were taken 1.5 m above floor level.
- Positively and negatively charged small atmospheric air ions, with a mobility range of 0.05 cm^2/ sec/ V (Medion specification sheet, 1975), were counted in and out of doors using an Atmospheric Ion Analyser, type 134A (calibration tolerance ± 5%) Medion, Oxted, England. All measurements were taken 1 m above floor level.
- Electrostatic fields were recorded with a static locator, model SCANFIELD, with a variable range of '+' or '-' , 0 to 100 kV depending on the proximity to a source. All measurements were taken 0.5 m above floor level.
- Details of climatic conditions were noted including temperature, relative humidity, wind direction and wind speed. Government Meteorological Office reports were used to verify recorded details.

- Moisture (Damp) on wall surfaces and in the actual fabric of the walls was recorded by a PROTIMETER, made by Protimeter PLC, Marlow, UK. The Protimeter measures Wood Moisture Equivalent (the moisture that timber would adopt if kept in contact with the material measured, over time) with an accuracy of ± 1%.
- Carbon monoxide (CO) was measured with a CO detector (measuring in parts per million - ppm), made by Kane International, Welwyn Garden City, UK.
- Gas samples (for analysis of CO_2, NO_x and other gases) were collected in 100 ml syringes with a multi use sealing system, allowing subsequent analysis by Fourier Transform-Infra Red spectroscopy (FT-IR).
- Mould spores were collected on Hygicult slides with a 18 cm^2 growth/ collection area, made by Orion Corporation, Orion Diagnostica, Finland. The slides were exposed for one hour, then cultivated at room temperature in their plastic containers for 7-10 days. The Hygicult slides' growth medium was pre-moistened. A colour photograph was taken of each slide after cultivation.
- Dust samples were taken for later analysis off site to determine the levels of dust mite allergens present. The samples were trapped on a special filter material using a VorWerk VK 130, vacuum cleaner (without the EB 350 attachment) made by VORWERK, Germany. The filter material (VILENE), was made by Vileda, Germany. It is a breathable, saturation bonded mixture of 30% viscose, 30% polyester and 40% polyamide fibres. Basis weight 90 ± 10% g/ m^2. The dust samples were then sent for laboratory analysis of HDM allergen (Der p 1) content in the collected dust, according to the Elisa process (as described by Luczynska et al, 1989).

A case study of 116 Local Authority houses

General

A community worker with a good local knowledge, booked each house visit by correspondence and verbal confirmation with householders. The Researcher/ data collector was chosen from a different town with no connections with the Tenants or their surroundings. The researcher was instructed not to afford any help or comments during each visit even when Tenants expressly asked questions about the survey in general or results from measurements within their house (Tenant participation: Year 1 - 91%; Year 2 - 93%). Measurements were taken in the living room of each house and in a selected bedroom (SB), where at least one person regularly slept, who suffered from a respiratory illness. The houses had a similar internal layout, with a total volume of approximately 220m^3.

Site description

The housing estate was situated in a dedicated residential area, far from any major roads, with no through traffic or industry nearby. Virtually the only diesel driven vehicles on the estate were a regular bus service (once per hour), delivery vans and a few private cars. There were only 8 houses using coal fire as their only source of heating on the estate. The other houses used various combinations of gas and electric central heating.

Time scale

The study had to fit in with the house renovations, with time allowed for the Tenants to adjust to the renovations before an IAQ assessment took place. The Local Authority renovated the houses during suitable weather conditions, (to avoid rain when re-roofing the houses). Hence, the timing for the execution of the study coincided with the coldest period of the year, from the end of

January to mid-March. During this period all children of school age were away from the houses for most of the day. The data could only be collected between 09:30 and 15:00 from the houses to minimise disruption for the Tenants.

The staggered plan of renovation allowed different data sets to be recorded as follows;
Year 1 – Comparisons were made between individual houses and the whole data set for any parameter.
(Between year 1 and 2, 50% of the houses were renovated to meet Government recommendations).

Year 2 - Measurements as for year 1, plus;
comparisons can be made between non-renovated and renovated houses, by comparing to Year 1 results and between the different houses within Year 2.
(Between year 2 and 3, the remaining houses will be renovated).

Year 3 - Measurements as for year 1, plus;
comparisons can be made between non-renovated and renovated houses by comparing to the Year 1 & 2 results respectively.

Eventually comparisons can be drawn between IAQ, social and personal conditions for Tenants and between the renovated houses and the non-renovated houses from previous years. The results can be divided into groups of houses with smokers and non-smokers. This distinction is important since tobacco smoke has such a major influence on the number of fine particles indoors and the deposition of tobacco related compounds (Abt et al, 2000).

Modifications made to the universal Tool Kit for the case study

- Dust samples were collected from a mattress in the SB. 1 m^2 of the mattress was vacuumed during a 1 minute period. The mattress was chosen as the sampling point as there is a significant exposure to HDM when in bed (Antonicelli et al, 1991; Htut, 1994).
- Since all the houses had a similar internal layout, measurements could be taken in the same place in every house, except for variations in the position of the SB. Measurements for damp were only carried out in the SB, wherever damp was visible or suspected.
- The Researcher made observations of any unusual circumstances experienced i.e. houses surrounded by excessive coal fire smoke. Sometimes, against recommendations, Tenants would vacuum clean the whole house just before the Researcher visited, thereby distorting measurements of air borne particles.

The assessment of ventilation rates in the houses whilst people were present (given limited time) was not possible using conventional measuring systems, such as releasing smoke or carbon dioxide. Ventilation rates can however be empirically determined by comparing in/ and out of door values for a number of parameters.

Results and Discussion

The quantitative results gained from the first year of the case study serve as a good example of the results that could be expected from the Tool Kit. As the data from the study were so extensive only a few results will be discussed in detail. Examples of how these results can be represented are given in figures 1 - 5. Figure 1 shows the average difference (n = 116) between outdoor and indoor levels of certain parameters. To test for significant statistical correlation's between certain parameters a Pearson correlation (2 tailed) test was conducted using SPSS 9.0 for Windows.

PM_3 - The results showed a strong correlation ($p < 0.01$) between the number of PM_3 and the number of smokers per household (see Figure 2). The ratio between PM_3 in the SB compared to the level of PM_3 outdoors was 1.4:1 for households with no smokers and 4.7:1 for households with smokers.

PM_7 - The results showed a strong correlation ($p < 0.01$) between the number of PM_7 and the number of people and large pets per household. The number of large pets was added as they also markedly affect PM_7. Figure 3 illustrates how the number of PM_7 increases with an increasing number of 'bodies' in the houses. The average ratio between PM_7 in the SB compared to the level of PM_7 outdoors was 2.5: 1 for all households. The average ratio between PM_7 in the living room compared to the level of PM_7 outdoors was 3.7:1.

RH & Temperature - The average RH for all houses was found to be lower indoors than outdoors, however when calculated as absolute humidity, the moisture content of the air was actually greater in the SB (13.1 g of water/ Kg of air compared to 9.2 g/Kg outdoors).

CO_2 - Carbon dioxide levels were compared indoors and outdoors (Figure 4) for each house. Although in theory comparisons can be drawn between the number of people in the house, the CO_2 concentrations and the rate of ventilation, in practice this does not provide a reliable indication of ventilation. This is because the number of permanent residents were not representative of the number of people actually present when the samples were taken.

Damp - The wall surface dampness in the houses varied from completely dry walls to walls saturated with water and visible mould. In the selected bedrooms, 46% of the houses had a RH of 45-55%. The average number of mould colonies in the bedrooms was 9.4 per slide. The variation in the number of moulds per house is shown in Figure 5. Figure 5 also shows that there is no visible increase in the number of mould colonies when compared with increasing RH.

HDM - The average amount of HDM allergen Der p 1 in 1 g of dust taken from the mattresses in the bedrooms was 2.72 µg. This value is above the critical level of allergen for sensitisation of > 2µg/ g suggested by the International Workshop on dust mite allergens and asthma (International Workshop Report, 1989).

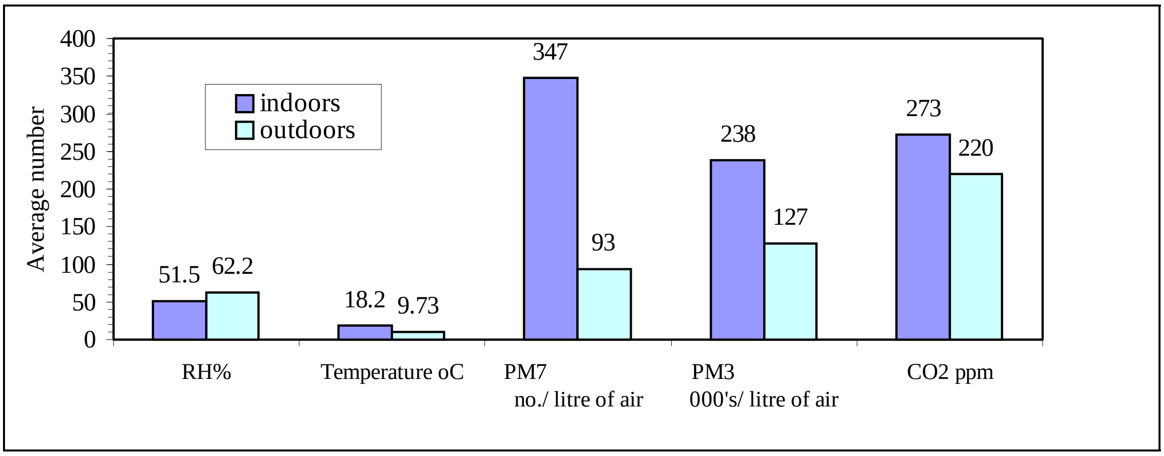

Figure 1: Comparison of the average value indoors against outdoors, for five parameters.

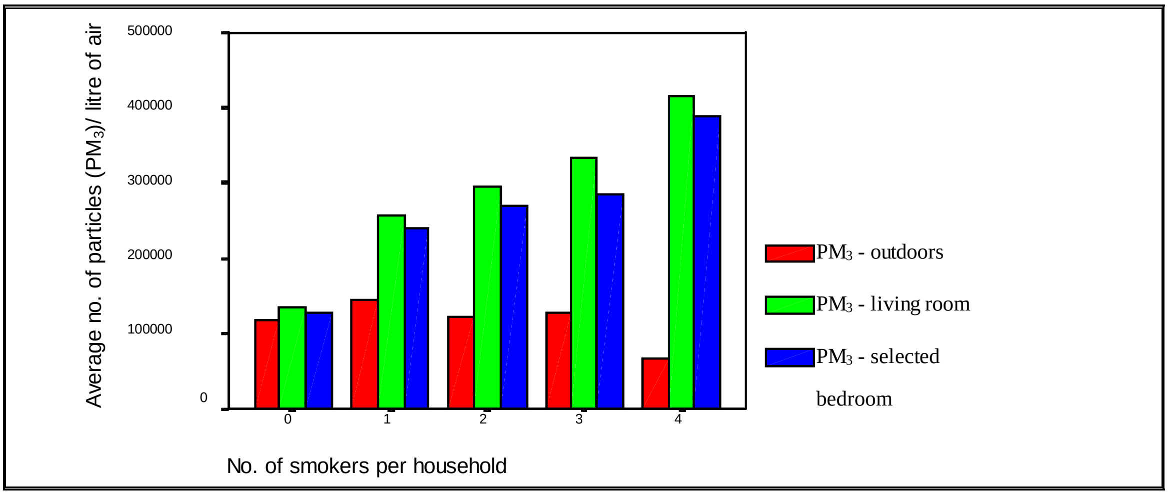

Figure 2: The effect of the number of smokers per household, on the number of PM_3.

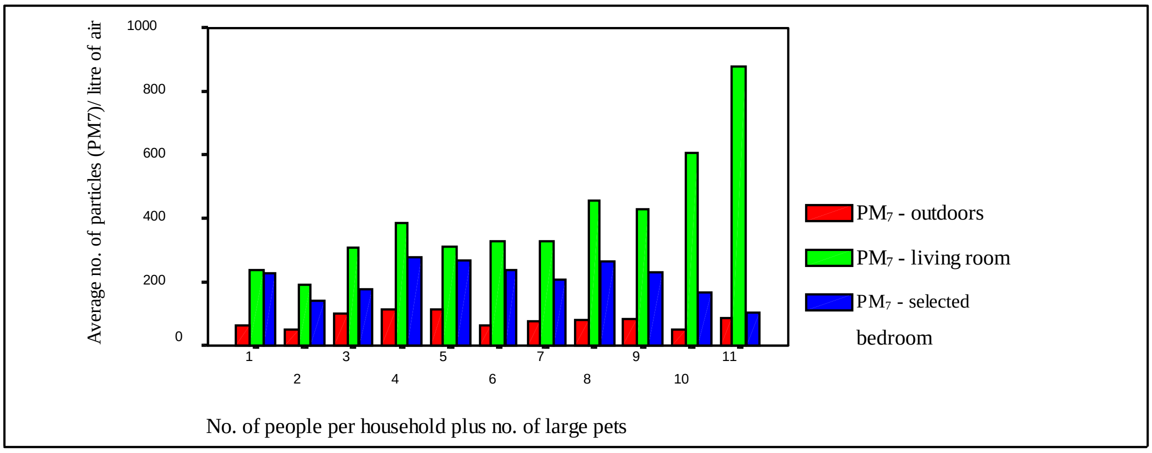

Figure 3: The effect of the number of people and large pets per household, on the number of PM_7.

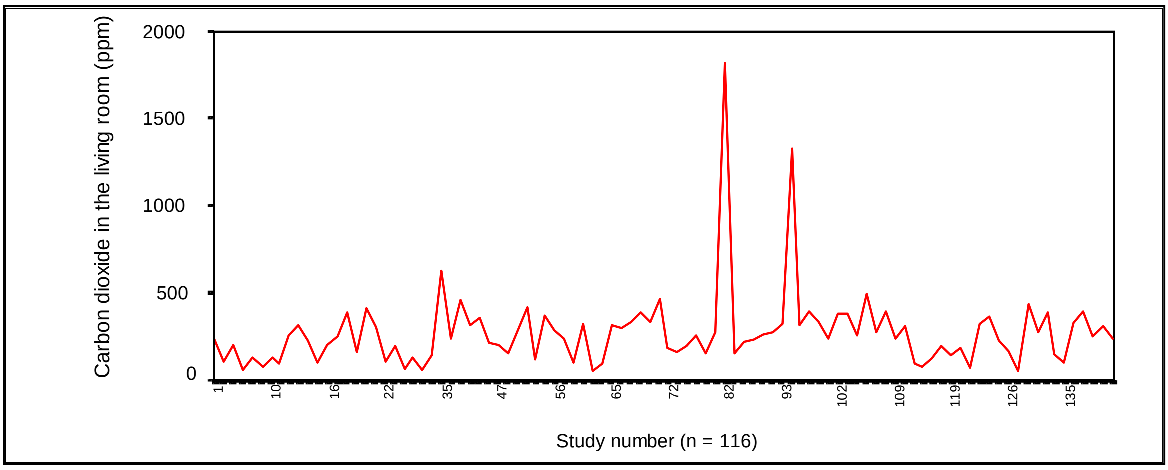

Figure 4: The level of carbon dioxide in the living rooms of individual houses.

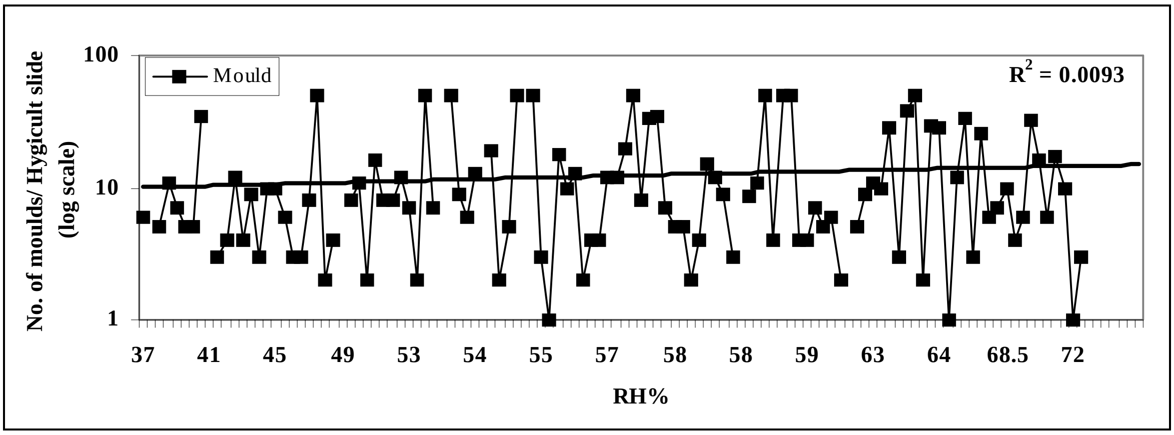

Figure 5: Comparison of the number of moulds per slide against Relative Humidity (RH%).

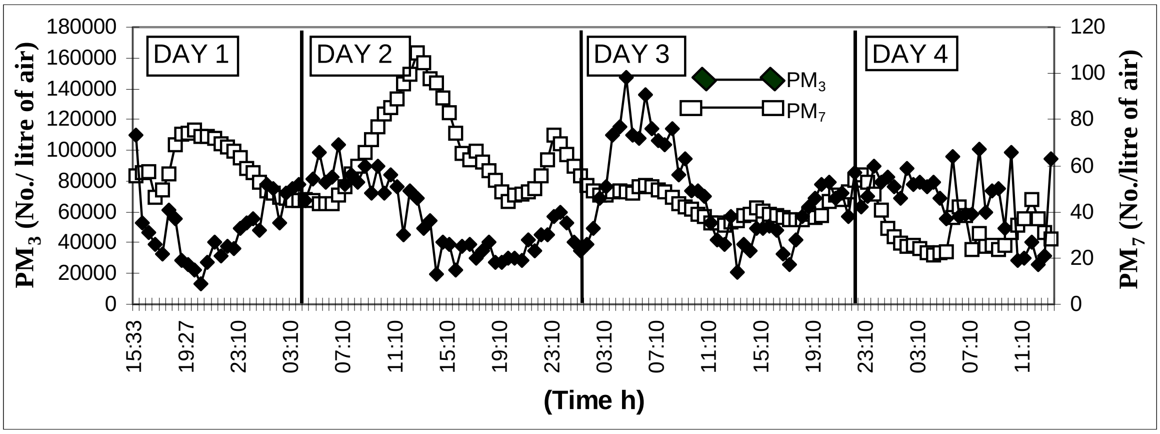

Figure 6: An example of how particulate numbers vary throughout the day in a city centre office.

Quantification of ventilation rates

Since PM_3 indoors can only be removed by movement of air through adequate ventilation, the total number of PM_3 indoors is a relevant parameter for gauging the degree of ventilation in a locality. By comparing the difference between the total number of PM_3 indoors to outdoor levels, past and present rates of ventilation can be assessed.

However, relative humidity is not easily comparable with outdoor values as there is generally a higher level outdoors. A comparison can be made of internal RH, for example between the SB and the living room. Internal air movement should equalise RH throughout the house, given time. For example, during the night exuded moisture in the bedrooms remains trapped if there is no internal air movement. Internal temperature is also difficult to compare with outdoor values. Whilst it is possible to appreciate that during cold weather people prefer not to ventilate because of increased heating costs, this makes it difficult to compare temperature in/ outdoors to gauge ventilation. If major differences were found in the temperature of different rooms, this would suggest low internal air movement.

Given the circumstances of the case study the use of CO_2 levels as a measurement of ventilation rates was extremely difficult.

The ideal proliferation and living conditions for HDM are not solely dependent on ventilation, but also temperature, RH and household management. The recorded conditions for the case study do not initially assist in determining ventilation rates.

Analysis of the Tool Kit methodology

The Tool Kit has been used over a period of 2 years under widely differing circumstances and in each case has provided robust information for all parameters recorded. The Tool Kit has shown that it is possible to use a standard approach when assessing IAQ irrespective of local environmental factors. However, the studies using the Tool Kit have revealed some difficulties that need to be addressed for any future major study:

- To remain impartial when dealing with the occupants/ owners of a locality. It is very difficult to remain courteous and yet not respond to direct questions from people within a locality being tested about any problems with their indoor environment. Advice was not given to the Tenants in the case study since it may have influenced future results.
- As the gas samples had to be analysed off site there are concerns that the chemical composition of the samples may change during transport.
- Mould samples were not speciated. Counting the number of colonies gave a good indication as to the quantity of mould circulating in the air but no assessment was made whether the moulds were particularly harmful to health.
- The recording of electrostatic fields in the living room did not contribute any useful information, since few significant fields were encountered. In subsequent studies, measurements will be made of electrostatic fields 70 cm in front of ordinary television sets, since some TV sets give rise to substantial electrostatic fields.
- Given the time limit of one hour, it was not possible to measure particulates in $\mu g/m^3$, as the equipment required for this needed a longer sampling time.
- To be able to use CO_2 recordings as a measure for 'ventilation', the recordings will have to be set against the number of people present at the time of and just prior to measuring.

The Tool Kit gave a very comprehensive set of results, which were easy to manipulate, even though the interpretation was time consuming. The results from the case study show the types of statistical and graphical interpretations that can be made. The Tool Kit has so far proven to be reliable, operational in sensible time periods and is easily handled by one person. When used in conjunction with results from health studies etc., further statistical analysis will be applied to the data, including regression analysis to search for any links between the IAQ and the health of any occupants.

When the Tool Kit has been in use for some time and a substantial bank of data on IAQ/ and ventilation rates has been collated, it should be possible to develop guidelines on how to establish good quality indoor environmental conditions. How house owners will be able to measure parameters to meet recommendations, without reliance on outside expertise is difficult to understand at the moment, since a complete Tool Kit costs around £10,000. Furthermore if Local or Central Government were to introduce legislation on minimum standards, the enforcement of such legislation would be extremely difficult.

Whilst it is possible to manipulate the data sets presented herein in many different ways it is not possible to generate data continuously over a longer period of time. The enclosed Fig 6 exemplifies how human activities influence particles throughout an extended time period in an office locality used only during the day and equipped with a central air processing system. A substantially modified Tool Kit, with associated cost implications, would be required to monitor the changes in temperature, RH, PM_7, and PM_3 over an extended time period.

Further analysis needs to be carried out to determine the minimum number of localities required to generate statistically reliable results, for an extremely large number of localities. It may be that a smaller study would be sufficient to represent the whole number. In the future an analysis will be conducted in order to reduce the parameter set i.e. where two or more variables have very high correlation's, there will only be a need to measure one of them.

Specifically for the case study, the combination of the results from the parallel studies and the assessment of IAQ, might clarify any effect of housing improvements on changes in respiratory health. If a locality still has unexplained problems despite the fact that a full study has been made using the Tool Kit, then the locality would have to be re-examined for other more unusual pollutants. The Tool Kit will possibly enable other interested parties to pinpoint which householders in the reviewed case study need help to get the best from their renovated houses in order to improve IAQ. Using a standardised tool kit would allow an insight into possible relationships between illnesses presented in doctors' surgeries and the domestic indoor environment.

Conclusions

Case study

The Tool Kit's full potential cannot be fully assessed since only two years of the case study has been completed and no comparisons have been drawn between the environmental assessment and the other parallel studies. Therefore no conclusions can be made as to whether the Tenants have poor IAQ, or if their housing conditions are influencing their health. Once the data is available for the renovated houses, it will be possible to assess the effect of housing improvements on respiratory illnesses.

Rates of ventilation

Although the Tool Kit cannot give direct ventilation rates expressed in m^3 / sec, it is possible to relate degrees of ventilation with the level of certain parameters.

General

The Tool Kit has so far met the criteria set, however, when more details are available from these studies an in depth analysis of the efficacy of the Tool Kit will be made.

Abbreviations

Term used	**Definition**
Der p 1	allergen from HDM.
FT-IR	Fourier Transfer -Infra Red spectroscopy.
HDM	House Dust Mites, *Dermatophagoides pteronyssinus*.
IAQ	Indoor Air Quality.
PM_x	particulate matter with an x aerodynamic diameter given in microns.
ppm/ ppb	parts per million/ parts per billion
RH	Relative Humidity %.
SB	selected bedroom where somebody regularly slept that had breathing problems.
μm/ μg	micron or micro-meter/ micro-gram. 1μm/ μg is equivalent to 0.001mm/ 0.001 mg.
WME	Wood Moisture Equivalent %.

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