A FIELD TRIAL OF MECHANICAL VENTILATION WITH HEAT RECOVERY IN LOCAL AUTHORITY, LOW-RISE HOUSING

FINAL REPORT

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EXECUTIVE SUMMARY

INTRODUCTION

The Derwentside Project was set up to explore the application of balanced whole-house mechanical ventilation with heat recovery within the existing UK housing stock, through the medium of a field trial of the technology in a small number of occupied dwellings. The project was supported financially by National Power and the Department of the Environment (now DETR). Overall project management was undertaken by NEA, and monitoring and evaluation of the project were undertaken by Leeds Metropolitan University. Derwentside District Council acted as the host organisation, supplying the field trial dwellings. Additional support for the project was provided by REGA Metal Products Ltd and ADM Indux Ltd.

The Project ran from October 1995 until September 1997. The detailed objectives of the project were to explore:

- to assess the effectiveness of the whole house mechanical ventilation and heat recovery (MVHR) systems, installed as part of a comprehensive energy efficiency and environmental improvement package in existing housing, in terms of energy use, thermal comfort, internal air quality and acceptability to tenants.

- to identify and quantify the cost of any additional airtightness measures that are required in local authority low-rise housing, in order to enable the effective functioning of mechanical ventilation and heat recovery units.

- to identify the type of advice that tenants occupying dwellings with such units require in order to effectively operate the units, and to examine their behaviour.

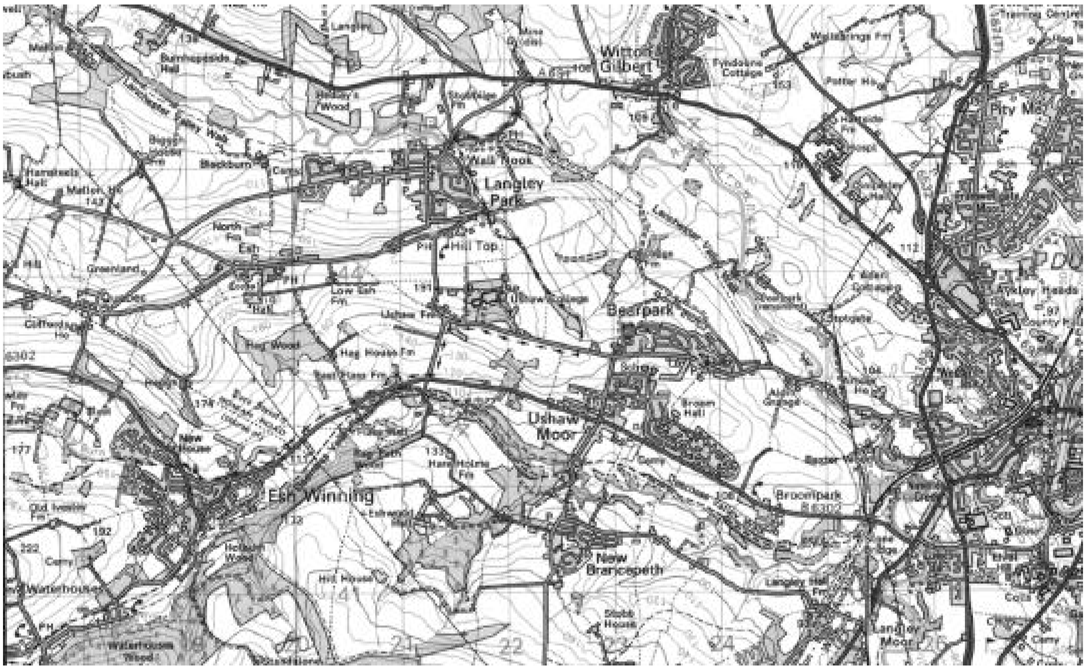
- to determine the energy implications of MVHR systems compared to natural ventilation systems and other passive and mechanical systems.

- to estimate the future energy savings possible from the use of efficient MVHR units.

- to determine if any possible landlord benefits exist from the installation of such units.

THE FIELD TRIAL DWELLINGS

The field trial was based on a group of 12 local authority houses, constructed in the early 1970’s, on the western edge of the village of Eshwinning, in County Durham (see map).



Map of part of Co. Durham, showing the village of Eshwinning in the bottom left quadrant and the City of Durham at lower right. ©Crown Copyright, ED 23772 D001.

The village is in a valley at about 145 m (500 feet) above sea level, and was until recently a mining village. The field trial houses are on two storeys, arranged in short staggered terraces running predominantly Northwest-Southeast. The houses have external walls of brick-block cavity construction, dry-lined internally with plasterboard on cement dabs. Ground floors are ground-supported concrete slabs. First floors are of tongued and grooved chipboard, with joists supported on gable, party and internal walls. The low pitched roofs are supported by conventional timber roof trusses, and are clad externally with concrete interlocking tiles. The original windows were single-glazed in steel window frames. Each dwelling has a small, single-storey flat roofed extension, which houses an entrance lobby, WC and outside store cupboard.

The approximate gross floor area of the dwellings at Eshwinning was 92 m^2, including 3 m^2 for the extension. The field trial houses are typical of post-1970 dwellings, which in 1991 constituted around 23% of the total GB housing stock (Shorrock & Bown, 1993), and are likely to be broadly typical of many of the houses which will be refurbished in the UK over the next twenty years or so.

THE EXPERIMENTAL PROGRAMME

The field trial was based on a comparison of an experimental group of houses fitted with whole house balanced MVHR, and a control group in which natural ventilation was supplemented by extract fans in kitchens, bathrooms and WCs. Despite the small number of houses involved, significant results were obtained, particularly in the area of air quality.

In October 1995, the houses at Eshwinning were in a poor state of repair. A refurbishment programme was designed by Derwentside District Council and carried out between November 1995 and March 1996 by Derwentside's Direct Services Organisation (DSO). A programme of airtightness work was undertaken in parallel with this work by LMU.

The initial target for this programme was to achieve an air leakage measured by fan pressurisation, of 3 ac/h at 50 Pa. However, following a preliminary survey, which showed that the field trial dwellings were roughly twice as leaky as the UK average, the leakage target was revised upwards to 8 ac/h at 50 Pa. The final average for all 12 field trial houses was 10.9 ac/h. The reasons for this high leakage, and the lessons learnt from the attempt to achieve a reasonable degree of airtightness in these houses are discussed at length in the body of this report. However the main contributing factor to high leakage rates was almost certainly the fact that walls in the field trial dwellings were finished with plasterboard-on-dabs rather than the traditional and much more effective wet plaster.

The high background leakage of the field trial dwellings meant from the outset, that it was unlikely that the effect of ventilation heat recovery would be detectable in measured space heating consumption data.

All 12 of the houses were monitored continuously by Leeds Metropolitan University over a one year period which ran from May 1996 to June 1997. Physical monitoring was sufficiently detailed to allow disaggregation of delivered energy use into the main end use categories. Internal temperatures and relative humidity were measured in four rooms in each dwelling, and CO_2 was measured in the main bedroom to provide a measure of thermal comfort and indoor air quality. Because of the relative remoteness of Eshwinning, data were logged on site by a datalogger in each field trial house, and transmitted back to Leeds Metropolitan University by modem link.

In addition to physical monitoring, a social survey was undertaken to determine the views of the tenants of the field trial houses on a range of matters broadly related to the operation of the ventilation in their houses.

INSTALLATION AND COMMISSIONING OF THE MVHR SYSTEMS

MVHR systems in the six experimental houses were designed, supplied, installed and commissioned by REGA Metal Products Ltd. and ADM Indux Ltd. Examination of the quality of installation and commissioning of the MVHR systems, revealed a number of problems. These varied from relatively minor, to errors which, if left uncorrected, would have completely undermined functioning of the systems.

These observations and measurements lead to the following conclusions:

- There is an absolute and over-riding need to install and commission MVHR systems correctly.
- MVHR systems should be designed so as to provide locations at which total extract and supply airflow can be measured simply and cheaply, and with an appropriate

level of accuracy (we would suggest ±15% the Canadian Standard CAN/CSA-F326-M91).

- There is a need for a much more comprehensive standard on installation and commissioning than either of the documents currently available in the UK - again we would point to CAN/CSA-F326-M91 as a model.
- There is a need for installation and commissioning information to be made available to the landlord or owner of a house fitted with an MVHR system, so that in the years following the installation, problems can be quickly identified and the system returned to its design condition.

IMPACT OF MVHR ON AIR QUALITY AND HUMIDITY

Air quality was significantly and consistently better in the MVHR houses than in the control houses which were fitted with extract-only systems. The main reason for this is probably that extract systems were not operated for more than a small number of hours in any of the control houses.

This result was derived from measurements of humidity at four locations, and from CO_2 measurements in the main bedroom in each dwelling. The result was robust and, given the leakiness of the field trial houses, unexpected. The difference indicates the importance of continuously operating mechanical ventilation, with or without heat recovery, and is powerful argument for the installation of such systems in both existing and new dwellings.

At Eshwinning, continuously operating MVHR reduced the inferred incidence of condensation on single glazed windows by a factor of 8, and reduced average CO_2 concentrations by a factor of 1.5 in bedrooms. The presence of continuously operating MVHR systems appeared to affect occupant behaviour and perceptions of their dwellings. Though these observations need to be treated with some caution, tenants stated that their dwellings no longer felt “stuffy” and that they needed to open their windows less frequently for ventilation.

Samples of house dust were collected and analysed for dust mite content. This exercise demonstrated a wide scatter between individual houses, but did not show any clear difference between the control and MVHR groups.

IMPACT OF MVHR ON ENERGY USE AND TEMPERATURES

The impact of MVHR on energy use for space heating could not be determined from the measured data. This negative result is due to the following factors:

- The field trial dwellings were too leaky, by a factor of 4 or more, to provide a good basis for demonstrating balanced mechanical ventilation with heat recovery.
- Installation and commissioning problems reduced the performance of a number of the MVHR systems to a level at which energy savings would have been negligible even in airtight dwellings.

- Fabric heat losses in the field trial dwellings were high. The effect of this was to increase the background variability against which we were attempting to measure the effect of MVHR.

Measurements made on the MVHR systems showed a very wide range of performance. Use of energy efficient motors and smooth ductwork in the more efficient of the two systems studied, more than halved electricity use, and led to a projected coefficient of performance of approximately 11. This performance proved to be easily degraded by poor commissioning. The coefficient of performance of the less efficient of the two systems was dramatically affected by poor commissioning, and was less than 3.

One of the most important questions in this area is, to what level must air leakage be reduced before balanced MVHR begins to yield absolute reductions in energy use in real occupied dwellings, compared with other ventilation strategies? We were unable to address this question directly in this field trial. We were, however, able to construct a model of ventilation rate and ventilation heat loss in dwellings, based on the physical principles involved. This model was used to predict space and electricity consumption over a heating season for a variety of airtightness levels, for three ventilation strategies - natural, extract-only and balanced MVHR.

This exercise confirmed the widely held view that balanced MVHR performs best in airtight dwellings. Energy savings and carbon emission reductions were significantly reduced in dwellings with an airtightness above 3 ac/h at 50 Pa. Modelling showed that inefficient MVHR systems used more energy and emitted more carbon than extract-only ventilation systems in dwellings leakier than 0.5 ac/h at 50 Pa. While this level of airtightness is regularly and routinely produced in Canada, Sweden, and Switzerland, it has to our knowledge never been achieved in the UK.

Conversely the exercise showed that an efficient MVHR system would **always** outperform an extract-only system. This result was unexpected, but we believe that it adds weight to the efforts of MVHR system manufacturers to improve the overall performance of their products.

OCCUPANT ACCEPTABILITY

Apart from some initial complaints about noise, there were no problems of user acceptability with the MVHR systems. The occupants of these houses had been assured at the outset of the field trial that the cost of electricity used by the units would be small, and that they would be more than compensated financially for this cost. Perhaps as a result there appeared to be little concern about operating cost. Tenants in the experimental houses stated that their houses were less stuffy, and that they did not need to open windows to achieve adequate ventilation. This suggests that the improvements in air quality which were achieved in the experimental houses despite the high background leakage, was noticeable to and valued by occupants.

It was observed that control group households made very little use of their extract-only ventilation systems. This suggests that there maybe a problem of occupant acceptability with these systems. Whether this relates to noise, perceived energy consumption (the electricity use of the latest generation of whole house extract systems can correctly be described as negligible), or to draughts caused elsewhere in the dwelling when the extract unit operates, is not known. It is possible that extract systems controlled by on-off switches (whether manually operated or controlled by humidity sensors) may be more annoying than systems which operate continuously.

THE FUTURE FOR MVHR AND VENTILATION RESEARCH

This research project has thrown up a number of issues that appear to require further research and development. These are:

- the need to develop improved UK guidelines for the installation and commissioning of MVHR systems;
- the need for continued technical and product development to raise the thermal efficiency and reduce the electricity consumption of MVHR systems on the UK market;
- the need to examine the long term performance of MVHR systems, and the impact of maintenance;
- the need to design MVHR systems to minimise the scope for errors in installation and commissioning;
- the apparent reluctance of people to make use of extract-only ventilation systems.

One of the most important results from this field trial was that the original airtightness target was not achieved. We feel that this indicates:

- the need for a programme of applied research which aims to develop a library of construction techniques for achieving high levels of airtightness in new and existing dwellings
- the need for a programme to demonstrate the achievement of air leakage rates in the range of 1 - 3 ac/h at 50 Pa, in the field, in a wide range of new and existing housing.

This field trial has demonstrated that continuous mechanical ventilation improves air quality in dwellings which are typical of much of the UK housing stock. It has been unable to demonstrate a corresponding reduction in space heating from heat recovery in mechanical ventilation systems. Any future attempt to demonstrate such a saving must be made in the context of airtight dwellings with low fabric heat losses.

Enhanced airtightness reduces the energy used for ventilation, and improves the performance in terms of thermal comfort, regardless of which ventilation strategy is chosen. There appears to us to be little point in conducting research into the energy implications of mechanical ventilation systems of any type, without simultaneously addressing the problems associated with making houses airtight.

1 INTRODUCTION

1.1 ORIGINS, AIMS AND OBJECTIVES

The Derwentside Project was set up following a series of discussions between BRECSU, Leeds Metropolitan University, NEA and National Power in 1994 and 1995, to explore the application of balanced whole-house mechanical ventilation with heat recovery within the existing UK housing stock, through the medium of a field trial of the technology in a small number of occupied dwellings. The project was supported financially by National Power and the Department of the Environment. Overall project management was undertaken by NEA, and monitoring and evaluation of the project were undertaken by Leeds Metropolitan University. Derwentside District Council acted as the host organisation, supplying the field trial dwellings. Additional support for the project was provided by REGA Metal Products Ltd and ADM Indux Ltd.

The Project began in the Autumn of 1995 and continued until June 1997. The aim of the Project was to explore the feasibility of incorporating mechanical ventilation with heat recovery (MVHR) into traditional low-rise housing, in the context of a normal local authority refurbishment programme.

The specific objectives of the Project were:

- to assess the effectiveness of the whole house mechanical ventilation and heat recovery (MVHR) systems, which were installed as part of a comprehensive energy efficiency and environmental improvement package in existing housing, in terms of energy use, thermal comfort, internal air quality and acceptability to tenants.

- to identify and quantify the cost of any additional airtightness measures that are required in local authority low-rise housing, in order to enable the effective functioning of mechanical ventilation and heat recovery units.

- to identify the type of advice that tenants occupying dwellings with such units require in order to effectively operate the units, and to examine their behaviour.

- to determine the energy implications of MVHR systems compared to natural ventilation systems and other passive and mechanical systems.

- to estimate the future energy savings possible from the use of efficient MVHR units.

- to determine if any possible landlord benefits exist from the installation of such units.

It has been possible within the scope of the Derwentside Project to address all but the last of these objectives. LMU has carried out an extensive programme of monitoring and evaluation over a period of more than a year. The small number of dwellings in the field trial has not allowed us to make extensive use of statistical inference, but the project has yielded a number of qualitative results that are likely to be of considerable importance in the development of research and practice in this area in the future.

1.2 BACKGROUND TO THE PROJECT

Domestic ventilation is a complex subject with links to individual thermal comfort and health, energy conservation and climate change and to the problems of fuel poverty and poor housing conditions. Domestic ventilation affects the indoor and global environment - the removal of air contaminants maintains indoor air quality, while the removal of heat from the dwelling creates a demand for space heating which results, under present conditions, in the emissions of CO_2 and a variety of other atmospheric pollutants. Total energy use due to domestic ventilation in the UK housing stock is of the order of 300 PJ/a. If provided entirely by gas central heating, this results in the emission of some 5 million tonnes of carbon into the atmosphere annually - 3% of the UK total.

In recent years considerable effort has been devoted to reducing the energy cost of ventilation in existing housing by draught stripping naturally ventilated dwellings. This approach is relatively cheap and effective in very leaky dwellings. It typically results in a desirable increase in internal temperatures and reduced draughtiness, but at the cost of higher concentrations of indoor contaminants and potential problems from condensation and mould growth. A number of measures have been taken to ameliorate the problems of under-ventilation in dwellings, including the use of trickle vents, the introduction of mechanical extract systems, and the use of passive stack ventilation systems. The option of balanced mechanical ventilation with heat recovery has not generally been favoured, for a number of reasons - background air leakage in UK dwellings is generally too high, the UK climate is not severe and indoor temperatures have tended to be low. Finally, the cost and environmental impact of space heating (predominantly by natural gas) have been perceived to be too low to justify the cost of installing and operating balanced MVHR systems.

Much of this background is now changing. Indoor temperatures in UK homes have increased steadily over the last few decades (Shorrock et al., 1992), and the importance of adequate indoor temperatures and air quality is now realised. Recent work has shown the practical possibility of very much higher levels of airtightness, in both new and existing dwellings (Lowe et al. 1994; Bell & Lowe, 1997). The need to contain and reduce carbon emissions has placed the combustion of natural gas in a less favourable light, and the carbon intensity of electricity, which has declined steadily for the whole of the post war period is likely to continue to fall to the end of the century and beyond. Considerable experience of balanced mechanical ventilation with heat recovery has been gained in Scandinavia and Canada over the last 20 years. The time therefore appeared to be ripe for a field trial to assess the effectiveness of such an approach in the UK.

1.3 DOMESTIC VENTILATION STRATEGIES.

The simplest domestic ventilation strategy is that of natural ventilation, which relies on a combination of adventitious leakage of air through the thermal envelope of the dwelling, together with movement of air through purpose made vents - normally windows. The main advantages of this approach are that no electrical energy or equipment is needed to drive the airflow through the dwelling. The major disadvantages are that ventilation rates are highly variable, and that heat recovery is difficult[1]. A recent modification of this approach is passive stack ventilation, which attempts to reduce the variability in ventilation rates by more effective use of bouyancy forces.

The alternative to natural ventilation is mechanical ventilation. The simplest form of mechanical ventilation is mechanical extract, but several other configurations are possible. The major advantages of mechanical ventilation are that it can provide a much more steady air flow than natural ventilation, with potentially better air quality, and that heat recovery is considerably easier due to the higher pressure differences available. The major disadvantages arise from expense and reliability of mechanical equipment and ductwork systems, the use of electricity required to drive the fans, and from the need to maintain the system over a period of many years.

The commonest configuration for mechanical ventilation with heat recovery (MVHR) involves a balanced ventilation system, in which supply and exhaust air are ducted through a heat exchanger. Such a system can potentially cut ventilation heat loss by 70% or more. But in order to achieve any reduction in space heat requirements, the MVHR system must be the main source of fresh air in the dwelling. If the dwelling is so leaky that reasonable demands for fresh air can be met by natural ventilation, then the effect of an MVHR system is to over-ventilate the dwelling and therefore to increase the space heating requirement.

In an air tight building, the heat recovered annually by an MVHR system is proportional to the temperature difference between the inside and outside of the building. The case for MVHR in the UK has historically been weak both because of the leakiness of dwellings, and the low internal temperatures typically maintained. There has however been a tendency for internal temperatures in UK housing to rise, and the importance of warm housing is increasingly recognised (Boardman, 1991).

One of the questions addressed by this report is, how airtight does a dwelling have to be before a balanced MVHR system will perform better than a simpler and cheaper extract-only system? A variety of target figures has been given for the level of leakage which is desirable in houses with MVHR. The first national building regulations to require MVHR were the Swedish Building Regulations of 1982 (Anon, 1983). These required dwellings to achieve an airtightness of 3 ac/h at 50 Pa. More recent recommendations appear to be more stringent. The Canadian R2000 programme requires houses to achieve an airtightness of 1.5 ac/h at 50 Pa, while the more recent Advanced House Programme sets a limit of 0.75 ac/h at 50 Pa. A review of national

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[1] Many commentators would say impossible. There have however been proposals for heat recovery in passive stack ventilation systems (see eg. Riffat & Gan 1997).

recommendations and regulations by Liddament (1993) suggests a figure of around 1 ac/h at 50 Pa. For a dwelling at this latter level of airtightness fitted with an MVHR system with a 70% heat recovery efficiency, air leakage would represent approximately 25% of the total ventilation heat load.

Analysis carried out as part of the Derwentside Project goes some way to supporting the idea of a threshold level of airtightness for balanced MVHR, but shows that the question is rather more complex and interesting than is suggested by the concept of a fixed airtightness limit.

The average leakage rate for UK dwellings is approximately 14 ac/h at 50 Pa (Perera & Parkins, 1992). It is difficult to see how a case can be constructed for installing MVHR in existing dwellings, based purely on energy consumption or carbon emissions, unless such leakage rates can first be reduced. A corollary of this is that there is little scientific point in undertaking field trials of MVHR in existing UK dwellings unless air leakage can be reduced, since high air leakage simultaneously reduces the expected magnitude of the effects of MVHR, and increases the background noise against which those effects are being sought.

However, recent UK experience suggests that both new and existing houses can be made very much more airtight at little cost. Air leakages rates of 3 ac/h or below have been achieved in a number of new houses, and leakage rates down to 5 ac/h after refurbishment of existing houses (Lowe et al., 1994; Olivier, 1994; Scivyer et al. 1994). It is likely that, in the context of a major refurbishment, leakage rates of 3 ac/h or below can be produced in many existing UK houses at modest extra cost.

1.4 THE FIELD TRIAL DWELLINGS

The field trial was based on a group of 12 local authority houses, constructed in the early 1970's, on the western edge of the village of Eshwinning, in County Durham. The village is in a valley at about 145 m (500 feet) above sea level, and was until recently a mining village. The field trial houses are on two storeys, arranged in short staggered terraces running predominantly Northwest-Southeast. To provide variation within the estate, two house types were used, type A and type B. These have identical floor areas. The houses have external walls of brick-block cavity construction, drylined internally with plasterboard on cement dabs. Ground floors are ground-supported concrete slabs. First floors are of tongued and grooved chipboard with timber joists supported on gable, party and internal walls. The low pitched roofs are supported by conventional timber roof trusses, and are clad externally with concrete interlocking tiles. The original windows were single-glazed in steel window frames. Each dwelling has a small, single-storey flat roofed extension, which houses an entrance lobby, WC and outside store cupboard. Two of the external walls of this extension consisted of the same brick-block cavity wall construction as the rest of the house, whilst the third wall consisted of a timber-frame wall with an external timber cladding. The approximate gross floor area of the dwellings at Eshwinning was 92 m^2, including 3 m^2 for the extension. Many of these features are common in post 1970 GB dwellings, which in 1991 constituted around 23% of the total GB housing stock

(Shorrock & Bown, 1993). The houses at Eshwinning are likely to be broadly typical of many of the houses which will be refurbished in the UK over the next twenty years or so.

The original heating system in these houses consisted of a solid fuel enclosed stove in the living room, with gravity fed radiators and hot water cylinder. Control of the heat output of this device was manual. Both the nature of this original heating system and the fact that coal mining was until very recently the economic mainstay of the community, significantly affected the way in which tenants used the field trial dwellings.

In 1994 the field trial houses had not been refurbished since their construction, and were in a state of some disrepair (see Figure 1.1). Derwentside District Council was, at this time, planning a refurbishment. The refurbishment was to include a new gas-fired central heating system, cavity fill and additional loft insulation and new single glazed timber framed windows. The total area of glazing was to be significantly reduced by bricking up the bottom half of the full height windows on the ground floor of each dwelling. This planned refurbishment provided the opportunity to undertake the additional works - additional air sealing, and the installation of MVHR and monitoring systems - that were necessary to allow the proposed field trial to proceed.

Figure 1.1 View of field trial dwellings before refurbishment

1.5 THE EXPERIMENTAL PROGRAMME

It was decided from the outset that the Project would be based on a comparison of an experimental group of houses fitted with balanced MVHR systems, and a control group of houses which would be fitted with trickle vents and extract fans in bathrooms and kitchens accordance with current practice.

The intention was to undertake a programme of airtightness improvements on the houses before monitoring began. This programme was carried out in parallel with the refurbishment of the dwellings which was undertaken by Derwentside's direct labour organisation, DSO. An air leakage target of 3 ac/h at 50 Pa, which appeared to be a challenging but not unobtainable target for dwellings of traditional construction, was adopted for the group of houses which were to be fitted with MVHR. Initially the control houses were not to receive the programme of airtightness measures, since there was a risk that this would have made them too airtight for mechanically assisted natural ventilation[2].

An initial survey established that the field trial estate was constructed in the early 1970s using plasterboard on dabs, and that the unrefurbished houses were in a poor state of repair. Initial pressurisation tests were undertaken by Leeds Metropolitan University on two of the houses from the field trial estate, one of which had already been refurbished (these houses were **not** subsequently included in the field trial). These tests indicated a very high leakage rate in the unrefurbished house (28.9 ac/h at 50 Pa). The results of this survey led to the leakage target for the dwellings involved in the field trial being revised upward to 8 ac/h at 50 Pa. In addition, the decision was taken to apply the airtightness measures to the houses in the control group, as well as to those in the experimental, MVHR group. Following the refurbishment and airtightness work, each house was pressure tested. Details of this work are presented in Chapter 2.

All 12 of the houses were monitored continuously by Leeds Metropolitan University over a one year period which ran from May 1996 to June 1997. Physical monitoring was sufficiently detailed to allow disaggregation of delivered energy use into the main end use categories. Internal temperatures and relative humidity were measured in 4 rooms in each dwelling, and CO_2 were measured in the main bedroom to provide a measure of thermal comfort and indoor air quality.

In addition to physical monitoring, a social survey was undertaken to determine the views of the tenants of the field trial houses on a range of matters broadly related to the operation of the ventilation in their houses.

[2] It was not the intention of this field trial to explore the option of continuously operating mechanical extract ventilation in relatively airtight houses (3-5 ac/h @ 50 Pa).

1.6 DESCRIPTION OF THE EXPERIMENTAL AND CONTROL GROUPS

The field trial groups contained a mixture of both mid and end terraced house types, as well as a mixture of *'Type A'* and *'Type B'* dwellings (see below). The floor plans and energy characteristics of the *'Type A'* and *'Type B'* field trial dwellings are presented in **Appendix 2**. The internal volume of the *'Type A'* and *'Type B'* dwellings are the same, the only difference between the two dwelling types is the shape of the floor plan and the internal layout.

Figure 1.2 Type A dwelling, front aspect

Figure 1.3 Type A dwelling rear aspect

Figure 1.4 Type B dwelling front aspect

Figure 1.5 Type B dwelling rear aspect

The mix of each house type in the two separate groups can be seen in **Table 1.1** below.

House Type	Experimental group	Control group
A - mid terrace	1	1
A - end terrace	2	2
B - mid terrace	1	1
B - end terrace	2	2
Total	6	6

Table 1.1 House types in each group

Table 1.1 shows that, at least at the level of mix of plan forms, the experimental and the control groups were well matched. This allowed results from the two groups to be compared without significant corrections having to be undertaken.

1.7 THE BASIC REFURBISHMENT PROGRAMME

A basic refurbishment programme was carried out by Derwentside DSO on all of houses from the Briardene estate which were chosen to take part in the field trial project. This programme ran from the beginning of October 1995 to the end of February 1996, and included a number of measures which were implemented in order to reduce the energy consumption of the dwellings. The measures carried out on the dwellings were as follows:

- wall cavities were insulated with blown mineral fibre cavity wall insulation;
- the existing storey-height windows (see figure 1.1) were removed, and the window openings were bricked up to waist level. New single-glazed wooden framed windows with trickle ventilators were installed;
- the existing external doors and frames were removed and replaced. All of the new external doors were draughtproofed;
- existing loft insulation was ‘topped-up’ to 250mm; and,
- existing solid-fuelled heating systems were replaced with gas-fired wet central heating systems with non-condensing combination boilers. In addition, an on-peak electric feature fire was installed in each living room[3].

Apart from the choice of the focal point fire, none of the thermal envelope measures listed above was deliberately undertaken to improve the airtightness of the dwellings. Nevertheless it was expected that repairs to the plasterboard, and to the junctions in between the plasterboard and the windows and doors, would reduce the very high leakage rates which were experienced in the unrefurbished field trial dwellings, even in the absence of a programme of airtightness work.

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[3] An electric fire was installed instead of a gas fire to avoid the need for flue and air inlets, which would have significantly increased the leakage rate of the dwellings. The option of not having a focal point fire at all, was not thought to be acceptable to the occupants of the field trial dwellings.

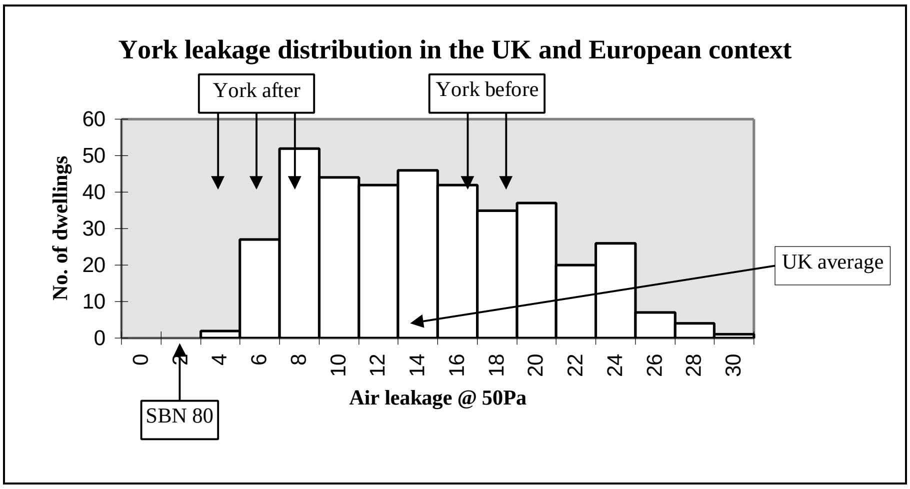
2 AIRTIGHTNESS OF THE FIELD TRIAL DWELLINGS

2.1 INTRODUCTION

When the present field trial was first proposed, the intention was to undertake a programme of airtightness improvements on the experimental houses before monitoring began. The original target for this work was 3 ac/h at 50 Pa, though this was revised upward to 8 ac/h following preliminary tests in two houses on the field trial estate in July 1995 (see Appendix 3).

2.1.1 The work at York

The York dwellings were constructed in the 1930s and 1950s using traditional construction techniques, including wet plastered walls. They were comprehensively refurbished in 1992 with replacement double glazed windows, new doors and 200mm of loft insulation. The air leakage rates of these dwellings both before and after the refurbishment can be seen in **Figure 2.1** below. The figure also shows the approximate distribution of air leakage in the UK housing stock, the UK mean leakage rate of 14 ac/h (Perera & Parkins, 1992), and the level of airtightness required by the 1980 Swedish Building Regulations (Anon 1983).



UK data source: (Perera & Parkins, 1992)

Figure 2.1 Air leakage at York in the UK and European Context

These results show a 2.5 to 3 fold improvement in the airtightness of the York dwellings. This improvement was brought about by a combination of some simple measures, which included: draughtstripped replacement windows and doors; covering of tongued and grooved floors with 3mm plywood sheeting (not sealed around skirting boards); and, repair of obvious damage to plasterwork around doors and windows.

The leakage rates of the York dwellings before the refurbishment was undertaken were higher than the UK average, although they were by no means extreme. The leakage rates after the refurbishment was undertaken are in the bottom quartile of the BRE database of 385 UK dwellings (Perera & Parkins, 1992), with one of these dwellings having an air leakage of below 5 ac/h[4]. In 1992, this airtightness figure was exceeded by only 2 dwellings in the BRE database, and approaches the 1980 Swedish Building Regulations standard (Anon, 1983) of 3 ac/h @ 50 Pa for new housing. An important aspect of this finding is that this air leakage rate was achieved without significant attention to detail, workmanship, or site supervision. Moreover, at the time of testing, a number of design and construction defects were evident. The significance of these measurements is that they suggest the possibility of achieving air leakage rates of 3 ac/h or less in existing masonry houses in the UK, with the application of modest additional effort.

2.1.2 The implication for the field trial dwellings

From the results obtained at York, it was initially proposed that an air leakage rate of 3 ac/h @ 50 Pa would be the target value for the experimental dwellings in the field trial project which were to be fitted with balanced MVHR systems. The control houses, on the other hand, were not to receive the programme of airtightness measures, since this would make them arguably too airtight for mechanically assisted natural ventilation.

In July 1995, an initial survey was undertaken on two houses from the Briardene estate at Eshwinning, County Durham. A copy of this survey can be seen in **Appendix 3**. This survey established that the field trial estate was constructed in the early 1970's using plasterboard on dabs, and that the unimproved houses were in a poor state of repair. A pressurisation test in house X (not included in the field trial) showed a very high leakage rate of 28.9 ac/h @ 50 Pa, which would put this dwelling in the top 1% of UK dwellings[5]. Due to this high leakage rate, the air leakage target for the field trial dwellings was revised upward to 8 ac/h @ 50 Pa, just above the Electricity Association's Medallion 2000 scheme air leakage rate of 7 ac/h @ 50 Pa. In addition, the decision was also taken to apply the airtightness measures to the field trial houses in the control group, as well as to those in the experimental, MVHR group.

2.2 THE AIRTIGHTNESS MEASURES

A programme of airtightness work was undertaken by Leeds Metropolitan University on all of the field trial dwellings at Eshwinning, between October 1995 and the end of February 1996. This work was undertaken in parallel with the basic refurbishment

[4] In this house, after the refurbishment, it was only possible to measure the dwelling's air leakage with the MVHR system unsealed. The effect of sealing this system was estimated from measurements made on the adjoining house.

[5] This achievement drew the comment that the house could be seen, but it couldn't be detected using the blower door.

package which was being carried out by Derwentside DSO. This imposed considerable constraints on the former.

The airtightness work undertaken in the field trial dwellings took place in two distinct phases:

1. general airtightness work; and,

2. targeted airtightness work.

Measurements of air leakage were made in a number of the houses before and during the programme of airtightness works, and in all of the houses after the airtightness programme had been completed. These measurements were made using Leeds Metropolitan University's Minneapolis blower door, and are accurate to ±10% when made under good weather conditions. The principles involved in undertaking these air leakage tests can be seen in **Figure 2.2** below.

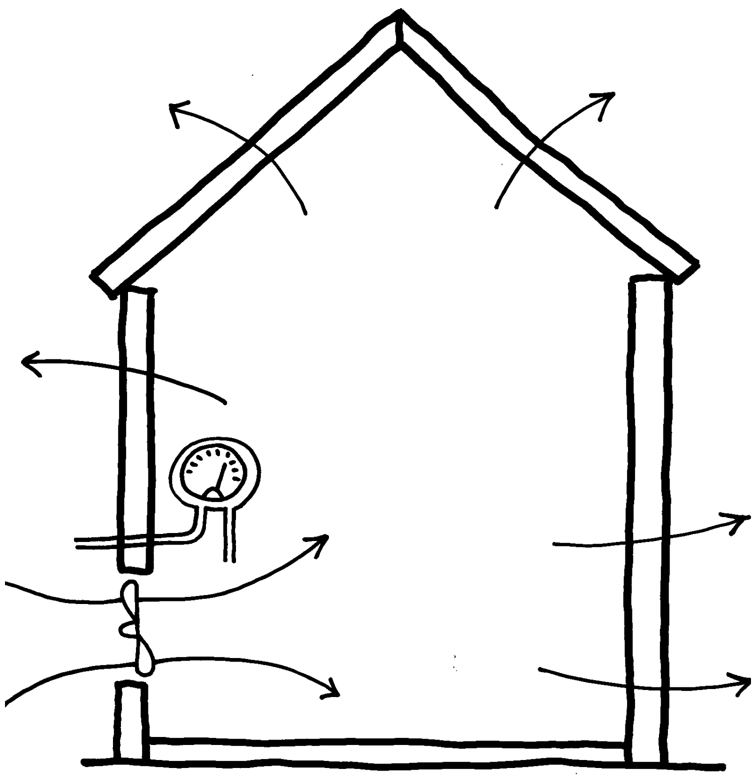


Figure 2.2 Blower door pressurisation test.
Air is force into the dwelling by the fan, and finds its way out through leaks in the thermal envelope. The relationship between rate of flow and pressure difference across the thermal envelope defines the leakage characteristic of the dwelling. Depressurisation is accomplished by reversing the fan direction.

The need for the programme of airtightness work to keep pace with the refurbishment programme being undertaken by the local authority, meant that it was not possible to measure the separate effect of each airtightness measure in as many cases as had originally been hoped for, and it was not possible to measure the air leakage of every house before the basic refurbishment programme began. It was also not possible to undertake any of the airtightness work in one of the field trial houses, house E (control group dwelling). Although this was unfortunate in terms of the goals of the field trial, it did provide a useful check on the relative importance of the airtightness work undertaken by LMU, and the general refurbishment work undertaken by the local authority.

2.2.1 General airtightness work

The general airtightness work involved undertaking a series of standard building envelope measures. The most important of these was the injection of expanding polyurethane foam into the area between the block inner leaf and the plasterboard inner skin of the dwellings (see **Figure 2.3**). This required the drilling of 9 mm diameter holes at approximately 100 mm centres around the edges of each continuous sheet of plasterboard on the external and party walls, and around the windows and the external doors (see **Figure 2.4**).

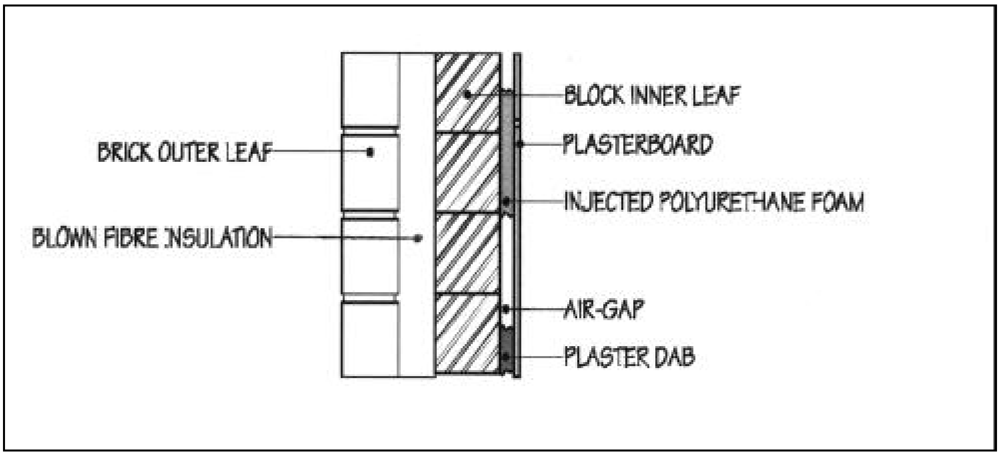


Figure 2.3

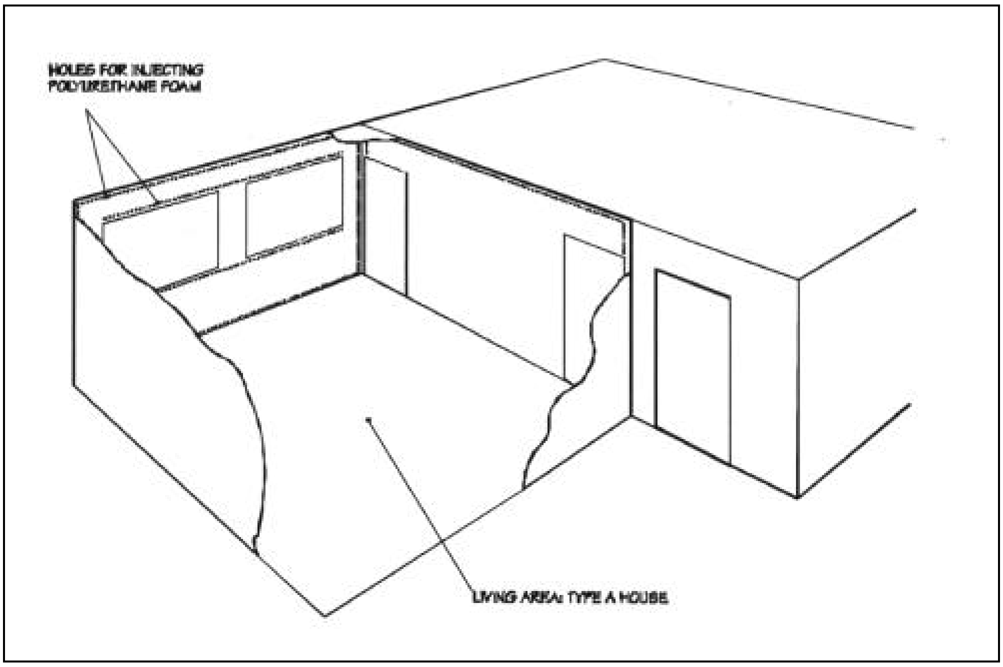


Figure 2.4

The objective of injecting the foam into this area was to form a continuous ribbon of foam in the cavity between the plasterboard and the inner block leaf of the walls, which would prevent air movement into this cavity from interior partitions and the first floor void. Expanding polyurethane foam was also injected into the wall cavity around the windows and doors to prevent air leakage from reveals. The original intention was to pressure test each dwelling after completion of this work.

In two of the dwellings, one Type A (house B) and one Type B (house F), it was possible to undertake a series of pressure tests at stages, as the general airtightness work progressed. This enabled a rather more detailed picture of the effectiveness of each stage of the work to be gained.

2.2.2 Targeted airtightness work

The targeted airtightness work was carried out once the general airtightness work had been completed, and was undertaken on the MVHR dwellings only. The targeted work involved depressurising the house, and then identifying leaks by feeling for draughts, and by using smoke pencils. These leaks were then sealed where possible using polyurethane foam or silicone mastic. In one of the dwellings (house G), draughtproofing was carried out in a number of areas of this dwelling, such as the external doors and the loft hatch during this phase of work. In this house, pressure tests were undertaken at 5 stages throughout this programme of work, enabling the relative importance of each of the steps to be gauged.

In all of the houses, the targeted airtightness work carried out by Leeds Metropolitan University was followed up by the application of an external mastic seal to all of the windows and external doors by Derwentside DSO. All of the field trial dwellings were pressure tested after this final stage of work, and in addition, three of the field trial dwellings were also tested before it.

2.3 PRESSURE TEST RESULTS

A summary of the pressure tests that were carried out on the field trial dwellings, at all stages of the airtightness programme, are shown below in **Table 2.1**. Initial pressure tests were carried out between September and November 1995, the general airtightness work was carried out in between December 1995 and January 1996, and the targeted airtightness work was undertaken in between January and February 1996. The final pressure tests were conducted in June and July 1996 after the windows were masticed up externally by Derwentside DSO.

HOUSE	Initial test	After general work	After targeted work	Final test
A (Control)		14.4		9.2
B (Control)		11.5		8.5
C (Control)		13.4		9.0
G (MVHR)		11.1	9.2	9.2
D (Control)				11.6
H (MVHR)		15.0	14.1	13.1
I (MVHR)	24.5			13.3
J (MVHR)		14.3	13.4	12.6
K (MVHR)	25.3			13.5
L (MVHR)		12.3		10.3
E (Control)				18.4
F (Control)	26.1	12.1		9.1
Average leakage rates	25.3	13.0	12.2	10.9

Table 2.1 Pressure test results

The distributions of air leakage both before and after the refurbishment and airtightness work are shown in **Figure 2.5** below.

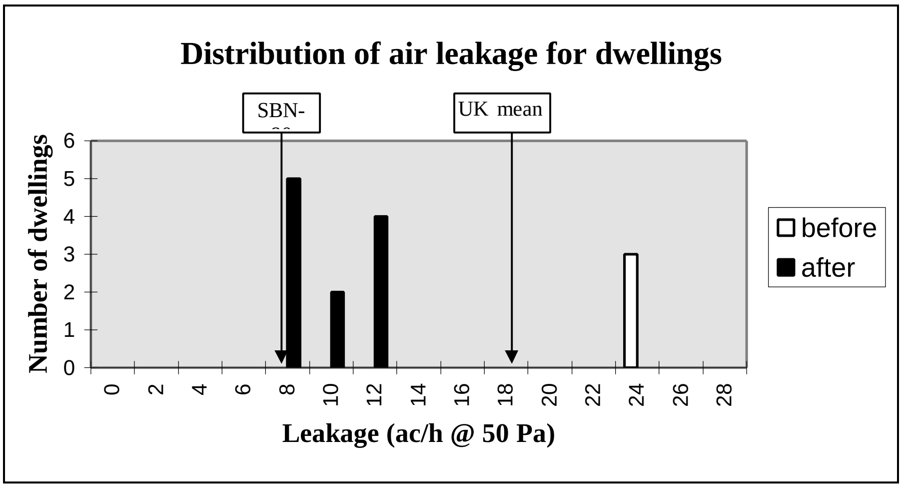


Figure 2.5 Distribution of air leakage for dwellings

The pressure tests show that before refurbishment, the air leakage rates of the dwellings at Eshwinning lay between 24-26 ac/h at 50 Pa, substantially in excess of the UK mean of 14 ac/h (Perera & Parkins 1992) and a factor of 8 greater than the 1980 Swedish Building Regulations standard of 3 ac/h for new housing (Anon, 1983), which was the original airtightness target for the experimental houses fitted with MVHR. The mean leakage rate after the refurbishment and the airtightness work was completed was 10.9 ac/h, a reduction of 56%. This represents a considerable improvement in the airtightness of these dwellings, which are now more airtight that the UK mean. However, this improvement in airtightness still leaves the experimental group of field trial dwellings (those fitted with MVHR), considerably leakier than had originally been hoped for.

The majority of the improvement in these dwellings is accounted for by a combination of the general airtightness work and the effects of the local authority's refurbishment. The results from house E, which received only the refurbishment and no airtightness work, suggests that the refurbishment work and the total package of airtightness work undertaken by Leeds Metropolitan University, made similar contributions to the overall reduction in air leakage in these houses[6]. This tentative conclusion is however based on a measurement made in only one house.

As mentioned previously, in two of the houses (house B and F) it was possible to measure the effects of each stage of the general airtightness work. The results of these measurements are shown in **Table 2.2** and **Figure 2.6** below.

[6] It must however be noted that successive airtightness measures are not in general independent.

Measures undertaken	Air leakage (ac/h @ 50 Pa)	
	House B	**House F**
Before general airtightness work		26.1
External walls sealed	15.3	17.5
Windows sealed	14.3	14.4
External door sealed	14.0	
Edges of party walls sealed	13.1	13.4
Top and bottom of party walls sealed	11.5	12.1

Table 2.2

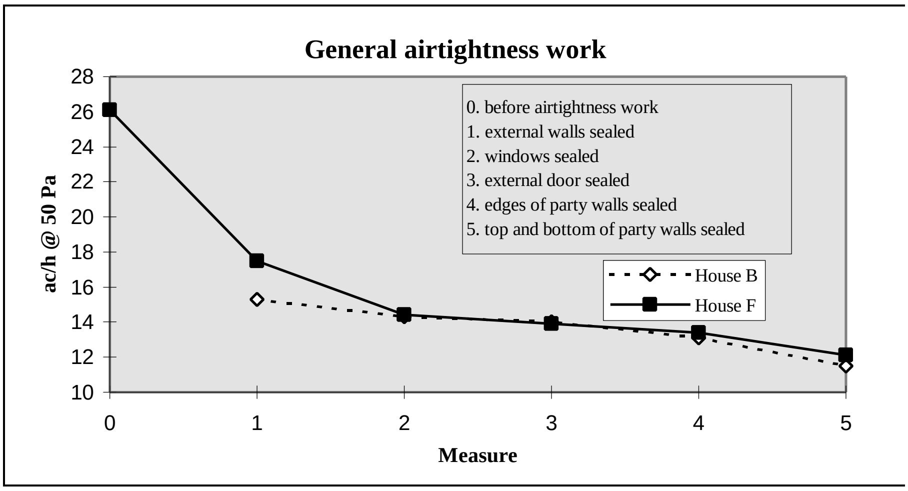


Figure 2.6

The pressure tests undertaken in these two dwellings suggest that the most important general airtightness measure to be undertaken by LMU was the sealing of the external walls, which can reduce the air leakage rate of the dwelling by more than 8 ac/h @ 50 Pa. Next in importance was the sealing of the tops and bottoms of the party walls which resulted in an improvement of around 1.5 ac/h @ 50 Pa. Finally, sealing the external doors and windows each resulted in a total improvement of around 1 ac/h @ 50 Pa.

Unfortunately, it was possible to undertake the targeted airtightness work on only three of the experimental MVHR dwellings (houses G, H and J). In one of these dwellings (house G), it was possible to measure the effect of the targeted airtightness work at four intermediate stages. The results of this work are presented in **Table 2.3** and **Figure 2.7** below.

Airtightness measure	Air leakage (ac/h @ 50 Pa)		
	House G	House H	House J
General airtightness work	11.1	15	14.3
Loft hatch draught sealed	11.0		
Window frames sealed	10.1		
Sockets on external/party walls sealed	10.0		
Front and back door frames sealed	9.4		
Space around boiler sealed	9.2	14.1	13.4

Table 2.3

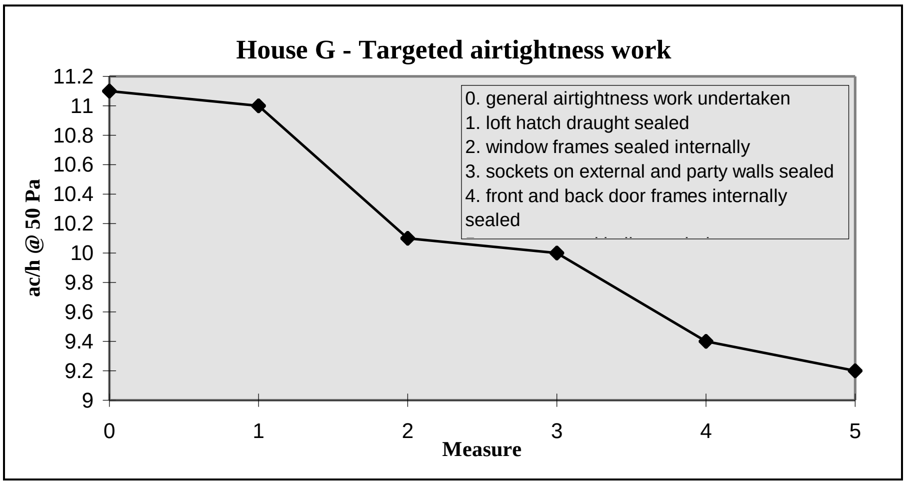


Figure 2.7

The graph above shows the progressive improvements in airtightness that can be achieved by implementing the various measures mentioned. The graph also clearly shows that the most important targeted airtightness measure undertaken involved internally sealing the window and door frames to the plasterboard lining of the wall. These measures resulted in a drop of 0.9 and 0.7 ac/h @ 50 Pa respectively. The least important targeted airtightness measures undertaken were the sealing of the loft hatch, and the sealing of the electrical sockets.

One of the most interesting aspects of the work at Eshwinning is the suggestion in the data that the effectiveness with which the measures were applied improved over a 4 month period. The first houses to be completed were originally pressure tested in December 1995. The mean leakage rate for these houses, was 12.6 ac/h. The rest of the houses were completed and pressure tested for the first time between March and June 1996. The mean leakage rate of these houses excluding house E, was 9.4 ac/h, and only one had a leakage rate greater than 10 ac/h. The reasons for this improvement are difficult to pin down. Part of the improvement probably relates to a number of suggestions made by the LMU team to Derwentside District Council at a progress meeting in December 1995. These related particularly to the care with which the new window frames were installed by Derwentside's DSO. It also seems likely that the quality of the work done by the LMU team was also improving over this period, but it is difficult to go much further than this.

2.4 COSTS OF THE AIRTIGHTNESS WORK

The total time required to undertake the general airtightness work was reduced with practice and by the end of the period was of the order of 3 man days per house. The time required to carry out the targeted airtightness work and the pressurisation testing was approximately 1½ man days per house.

During the general airtightness work, approximately 40 kg of expanding polyurethane foam, costing approximately £180, was required per house. Material costs for the targeted airtightness work were minimal, with the greatest cost incurred being for labour.

2.5 FACTORS AFFECTING AIR LEAKAGE

It is clear that the airtightness of the field trial houses falls short of what had originally been hoped for - the mean leakage rate after the refurbishment and the airtightness work had been undertaken was 10.9 ac/h @ 50 Pa, compared to the revised air leakage target of 8 ac/h. The reasons for this are as follows:

- a combination of original construction method;
- wear-and-tear to the plasterboard linings of the dwellings;
- detailing and workmanship during the present refurbishment; and,
- the partial nature of the refurbishment programme.

In fairness to all concerned, it must be pointed out that very few refurbishment teams have ever had the fruits of their efforts evaluated in this much detail by pressurisation testing, and that our initial findings are not a criticism of anybody who has been involved in this work. It is nevertheless instructive to describe some of these problems in more detail.

2.5.1 Basic construction and built form

The form of the dwellings contributed in a number of ways to poor airtightness. The field trial is based on two storey houses, with low pitched trussed roofs, each with a small single storey flat-roofed extension housing a WC, entrance lobby and coal store. This extension consisted of two walls of brick-block construction and a third which was timber clad. The houses are arranged in short staggered terraces. External walls are of brick-block or block-block cavity construction, lined internally with plasterboard-on-dabs. Internal load-bearing walls are of blockwork, lined on both sides with plasterboard-on-dabs. Ground floors are ground-bearing concrete slabs finished with thermoplastic tiles. First floors consist of structural timber joists supported on gable, party, and internal load-bearing walls and finished with chipboard. A soil stack runs within the inner block leaf of the external walls, and connections to it are made through the inner plasterboard lining of the wall.

The plasterboard-on-dabs construction was inherently leaky and difficult to seal. The plaster dabs which fixed the plasterboard to the external and party walls may have interfered with the flow of foam behind the plasterboard. Attempts to form a continuous ribbon of polyurethane foam behind each area of plasterboard were difficult to monitor, although the LMU team were reasonably confident, by the end of the programme, that they could achieve this in most cases. The staggered terraces meant that cavities within party walls were continuous with those in external walls, and communicated freely into attic spaces and first floor voids. The impact of such factors on thermal bridging, as well as on air leakage, appears not to be appreciated by architects.

There had been little attempt, during the original construction process, to seal around connections into soil stacks. Many of these connections took place behind kitchen units and WC’s and were inaccessible. The existence of leaks at these points was attested to by discovery of cavity fill in kitchen units following the filling of the external wall cavities during the refurbishment. Attempts were made to seal connections between the house and the space around the soil stack with polyurethane foam, but this was made more difficult by presence of mineral fibre cavity fill in this space.

2.5.2 Wear-and-tear

Damage to the plasterboard linings had occurred in a number of places. The most important was at the edges of walls, around doors and windows, and behind sink units. Much of this damage was not repaired during the basic refurbishment programme undertaken by Derwentside DSO. This was particularly the case behind kitchen units, and behind baths, which were not replaced during the refurbishment process. Such damage made it difficult to undertake the general air-tightening work, as this depended on plasterboard being sound. Detachment of plasterboard from its supporting dabs was also evident from vibration during pressure testing. When foam is applied behind such plasterboard, there is a tendency for the plasterboard to lift away from the wall behind as the polyurethane foam expands. The resultant lack of constriction may have reduced the spread of foam behind the plasterboard.

2.5.3 Detailing and workmanship

The pressurisation testing revealed detailing and workmanship problems in a number of areas. These were as follows:

- It was initially found that plasterboard linings around windows and doors did not finish flush with reveal linings. The resultant gap was up to 1cm in some instances. This was particularly common under window cills, and was difficult to seal. This problem was noted early in the programme of work and was brought to the notice of Derwentside DSO, who took appropriate steps to rectify this problem. As noted earlier, dwellings which were completed later in the programme were significantly improved in this respect.

- The central heating boiler mounting plates were screwed directly to the masonry of the inner leaf of external walls. In order to achieve this, the plasterboard was cut away, so that the boiler mounting plate could be installed. The boiler mounting plate was smaller than the original hole cut in the plasterboard, which resulted in a continuous gap between the plasterboard and the inner leaf around the perimeter of the boiler mounting plate. No attempt was made to seal this gap, which had an unobstructed area of the order of 0.06 m^2. This on its own would be sufficient to add approximately 2 ac/h @ 50 Pa to the background leakage of each dwelling. Once the boiler had been installed, it became extremely difficult to seal this junction.

- In a number of houses, kitchen units had been built across full height windows. When these were partially bricked up during the refurbishment, it was not possible to fix plasterboard to the inner side of the new wall without removing the kitchen unit, or to seal the edges of the plasterboard covering the rest of the wall at this point. Airtightness at this point was, optimistically, provided by the kitchen unit itself.

- In a number of cases, new external doors were fitted in such as way that the draught strip was not compressed on closing the door.

- Large cracks and spaces were left in the chipboard covering of the first floors. Although attempts were made by the LMU team to fill these gaps where possible, in most cases the gaps were covered with carpet when the houses were reoccupied. These cracks and spaces allow significant leakage to occur into the floor voids of the dwellings. Carpet is highly permeable, and does not significantly obstruct air movement.

2.5.4 The partial nature of the refurbishment programme

Damage to the plasterboard linings had occurred in a number of places. The most important was at the edges of walls, around doors and windows, and behind sink units.

Derwentside DSO only undertook a **partial** refurbishment of the field trial dwellings. The existing bathrooms and kitchens in these dwellings were not refurbished in almost all of the cases. Therefore, it was impossible to ascertain the condition of any plasterboard or flooring contained behind and under the existing kitchen and bathroom fittings. While in some cases, it was possible to observe damage to the existing plasterboard and floors in these areas, it was impossible to gain access to these areas without removing the existing fittings.

2.6 DISCUSSION AND CONCLUSIONS

A considerable amount of quantitative data was collected whilst carrying out the refurbishment and airtightness work on the field trial houses at Eshwinning, County Durham. The most important results in this area were:.

- refurbishing these houses and implementing a planned programme of airtightness work reduced their air leakage from between 24 and 28 ac/h at 50 Pa to between 8.5 and 13.5 ac/h;

- approximately half of this reduction was accounted for by a programme of remedial airtightness work undertaken by Leeds Metropolitan University;

- a significant reduction in air leakage occurred after problems of workmanship were identified by Leeds Metropolitan University, and recommendations were fed back to Derwentside District Council.

However, perhaps more importantly, a number of conclusions can be drawn from this exercise. The most important of these conclusions were that, in spite of a considerable effort on the parts of all of those involved in the airtightness work, it was not possible to achieve the levels of airtightness in the field trial houses that are normally required to justify the installation of balanced MVHR on energy efficiency grounds i.e. an air leakage rate of 1 to 3 ac/h @ 50 Pa. Instead, all that was achieved was a reduction in the air leakage of the field trial dwellings to a mean leakage rate of 10.9 ac/h @ 50 Pa, approximately 25% less than the UK mean leakage rate of 14 ac/h @ 50 Pa.

Technically the most important factor that contributed to air leakage was the method used to construct the walls of the dwellings. The use of plasterboard-on-dabs effectively interconnects all the leakage paths in the house. Geometrically the house, rather than being a simple cuboid consisting of a roof, external walls and a ground floor, becomes a highly complex network of inter-penetrating voids. Many of the junctions between these voids are hard to access, and even where access can be gained, there is little possibility of a visual check on the continuity of the retrofitted seals. In addition, the construction method interacted adversely with the partial nature of the refurbishment carried out on the field trial houses, which meant that significant parts of the external walls could not be accessed from the inside of the dwelling. It was felt that if a full refurbishment programme had been undertaken, or if it was possible to gain access to these parts of the external wall, the final air leakage rates of the field trial dwellings could have been lower

A check on the impacts of the method used to construct the walls of the dwellings was provided in July 1995, by a pressure test that was undertaken in a house on the field trial estate (see house Y in **Appendix 3**). This house had previously been gutted by fire. All internal fittings had been removed and replaced, and the plasterboard linings on all walls had been replaced by a conventional coat of plaster. No additional airtightness measures were undertaken in this house, but in most other respects it resembled the field trial houses following their refurbishment. The leakage rate in this house was 9.4 ac/h @ 50 Pa. This result is in line with measurements made in other refurbished houses of traditional wet-plastered construction (Lowe et al. 1994, Bell & Lowe 1996). If an allowance is made the effects of the open flued gas fire in the living room in this house, it would have been the most airtight of all the houses tested. An important aspect of this finding is that this air leakage rate was achieved without significant attention to detail, workmanship or site supervision. If all of these factors were taken into consideration during the refurbishment of this property, it is possible that the air leakage rate of this dwelling could approach the values previously achieved at York (down to 5 ac/h @ 50 Pa). It appears likely that, had the field trial houses been wet-plastered rather than dry-lined, much lower final leakage rates would also have been achieved following a revised airtightness programme.

One possible consequence of the poor overall airtightness achieved at Eshwinning, is to underemphasise the effects of a number of measures that might, in more airtight dwellings become significant. Examples include the importance of draughtstripping the loft hatch, and sealing electrical back boxes, each of which reduced air leakage by 0.1 ac/h. In the context of an attempt to reduce leakage rates from 25 to 10 ac/h, these measures are insignificant, but if the objective were to seal the dwelling to 1 ac/h, they would become rather important.

Although the programme of work at Eshwinning was not intended to elicit information on knowledge and attitudes of the original design team, or of the people engaged on the refurbishment, a limited amount of qualitative information was either elicited directly, or inferred in these areas. One of the most interesting observations was the general lack of knowledge on the part of those involved in the refurbishment, as to the relative importance of various technical determinants of airtightness. This lack of knowledge could be inferred from a comparison of the considerable care with which e.g. window frames were sealed externally to brickwork (a measure with a relatively small impact on airtightness), with the lack of care expended on the junction between boiler flue and plasterboard, or on the plasterboard behind bricked-up windows in kitchens (which would have had a large impact on airtightness). It became clear on talking with representatives of Derwentside's Architects' Department, that this lack of knowledge existed amongst design staff too. The explanation given for the choice of plasterboard-on-dabs was that, on paper, it resulted in a lower U value than an original wet plastered wall. When the houses were being designed, there was no published information either on the comparative leakage characteristics of different construction techniques, nor on measured U values, and no easily available method for making direct measurements. The response of design staff who witnessed pressurisation testing at Eshwinning appeared to be a rapid re-evaluation of their approach to airtightness, coupled with considerable frustration at having had to work without reliable sources of information on airtightness, and without practical tools to measure airtightness themselves.

The experience at Eshwinning suggests a need for effective dissemination of reliable information on airtightness. One way of providing this directly would be through the much more widespread use of pressurisation testing in the process of construction and refurbishment of dwellings.

3 INSTALLATION, COMMISSIONING AND PERFORMANCE OF THE MVHR SYSTEMS

3.1 INTRODUCTION

The quality of the installation and commissioning of the MVHR systems at Eshwinning was important for two main reasons: first because inadequacies in these areas could reduce the significance of subsequent findings from the field trial, and second because information gained could be fed back in the form of recommendations for future practice. Observations were made on the installation of the MVHR units in February 1996 after all of the units had been installed and commissioned by representatives of the relevant manufacturers, whilst a number of further checks were made on the commissioning of the MVHR units between January and March 1997. From these observations, it became apparent that significant discrepancies existed between the manufacturers' installation and commissioning intentions and the observed status of the MVHR systems.

In some cases these discrepancies represent major failures of installation and commissioning. Although in the context of the Eshwinning field trial, they were quickly identified, brought to the notice of the manufacturers, and set right, this may not happen in a normal commercial installation. By documenting the problems that occurred at Eshwinning, we hope to highlight the need for care to be taken in the installation and commissioning of such systems, and the need for the appropriate training for the installers of such units. If such care is not taken during these processes, the performance of MVHR systems can be seriously degraded, and may ultimately lead to the systems being deemed inoperable by the occupants of the dwellings and/or landlords.

3.2 DESCRIPTION OF THE MVHR SYSTEMS

This section presents a general description of the MVHR systems installed at Derwentside. Additional technical information may be found in Appendix 4.

The MVHR systems installed in the field trial dwellings were donated by two UK manufacturers. These systems were designed to control the ventilation rates within the dwellings chosen, and consisted of an supply and an extract fan, an air-to-air heat exchanger to transfer heat from the extract air to the inlet air stream, and ductwork to distribute the air around the dwelling. The systems operated by extracting warm moist air from the 'wet' rooms of the dwelling - the bathroom and the kitchen, and by supplying fresh air to the living room and bedrooms. Both of these air flows were ducted through the heat exchanger unit.

There were significant differences between the systems supplied by the two manufacturers. The system supplied by Manufacturer A was a prototype based on an existing design, and incorporates a range of features designed to increase heat recovery efficiency and reduce electricity consumption. These include electronically commutated DC motors to drive the system fans, an enlarged heat exchanger, the use of pre-insulated panels to form the casing for the central unit, and the use of rigid, smooth ductwork.

The system supplied by Manufacturer B has been on the UK market for some years, and is aimed at DIY installers and local authorities. It has been designed to minimise first cost in a market that is sensitive to this factor, and for simplicity of installation. It makes use of conventional AC motors, and flexible corrugated aluminium ducting. The systems installed at Derwentside were unmodified, ex-stock systems.

The MVHR systems were located in the following experimental field trial dwellings:

- **Manufacturer A** - House J (end-terrace), K (mid-terrace), and L (end-terrace) all of which are Type A dwellings

- **Manufacturer B** - House G (end-terrace), H (mid-terrace), and I (end-terrace) all of which are Type B dwellings

The MVHR units for all systems were installed in the loft spaces of the field trial dwellings. Manufacturer A units, in houses J, K and L were situated partly across the stairwell and partly across the adjacent bathroom and a bedroom. Manufacturer B units, in houses G, H and I were situated above the stairwell. Optimal location would have been across the bathroom and stairwell, since this would minimise noise transmission to bedrooms. However this was difficult to achieve in all houses, due to the low pitch of the roof, and the use of trussed rafters.

Fresh air supply and the stale exhaust vents are situated on the gable walls of dwellings G, H, I, J and L. It was not possible to install the air supply and extract vents on the gable wall of house K, and roof mounted vents were used in this house instead.

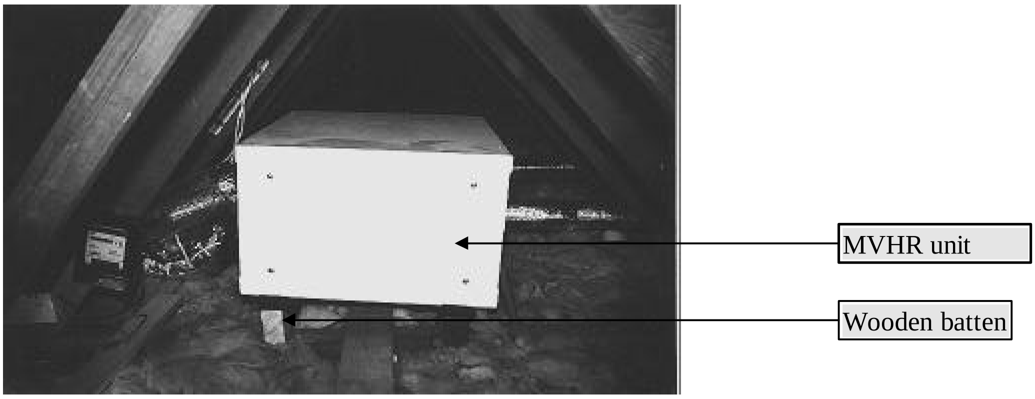
The majority of the associated ductwork for both sets of systems was located in the loft space of the dwellings. Vertical runs of ductwork were required to reach the rooms on the ground floor. This ductwork was located, as far as possible, in the corners of cupboards or in the corner of bedrooms, and was boxed in by Derwentside DSO.

It was originally intended that installation of the MVHR systems would be undertaken by the manufacturers themselves, in order to guarantee that systems were installed properly in accordance with manufacturers' instructions. For a variety or reasons it was not possible to arrange this. Manufacturer A's systems were installed by Northern Electric, while Manufacturer B's systems were installed by a third party, who proved in the event to have been unfamiliar with the system he was installing.

3.3 GENERAL DESCRIPTION OF SYSTEM INSTALLATION

3.3.1 Manufacturer A dwellings

The MVHR unit in these dwellings was located in the loft above the stairwell and close to the bathroom. The units were insulated internally with 12 mm of low density polyethylene foam, which would give a casing U value of approximately 2 W/m^2K (though the extent of thermal bridging has not been assessed). This unit was mechanically fixed at the base to two wooden battens (see below). These battens were of differing thicknesses, allowing the unit to sit at a slight angle. This angle allows any condensate in the unit to collect in the condensate drain tube.

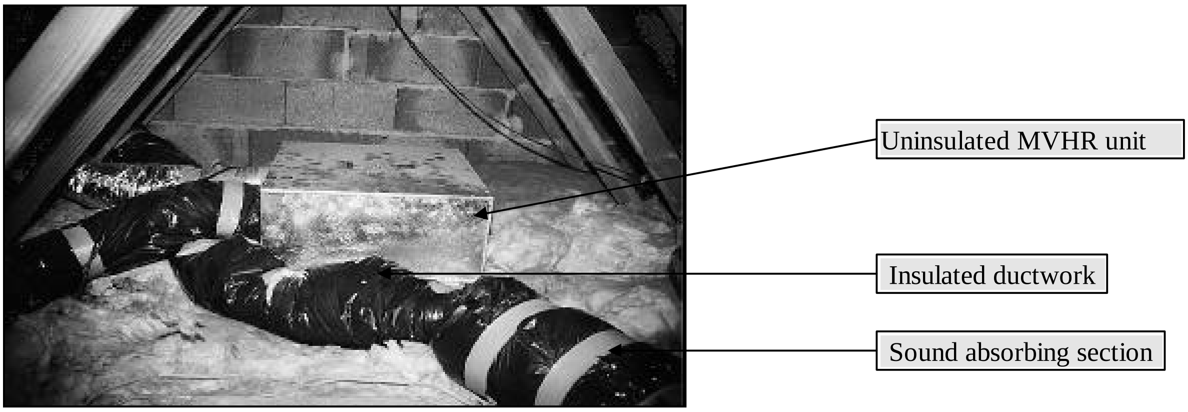


The condensate drain tube ran from the base of the MVHR unit to the outside via the soffit of the dwelling. However, this drain tube did not run in a continuous gradient from the unit to the discharge point. The battens were securely fastened onto a plywood board, which was in turn mechanically fixed to the ceiling joists of the dwelling, thus preventing the unit from being accidentally moved around. In order to prevent noise transmission through the building structure, a vibration and sound absorbent strip (approx. 25 mm thick) was sandwiched in between the wooden battens on the base of the MVHR unit and the plywood board. A separate speed controller box was also situated in the loft space, and was securely fixed on to on the roof truss members.

The majority of the ducting in the loft space consisted of 100 mm diameter rigid circular plastic sections which were laid out in straight sections as far as possible. Flexible circular aluminium ducting sections were only used in the loft to connect the MVHR unit to the straight duct runs, and to the outside. All of this ducting was insulated with a foil coated bubble wrap type material. Connections between the duct runs in the loft and the bedrooms, bathrooms, living and dining rooms below were made using straight rigid circular and rectangular plastic ductwork. Ductwork within the occupied volume of the dwelling was boxed in by Derwentside DSO.

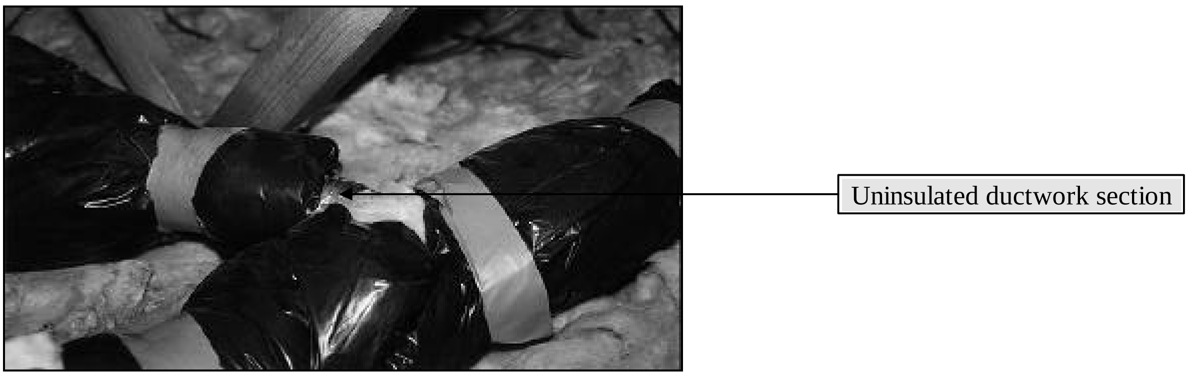
3.3.2 Manufacturer B dwellings

The MVHR unit in these dwellings was located in the loft space above the stairwell and the bathroom. The unit was uninsulated (see below) giving a casing U value of approximately 5 W/m^2K, except in one of the dwellings, where some mineral wool insulation had been loosely draped over the MVHR unit.



The MVHR unit of the Manufacturer B system was mechanically fixed at the base to two wooden battens. These battens rested flat on a sheet of plywood boarding but are not mechanically fixed to this board in any way. In the case shown above, the plywood board rests on top of a small amount of the existing mineral wool loft insulation which has been pulled up and over the ceiling joists. This board was not mechanically fixed to the ceiling joists, and it would therefore be possible for the MVHR unit to be accidentally moved around within the loft space.

All of the ducting used in the dwelling was of the flexible aluminium type. In the loft space, the use of the flexible ducting resulted in very few straight duct runs. Although all of the ducting in the loft was insulated with mineral wool, which was installed on site using duct tape. In some areas of the loft, the insulation was found to be away from the ducting, and some ductwork junctions were not insulated (see below).



Filters were installed in each of the room grilles in order to further improve the quality of the fresh air, and to help balance the air flow between rooms. The extract grilles were installed in the ‘wet’ areas of the dwelling, and were positioned as close to the main source of moisture as possible. The inlet grilles, on the other hand, were installed in the ‘dry’ rooms of the dwelling. Due to an error on the part of the installer working on behalf of Manufacturer B, ductwork was connected the wrong way round at the MVHR unit in all houses, with the result that the direction of airflow through the dwelling was initially reversed.

3.4 PERFORMANCE OF THE MVHR SYSTEMS

Measurements of air flow, temperature and electricity consumption were undertaken by Leeds Metropolitan University to examine the quality of installation and determine the performance of the field trial MVHR systems. These measurements in turn enabled temperature and thermal efficiency, and the coefficient of performance (CoP) to be estimated.

3.4.1 Airflow measurements

Airflow measurements formed an integral part of checking on the commissioning of MVHR systems, and were undertaken in order to determine the following:

- whether the MVHR systems were balanced or not;
- the effective air change rate provided by each MVHR system; and,
- how well the MVHR systems were commissioned, by comparing the measured flow rates with manufacturers’ literature.

Airflows in the MVHR systems were measured using two different methods: air flows were measured in ducts using a pitot static tube, and airflows were measured at terminal devices using a flow measurement hood. A description of both of these measurement methods and the results obtained are set out below.

Pitot static tube method

Duct airflow measurements were undertaken in all of the experimental field trial dwellings using a pitot static tube. These measurements were taken in the inlet and exhaust ductwork of each system, between the MVHR unit and the outside air. Measurement at this point avoided the problems posed by branching ductwork on the dwelling side of the MVHR unit.

In order to undertake the duct airflow measurements using the pitot static tube, the pitot static tube should be placed in a straight section of ductwork, which is as far as possible away from any bends or obstructions in the ductwork, in order to avoid any uneven airflow. However, it was not possible to find such a point in the existing ductwork of houses G, H, I, and L, where the ductwork in between the main MVHR unit and the supply/exhaust to outside consisted of non-straight flexible ductwork sections. In order to overcome this problem, a 500 mm[7] straight section of 100 mm diameter rigid plastic ductwork was inserted into the flexible ductwork in both the supply and extract side of the MVHR unit in an attempt to achieve as accurate as possible readings from the pitot static tube. A small access hole was then drilled in the inserted section of ductwork at the point where the flow measurement was to be made (see **Figure 3.1** below).

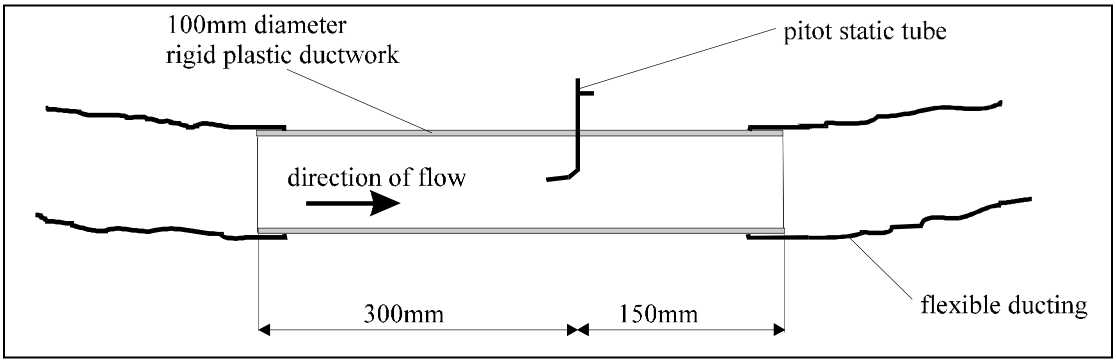


Figure 3.1 Section of ductwork inserted for airflow measurement

A number of simple preliminary induct airflow measurements were then made in two of the experimental dwellings (houses I and L) by traversing the duct across one diameter with the pitot tube connected to a micromanometer. These measurements were taken at the points shown in **Figure 3.2** below. All of these measurements were carried out with the MVHR units set at the 'normal' setting.

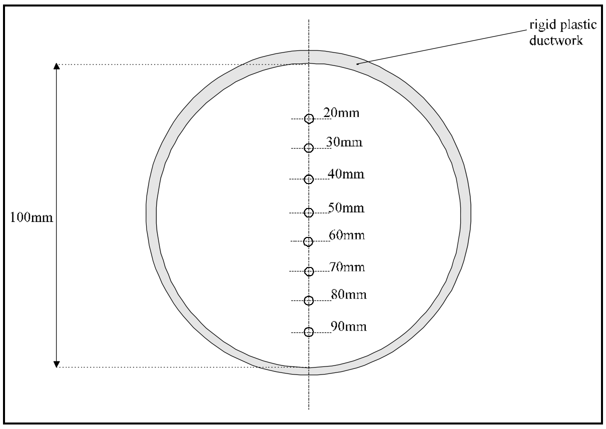


Figure 3.2 Measurement points across the ductwork

The preliminary duct airflow results obtained were clearly indicative of undeveloped airflow in the measuring section of ductwork in the MVHR systems. In order to

[7] Due to the limited space between the MVHR unit and the supply/extract to outside, the largest length of straight duct that could be installed at this point was 500 mm in length.

confirm the average airflow readings obtained above for both of the MVHR units, a second traverse was required at 90^o to the first traverse, with the same amount of measurements taken along the diameter of the duct.

A second access hole was therefore drilled in the inserted ductwork section at 90^o to the first, and a second traverse was undertaken along the diameter of the ductwork. Duct airflow measurements were then undertaken in all of the experimental field trial dwellings, with the exception of house G. The results of these measurements can be seen in **Table 3.1** below.

HOUSE	Average airflow in duct (m^3/h)			
	Extract	**Extract @ 90^o**	**Supply**	**Supply @ 90^o**
H	5.9	6.5	90.4	9.89
I	45.5	55.1	38.2	34.2
J	132.3	124.1	68.7	69.5
K	68.7	81.4	N/A	N/A
L	143.6	139.9	134.5	130.3

Table 3.1 Duct airflow measurements

These measurements confirmed that undeveloped airflow was occurring in the measurement sections of the ductwork. The reasons for this uneven airflow mainly relate to the use of flexible ductwork sections and bends in the space between the MVHR unit and the supply/extract to outside. Although a small straight section of rigid ductwork had been inserted into the space between the MVHR unit and the supply/extract to outside, this section was too small to make a significant difference to the duct airflow. The insertion of a larger section may have rectified this problem, however, this was impossible to achieve in the field trial dwellings due to the limited space available in the loft space, as well as the limited space in between the MVHR unit and the supply/extract to outside.

Measurement hood method

Due to the difficulties involved in measuring the duct airflow of the MVHR systems using the pitot static tube method mentioned above, a number of terminal airflow measurements were also taken using a flow measurement hood, which was placed directly over each of the MVHR supply and extract terminals located within the dwellings. The measurements were undertaken by John McConnell of ADM Indux, with assistance from personnel from Leeds Metropolitan University, using a Swemaflow 230 air velocity meter. Air flow measurements taken using this device are accurate to approximately ±5%.

Due to time constraints and access problems, it was only possible to undertake these measurements in three of the experimental dwellings, houses J, L and I (two Manufacturer A, and one Manufacturer B system). Whilst undertaking these measurements, it was found that both of the Manufacturer A systems that were tested had been commissioned with the MVHR units operating at too high an airflow rate, delivering around 0.6 ac/h as opposed to 0.5 ac/h. This problem was rectified by turning down the speed of the fans in both of these systems to the correct level. This resulted in the energy consumption of these units dropping from 50-60 W to 20-30 W The ability to vary the speed of the ECM motors continuously without significant loss of efficiency is a major advantage when commissioning MVHR units - the fact that fan power in these systems varies approximately as the square of air flow, shows that fan-motor efficiency varied by a factor of less than 1.4 over this range of air flow. The alternative methods of speed reduction, including throttling of air flow, all lead to significantly greater increases in specific fan power.

The results of the measurements that were undertaken using the flow measurement hood can be seen in **Tables 3.2** and **3.3**. Again, all of these measurements were undertaken with the MVHR units operating at the 'normal' setting.

EXTRACT

	Volumetric flow rate (m^3/h)		
Room	**HOUSE J**	**HOUSE L**	**HOUSE I**
Dining room	19.0	19.0	no extract
Kitchen	31.0	31.0	25.0
Bathroom	31.5	31.5	40.0
W.C.	13.2	13.2	3.0
Total flow rate	94.7	94.7	68.0

Table 3.2

SUPPLY

	Volumetric flow rate (m^3/h)		
Room	**HOUSE J**	**HOUSE L**	**HOUSE I**
Bedroom 1	25.4	25.4	13.0
Bedroom 2	14.1	14.1	4.5
Bedroom 3	16.9	16.9	3.0
Living room	37.6	37.6	14.0
Total flow rate	94.0	94.0	34.5

Table 3.3

It is apparent from the above that Manufacturer A's systems were balanced within the margin of measurement accuracy, while Manufacturer B's systems were significantly biased towards extraction over supply.

3.4.2 The effective air change rate of the MVHR systems

From the total volumetric flow rates mentioned in **Tables 3.2** and **3.3**, the effective air change rates of the MVHR systems can be determined. Assuming that all three of the dwellings have an internal volume of 220 m^3, and using the larger of the two volumetric flow rates for each of the dwellings, the calculated air change rates of these dwellings are as follows:

House	Air change rate of MVHR system (ac/h)
J (Manufacturer A)	0.43
L (Manufacturer A)	0.43
I (Manufacturer B)	0.31

Table 3.4

The results obtained above have been compared with the values contained within the manufacturers' trade literature. In both cases, the objective was to provide 0.5 ac/h mechanically. In the case of Manufacturer A systems, the difference between the design 0.5 ac/h and the measured 0.43 ac/h is close to the margin of measurement error. In the case of the Manufacturer B units the difference (0.31 compared with 0.5 ac/h) is significant.

It is apparent that in none of the houses investigated did the MVHR system as originally commissioned provide the design airflow of 0.5 ac/h. This indicates the need for accurate measurement of airflow rates in MVHR systems on commissioning.

3.4.3 Energy consumption of MVHR system fans

The energy consumption of the fans incorporated in both manufacturers' systems was measured. This information, combined with volumetric flow rates, gives the specific power consumption of the systems measured. The specific power consumption, which is the ratio of the airflow divided by fan power, is a measure of the efficiency with which the system moves air through the dwelling.

Manufacturer A (before adjustments)
Extract flow rate ≈ 36 ls-1
Average power consumption ≈ 55 Watts
Specific power consumption ≈ **1.5 W/ls^{-1}**

Manufacturer A (following adjustments)
Extract flow rate ≈ 26 ls^{-1}
Average power consumption ≈ 27 Watts
Specific power consumption ≈ **1.0 W/ls^{-1}**

Manufacturer B
Extract flow rate ≈ 19 ls^{-1}
Average power consumption ≈ 45 Watts
Specific power consumption ≈ **2.4 W/ls^{-1}**

There are no UK recommendations for specific fan power, but recommendations are contained in the technical requirements for the Canadian Advanced House Program (CANMET, 1992). This document requires that:

> "If the house does not incorporate a forced warm-air heating system, the heat-recovery ventilator fans shall have an electrical power consumption not exceeding 1.2 Watts per litre/s of air-flow capacity."

Following adjustments, the electricity consumption of Manufacturer A's systems was less than the Canadian Advanced House requirements, though as originally installed it was somewhat greater. Electricity consumption per unit air flow in Manufacturer B's system is over twice as high as the Advanced House requirements. This is particularly significant in view of the comparatively low flow rate in the house measured. The difference in performance between the two systems clearly shows the benefits of energy-efficient motor technology, combined with a low resistance ductwork system, but measurements on Manufacturer A systems also show how good design can be compromised by poor commissioning (in this case air flow rates set too high).

3.4.4 Heat recovery efficiencies

The thermal efficiency of an MVHR system requires careful definition, since it depends on the combined performance of the dwelling and the MVHR system. Considering the dwelling as a whole, system thermal efficiency can be defined as:

$$E_{thermal} = 1 - \frac{\Delta Q}{\Delta V \, c_p \, \Delta T}$$

where:

$E_{thermal}$ is the system thermal efficiency
ΔQ is the additional dwelling heat loss that results from installing and operating the MVHR system
ΔV is the additional rate of air change that results from installing and operating the MVHR system
c_p is the specific heat capacity of air at constant pressure
ΔT is the temperature difference between the inside and the outside of the dwelling

This definition is a simplification in that it assumes that air change rate can be defined unproblematically. Differences in the pattern of ventilation and therefore in ventilation efficiency between dwellings with and without MVHR, make this impossible. Lack of time and data unfortunately force us to set this problem to one side.

Another source of uncertainty in evaluating the above expression for system thermal efficiency is the relationship between the flow of air through ducts of the MVHR system and the net increase in ventilation heat loss brought about by the installation and operation of the MVHR system. To make any progress here we have made a number of assumptions:

- conduction losses from the MVHR unit and ductwork are negligible;

- the installation of the MVHR unit does not increase the leakiness of the dwelling;
- no condensation of water vapour takes place within the MVHR unit;
- any imbalance between the supply and extract flow rates through the MVHR system is directly compensated for by increased leakage across the thermal envelope of the dwelling.

The first two of the above assumptions seem unlikely to be true, due to the fact that the MVHR systems at Derwentside were installed outside the thermal envelope of the dwellings, with U values between 2 and 5 W/m^2K for system units (ie significantly higher than U value of the surrounding roof), and due to the fact that the installation process required holes to be made in the first floor ceiling. The third assumption will be true in relatively airtight dwellings ($n_{50} < 2$ ac/h), but because of the non-linearity of flow across the thermal envelope, will not be true in more leaky dwellings.

With these assumptions it can be shown that the thermal efficiency of an MVHR system is given by the following equations:

if $V_{extract} > V_{supply}$ then:

$$E_{thermal} = \frac{V_{supply}}{V_{extract}} \cdot \frac{(T_{supply} - T_{outside})}{(T_{house} - T_{outside})}$$

and if $V_{extract} < V_{supply}$ then:

$$E_{thermal} = \frac{(T_{supply} - T_{outside})}{(T_{house} - T_{outside})}$$

where

T_{supply} is the supply temperature from the heat exchanger to the rooms
$T_{outside}$ is the external temperature
T_{house} is the average internal temperature of the dwelling
V_{supply} is the supply volumetric flow rate
$V_{extract}$ is the extract volumetric flow rate

The system thermal efficiency as stated above is equal to the so-called temperature E_T provided that $V_{supply} > V_{extract}$. The temperature efficiency is given by:

$$E_T = \frac{(T_{supply} - T_{outside})}{(T_{house} - T_{outside})}$$

A misunderstanding of the relationship between temperature efficiency and thermal efficiency has led a number of manufacturers to favour unbalanced airflow in the design of MVHR systems. Consideration of the physics of the situation shows that reducing the supply air flow rate leads to increased temperature efficiency (supply air moves more slowly through the heat exchanger, and can therefore be warmed to a temperature closer to inside air temperature), but only at the expense of reduced overall performance. The limiting case, with zero supply air flow, gives a temperature efficiency in the region of 1, but the overall thermal performance cannot in principle exceed that of an extract-only ventilation, with a system thermal efficiency of zero.

Because of uncertainties in flow rates, it has been possible to estimate thermal efficiencies only in the cases of houses J, L and I. These results should be treated with some caution, because it was only possible to undertake the duct temperature measurements at one point in the centre of the ductwork, where the airflow was known to be undeveloped, and because air flow was estimates are based on a single set of measurements in each house.

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House	Thermal Efficiency
J	0.77
L	0.84
I	0.41

Table 3.5

It is apparent from the above table, that the thermal efficiency of houses J and L (Manufacturer A) are much greater than the thermal efficiency of house I (Manufacturer B). The main reason for this is the unbalanced flow (with extract exceeding supply by a factor of 2) in house I.

3.4.5 Coefficient of Performance (CoP) of the MVHR systems

Basing the arguments used to derive the thermal efficiency in the preceding section, the coefficient of performance (CoP) of the MVHR system is given by the following equation:

$$CoP = V_{supply} \cdot (T_{supply} - T_{outside}) \cdot \rho.c_p / W$$

where

$\rho.c_p$ is the volumetric specific heat of air
W is the total fan energy supplied

On this basis the CoP of house I (Manufacturer B unit) was approximately 2.5 over the year from June 1996 to June 1997. The CoP of houses J and L (Manufacturer A systems) following adjustments, and with the internal temperatures maintained at Eshwinning would have been in the was in the region of 11 over this period, though the actual average over the period from June 1996 to June 1997 was probably just above 7. This large difference is due to the combined effect of unbalanced airflow and larger specific fan power requirement of the system in house I. CoP’s in all houses were higher than they might otherwise have been due to the high internal temperatures maintained.

3.4.6 Comparison of airflow measurements with UK and Canadian standards

UK regulations relating to continuous mechanical ventilation are at an early stage of development. The most significant documents appear to be Part F of the Building Regulations (DOE & Welsh Office, 1995), A BRE Digest on Continuous Mechanical Ventilation (BRE, 1994), a HEVAC Association Technical Specification (HEVAC 1995) and an EA Technology Performance Specification for MVHR (EA Technology, undated). Current Canadian guidance is considerably more detailed, and it is useful to compare measured air flow rates with recommendations contained within the Canadian Standard for Residential Mechanical Ventilation Systems (CSA, 1993).

The Canadian Standard is designed to ensure a ventilation air supply rate of approximately 7.5 ls^{-1} per person, in order to control the concentrations of human bio-effluents. The Canadian Standard specifies individual room requirements, and requires individual room air flow rates to be measured on commissioning unless the design is such as to ensure that design airflows will be achieved. Supply and extract airflows to the whole dwelling are required to be balanced.

We have calculated the individual room airflow rates for the field trial dwellings at Eshwinning using the Canadian Standard. Because of the similarities between the two dwelling types (A & B), we have not distinguished between them.

Room	**Ventilation requirement (ls^{-1})**
Living	5
Dining	5
Kitchen	5
Bathroom (downstairs)	5
Bedroom 1	10
Bedroom 2	5
Bedroom 3	5
Bathroom (upstairs)	5
Total	45

From the ventilation requirements mentioned above, the required overall air change rate for the experimental dwellings, according to the Canadian Standard, is 0.74 ac/h.

For comparison, the EA Technology performance specification states that the MVHR unit should be designed so that the ‘normal’ flow rate should be capable of being pre-set by the installer at 0.45 ac/h supply and 0.5 ac/h extract on a whole house basis. It is recommended that the supply air volume should be shared in proportion to the room volume and the extract air volume shall be shared equally between the extract terminals. BRE Digest 398 states that the normal flow rate should be between 0.5 and 0.7 ac/h and that the flows should be balanced between supply and extract. No guidance is given in Digest 398 on the measurement of airflows, and in this and a number of other respects the document is incomplete. The HEVAC Association’s Technical Specification refers to BRE Digest 398.

The air change rates calculated using the Canadian Standard are well above those measured in the experimental field trial dwellings using the flow measurement hood. This can be justified by the fact that Canadian dwellings are generally much larger than the average UK dwelling. The air change rate of 0.43 ac/h measured for the Manufacturer A systems in houses J & L is close to the 0.45 ac/h supply - 0.5 ac/h extract rate recommended in the EA Technology Specification, and to the lower limit of 0.5 ac/h recommended in BRE Digest 398. The Manufacturer B system in house I, on the other hand, achieves a much lower measured air change rate of 0.31 ac/h. Based on the Canadian recommendation of 7.5 l/s per person, the systems at Derwentside would be suitable for dwellings occupied by between 2.5 and 3.5 people, close to the actual occupancy. Direct comparison between UK and Canadian practice is however muddied by the dramatic difference in uncontrolled air leakage typical of dwellings in the two countries.

3.5 SUMMARY OF INSTALLATION AND COMMISSIONING PROBLEMS

The installation and commissioning problems observed at Eshwinning were as follows:

- a number of the MVHR units were not insulated;
- condensate drains in general appeared to be installed with an insufficient gradients;
- sections of the ductwork associated with the Manufacturer B units remained uninsulated in the loft space;
- the supply and exhaust ductwork in all of the Manufacturer B units was originally wrong way round;
- All of the Manufacturer A systems were initially commissioned with the fans operating at too high a speed, resulting in these units consuming almost twice as much power as they should have; and
- In the one system from Manufacturer B which was investigated in detail, extract air flow was twice as great as supply airflow, resulting in a poor thermal efficiency. This, coupled with an almost two-fold difference in electrical consumption, led to a four-fold difference in CoP between the systems supplied by the two different manufacturers.

3.6 CONCLUSIONS

From the observations undertaken on the experimental field trial dwellings at Eshwinning, it became apparent that a number of discrepancies existed between the manufacturers' installation and commissioning procedures and the observed installation and commissioning of the MVHR systems. In some cases, these discrepancies represented major failures of installation and commissioning. Although in the context of the Eshwinning field trial, they were identified, brought to the notice of the manufacturers, and set right, this is may not happen in a normal commercial installation.

These observations serve to highlight a number of points. These are:

- the importance of correctly installing MVHR systems;
- the importance of correctly commissioning such systems;
- the importance of airflow measurements in checking the commissioning of systems
- the need for appropriate training for the installers of such units;
- the need for standards or guidelines on the installation of MVHR systems;
- the need for the commissioning process to be documented and information on to be passed on to dwelling occupants and/or landlords;
- the need to engineer MVHR systems so as to minimise problems encountered in installation and commissioning, and to reduce the probability of major errors in the installation and commissioning process.

4 SURVEY OF OPINIONS AND ATTITUDES

4.1 INTRODUCTION

As part of the monitoring programme, two tenant questionnaires have been undertaken by Leeds Metropolitan University on the tenants of the field trial dwellings. The objective of these questionnaires was twofold. Firstly, to establish the tenants' opinions and attitudes towards the field trial dwellings, and secondly, to determine how the tenants interacted with their dwellings and the heating/ventilation systems installed within them. Information obtained from these questionnaires was also used to explain aspects of the physically monitored data collected during the field trial.

The first of these questionnaires was undertaken in January 1997, and a follow up questionnaire in early August 1997. Both the experimental and the control groups were surveyed on each occasion. The questionnaires were deliberately designed to be undertaken during the winter and summer, in order to establish whether seasonal differences and attitudes affect the tenants interaction with the dwellings, and their subsequent responses to the questions contained within the questionnaire. This chapter presents a summary of responses to the questionnaire. The wording of the questionnaire, and a more extensive summary of responses is contained in Appendix 5.

4.2 METHOD

Initially, a semi-structured pilot tenant questionnaire was developed by Leeds Metropolitan University in November 1996. This questionnaire was piloted in early January 1997 on three tenants from the Langley Park area of Derwentside, who were unconnected with the MVHR field trial. It was concluded from this exercise, that the questionnaire would elicit appropriate responses from the tenants of the field trial dwellings.

The questionnaire was then administered to the tenants of the field trial dwellings during the middle of January 1997, during face-to-face interviews. A total[8] of 11 interviews was conducted, 5 in the experimental group of dwellings with MVHR, and 6 in the control group. A second questionnaire survey was undertaken in August 1997.

4.3 QUESTIONNAIRE FINDINGS

This section summaries the tenants' responses to the first of the questionnaire surveys. As the study involved small numbers of respondents, these results should be treated with care, as confidence on small samples is low. It is also important to note that the

[8] Initially, tenants from all of the 12 field trial dwellings were to be interviewed. However, due to one of the tenants' moving away, it was only possible to undertake 11 interviews.

weather for the fortnight leading up to the first tenant questionnaires had been particularly cold. This may have influenced the responses obtained from the tenants. Responses to the second of the two surveys were very similar to those reported here.

Attitudes to field trial dwellings

- Although only half of the tenants had lived in the field trial dwellings before they were refurbished, the majority of the tenants preferred their refurbished dwelling to the previous dwelling that they had lived in. The refurbished dwellings were described as being “ideal”, “much improved”, “100 times better than the previous dwelling”, and, “a lot better”.

Refurbishment work

- Although the majority of the tenants were happy about the refurbishment work carried out, 4 tenants did complain about the front and back doors of their dwellings being draughty. Out of these 4, 3 of the tenants mentioned that they had experienced snow coming into their dwelling through these doors.

- 2 tenants also complained that the windows of their dwellings were draughty. One of these complainants was the tenant of house E, which was the only field trial dwelling that **did not** receive the airtightness work. This suggests that the airtightness work, and in particular the injection of expanding polyurethane foam around the windows of the dwellings had a positive effect.

Heating systems

- All of the tenants were happy with the heating system installed in their dwelling. The heating systems were described by the tenants as being “ideal”, “champion”, and “brilliant”.

- One tenant, house J (Manufacturer A MVHR system), mentioned that the sitting room was a lot cooler than it had been before the refurbishment work was carried out. The tenant believed that this was being caused by the MVHR system. However, although it is known that the MVHR system in this house was commissioned with too high a fan speed (see Chapter 3), it appears at least possible that part of the reason for the sitting room feeling colder was the change from a coke to a gas-fired central heating system.

- The majority of the tenants reporte having received some form of verbal advice relating to the operation of their heating system. This came mainly from an employee of Derwentside District Council, and related to how to switch on and off the boiler. Only 4 tenants claimed to have received advice from LMU, although each tenant did receive a tenant advice sheet from LMU (see Appendix 8). It can be concluded, that an advice sheet is not a particularly effective way of providing this information.

- The majority of the tenants, 8 out of 11, believed that they fully understood the operation of the heating system. The other 3 tenants believed that they could operate the system, but did not understand it.

- Control of the central heating system was achieved in almost all of the dwellings using the on/off switch on the boiler. The thermostat was then used to regulate the internal temperature, and as an additional on/off device for the central heating system.

Mechanical Ventilation and Heat Recovery system

- All of the tenants were generally happy with the MVHR system installed in their dwellings, and indeed appeared hardly to notice that it was there. They also felt that the MVHR systems were successful because they removed condensation and kitchen smells. A number of the tenants also noted that they no longer had to open their windows as often for ventilation. In addition, the tenant of house J (Manufacturer A system) noticed that the system removed the smell from aerosol paints, which this tenant used for model making. Only one tenant (house J) felt that the MVHR system did not remove anything.

- Two tenants voiced complaints over the Manufacturer A system. The tenant of house L noticed a slight draught in one of the upstairs bedrooms, and also felt that the system was noisy. Both of these points are expected to have been overcome by reducing the fan speed of the Manufacturer A system. The other tenant, house J, mentioned that their sitting room was a lot cooler than before, which they felt was caused by air supplied by the MVHR system. However, as mentioned earlier, it is more likely that this difference can be attributed to the change from a coke to a gas-fired central heating system.

- The majority of the tenants stated that they had not received advice on the operation of the MVHR systems, although LMU did give each tenant an advice sheet. This reinforces the earlier conclusion that an advice sheet is not a particularly effective method of providing this information.

- None of the tenants claimed fully to understand the operation of the MVHR system. 3 out of the 5 tenants (two Manufacturer A and one Manufacturer B), felt that they could operate it but didn’t understand it, whilst the other 2 (one Manufacturer A and one Manufacturer B) felt that they did not understand the operation of the MVHR system.

- MVHR systems in all 6 experimental dwellings were operated continuously.

- The speed controller on the MVHR system was used by only one tenant (house I - Manufacturer B system). The speed controller on a second Manufacturer B system was left on at about 1/3 of full speed, whilst the boost switch in the Manufacturer A systems was left at the ‘normal’ position.

- Initially all the MVHR systems were classed as noisy until the tenants got used to them. At the time of the initial survey, most of the tenants no longer noticed them. Only one tenant (house L - Manufacturer A system) still felt that the system was noisy. However, it is known that the fans in this system were running at a higher speed than required. This was subsequently rectified and should have resulted in quieter operation.

- 3 out of 5 tenants felt that the MVHR systems were draughty. 2 of these tenants had Manufacturer A systems, which were known to be running with too high a fan speed. Again, this problem was subsequently rectified, and should have resulted in a reduction in draughts from this system.

- All of the tenants reported opening their windows a couple of times a week for a few hours when the MVHR system was operating. The main reasons were: for fresh air and ventilation, to “air” the rooms, and when it was too warm (mainly during the summer).

Mechanical extract fan system

- All of the tenants were generally happy with the extract fans installed in their dwelling, because they came on automatically, and removed kitchen smells and condensation.

- Only one tenant, house E, stated that he had received advice on the operation of the extract fans. This advice came from LMU verbally, and in the form of a tenant advice sheet. Again, this reinforces the earlier conclusion that an advice sheet is not a particularly effective method of providing this information.

- All of the tenants felt that they fully understood the operation of the extract fans.

- Two tenants (houses B and F) had switched their extract fans off. In house B, the kitchen extract fan was switched off because the tenant did not do very much cooking, and believed that he did not need the fan. In house F, the tenant had switched off the upstairs bathroom extract fan because the fan seemed to run when not required i.e. when there was no sign of condensation or steam in the room.

- Half of the tenants felt that the extract fans were fairly noisy, whilst the other half felt that they were not.

- Only 2 of the tenants (houses B and D) opened their windows when the extract fans were operating. The rest of the tenants felt that they did not have to.

Window/door opening pattern

- Only 3 of the tenants (two control, and one experimental) never or only very rarely opened their windows. The rest of the tenants opened their windows mainly to “air” the rooms, but also to get rid of condensation, kitchen smells, and cigarette smoke

- Only 3 tenants (two control, and one experimental) opened their bedroom windows at night. In the control houses the bedroom windows were opened for fresh air and when it was too hot, whilst in the experimental house the bedroom window was opened only when it was too hot.

- 6 out of 11 tenants stated that they did use the trickle ventilators in their dwelling. Of these houses, 4 were control dwellings, and 2 were experimental dwellings. In the control dwellings, the majority of the tenants had all of their trickle ventilators open all of the time mainly for ventilation, and sometimes they were used to get rid of condensation. However, in the experimental dwellings the trickle ventilators were opened less frequently. In house I they were used in the bedroom and living room to let in fresh air, whilst in house K they were used mainly in the summer, and rarely in the winter, for ventilation. As noted before, the tenant in house K was a keen model maker who frequently used aerosol paints, etc.

- Only 4 tenants stated that they had opened the trickle ventilators in their bedrooms in the week preceding the interview. All of these tenants lived in control dwellings, and used trickle vents for ventilation.

Condensation and mould growth

- Just over half of the tenants had experienced problems with condensation and mould in their previous dwelling. 5 out of the 6 who had experienced these problems, happened to live in control dwellings.

- Six tenants reported condensation on their windows after the refurbishment work. 3 of these tenants were from the control group, and 3 from the experimental group. In the control group, condensation occurred when the tenants were drying clothes on the radiators in the house, when they were cooking, and if they were washing or bathing. In the experimental group (houses J and L), the condensation occurred on the kitchen window when the tenants were cooking. Neither of these tenants had been using the boost switch on their MVHR system.

- Only one dwelling, house C, had suffered from condensation (other than on windows) and mould since the refurbishment. Both condensation and mould had occurred in the bathroom and downstairs cloakroom of the dwelling. However, the mould and condensation in these areas had been present before the tenants moved into the dwelling, and appears to have been caused by a number of pipe bursts during the refurbishment work.

Occupancy

- Only two of the houses were unoccupied during the day, house A (control) and K (experimental). In all of the other dwellings, there was somebody in most of the day, every day.

Health

- None of the tenants reported any health problems in few months preceding the survey.

- Apart from houses H (experimental) and F (control), there is at least one smoker in each field trial dwelling.

4.4 COMMENTS ON FINDINGS

There are a number of points in the above which deserve emphasis.

- Tenants of MVHR houses appeared to recognise the effect of the MVHR systems on air quality in their houses. This recognition can be seen in the perception that the systems removed kitchen and other smells and controlled condensation, and that window opening and trickle vents were not required for ventilation. This in turn suggests that tenants were reducing the amount of natural ventilation in their dwellings. Such a change in behaviour is essential if whole-house MVHR is to result in savings of space heating energy, in addition to improvements in air quality.
- Tenants appeared to have more difficulty understanding the operation of MVHR systems than simple mechanical extract systems.
- All tenants reported noise from MVHR systems, though the salience of this problem appears to have declined as tenants became used to their systems. Noise was also reported from extract only systems, but it is difficult to make a direct comparison of the significance of this noise between the two groups.
- A number of tenants in MVHR houses reported draughts from their systems. For a given air flow, draughts are likely to be significantly worse without heat recovery. This suggests that heat recovery may be an important element in making continuous mechanical ventilation acceptable to tenants.
- A third of the tenants in the houses with mechanical extract systems had turned them off. This is consistent with information on energy use by mechanical extract systems obtained by physical monitoring (this showed that very little use was made of these systems). Tenants in the MVHR houses would have found it much more difficult to turn off their systems, and consequently left them running.
- The fact that exterior doors were manifestly not draught proof in one third of the properties is a major cause for concern, but one that is not unique to this project (see for example, Bell & Lowe 1997).

5 INDOOR AIR QUALITY ANALYSIS

5.1 INTRODUCTION

One of the original objectives of the field trial was to assess the effectiveness of the whole-house MVHR systems in terms of the indoor air quality of the dwellings. Indoor air quality is a complex multi-dimensional and imprecisely defined quantity, and in principle its assessment requires the simultaneous monitoring of a large number of variables. In this field trial, two parameters were used as proxies for indoor air quality. They were:

- CO_2 concentration in one of the double bedrooms. This location was chosen because the highest concentrations of CO_2 and the poorest air quality are likely to occur in these rooms during the night whilst the occupants are asleep;

- relative humidity, which was logged by sensors which were installed in the bedroom, lounge, kitchen and bathrooms of the dwellings.

These two parameters were logged in the field trial dwellings over the period from June 1996 to June 1997. They are strongly related to occupant activity in dwellings, and are good indicators of the effectiveness of the ventilation system at removing biogenic pollutants from the indoor environment. A third parameter, indoor air temperature, was logged by sensors which were installed alongside the relative humidity sensors in the bedroom, lounge, kitchen and bathrooms of the dwellings. While less obviously related to indoor air quality, air temperature is closely related to relative humidity. In addition to these electronically logged parameters, a single survey of house dust was undertaken in June 1997, to determine whether the operation of MVHR had any impact on dust mite populations.

In order to place CO_2 and humidity measurements in context, the rest of this section is devoted to a review of recommended ranges for these two variables.

5.1.1 Limits on carbon dioxide concentrations in occupied buildings

Carbon dioxide is a natural constituent of the atmosphere. The atmospheric concentration of CO_2 depends on the locality, and is thought to vary from approximately 360 ppm in rural areas to around 400 ppm in city environments. In the indoor environment, increased concentrations of carbon dioxide occur due to human and animal metabolism and by the burning of fossil fuels. Indoor concentrations of CO_2 depend upon the outdoor concentration level, as well as the production rate of CO_2 within the space. The production rate of CO_2 for different activities is relatively well defined, and is dependent upon metabolic activity. Therefore, it is not surprising that recent years have seen increased interest in the measured values of metabolically produced CO_2 within a space, as these values can be used to evaluate the ventilation rate within a space, to control ventilation systems, to provide an indication of perceived indoor air quality, and to measure compliance with a number of Codes and Standards.

A number of organisations have published recommended maximum limits for indoor CO_2 concentrations. The Chartered Institute of Building Services Engineers (CIBSE) recommends a maximum CO_2 concentration of 0.5% (5,000 ppm or 14 times background) for an 8 hour occupation (CIBSE, 1988). At this level, and in the absence of other pollutants, there is no noticeable discomfort. This recommendation is based upon physiological data, and is essentially the same as the occupational exposure limit for CO_2 contained in BS 5925: 1991 (BSI, 1991). Levels as high as 10% can be tolerated without serious health effects (Liddament, 1996), though anxiety may be induced at concentrations of over 5%. In the 19th century CO_2 concentrations approaching 50% were used as a narcotic for surgery (Liddament, 1996).

Where one is concerned with the general air quality, and in particular where CO_2 is being used as a proxy for other indoor air contaminants, much lower CO_2 concentrations are desirable. Swiss (Fehlmann, & Wanner, 1993) and Finnish (Kauppinen, 1993) authorities both recommend a maximum CO_2 concentration of 1500 ppm for occupied buildings, while an even lower concentration limit of 1000 ppm has been set by the American Society of Heating, Refrigerating and Air-conditioning Engineers (ASHRAE, 1989).

5.1.2 Humidity limits in occupied buildings

Humidity can be expressed in a number of ways. The most common are relative humidity and absolute humidity.

The absolute humidity is the more fundamental, and is simply the ratio of masses of water vapour and dry air in a space. Absolute humidity is often expressed in units of grammes of water vapour to kilogrammes of dry air (known as the mixing ratio). Absolute humidity has a clearly defined upper limit, which is a rapidly increasing function of temperature. This upper limit is known as the saturation humidity. Absolute humidity is simply related to mass flow of water vapour through a space. Crudely:

$$AH_{in} = AH_{out} + (1/m').[\Sigma \text{ sources } + \Sigma \text{ sinks}]$$

where:

m' is the rate of mass flow of air through the dwelling (kg/s)
AH_{in} is the internal absolute humidity
AH_{out} is the external absolute humidity

The environment in dwellings is dominated by sources of water vapour such as human respiration, cooking and washing. Certain building materials, such as plaster, may act as transient sinks, but the most important sinks involve condensation on the inside of the thermal envelope, most importantly on single glazed windows. In well insulated dwellings, condensation is negligible.

Relative humidity is defined as the ratio of relative humidity to saturation humidity at a given temperature, and is often expressed as a percentage. Relative humidity is related to the tendency of wet materials to dry out. Thus, low relative humidities are associated with respiratory complaints such as dry throats, damage to certain building materials (eg. shrinkage and cracking in wood), and to the build-up of static electricity. High relative humidities on the other hand can lead to condensation and mould growth, can support the growth of a number of pathogenic and allergic organisms such as fungi and dust mites, and can lead to thermal discomfort by reducing the rate at which sweat can evaporate from the surface of the body.

A number of guidelines exist for the acceptable levels of relative humidity in the indoor environment. The most widely recognised guidelines are those set by ASHRAE and CIBSE. ASHRAE guidelines state that the relative humidity in habitable spaces preferably should be maintained between 30% and 60% relative humidity to minimise the growth of allergenic or pathogenic organisms (ASHRAE, 1989). The CIBSE recommends a similar range, 40% to 70%, for most applications (CIBSE, 1988).

Although there do not exist any codes or standards relating to absolute humidity values, a number of authors have identified moisture content limits below which house dust mite populations show a marked decline (Korsgaard, 1991; McIntyre et al. 1995; McIntyre & Stephens, 1995). The absolute humidity limit identified by these authors is 7 g/kg, corresponding to a relative humidity of 48% at 20^{o}C. For a number of reasons, this limit is unlikely to apply, except within a narrow range of temperature, and is likely to be a bad guide to the incidence of moisture related problems in UK dwellings, which are characterised internal temperatures which can be well below 20°C. However for the sake of completeness, we have referred to it in the following.

5.2 SUMMARIES OF CO_2 AND HUMIDITY DATA

For those components of indoor air for which human occupants are a significant source, concentrations in a given space will be related in principle to the number of people in that space and the effective air change rate. Equilibrium concentrations will be of the order of:

$$C = C_{background} + e.N./ v'$$

where:

C is the equilibrium volumetric concentration ratio
$C_{background}$ is the background volumetric concentration ratio outside the dwelling
e is the volumetric emission rate of the component
v' is the volumetric flow of air through the dwelling
N is the number of occupants in the space

The main difference between humidity and CO_2 concentrations is that background absolute humidity varies widely from day to day while background CO_2 concentration is effectively constant at around 360 ppm. The effective ventilation rate in the above equation can be thought of as having two components - background infiltration, and a component due to the operation of the MVHR system (if present). Background infiltration can vary widely, from close to zero under mild windless conditions, to several air changes per hour at times when there is a very low outside air temperature or there are high wind speeds, or both. The ventilation provided by the MVHR system is effectively constant, at around 0.5 ac/h.

The air quality in each dwelling will vary stochastically, and the effect of the MVHR system on the field trial dwellings should be a shift in the probability distribution functions of CO_2 concentration and absolute humidity. This shift may not be apparent in the relative humidity values obtained for the dwellings, as relative humidity is more strongly affected by the temperature than by the moisture content of indoor air. Under conditions of high wind speed or low external temperature, background infiltration will be dominant, and one would expect to see little difference between the experimental MVHR houses and the control houses. Under mild windless conditions, the effective ventilation rates are likely to differ significantly between the experimental MVHR houses and the control houses, and one would expect to see significant differences in the internal air quality between the two groups. The biggest differences should occur under mild windless conditions, which should give significantly higher CO_2 and humidity in the control houses compared with the experimental MVHR houses. One would expect a relatively well-defined upper limit to the CO_2 and water vapour concentrations in the experimental MVHR group, and a long ill-defined tail with non-zero probabilities of very high concentrations in the control group.

Care is needed to ensure that the effect of the MVHR system on the internal air quality are not confounded by inter- or intra-group differences in occupancy or lifestyle. One of the most important variables in this area is the number of occupants in each dwelling. This information is shown in Table 5.1 below.

House	No. of occupants
A (Control)	1[9]
B (Control)	1
C (Control)	4
D (Control)	3
E (Control)	6
F (Control)	1
G (MVHR)	3
H (MVHR)	2
I (MVHR)	5
J (MVHR)	4
K (MVHR)	2
L (MVHR)	2

Table 5.1

9 To minimise the possibility of bias, house A has been removed from the kitchen, lounge and bathroom analysis because the tenant is very rarely in the dwelling.

It can be seen from the above table that the occupancy levels in the two separate groups of dwellings are virtually the same, with mean occupancy in both the control and experimental dwellings of 3. This should allow gross comparisons to be made between the two groups without correction.

With respect to CO_2 and humidity data for the main bedroom, the number of people who normally sleep in this bedroom is likely to be more important than the total number of people in the dwelling. This information is presented below:

House	No. of occupants sleeping in bedroom containing CO_2 sensor
A (Control)	None
B (Control)	None
C (Control)	2
D (Control)	3
E (Control)	2
F (Control)	1
G (MVHR)	Unknown
H (MVHR)	2
I (MVHR)	3
J (MVHR)	2
K (MVHR)	1
L (MVHR)	2

Table 5.2

It is apparent from this table that the control and MVHR groups are not perfectly matched and that three of the houses, A, B and G, pose particularly severe problems in this respect. To minimise the possibility of bias, these houses have been omitted from the subsequent analysis of the bedroom data. Of the remaining houses, the mean bedroom occupancy in both control and MVHR groups is 2, allowing the two groups to be compared without correction.

The purpose of the rest of this chapter is to provide a summary of indoor air quality in the field trial houses, in the form of brief comments and graphs of mean monthly CO_2 and humidity for the two groups of dwellings. This form has been chosen to show the seasonality of ventilation effectiveness. The data are presented more fully, in the form of monthly probability exceedence curves, in Appendix 6.

5.2.1 Bedroom CO_2 and humidity data

One might expect the clearest differences to emerge from an analysis of the bedroom data, since this is the room with the highest mean occupancy, and the lowest variability in occupancy. The results of this analysis are as follows.

Carbon dioxide - The probability distribution curves for the CO_2 concentrations in the main bedroom of the field trial dwellings can be seen in **Appendix 6** as **Graphs 1** to **12**, and are summarised in **Figure 5.1** below.

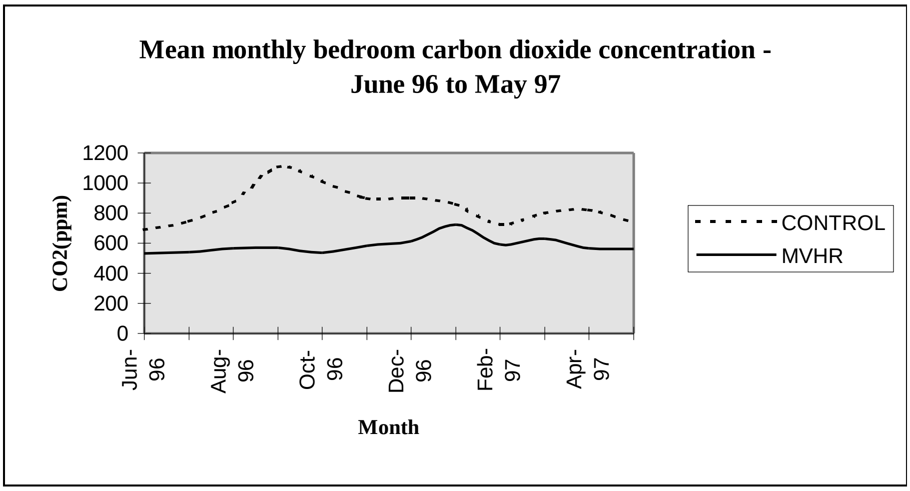


Figure 5.1

It is apparent from these graphs, that there is a distinct difference between the CO_2 concentrations obtained in the bedrooms of the MVHR dwellings and those obtained in the bedrooms of the control dwellings, with the MVHR dwellings measuring considerably lower CO_2 concentrations for the majority of the time. The average CO_2 concentration over the monitoring period for the MVHR dwellings was 584 ppm and for the control dwellings it was 847 ppm. Average CO_2 concentration in the control dwellings is almost 1.5 times as high as in the MVHR dwellings.

An analysis was also undertaken on the percentage of the monitored period in which each group of dwellings exceeded the recommended ASHRAE CO_2 concentration limit of 1000 ppm. The MVHR dwellings exceeded the limit for 7% of the time, whilst the control dwellings exceeded the limit for 26% of the time.

Absolute humidity - The probability distribution curves for the absolute humidity values obtained in the bedroom of the field trial dwellings can be seen in **Appendix 6** as **Graphs 13** to **24**, and are summarised in **Figure 5.2** below.

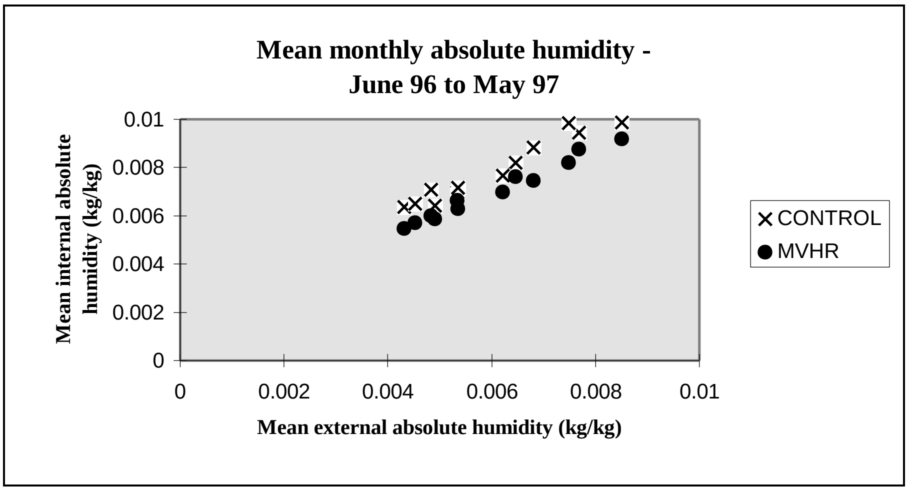


Figure 5.2

These graphs show that absolute humidities are lower in the bedrooms of the MVHR dwellings than in the bedrooms of the control dwellings. The average absolute humidity over the monitoring period was 7 g/kg for the MVHR dwellings and 8 g/kg for the control dwellings.

An analysis was also undertaken on the percentage of the monitored period in which each group of dwellings obtained an absolute humidity value below the Korsgaard limit of 7 g/kg (Korsgaard, 1991). The MVHR dwellings remained below the Korsgaard limit for 53% of the time, whilst the control dwellings were below for 35% of the time.

Relative humidity - The probability distribution curves for the relative humidity values obtained in the bedroom of the field trial dwellings can be seen in **Appendix 6** as **Graphs 25** to **36**, and are summarised in **Figure 5.3**.

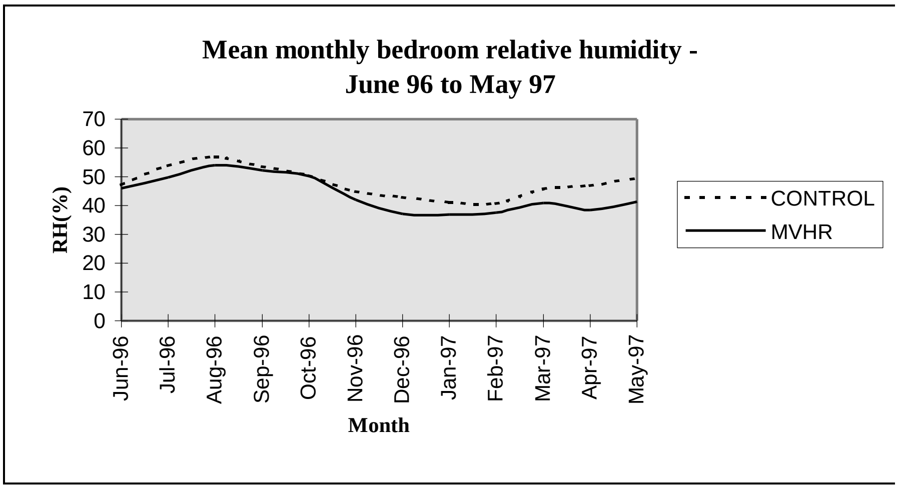


Figure 5.3

These graphs show a small difference between the two groups of houses, with slightly lower relative humidities in bedrooms in the MVHR dwellings. The average relative humidity over the monitoring period for the MVHR dwellings was 43%, whilst the relative humidity for the control dwellings was 48%, a difference of only 5%. It must be remembered that relative humidity is more strongly affected by changes in air temperature than it is by the actual moisture content of the air (as measured by absolute humidity), and thus this small difference in relative humidity may not be significant.

An analysis was also undertaken on the percentage of the monitored period in which bedrooms in each group of dwellings were below 30% and above 70% relative humidity. The MVHR dwellings achieved a relative humidity value below 30% for 35% of the time and a relative humidity value above 70% for 1% of the time. The control dwellings achieved a relative humidity value below 30% for 19% of the time and a relative humidity value above 70% for 2% of the time. In both cases the small fraction of time spent above 70% RH is more a testament to the high (in some cases, heroically high) internal temperatures maintained by the occupants of the field trial houses, than to the effectiveness of the ventilation systems.

Condensation analysis - An analysis was carried out to determine the probability that condensation would occur on the inside pane of the single glazed windows in the bedroom of the field trial dwellings. This analysis was carried out over the heating season, from the beginning of October 1996 to the end of April 1997, and was based on an assumed U-value for single glazing of 4.7 W/m^2K. The analysis showed that condensation would be present for 2% of the time in the MVHR dwellings and for some 19% of the time in the control dwellings, an 8 fold difference. This analysis was also repeated assuming that the single glazing was replaced with low-emissivity double glazing with a U-value of 2 W/m^2K. This analysis indicated that double glazing would completely eliminate condensation on windows in all field trial dwellings.

5.2.2 Living room humidity data

Absolute humidity - The probability distribution curves for the absolute humidity values obtained in the living room of the field trial dwellings can be seen in **Appendix 6** as **Graphs 37** to **48**, and are summarised in **Figure 5.4** below.

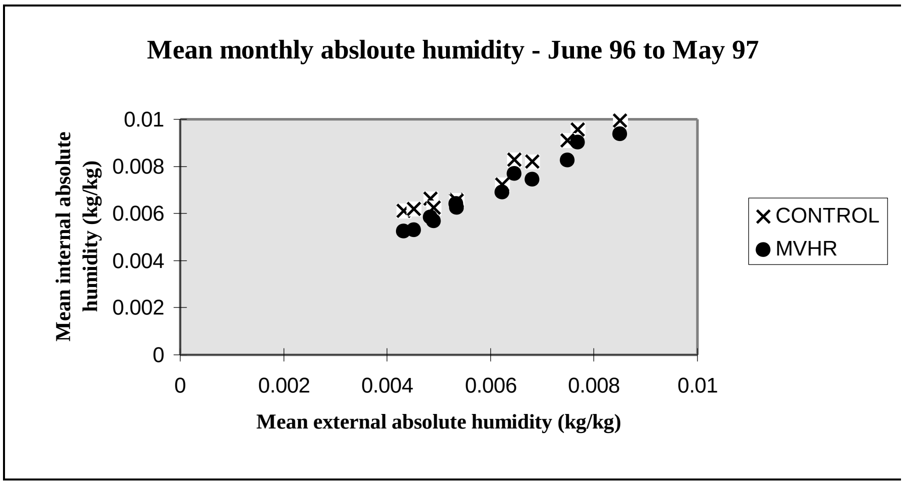


Figure 5.4

These graphs show once again lower absolute humidities in living rooms in the houses with MVHR. The difference is modest with an average over the monitoring period of 7 g/kg for the MVHR dwellings and 7.6 g/kg for the control dwellings.

The living rooms of dwellings with MVHR were below the Korsgaard limit for 57% of the time, whilst the control dwellings were below this limit for 48% of the time.

Relative humidity - The probability distribution curves for the relative humidity values obtained in the living room of the field trial dwellings can be seen in **Appendix 6** as **Graphs 49** to **60**, and are summarised in **Figure 5.5** below.

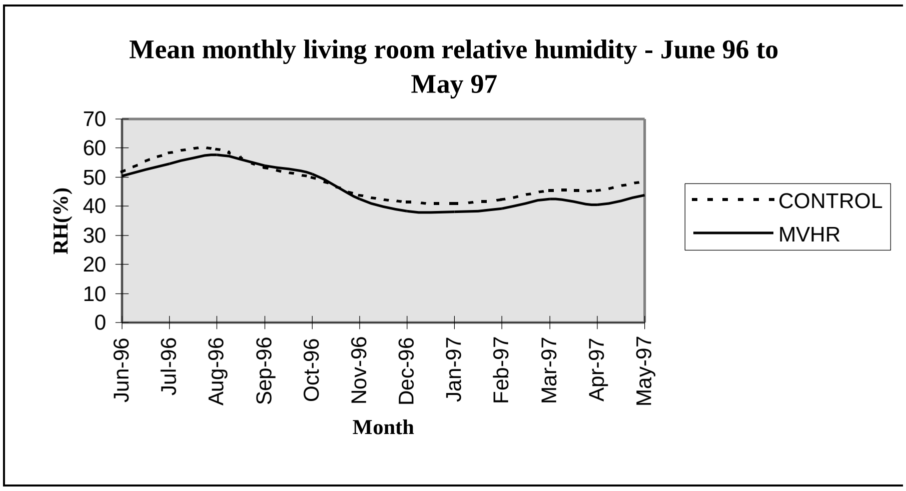


Figure 5.5

These graphs show a small difference in humidities between the two groups of houses. The average relative humidity over the monitoring period for the MVHR dwellings was 46%, whilst the relative humidity for the control dwellings was 48%.

The MVHR dwellings achieved a relative humidity value below 30% for 2% of the time and a relative humidity value above 70% for 1% of the time. The control dwellings achieved a relative humidity value below 30% for 2% of the time and a relative humidity value above 70% for 6% of the time.

5.2.3 Kitchen humidity data

Absolute humidity - The probability distribution curves for the absolute humidity values obtained in the kitchen of the field trial dwellings can be seen in **Appendix 6** as **Graphs 61** to 7**2**, and are summarised in **Figure 5.6** below.

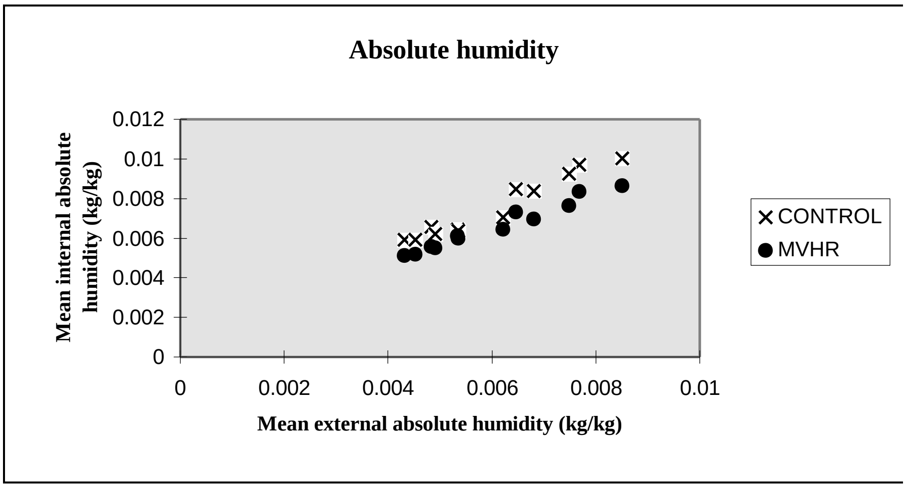


Figure 5.6

These graphs show that the kitchen absolute humidities were considerably lower in the dwellings with MVHR. The average absolute humidity over the monitoring period was 6.4 g/kg for the MVHR dwellings and 7.5 g/kg for the control dwellings. The Korsgaard limit of 7 g/kg was achieved for 64% of the time in the MVHR dwellings and 46% of the time in the controls.

Relative humidity - The probability distribution curves for the relative humidity values obtained in the kitchen of the field trial dwellings can be seen in **Appendix 6** as **Graphs 73** to **84**, and are summarised in **Figure 5.7** below.

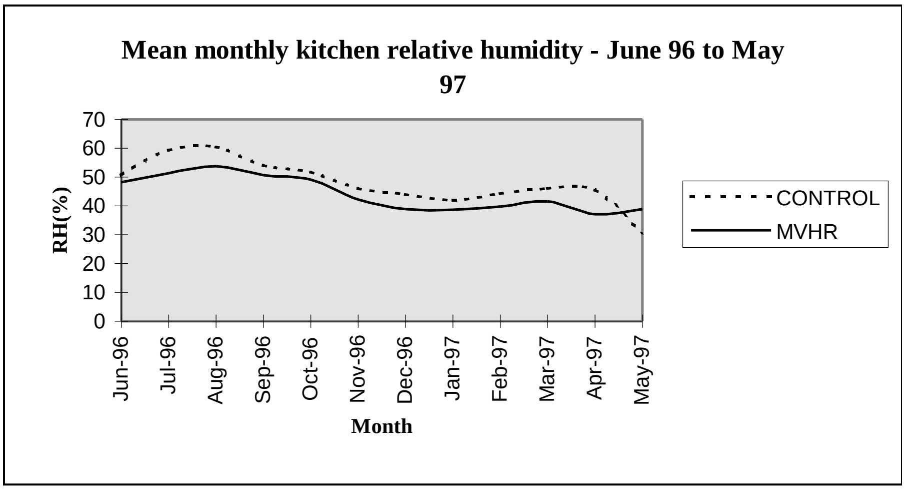


Figure 5.7

These graphs show lower relative humidities in kitchens in the MVHR dwellings than in the controls. The average relative humidity over the monitoring period was 44% for the MVHR dwellings, and 48% for the control dwellings. There is a suggestion in the data that there may be a cross-over in late spring, which may be due to a greater readiness to open windows in the control houses at this period.

The MVHR dwellings achieved a relative humidity value below 30% for 5% of the time and a relative humidity value above 70% for 1% of the time. The control dwellings achieved a relative humidity value below 30% for 1% of the time and a relative humidity value above 70% for 7% of the time.

5.2.4 Bathroom humidity data

Absolute humidity - The probability distribution curves for the absolute humidity values obtained in the bathroom of the field trial dwellings can be seen in **Appendix 6** as **Graphs 85** to **96**, and are summarised in **Figure 5.8** below.

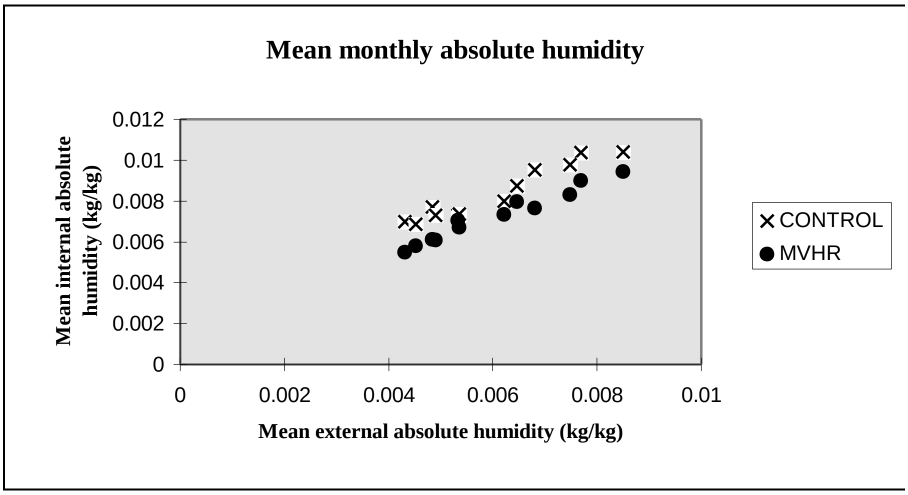


Figure 5.8

These graphs show that the bathroom absolute humidity values were considerably lower in the MVHR dwellings than in the control dwellings. The average absolute humidity over the monitoring period was 7.2 g/kg for the former and 8.4 g/kg for the latter.

Humidities below the Korsgaard limit were achieved for 47% of the time in the MVHR dwellings, and for 29% of the time in the control dwellings.

Relative humidity - The probability distribution curves for the relative humidity values obtained in the bathroom of the field trial dwellings can be seen in **Appendix 6** as **Graphs 97** to **108**, and are summarised in **Figure 5.9** below.

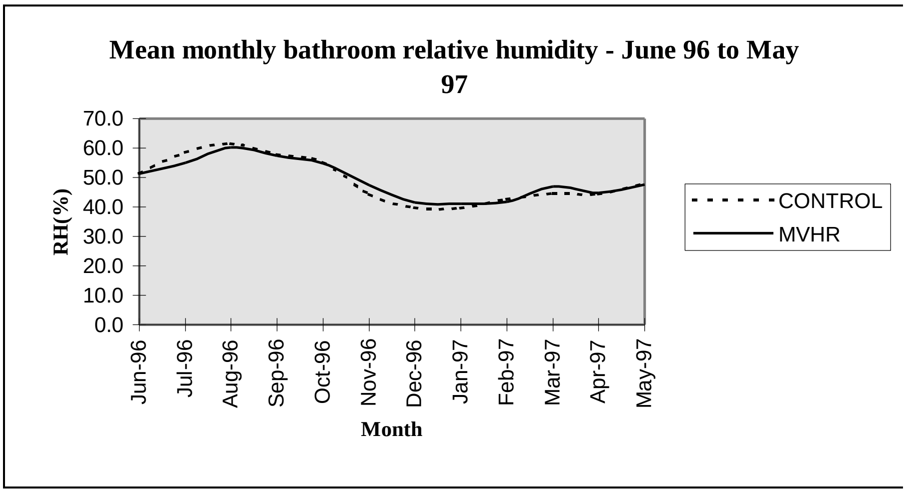


Figure 5.9

These figures show very little difference in relative humidities in bathrooms in the two groups of houses. The average relative humidity over the monitoring period for both the MVHR and the control dwellings was 49%.

The MVHR dwellings achieved a relative humidity value below 30% for 2% of the time and a relative humidity value above 70% for 1% of the time. The control dwellings achieved a relative humidity value below 30% for 2% of the time and a relative humidity value above 70% for 6% of the time.

5.3 DUST MITE DATA

A dust survey was undertaken in June 1997, using a specially modified vacuum cleaner supplied by BRE. Dust was taken from the main bedroom and the living room in each house, following BRE's dust mite survey protocol (see Appendix 9). The dust was then couriered to BRE for analysis, which was undertaken by Dr Colin Hunter.

The analysis consisted of estimating the number of dust mites per gramme of house dust. The results show a very wide range in this measure (from zero to almost 400 mites/gramme) in both groups of dwellings. There is some tendency for dwellings which have high dust mite counts in bedrooms to have high counts in living rooms, and vice versa. Mean dust mite counts are somewhat higher in bedrooms, and nearly a factor of 10 lower in living rooms, in the houses with MVHR compared with the controls. It is possible that the distribution of dust mites is bi-modal in both groups of houses. Otherwise it is hard to see any consistent pattern in the data. Given the small sample sizes and large scatter in the data, little weight can be attributed to these results. They do however suggest that a qualitative study of the behavioural and lifestyle factors that affect dust mite populations might be enlightening. A summary of the dust mite data is presented below.

dust mite data (mites/gramme)				
		sample mean	standard deviation	number in sample
control	bedroom	56	37	5
	living rooms	141	149	6
MVHR	bedrooms	77	72	5
	living rooms	15	31	4

Table 5.1

5.4 CONCLUSIONS

With such small numbers of houses in the field trial, the application of formal statistical techniques to the data set is unwarranted. The conclusions that we have come to are therefore provisional and would need to be tested in a larger field trial if formal statistical inferences were required. Nevertheless, perusal of the data presented here and in Appendix 6 suggests that there is a clear difference between the two groups of dwellings in terms of the two indicators of air quality that were measured - humidity and CO_2 concentration. The difference in bedroom CO_2 concentrations is stark, and we believe that it unlikely to be due to a statistical quirk. Although the absolute humidities in the various rooms of the field trial dwellings are not strictly independent (a household with a high bedroom humidity may well have a high kitchen humidity), it is striking that the data shows lower absolute humidities in the MVHR houses in all rooms and for all months for which data were collected. It appears that even in houses as leaky as these, continuously operating mechanical ventilation is able to provide higher indoor air quality, than a combination of natural ventilation and rarely-used mechanical extract systems.

We do not consider the fact that the ventilation systems in the experimental houses were balanced ducted MVHR systems, as opposed to continuous extract, to be significant, except insofar as it may have affected occupants' perceptions of their systems and consequently the way in which the systems were operated. The fact that tenants in the MVHR houses could only switch their systems off by climbing into the attic, while tenants in the control houses could turn their extract fans off using a switch on the wall, is likely to have been more significant.

The conclusions from indoor air quality analysis are:

- In general, the greatest differences in humidity occur in the bedrooms and bathrooms of the field trial dwellings.

- The CO_2 concentrations measured in the bedrooms of the field trial dwellings are around 1.5 times lower in the MVHR dwellings than in the control dwellings.

- Condensation is almost 8 times more likely to occur on the single glazed bedroom window of the control dwellings than in the MVHR dwellings. If the single glazed windows were replaced with double glazing with a U-value of 2 W/m^2K, no condensation would have occurred on the bedroom windows in any of the field trial dwellings.

- The absolute humidity values obtained in all of the rooms are lower in the MVHR dwellings than in the control dwellings. An absolute humidity value of less than 7 g/kg is achieved roughly 1.5 times more often in the MVHR dwellings than in the control dwellings.

- The relative humidity values in all of the rooms are either roughly the same or very slightly lower in the MVHR dwellings than in the control dwellings, depending on which room is studied. Relative humidity values below 30% are achieved more often in the MVHR dwellings, whilst relative humidity values greater than 70% are achieved more often in the control dwellings.

The conclusions obtained from an analysis of the physically monitored data are also backed up by anecdotal evidence obtained from the tenant questionnaire (see **Chapter 4**). The tenants of the MVHR dwellings mentioned that they no longer have to open their windows as often for ventilation, with one of these tenants mentioning that their house no longer felt “stuffy”.

6 ANALYSIS OF ENERGY USE AND INTERNAL TEMPERATURES

6.1 INTRODUCTION

This central function of this chapter is to summarise the data that were collected from the field trial houses on energy consumption and internal temperature. However in order to place this raw data into context, it was necessary to undertake a theoretical analysis of the two groups of dwellings at Eshwinning - first to establish how well the two groups were matched, and second to estimate the differences that would be expected to occur between them, other things being equal. The tool that was used for this work was NHER evaluator.

As has been noted in Chapter 5, occupancy levels in the MVHR and the control dwellings were broadly similar, with an average of 3 persons (1.6 adults and 1.4 children) in the control group and 3 persons (1.8 adults and 1.2 children) in the experimental MVHR group, thus enabling both groups of dwellings to be compared without correction.

6.2 NHER PREDICTIONS

6.2.1 Matching of experimental and control groups

The first NHER predictions to be undertaken on the field trial dwellings were concerned with determining if any inherent differences exist between the two groups of dwellings. In order to do this, both groups were modelled assuming that they had the same ventilation strategy, namely natural ventilation[10]. All of the predictions were undertaken using measured air leakage data and the occupancy data determined from the questionnaire. The average energy consumption and internal temperature values obtained from these predictions were compared, and the results of this comparison can be seen in **Table 6.1** below.

Summary of Characteristics of the Experimental and Control Groups - Group averages (kWh/a)					
Group	Space heating	Water heating	Cooking, lights & appliances	Total	Mean internal temp (^oC)
Experimental - natural vent.	15840	3344	3182	22366	18.3
Control - natural vent.	16157	3338	3266	22761	18.6
Difference	317	6	84	395	0.3

Table 6.1 NHER projections for energy and internal temperatures.

[10] This is appropriate because the mechanical extract fans in the control dwellings were seldom used, and consumed a small amount of energy.

It is apparent from this table, that the two groups of dwellings are remarkably similar in terms of predicted average energy consumption and mean internal temperature. The slightly higher predicted space heating consumption obtained in the control group is most probably explained by its slightly higher mean internal temperature. All things being equal, if both groups of dwellings had been naturally ventilated throughout the period of the field trial, then one would expect to see no significant measurable difference in the energy consumption and internal temperatures in the two groups.

6.2.2 Using NHER to predict the effect of MVHR in the field trial dwellings

A further NHER modelling exercise was undertaken to establish *a priori* estimates of the effect of MVHR on the energy consumption and the internal temperatures of the field trial dwellings. These estimates enabled the authors to review the likelihood of finding significant differences in energy consumption in the measured data, and the approaches to data handling that might reveal such differences before dealing with the raw data. The results of this exercise are summarised below:

Summary of Characteristics of the Experimental and Control Groups - Group averages (kWh/a)					
Group	Space heating	Water heating	Cooking, lights & appliances	Total	Mean internal temp (^oC)
Experimental - natural vent.	15840	3344	3182	22366	18.3
Experimental - with MVHR	15668	3344	3455	22467	18.3
Difference	-172	0	273	101	0

Table 6.2 NHER predictions of impact of MVHR on energy use and temperatures in experimental dwellings.

NHER predicts that the installation of MVHR into the naturally ventilated experimental dwellings will result in an increase in the electrical consumption of almost 300 kWh/a, and a reduction in space heating energy use by about 200 kWh/a.

In principle, the effect of MVHR on space heating depends critically on assumptions made about dwelling airtightness, and changes to infiltration and the user controlled portion of natural ventilation which result from the installation of MVHR In NHER Evaluator, the air change rate is calculated using the following equation:

$$\text{air changes} = \text{shelter factor} \times \text{infiltration} \qquad (1)$$

If the air change rate in a naturally ventilated dwelling is small (i.e. less than 1) then NHER assumes that the occupants of these dwellings will deliberately open their windows to increase the air flow, and an occupant component is added onto the air change equation (1). In the mechanically ventilated dwellings, NHER calculates the air change rate by adding on a mechanical ventilation component to equation (1), which in the case of mechanically ventilated system with heat recovery, is equal to

$$0.4 \times (1 - E_T).$$

where E_T is the thermal efficiency of the MVHR system.

In practice, NHER assumes that the value of the occupant component in the naturally ventilated dwellings is greater than the MVHR component in the mechanically ventilated dwellings; in other words NHER predicts that the effective air change rate in field trial dwellings will be greater when they are naturally ventilated than when they are fitted with MVHR.

The difference in energy use and internal temperatures predicted by NHER for the naturally ventilated control dwellings and for the experimental dwellings with MVHR, gives an *a priori* estimate of the magnitude of the differences that might expected in the experimental data. The results of this comparison can be seen in **Table 6.3** below.

Summary of Characteristics of the Experimental and Control Groups - Group averages (kWh/a) based on NHER predictions					
Group	Space heating	Water heating	Cooking, lights & appliances	Total	Mean internal temp (^oC)
Control - natural vent.	16157	3338	3266	22761	18.6
Experimental - with MVHR	15668	3344	3455	22467	18.3
Difference	-489	6	273	-294	0.3

Table 6.3 NHER estimates of energy use and temperatures in MVHR and control houses at Eshwinning.

This table shows that NHER predicts:

- an increase of 273 kWh/a, or 8% in electricity consumption in the MVHR group, due to electricity use by fans in the MVHR systems;

- a difference of almost 500 kWh/a, or 3% in space heating consumption in favour of the MVHR dwellings; **two thirds of this is due to minor differences in occupancy and dwelling form and only one third to the installation of MVHR systems**;

- a difference in the mean internal temperature of 0.3°C, again mainly due to minor differences in occupancy and dwelling form.

These overall differences in energy use, particularly in space heating, that are predicted by NHER are far too small to detect in practice in a field trial of this size. The bleakness of this conclusion must be however tempered by an awareness of the very large number of assumptions upon which it is based. The next part of this chapter is devoted to an analysis of the experimental data, with a view to establishing the extent to which this conclusion is justified.

6.3 ANALYSIS OF EMPIRICAL DATA

6.3.1 Annual average data

Summary data on annual energy use and mean whole house internal temperatures in the field trial houses is presented below. Because of prolonged absence in one dwelling and changes in tenancy in two others, annual data is not presented for houses F, G and H.

House	Gas (kWh)	Fan energy (kWh)	Lights & appliances (kWh)	Mean internal temp (°C)
A	13446	3	2074	17.4
B	23649	1	2417	22.0
C	25238	53	4392	22.0
D	24055	3	3817	20.2
E	34014	5	4235	23.1
F				
G				
H				
I	30526	395	3163	22.0
J	28270	474	4249	21.0
K	16939	554	2834	19.0
L	24002	366	2327	20.6

Table 6.4 Summary of annual average energy and temperature data

6.3.2 Dependence of internal temperatures on external temperature

Energy consumption is dependant on the temperature difference between the inside of the dwelling and the outside. An important variable in identifying possible differences between the two field trial groups, will be the level of internal temperatures maintained in the dwellings. The measured mean internal temperatures achieved in the dwellings have been plotted against the corresponding mean external temperatures, for both the control and the experimental group (see in **Figure 6.1** below).

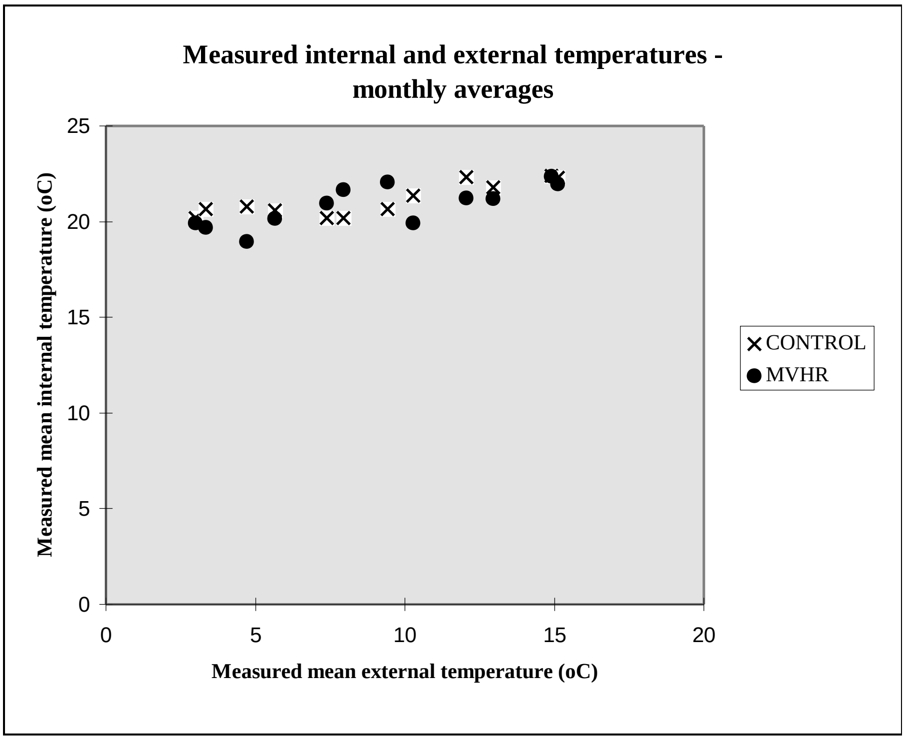


Figure 6.1

The scatter of the data points in **Figure 6.1** above indicates that there is very little difference between the two groups of dwellings. This is true, even during the heating season when the mean external temperatures are at their lowest, and the mean internal temperatures achieved in the dwellings are strongly influenced by the level of heating. As summer temperatures are reached, the scatter of the data points reduces indicating that the mean internal temperatures achieved within the dwellings are influenced more by the mean external temperature, rather than by the level of heating.

Despite the fact that the two groups of dwellings are operating at very similar mean internal temperatures, a small temperature difference of about 0.3 ^{o}C exists between the control and the experimental MVHR group, with the experimental MVHR group operating at the lower temperature. This difference in mean internal temperature is identical to the difference predicted by NHER Evaluator in **Chapter 6.1.2**, although this is unlikely to be significant. However, the mean internal temperatures measured in both groups of dwellings are around 2.5^{o}C higher than those predicted by NHER Evaluator. The average internal temperatures were 20.7 ^{o}C for the experimental group and 21.1^{o}C, for the control group over the monitored period. The levels of internal temperatures being maintained in both groups of dwellings are particularly high, even by UK standards, and show little tendency to droop in the colder months of the year.

Although we do not have measured data from before the refurbishment, it appears that in both groups of dwellings, the energy efficiency improvements undertaken in these dwellings have been taken up by the tenants as a substantial improvement in thermal comfort. Anecdotal evidence obtained from an analysis of the tenant questionnaire, as well as subsequent evidence received from the monitoring team, indicates that this is the case. Although the tenant questionnaire was undertaken after the field trial dwellings were modernised, the tenants of both groups felt that their dwellings were warmer after the refurbishment work had been completed, and they displayed high levels of satisfaction with their heating systems. The monitoring team found, while visiting the dwellings on a number of occasions, that internal temperatures bordered on the uncomfortable.

6.3.2 Measured energy consumption

Physical monitoring of the energy consumption in all of the field trial dwellings was sufficiently detailed to allow the disaggregation of delivered energy into the main end-use categories. These were: space and water heating energy consumption; the energy consumption associated with cooking, lights & appliances and the MVHR system energy consumption; and, the energy consumption associated with the mechanical extract fans. The observed difference in the average measured energy consumption for each of these end-uses, can be seen in **Table 6.5** below.

Summary of Characteristics of the Experimental and Control Groups - Group averages (kWh/a)					
Group	Space & water heating	MVHR system	Mechanical extract fans	Cooking, lights & appliances	Total
Measured:					
Experimental	24080	447		3387	27914
Control	24934		13	3590	28537
Difference	854	447	13	203	623

Table 6.5

The reasons for the observed energy data, and differences between groups is best explained in the form of a series of graphs. The first of these is a plot of measured energy consumption of each dwelling was plotted against the corresponding measured mean internal temperature (see Figure 6.2 below). The slope of a line drawn through the origin to each data point on this plot (and suitably scaled) will be a crude measure of whole house heat loss coefficient for each dwelling. Any systematic differences in envelope or heating system efficiency between the two groups of dwellings will appear as a shift in the corresponding datapoints upward or downward.

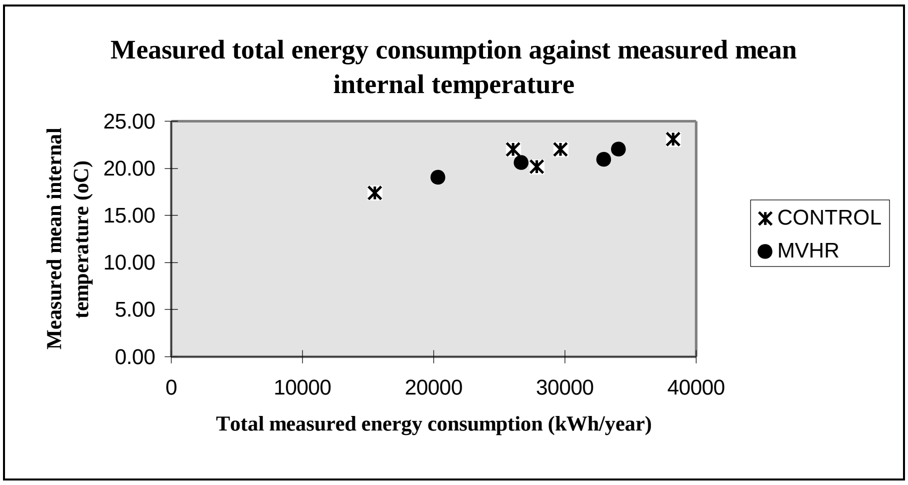


Figure 6.2

The scatter of the plots in **Figure 6.2** above indicate that there is very little difference between the two groups of dwellings. Any differences that can be detected between the two groups can be adequately explained by differences in dwelling occupancy and form, and not to the installation of MVHR. Two of the dwellings (one control and one experimental) do have noticeably lower mean internal temperatures and total energy consumption figures. From an analysis of the tenant questionnaire (see **Chapter 5**), it is known that the occupants of these dwellings spend less time in their dwellings than the rest of the field trial occupants. In addition to this, one of the control dwellings (house F) has a noticeably higher energy consumption that the rest of the field trial dwellings. This can be explained by the fact that this dwelling did not receive any of the airtightness work.

The second of these plots is a scatterplot of measured versus NHER predicted energy use. For the two dwellings with internal temperatures close to NHER predictions, measured energy use is close to predicted (within ±10%). Most of the houses in both groups lie well to the right of a 45° line drawn through the origin. This plot reveals the significance of the high internal temperatures observed in the houses at Eshwinning. Energy use at Eshwinning exceeded the national average energy use per square metre of domestic accommodation by up to 40%.

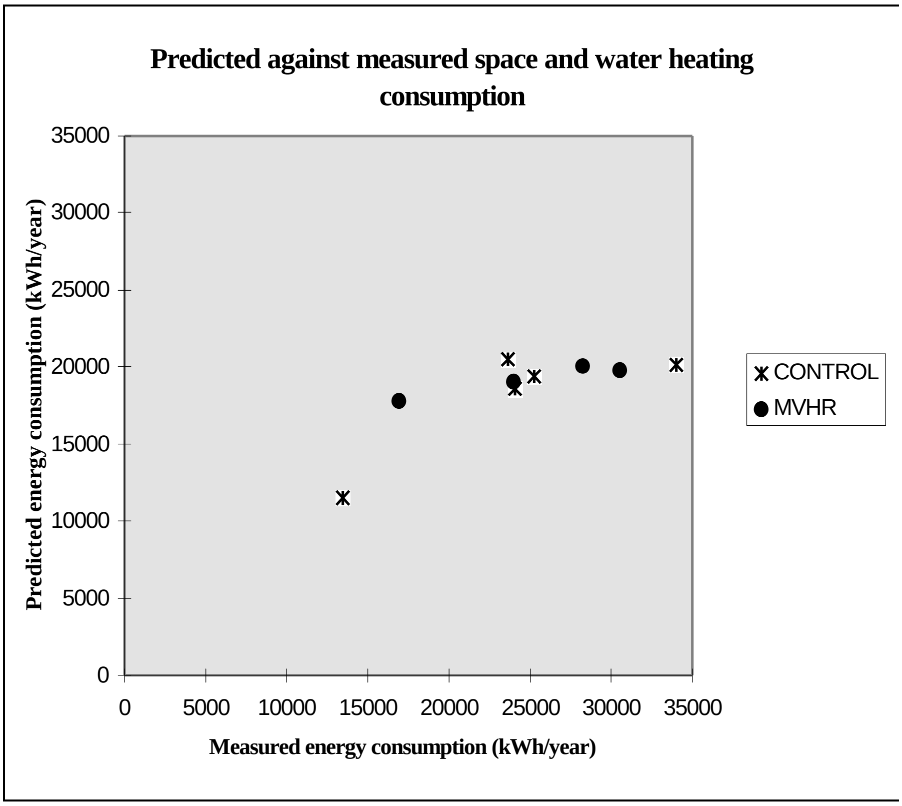


Figure 6.3

It is apparent from **Table 6.5**, that the between-groups differences observed in the energy consumption for space and water heating, cooking, lights and appliances are small, and given the number of houses involved, are not likely to be statistically significant. The only end-use where a noticeable and statistically highly significant difference occurs is in energy consumed by ventilation systems - either MVHR systems, or extract fans. The observed difference between these two end-uses is some 434 kWh/a. This difference would have been much smaller if the mechanical extract fans had actually been used to an appreciable extent by the occupants of the control dwellings.

A comparison was also made between the measured energy consumption of MVHR systems from the two different manufacturers. The results of this can be seen below.

Manufacturer	**Average electricity consumption (kWh/a)**
A	465
B	395

Table 6.6 Measured electricity use in MVHR systems.

It is apparent from the above table, that the actual electricity consumption of the Manufacturer A systems was higher than those of Manufacturer B, and that both are higher than the electricity use predicted by NHER. This is consistent with spot measurements reported in Chapter 3, given that the adjustment of fan speeds in Manufacturer A systems did not take place until late in the monitoring programme, and given that all 6 systems operated at ‘normal’ setting for most of the year. Evidence from the tenant questionnaire (see Chapter 4) indicates that this would have been the case.

Had the speed adjustment in Manufacturer A systems taken place at the beginning of the monitoring period, electricity use in these systems would have been around 240 kWh/a, with a running cost of about £20 per annum at current prices.

6.4 CONCLUSIONS

The conclusions from the energy and temperature analysis are:

- NHER predictions indicate that if both groups of dwellings are modelled with the same, natural ventilation strategy, the MVHR and the control dwellings are remarkably similar in terms of energy consumption and mean internal temperature.

- the differences in energy use and internal temperatures in the control and experimental houses predicted by NHER are:

  273 kWh/a in electricity consumption, due almost entirely to fan energy;

  489 kWh/a in space heating consumption, mainly due to minor differences in occupancy and dwelling form;

  0.3^{o}C in mean internal temperature, again mainly due to minor differences in occupancy and dwelling form; and

- The measured data indicates that there is very little difference between the two groups of dwellings in terms of energy consumption and mean internal temperature. There is a wide scatter within each group, in both internal temperatures and energy use. The only end-use where a noticeable difference occurs relates to the energy consumed in the MVHR systems compared with the mechanical extract fans, where the MVHR systems consume 434 kWh/a more. This difference would have been smaller if the extract fans had been used to an appreciable extent.

- The mean electricity consumption of MVHR systems from the two manufacturers differed by about 15%. Systems supplied by Manufacturer B consumed about 70 kWh/a less than those supplied by Manufacturer A. This was due mainly to the fact that, as originally commissioned, Manufacturer A’s systems supplied roughly twice as much air as Manufacturer B’s. The sensitivity of electricity consumption to air flow rate in MVHR systems is illustrated by the fact that electricity use in

Manufacturer A systems fell by almost a factor of 2 following a 30% reduction in air flow.

Although we do not have measured data from before the refurbishment, it appears that in both groups of dwellings, the energy efficiency improvements undertaken in these dwellings have been taken up by the tenants as a substantial improvement in thermal comfort. Anecdotal evidence obtained from an analysis of the tenant questionnaire, as well as subsequent evidence received from the monitoring team, indicates that this is the case.

7 MVHR, ENERGY USE AND CO_2 - A THEORETICAL APPROACH

7.1 INTRODUCTION

One of the reasons for our interest in MVHR is the possibility that this technology offers for reducing energy use in dwellings. Figures have been presented earlier for the energy used to heat the air that passes through UK dwellings, and for the CO_2 that is emitted into the atmosphere as a result. In principle MVHR coupled with airtightness can reduce delivered energy use by a factor of 3-4 and can more than halve CO_2 emissions, while at the same time offering improved comfort and air quality. The simple theoretical example presented in the table below shows how these energy savings arise. The table shows the approximate quantity of natural gas required to heat ventilation air and resulting CO_2 emissions in the case of i) a naturally ventilated dwelling with an effective air change rate over a heating season of 0.65 ac/h and ii) an airtight dwelling equipped with an efficient balanced MVHR system.

ventilation system	equivalent ventilation rate (ac/h)	ventilation heat loss (kWh/a)	equivalent gas use (kWh/a)	electricity use (kWh/a)	CO_2 emissions (kg/a)
natural	0.65	2402	2669	negligible	534
high performance MVHR	0.10	370	411	263	235

The dwelling used as the basis for these figures has an internal volume of 220 m3. Energy use is calculated on the basis of 2100 degree days per annum. Heating is assumed to be by condensing gas boiler with a 90% efficiency. The carbon intensities of natural gas and electricity are taken as 0.2 and 0.58 kg/kWh respectively. The MVHR system is assumed to have 80% efficient heat recovery and a specific fan power of 1 J/l The air leakage in the MVHR case is assumed to be zero.

Table 7.1

Unfortunately, we have not been able to measure actual savings in energy use in this field trial. The reasons for this failure are simple and have been discussed throughout this report. They are:

- a saving of 2-3000 kWh per annum of natural gas will only be realised in an airtight dwelling; in a dwelling with a non-zero air leakage, savings will be less than this, and at the leakage rates achieved at Derwentside, gas savings maybe zero or negative;
- total energy use in the field trial dwellings was high, because of relatively poor thermal envelope performance - this required us to estimate a small energy saving against a much larger and noisy total.

It is clear that any attempt in the future to demonstrate energy savings from MVHR will need to be made in the context of much higher levels of airtightness and overall energy efficiency than was achieved at Derwentside. It is perhaps worth noting that this was the initial intention of the Derwentside field trial, but for a number of reasons, it was not possible to meet the exacting envelope specifications within the time available.

In the light of these observations, the only alternative is to construct a detailed theoretical model of infiltration and ventilation in UK dwellings, and to use this to explore the questions that we have not been able to address empirically. We have constructed such a model, and the rest of this chapter is devoted to describing it and discussing the results that flow from it.

7.2 MODELLING INFILTRATION AND VENTILATION

Air flows across the thermal envelope of a dwelling may be driven by naturally generated pressure differences (arising from wind and temperature differences), and by pressure differences generated by mechanical ventilation systems. The magnitude of these flows can be predicted from theoretical assumptions about air flow through openings, or from empirical expressions based on measured data. A theoretical model of air flows can be constructed that predicts, either from first principles or based on empirical flow/pressure relationships, the ventilation rate and ventilation heat load in a dwelling under any combination of weather conditions and internal temperature, with and without mechanical ventilation. Such a model can be used in conjunction with files of real or simulated weather data to produce estimates of the impact of choice of ventilation system and dwelling air leakage on energy use over a typical year. Given the difficulty of conducting field trials of MVHR, and the large number of parameters that such field trials would need to investigate to yield a comprehensive picture, such a theoretical approach is an essential compliment to empirical studies.

A number of attempts have been made over the years to construct theoretical frameworks for modelling ventilation rates in dwellings. Two of the earliest were the model constructed by Warren in the early 1980s (Warren 1982; Warren 1983), and the model constructed by Sherman and Grimsrud (Sherman & Gimsrud 1982). Both of these are based on the assumption that pressure differences and air flows arising from different physical mechanisms can be added in quadrature to give an effective whole house mean pressure difference and total ventilation rate.

Lydberg (1997) shows that this assumption, while yielding plausible results in certain circumstances, is physically unrealistic in the case of wind and buoyancy induced ventilation. Lydberg presents a framework in which pressure differences across each section of the thermal envelope of a dwelling are estimated explicitly, and the resulting airflows integrated over the whole envelope to give a total ventilation rate. This approach appears to offer a much better starting point for the calculating airflows and comparing ventilation strategies, and it is the one that we have pursued.

7.3 THE LYDBERG MODEL OF VENTILATION.

Lydberg's approach to modelling ventilation is based on the following equation:

$$Q_{net} = \int\int A.\ F(|\Delta p|)\ .\ \varepsilon(\Delta p).\ dS\ +\ Q_{mv} \qquad 1.$$

where:

A = relative leakage area
Δp = pressure difference across an infinitesimal section dS of the thermal envelope
$\varepsilon(x)$ = +1 if $x > 1$
-1 if $x < 1$
Q_{mv} = net flow of air out of the dwelling caused by a mechanical ventilation system, where one is fitted
Q_{net} = net flow of air across the thermal envelope; clearly mass conservation requires that $Q_{net} = 0$
F = flow function.

Pressure differences across the thermal envelopes arise from buoyancy and the action of wind. The pressure difference due to buoyancy can be written:

$$\Delta p_{stack} = -\rho g \Delta T/T\ (z-z_0)$$

where:

z = the vertical height above some datum, conveniently the bottom of the building
z_0 = the height of the so-called neutral plane
ρ = the density of air
g = the acceleration due to gravity
ΔT = the inside-outside temperature difference across the thermal envelope
T = the geometric mean of the inside and outside temperatures ($\approx$ 300 K)

The pressure difference due to wind acting on the outside of the building can be written:

$$\Delta p_{wind} = \rho/2\ .\ v^2\ .\ c_p$$

where:

v = the wind speed at a reference point (normally taken to be at the height of the building, at a location not disturbed by the presence of the building)
c_p = pressure coefficient at a point on the building thermal envelope

The total pressure difference across an element of the thermal envelope is, to a very good approximation, equal to the sum of the stack and wind pressures. If one makes suitable simplifying assumptions about the variation of the pressure coefficients over the thermal envelope (for example that the pressure coefficient is constant over each exposed plane fact of the building) then the integral in equation 1 can be evaluated analytically and the equation solved for z_0, the neutral plane height.

7.4 MODELLING A UK DWELLING

We have developed a model of a mid-terrace dwelling based on this approach, and on the following assumptions:

1. the party walls, roof and ground floor of the dwelling are airtight - leakage occurs only through the front and back walls of the dwelling
2. pressure coefficients on the windward and leeward walls of the terrace are 0.7 and -0.3
3. shelter, and the effects of non-normal incidence each reduce these pressure coefficients by a factor of 2, resulting in an overall reduction by a factor of 4.
4. a flow function defined by[11]:

$$F = (\rho.|\Delta p|/2)^{1/2}$$

For the purposes of this exercise, the modelled dwelling has the same dimensions as the field trial houses, minus the single storey extension. The internal floor area is 89 m^2 and the volume is 223 m^3.

The model has been used with weather data for Kew 1967 to generate air change rates and estimates of ventilation heat loss for each hour of a heating season that runs from 1st October to 30th April. This particular weather datafile did not include wind direction, hence the correction for off-normal incidence. It would be trivial to extend the model to include the effect of wind direction explicitly, but the results are unlikely to be affected significantly. Some of the results from this exercise are presented below.

Natural ventilation

The following graph shows the performance characteristics of natural ventilation and some of the fundamental problems associated with it. Ventilation ratio is the ratio of mean ventilation rate to design ventilation rate - taken here as 0.5 ac/h. The underventilation index is the fraction of hours in the heating season for which a naturally ventilated dwelling will be underventilated without additional window opening. At leakage rates below about 8 ac/h at 50 Pa, underventilation is almost assured. However even at this level of leakage, the ventilation rate averaged over the heating season is significantly greater than the design ventilation rate. A dwelling of average UK leakiness (about 14 ac/h at 50 Pa) maintained at an internal temperature of 20°C, will almost always be adequately ventilated during the heating season, but the mean ventilation rate over the heating season will be more than twice the design ventilation rate. This overventilation leads to significant penalties in terms of energy consumption and carbon emissions, as well as to thermal discomfort (draughts under

[11] The analysis can easily be extended to allow for pressure exponents other than 0.5 -empirical values of the pressure exponent tend to lie in the range 0.6-0.7.

windy conditions and excessive vertical temperature gradients under calm, cold conditions). In practice, lower internal temperatures would lead to lower ventilation rates, particularly in the warmer parts of the year.

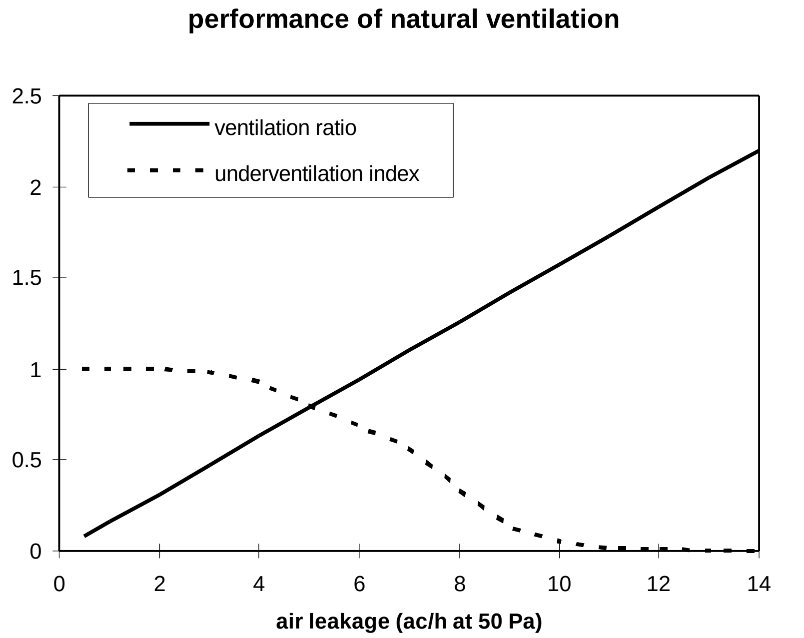


Figure 7.1

There are significant omissions from the analysis presented here. The most important is that of window opening behaviour. Window opening increases the ventilation rate in dwellings significantly, and in principle can prevent underventilation in airtight dwellings. This would tend to raise the ventilation ratio, and reduce the underventilation index in the above figure, at values of n_{50} below about 10 ac/h. It is likely that window opening behaviour in practice is hysteretic and imprecise, resulting in wide swings in ventilation rate, with periods of underventilation alternating with periods of overventilation. In households that valued air quality, the ventilation ratio might rise above 1 even in an airtight dwelling. Simultaneously, the index of underventilation would fall, but probably not to zero. In houses that place greater value on energy conservation than on air quality, it is possible for natural ventilation in an airtight house to outperform mechanical ventilation in terms of energy and carbon emissions, by the simple expedient of not opening the windows.

Mechanical extract ventilation versus balanced MVHR

Once the decision has been taken to rely on mechanical ventilation, measures to increase airtightness will tend to reduce the space heating requirement of the dwelling, and reduce the effect of external weather conditions on the distribution of ventilation within the dwelling.

There is a subtle difference in the way in which extract-only and balanced MVHR systems interact with external weather as air leakage is reduced. This difference arises because balanced MVHR systems do not affect the pressure difference across the dwelling envelope, while extract-only systems do.

As a dwelling fitted with an extract-only ventilation system is made more airtight, one observes a transition from a situation in which the flow of air across the dwelling envelope is controlled by naturally occurring pressure differences arising from wind and bouyancy, to a situation in which air flow is determined by the action of the mechanical extract system and is independent of external weather conditions. Modelling suggests that this transition takes place at an $n_{50} < n_{design}/6$, corresponding under typical UK conditions to an air leakage of about 3 ac/h at 50 Pa for dwellings with a design ventilation rate of 0.5 ac/h. We will refer to this level of air leakage as the critical air leakage, $n_{critical}$. With extract-only ventilation, when air leakage has been reduced to $n_{critical}$, further reductions in air leakage have little or no effect on ventilation heat loss. These comments are summarised in the following table:

effect of air leakage on performance of extract-only ventilation	
$n_{50} > n_{critical}$	$n_{50} < n_{critical}$
ventilation heat loss falls as air leakage is reduced; distribution of air flow across dwelling envelope and between and within rooms, and heat loads in individual rooms are sensitive to external weather conditions; effective ventilation rate can fall to zero on leeward side of house.	total ventilation heat loss is independent of air leakage; distribution of air flow across dwelling envelope and between and within rooms becomes increasingly stable as air leakage falls towards zero.

Table 7.2

With balanced MVHR, there is no critical air leakage and no transition. Reductions in air leakage will reduce both total ventilation rate and ventilation heat loss, at all levels of air leakage down to zero.

Two sets of implications follow from the above.

1. Lowest levels of energy use and carbon emissions will be achieved in very airtight dwellings with efficient MVHR systems. If properly designed, installed and commissioned, these systems will also guarantee air quality, and a high level of thermal comfort. Detailed modelling suggests that an efficient balanced MVHR system in a very airtight dwelling can reduce carbon dioxide emissions by 200-300 kg/a compared with an extract-only system in the same dwelling.
2. If it is impossible to achieve levels of airtightness below $n_{critical}$, then extract-only ventilation may perform as well as or better than balanced MVHR, depending on the efficiency of the MVHR system.

The three graphs below show carbon dioxide emissions from a dwelling of the size of those at Eshwinning, for the three ventilation strategies - natural, extract-only and balanced MVHR, as a function of air leakage rate. The first graph is for an efficient MVHR unit (fan power 30 W, heat recovery efficiency 80%), the second for a unit of intermediate efficiency (fan power 50 W, heat recovery efficiency 60%), and the third is for an inefficient MVHR unit (fan power 80 W, heat recovery efficiency 50%). The picture presented by these three graphs is complex and worthy of some discussion.

The first graph shows that provided fan-motor and heat recovery efficiency are high enough (the figures assumed here are attainable using currently available technology), balanced MVHR will outperform extract-only systems at all levels of airtightness. The graph also shows that both mechanical ventilation options in reasonably airtight dwellings, will outperform unassisted natural ventilation in leaky dwellings. The performance advantage of MVHR compared with extract-only ventilation is of the order of 100 kg/a for $n_{50} \geq 5$ ac/h, but rises steeply for air leakage rates below the critical leakage rate. At a leakage rate of 0.5 ac/h, the performance advantage of balanced MVHR is more than 280 kg/a.

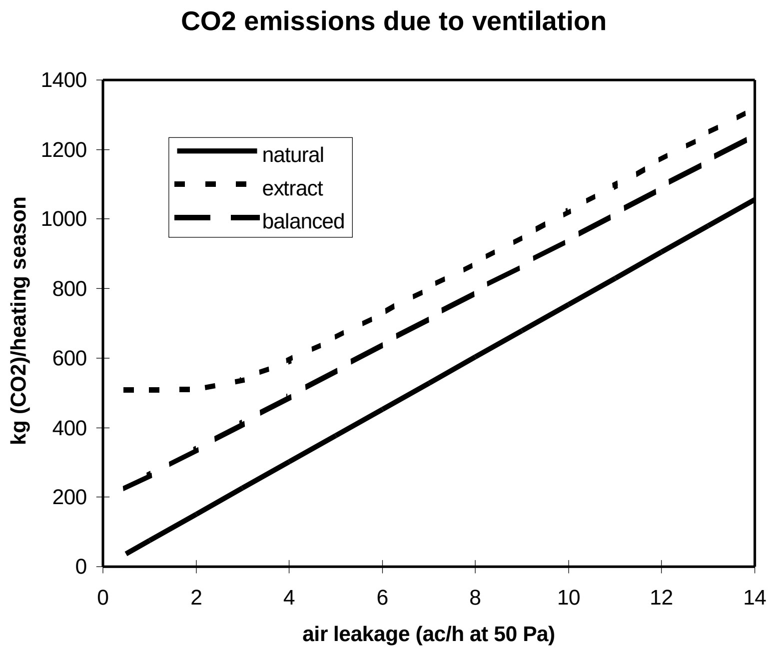


Figure 7.2 Ventilation-related carbon dioxide emissions: high efficiency balanced MVHR compared with extract-only and natural ventilation.

The second graph shows that with MVHR systems of intermediate efficiency, air leakage is the key factor in determining whether balanced MVHR or extract-only ventilation will give the lowest CO_2 emissions. In dwellings with air leakage above the critical value extract-only systems are likely to give the lowest overall emissions, while in more airtight dwellings, balanced MVHR gives the lowest emissions. With intermediate efficiency MVHR, the difference in performance between MVHR and extract-only ventilation is relatively small, ranging from +130 kg/a at n_{50} = 0.5 ac/h, to -70 kg/a for $n_{50} >> n_{critical}$.

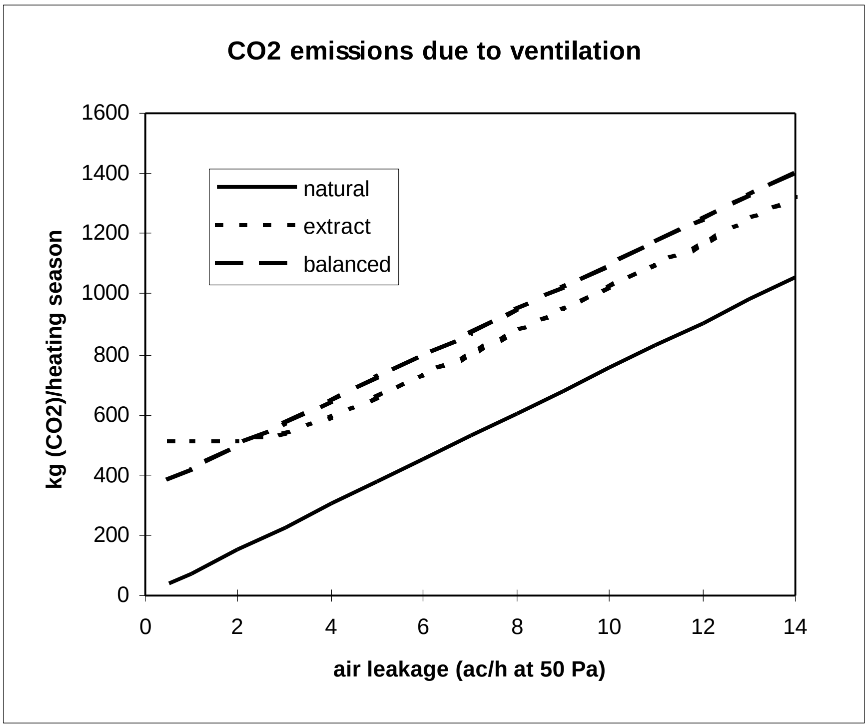


Figure 7.3 Ventilation-related carbon dioxide emissions: medium efficiency balanced MVHR compared with extract-only and natural ventilation.

The third graph shows that low performance MVHR systems will always be outperformed by extract-only ventilation. Intrinsically low performance arises where the MVHR unit is itself poorly designed and manufactured, with low efficiency fan-motor sets, under-sized heat exchangers, internal leaks that allow the heat exchanger to be bypassed, and so on. Low performance can also be caused by poor ductwork design, poor installation, and poor commissioning. The work at Eshwinning has shown how important the last two are.

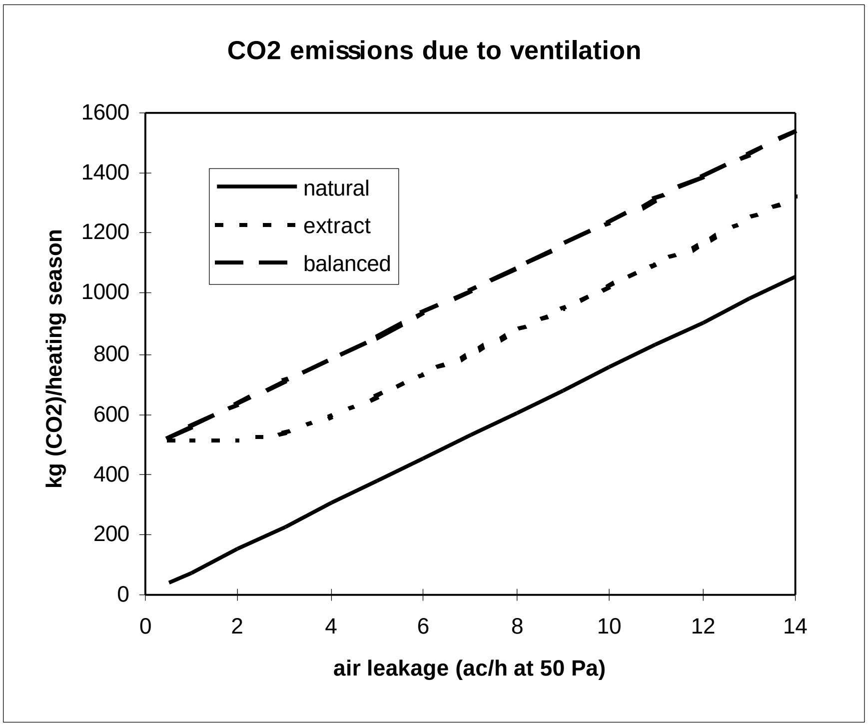


Figure 7.4 Ventilation-related carbon dioxide emissions: low efficiency balanced MVHR compared with extract-only and natural ventilation.

7.5 CONCLUSIONS

We have attempted to explore the circumstances under which balanced MVHR systems will lead to lower overall carbon dioxide emissions from ventilation than extract-only systems. This exploration has had to be undertaken on the basis of theoretical modelling, since the sample size and range of air leakage in the houses at Eshwinning were too small for the purpose. We are nevertheless confident that our conclusions are qualitatively robust, and that they can form the basis for further experimental and theoretical work in this area.

The most important conclusions from this work are as follows:

- The scope for achieving reductions in energy use with MVHR depends critically on the efficiency of the equipment used. Equipment of low efficiency may not achieve saving at all compared with the simpler and cheaper option of extract-only ventilation. Equipment of intermediate efficiency will achieve substantial savings only in relatively airtight dwellings. The point at which the two ventilation options break even is at a leakage of something like 3 air changes per hour at 50 Pa. Finally, equipment that is efficient by current standards may offer advantages at all levels of air leakage compared with extract only ventilation.

- Airtightness is the key to ventilation efficiency regardless of which mechanical ventilation strategy is chosen.

8 DISCUSSION AND CONCLUSIONS

8.1 AIRTIGHTNESS

It was clear from the start of this project that field trial dwellings would need to be significantly more airtight than normal UK housing. This required LMU to undertake a programme of supplementary airtightness work over and above the refurbishment that was carried out by Derwentside's DSO.

In practice before refurbishment, the field trial dwellings were roughly twice as leaky as the average for UK housing. Leakage rates measured by fan pressurisation were in the region of 24 -29 ac/h at 50 Pa, compared with the UK mean of 13-14 ac/h. A number of features contributed to this very high leakage rate. The first was the original method - plasterboard on dabs - used to construct the walls of the field trial dwellings. Other features contributing to a high leakage rate included the detailing around the vent stack which was inset into the inner leaf of the external wall of each dwelling.

The original target for the field trial was to achieve a leakage rate of 3 ac/h at 50 Pa in the experimental group of dwellings. Following the initial survey, this target was raised to 8 ac/h at 50 Pa. The basic refurbishment and supplementary programme of airtightness work together achieved an actual mean leakage rate 10.9 ac/h at 50 Pa. The reasons for this relatively poor performance, in addition to those mentioned above, include:

- the partial nature of the refurbishment carried out at Eshwinning, which meant that large areas behind kitchen fittings and the bath could not be made airtight;
- leakage through the single storey extension, which was not addressed in the supplementary airtightness programme;
- problems with draughtseals on the new external doors of the dwellings - these doors were fitted into new door frames on site, rather than being supplied as door and frame sets; tenants in three of the field trial dwellings reported that snow blew into the house through these external doors;
- problems of communication between the team at LMU and the DSO who undertook the basic refurbishment programme.

8.2 INSTALLATION AND COMMISSIONING

Examination of the quality of installation and commissioning of the MVHR systems, revealed a number of problems. These varied from minor problems, to errors which completely undermined functioning of the systems. Problems included:

- uninsulated MVHR units and supply and extract ductwork in the attic of several field trial dwellings - heat lost to a cold attic space from an MVHR unit and from ductwork on the house-side of the MVHR unit will significantly reduce the system heat recovery efficiency;

- unbalanced airflows in a number of dwellings, which would result in reduced system efficiency;
- airflows significantly below the design airflow - this would result in underventilation of an airtight dwelling, though in the context of the houses in this field trial the problem is a minor one;
- airflows significantly above the design level in three of the houses - as a result the power consumption of the units was roughly twice as high as it should have been, and the units would have been noisier;
- condensate drains which were installed with an insufficient gradient - condensation in MVHR units becomes more of a problem, the more efficient the heat exchanger is; in these dwellings condensation almost certainly occurred in some of the units;
- the supply and exhaust ductwork in three of the six MVHR units was all initially connected the wrong way round - this would lead to air moving from toilets, kitchens and bathrooms into bedrooms and living rooms and in principle to **worse** air quality than in an equivalent naturally ventilated dwelling.

These observations and measurements made in the field trial dwellings highlight a number of points. These are:

- the absolute and over-riding need to install and commission MVHR systems correctly;
- the importance of designing MVHR systems so as to provide locations at which total extract and supply airflow can be measured simply and cheaply, and with an appropriate level of accuracy - we would suggest ±15% following CAN/CSA-F326-M91;
- the need for a much more comprehensive standard on installation and commissioning than either of the documents currently available in the UK - again we would point to CAN/CSA-F326-M91 as a model.

The LMU team are unaware of any documentation on the installation and commissioning of the units in the field trial houses. There appears to be a need for installation and commissioning information to be made available to the landlord or owner of a house fitted with an MVHR system, so that in the years following the installation, problems can be quickly identified and the system returned to its design condition.

One of the aspects of MVHR system operation that was not well addressed in this field trial, was that of maintenance. Location of system units in attics would make access somewhat problematical for householders with mobility problems. Where MVHR system units are installed in attics, it would appear to be sensible to provide permanent access, possibly in the form of a retractable loft ladder, to reduce the risks involved in system maintenance. In Manufacturer B's system, the outside air filter in the attic is supplemented by filters in room terminals. To the extent that this reduces the need to gain access to the attic, it appears to offer some advantages.

Measurements and observations by the LMU team showed that extract-only systems were rarely used in any of the control houses. Extract-only ventilation in moderately airtight dwellings (3 ac/h at 50 Pa) is a viable alternative both to natural ventilation in leaky houses and to balanced MVHR, and will probably result in reduced energy use and improved air quality compared with the former. This strategy is however, only viable if occupants of dwellings actually use the systems provided. We are unclear why none of the control group households made use of their extract ventilation systems, and are reluctant to recommend the solution of making on/off switches inaccessible. Nevertheless, this approach worked in the MVHR houses.

8.3 MVHR SYSTEM PERFORMANCE

Three measures of MVHR system performance were evaluated. The first, specific fan power, is related to the efficiency with which the systems moved air through the dwellings. The second, the system thermal efficiency, is related to the ratio of air movement brought about by the operation of the system to the heat recovered. The third, the coefficient of performance (CoP), is the ratio of heat recovered to electricity consumed. On all of these measures, there was a significant difference in the performance of the systems from the two manufacturers. Manufacturer A's systems consumed less than half as much electricity to move a given amount of air, had a significantly higher thermal efficiency, and had a CoP which was roughly four times as high as that from Manufacturer B. These differences are due to the following factors:

- use smooth versus rough ductwork
- use of electronically commutated DC motors, instead of the more common and significantly less efficient AC motors
- use of a larger heat exchanger
- balanced versus imbalanced air flows.

These differences are larger than was expected, even allowing for the fact that Manufacturer A's system was based on a prototype MVHR unit, while Manufacturer B's is commercially available. The results emphasise the fact that the overall performance of an MVHR system is the product of performances of a number of sub-systems. Modest improvements in the performances of each of these sub-systems can lead to a large overall improvement in performance.

8.4 AIR QUALITY

Air quality was better in the MVHR houses than in the control houses which were fitted with extract-only systems. The main reason for this is that, as noted above, extract systems were not operated for more than a small number of hours in any of the dwellings.

This result was derived from measurements of humidity at four locations, and from CO_2 measurements in the main bedroom in each dwelling. The result was robust and given the leakiness of the field trial houses, unexpected. The difference indicates the importance of continuously operating mechanical ventilation, with or without heat recovery, and is powerful argument for the installation of such systems in both existing and new dwellings.

At Eshwinning, continuously operating MVHR reduced the inferred incidence of condensation on single glazed windows by a factor of 8, and reduced average CO_2 concentrations by a factor of 1.5 in bedrooms. The presence of continuously operating MVHR systems appeared to affect occupant behaviour and perceptions of their dwellings. Tenants stated that their dwellings no longer felt “stuffy” and that they needed to open their windows less frequently for ventilation.

8.5 MVHR, ENERGY CONSERVATION AND CO_2

We have been unable to demonstrate any effect of MVHR on the overall energy consumption of the field trial dwellings. Two different approaches have been used to model energy use in the dwellings, and to estimate the size of the effect that we might expect to see. The conclusion from both of these approaches is that the effect of MVHR on gas consumption in these dwellings is likely to be of the order of ±500 kWh/a, a figure which is too small to be detectable in the context of a field trial of only 12 houses.

The small size of the expected effect is due to three separate factors:

- The field trial dwellings were too leaky, by a factor of 4 or more, to provide a good basis for demonstrating balanced mechanical ventilation with heat recovery.
- Installation and commissioning problems reduced the performance of a number of the MVHR systems to a level at which energy savings would have been negligble even in airtight dwellings.
- Fabric heat losses in the field trial dwellings was high. The effect of this was to increase the background variability against which we were attempting to measure the effect of MVHR.

A preliminary statistical analysis of the problem of designing field trials of MVHR suggests that there would be a high probability of detecting differences in energy use, at the 95% confidence level, if the space heat demand in field trial dwellings could be reduced to between 2000 and 4000 kWh/a, and if the air leakage rate in field trial dwellings could be reduced to below 3 ac/h at 50 Pa. Analysis suggests that under these conditions, the expected impact of MVHR on space heating energy use would be in the region of 1000 - 2000 kWh/a, and a comparatively small field trial (perhaps two well matched groups of 16 dwellings) would be able to resolve the impact of MVHR to ±25% with 95% certainty.

One of the most important questions in this area is, to what level must air leakage be reduced before balanced MVHR begins to yield absolute reductions in energy use in real occupied dwellings compared with other ventilation strategies? We were unable to address this question directly, because the range of airtightness of the field trial houses did not include the range of likely answers. We were, however, able to construct a model of ventilation rate and ventilation heat loss in dwellings, based on the physical principles involved. This model was used to predict space and electricity consumption over a heating season for a variety of airtightness levels, for three ventilation strategies - natural, extract-only and balanced MVHR. The weather data used for this exercise was for Kew 1967.

This exercise confirmed the widely held view that balanced MVHR performs best in airtight dwellings. Energy savings and carbon emission reductions were significantly reduced in dwellings with an airtightness above 3 ac/h at 50 Pa. Modelling showed that inefficient MVHR systems used more energy and emitted more carbon than extract-only ventilation systems in dwellings leakier than 0.5 ac/h at 50 Pa. While this level of airtightness is regularly and routinely produced in Canada and Sweden, it has to our knowledge never been achieved in the UK.

Conversely the exercise showed that an efficient MVHR system would **always** outperform an extract-only system. This result was unexpected, but we believe that it adds weight to the efforts of MVHR system manufacturers to improve the overall performance of their products. It is significant that the prototype MVHR systems provided for this field trial by Manufacturer A performed at this level.

8.6 OCCUPANT ACCEPTABILITY

Apart from some initial complaints about noise, there were no problems of user acceptability with the MVHR systems. The occupants of these houses had been assured at the outset of the field trial that the cost of electricity used by the units would be small, and that they would be more than compensated financially for this cost. Perhaps as a result there appeared to be little concern about operating cost.

Field trial tenants were not asked to participate in the maintenance of the MVHR units. Given the location of the units in attics, it would have been interesting to have assessed occupants reactions to the requirements of system maintenance.

To fact that control group households made very little use of their extract-only ventilation systems suggests that there maybe a problem of occupant acceptability with these systems. Whether this relates to noise, perceived energy consumption (the electricity use of the latest generation of whole house extract systems can only be described as utterly negligible), or to draughts caused elsewhere in the dwelling when the extract unit operates, is not known. It is possible that extract systems controlled by on-off switches (whether manually operated or controlled by humidity sensors) may be more annoying than systems which operate continuously.

8.7 THE FUTURE FOR MVHR AND VENTILATION RESEARCH

This research project has thrown up a number of issues that appear to require further research and development. These are:

- the need to develop improved UK guidelines for the installation and commissioning of MVHR systems;

- the need to engineer MVHR systems to minimise the problems that are likely to be encountered in installation and commissioning, and to reduce the probability of major errors in the installtion and commissioning process;

- the need to continue to develop the performance of MVHR systems in terms of thermal and electrical efficiency;

- the need to conduct research into the long term performance of MVHR systems, including questions raised by the need to maintain systems;

- the need to research into the reasons why people seem reluctant to make use of extract-only ventilation systems.

One of the most important results from this field trial was that the original airtightness target was not achieved. We feel that this indicates:

- the need for a programme of applied research which aims to develop a library of construction techniques for achieving high levels of airtightness in new and existing dwellings

- the need for a programme to demonstrate the achievement of air leakage rates in the range of 1 - 3 ac/h at 50 Pa, in the field, in a wide range of new and existing housing.

Enhanced airtightness reduces the energy used for ventilation, and improves the performance in terms of thermal comfort, regardless of which ventilation strategy is chosen. There appears to us to be little point in conducting research into mechanical ventilation systems of any type unless the problems associated with making houses airtight are simultaneously addressed.

APPENDIX 1

THE DATALOGGING SYSTEM AND SENSORS

A1.1 DATALOGGING SYSTEM AND SENSOR SPECIFICATIONS

The specification of the computer logging system and the sensors which were used in the field trial dwellings are as follows.

Datalogger/modem. The data collection system consisted of a collection module (a Datataker 500 datalogger), a modem to transfer information remotely from the field trial site to Leeds Metropolitan University, and Windows based software. All of this equipment was provided by Dataelectronics.

Phone line. This line was installed for communicating with the modems, in order to enable the data from the datalogger to be remotely accessed. It was set up only to receive incoming calls, and consisted of a business phone line which was provided and installed by British Telecom.

Boiler gas meter. A UGI pulse output gas meter supplied by BSS, model UG R5 was used to measure the gas input to the boiler. These meters give one pulse per cubic foot of gas through a volt-free switch.

Total electric meter. This consisted of a pulsed output electric meter supplied by JW Instruments, and rated at 80 amps. This meter was used to log the total electricity use of the dwelling.

Temperature and humidity sensors. The temperature sensors consisted of a thermistor which was used to measure all of the room temperatures. This sensor is expected to be accurate to better than ±0.5 ^{o}C. The humidity sensors were provided by Vaisala (model HMW 50U), and measure relative humidity in the 10-90% range with an accuracy better than ±5% at +20^{o}C. In order to save space and for neatness, the thermistor was inserted into the box containing the humidity sensor. These sensors were installed at discreet locations throughout the dwellings.

Carbon dioxide sensor. The CO_2 sensor was provided by Vaisala (model GMP 111), and uses a single wavelength non-dispersive infrared gas sensor for detection. This technique makes the sensor highly gas specific; it is not sensitive to other gases including water vapour. The sensor is diffusion aspirated, with the gas entering the sensor through a gas permeable membrane. The sensor has a measurement range of 0-3000 ppm, and an accuracy of ±3% of full scale reading. These sensors were used in the master bedrooms of the dwellings in order to measure the air quality of these spaces. This location was chosen because the highest concentrations of CO_2 and the poorest air quality are believed to occur in these rooms during the night whilst the occupants are asleep.

Heat meter. The heat meters were supplied by HG Instruments of Denmark, model HG1-C-4, and/or HG-3-A-4. These meters were installed in two dwellings: one type A dwelling, and one type B dwelling. These meters were initially intended to measure total boiler output, however, the installation of a combination boiler in the dwellings meant that the heat meters were only be able to measure the demand for space heating. The original purpose of installing the meters, which was to measure the efficiency of the boilers, was therefore frustrated.

MVHR system electric meter. This consisted of a pulsed output electric meter supplied by JW Instruments, and rated at 80 amps. This meter was used to log the total electricity use of the MVHR equipment in the experimental houses.

Extract fan electric meter. This consisted of a pulsed output electric meter supplied by JW Instruments, and rated at 80 amps. This meter was used to log the total electricity use of the extract fans in the control houses.

Supply and exhaust air temperature and humidity sensors. The supply and exhaust air temperature of the MVHR unit was measured using a thermistor. The supply and exhaust air humidity was measured using a Vaisala (model HMD 50U) duct humidity sensor. The latter has a range of 10-90% relative humidity and an accuracy better than ±5% at +20^{o}C.

Pyranometer - The pyranometer measured horizontal global solar radiation, giving an output of 9.63 micro volts per Watt/m^2.

Anemometer - the anemometer measured wind speed, giving 0.8 pulses per ms^{-1}.

Windvane - Wind direction was measured using a windvane. Output from this device was an electrical resistance varying linearly from 0 to 1000 Ω over wind directions from 0^{o} to 360^{o}. Pyranometer, anemometer and windvane were mounted approximately 1 m above ridge height, on a mast which was attached to the gable wall of house A.

External temperature sensor - A thermistor in a naturally ventilated louvred solar radiation shield supplied by Delta T Devices (type AT1) was used to measure external temperature. The external temperature sensor was mounted at eaves height on house A.

Humidity sensor - The external humidity sensor was provided by Vaisala (model HMW 50U), and had a range of 10-90% relative humidity and an accuracy better than ±5% at +20^{o}C.

A1.2 SENSOR AND METER LOCATIONS

A1.2.1 Location of the sensors

All of the sensors installed in the field trial dwellings were mounted approximately 1.3 metres above the floor, i.e. around light switch height. These sensors were wired up using six core screened cable provided by RS Components to standard back boxes in the required locations. The sensor locations in each of the dwelling types were as follows:

TYPE A houses

Kitchen

1 Vaisala humidity sensor with a thermistor incorporated for temperature sensing. Sensor sited on internal wall shared with staircase.

Bathroom

As for kitchen. Sensor sited on wall common to upstairs cupboard, i.e. next to light switch.

Living room

Humidity/temperature sensor (as for kitchen) to be sited on internal wall common with the store.

Master bedroom (bedroom 1)

Humidity/temperature sensor (as for kitchen) and CO_2 sensor, sited on internal wall common to the stairwell.

Store room (underneath stairs)

The Datalogger and modem were installed in this location in a small wooden box which was secured to one of the walls of the store room. All of the equipment was hard-wired to prevent accidental switching off by the occupants of the dwelling.

Attic

In the MVHR dwellings, the supply and exhaust temperature and humidity sensors were situated in the ductwork in the attic.

Type B houses

Bathroom

Humidity/temperature sensors were situated on the wall between the window and the toilet.

Master bedroom (bedroom 1)

Humidity/temperature sensor were situated on wall adjacent to cupboard, close to entrance door. CO_2 sensor was situated next to humidity/temperature sensor on wall.

Kitchen

Humidity/temperature sensors were situated on wall common to stairs.

Living/dining room

Humidity/temperature sensors were situated on wall next to the door, front side of the house.

Upstairs cupboard

The Datalogger, modem, and BT phone line were installed in here, with details as in the Type A houses.

Attic

Duct temperature and humidity sensors were located in this space in the MVHR dwellings as in Type A dwellings.

A1.2.2 Location of energy meters

The gas, electric, and heat meters were installed in the field trial dwellings as follows:

<u>Type A houses</u>

Store room (underneath stairs)

Two electric meters were installed in this space. One of these meters measured the total electricity use of the dwelling, whilst the other meter measured the electricity use of the mechanical extract fans in the non-MVHR dwellings.

Upstairs Store

The gas meter was situated in this store next to the gas boiler, and was installed on the gas flow pipe just before it entered the boiler. The heat meter was also installed in this cupboard on the space heating circuit from the combination boiler. Both of these meters were installed in the pipework with isolating cut-offs to simplify installation/extraction and to minimise disruption related to decommissioning.

Attic

The electric meter which measured the MVHR electricity consumption, was located in this space in the MVHR dwellings. This meter was located on a separate spur which was run from the fuse box.

Type B houses

Downstairs store

Two electric meters were installed in this space, as in the Type A houses.

Upstairs cupboard

Gas meter and heat meter were installed in this cupboard as in the Type A houses.

Attic

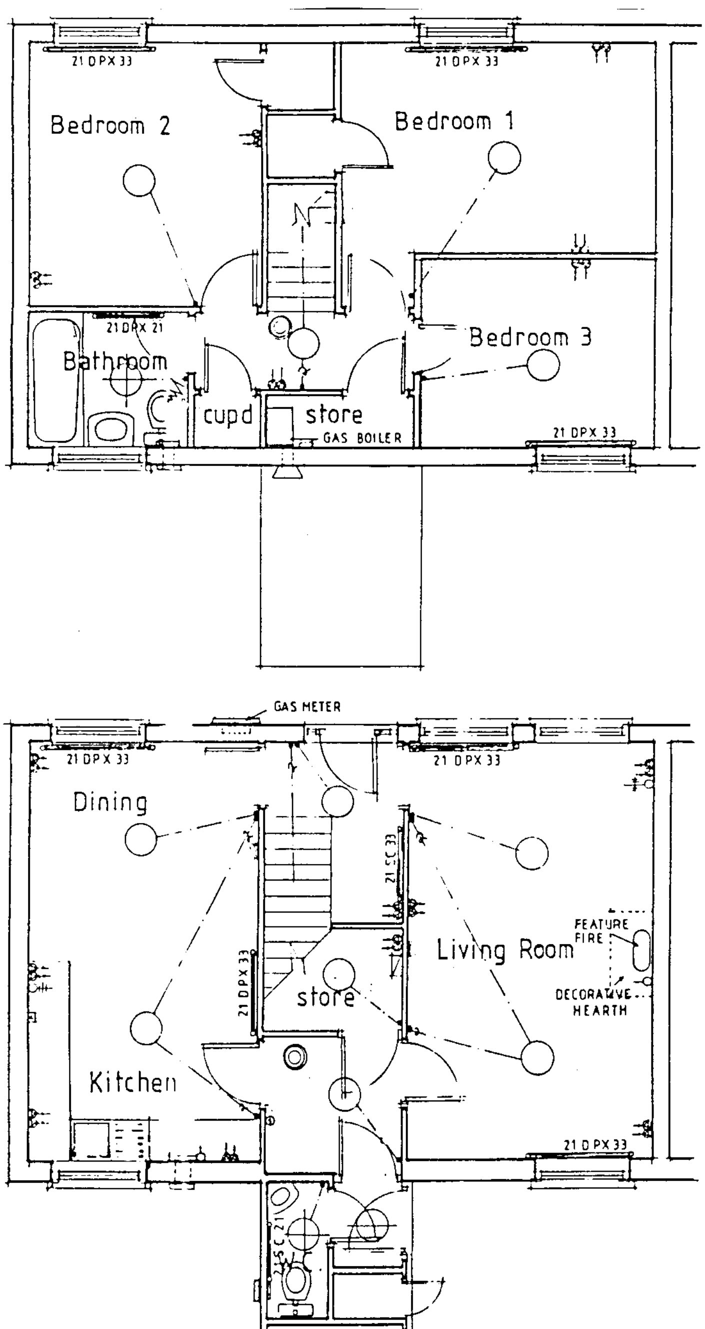
The electric meter which measured the MVHR electricity consumption was installed as in the Type A houses.

APPENDIX 2

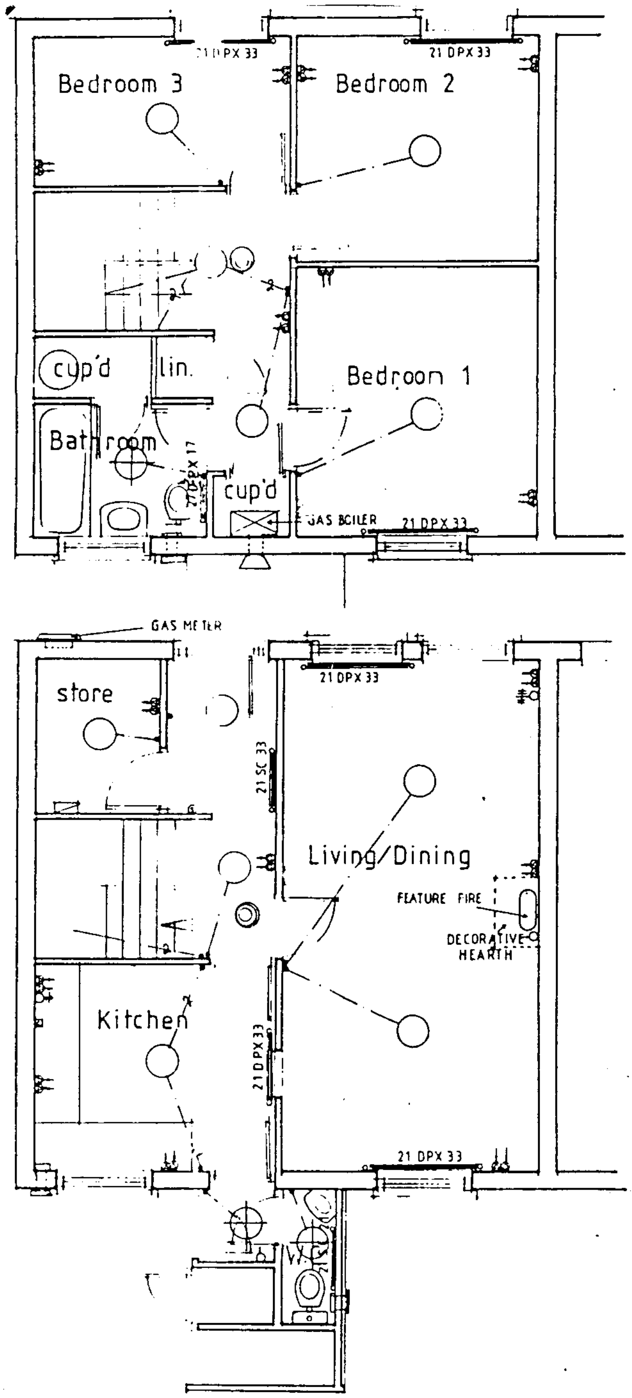
FLOOR PLANS AND HEAT LOSSES FOR THE FIELD TRIAL DWELLINGS

A2.1 HOUSE TYPES

The floor plans for the field trial houses are shown below.



House Type A


Bedroom 3
Bedroom 2
21 DPX 33
Bedroom 1
cup'd
lin.
Bathroom
cup'd
GAS BOILER
21 DPX 33
GAS METER
store
21 DPX 33
21 SC 33
Living/Dining
FEATURE FIRE
DECORATIVE HEARTH
Kitchen
21 DPX 33
21 DPX 33

House Type B

A2.2 FLOOR AREAS AND HEAT LOSS COEFFICIENTS

The floor areas and heat loss coefficients of the field trial dwellings can be seen below.

HOUSE	TYPE	FLOOR AREA (m^2)	VENTILATION HEAT LOSS (W/K)	SPECIFIC HEAT LOSS (W/K)
A	End ter. (Type A)	92	47	225
B	End ter. (Type A)	92	46	224
C	End ter. (Type A)	92	46	225
D	Mid ter. (Type B)	92	50	205
E	End ter. (Type B)	92	67	234
F	Mid ter. (Type B)	92	47	202
G	End ter. (Type B)	92	36	202
H	Mid ter. (Type B)	92	47	202
I	End ter. (Type B)	92	47	214
J	End ter. (Type A)	92	48	226
K	Mid ter. (Type A)	92	50	211
L	End ter. (Type A)	92	41	219

APPENDIX 3

SURVEY OF HOUSES AT ESHWINNING

A brief survey was carried out of two houses at Eshwinning in Derwentside, on 18th July 1995. The survey included pressurisation testing, and visual inspection. One of the houses was empty and in an unimproved state. The second had been gutted by fire, repaired and re-let.

Construction.
The houses were part of the Briardene estate built approximately 20 years ago. The basic form consists of terraces of shallow plan, two storey dwellings with a low pitched roof. The walls are constructed in cavity masonry, and were originally dry-lined with plasterboard on dabs. Internal walls are a mixture of blockwork and plasterboard on studs. Windows and doors are built flush with the inner surface of the external walls. Original windows are poorly fitting, and in the unimproved house that was surveyed, the front door frame had come loose from its fixings in one corner. The ground floors are concrete throughout. Original first floors are chipboard, with significant gaps between adjacent boards and between floors and skirting boards. The houses were built with a conventionally flued solid fuel stove in the living room. All properties have a small single storey flat-roofed extension in the middle of the rear wall. The construction of this is thought to be single skin masonry with dry-lining. The main soil stack runs within the thickness of the external wall. There is no plumbing in the roof void in either the unimproved or improved houses.

The improved house has had all dry-lining on external walls removed and the walls have been wet plastered. The solid fuel appliance has been replaced with an open gas fire in the living room, with a 150mm diameter flue, and a conventional gas-fired wet central heating system.

Airtightness.
The houses were pressure tested with a Minneapolis blower door. The results are shown below.

Pressurisation testing at Eshwinning, 18th July 1995			
	ac/h @ 50 Pa	ELA (m^2)	comments
unimproved house	28.9	0.3	wind speed < 3 m/s
improved house	9.4	0.1	wind speed < 7 m/s

If the unimproved house is representative of all unimproved houses, this result suggests that they are extremely leaky - 28.9 ac/h is at the top end of the range spanned by houses in the UK, a fact that is particularly significant given the exposed location of Eshwinning.

The improved house is comparatively airtight by UK standards, and represents a promising starting point for an MVHR field trial. The Electricity Association leakage Medallion 2000 target of 7 ac/h should be easily achievable with modest measures - simply leaving out the open gas fire is likely to be worth 1 ac/h. The achievement of 3 ac/h is less certain, but measures such as sealing the soil stack, draft sealing the door separating the extension from the rest of the house, and sealing the gaps and skirting board in the first floor are likely to have a considerable effect. The total leakage area in the house tested amounted to 0.1 m^2 (roughly 1 square foot), a considerable part of which is likely to be accounted for by the elements mentioned above.

Conclusions.

Much of the difference between the two houses is likely to be attributable to the replacement of badly fitting windows and doors, but a major part of it is likely to be due to the replacement of dry-lining with wet plaster. **This poses a problem for the field trial.** I would strongly recommend that the external walls in the 6 MVHR houses be wet plastered, and that we consider the same measure in the naturally ventilated houses as well.

The windows and doors used in the improved house appear to be relatively airtight, or can be made so by minor adjustments (the external doors in the house surveyed did not touch the draught seals). The doors themselves are robust, and unlikely to warp. The force needed to compress the draught seals in the external doors does appear to be high, and consideration should be given to using a softer seal.

The installation of MVHR systems will be hindered by the low roof pitch, and may require ductwork to be run in the thickness of the first floor. The latter may make it easier to achieve high levels of airtightness by reducing the need to penetrate the first floor ceiling.

The houses have plenty of room for the installation of monitoring equipment. Data loggers can be housed in internal or external cupboards.

Robert Lowe 20 July 1995

APPENDIX 4

TECHNICAL DESCRIPTIONS OF THE MVHR SYSTEMS

A description of the MVHR systems which were installed in the experimental dwellings can be seen below.

A4.1.1 Manufacturer A

This system consisted of a prototype version of the Vent-Axia HR250 system. A picture of the system unit can be seen below.

The technical information available which relates to this system is as follows.

- **Central air unit** - The central air unit consists of a stainless steel box which is mounted in the loft. This box contains the heat exchanger and the supply and extract fans, and is thermally insulated internally with 12 mm of low density polyethylene foam. A condensate drain is fitted to the bottom of the box, with the pipework leading to a suitable drainage point.

- **Fans** - The unit contains two radial forward curved fans, one for the fresh air supply, and one for the exhaust. The fans are powered by DC motors, and have sealed for life bearings. The Manufacturer has quoted the design electrical consumption to be 60W for a 35 l/s supply and extract rate (measured by the Vent-Axia Environmental Suite).

- **Heat exchanger** - Plastic cross flow heat exchanger. The Manufacturer has quoted the temperature efficiency of the system @ 35 l/s to be 67%, measured by the Vent-Axia Environmental Suite.

- **Ducting** - The ductwork installed in the dwellings consists of 110 mm circular sections, which are constructed in rigid plastic or flexible aluminium. Ductwork that is situated in the loft will be insulated with a foil coated bubble wrap type material. Insulation is not required in the ductwork contained within the living areas of the house.

- **Filters** - A filter is located in the fresh air duct coming from outside.

- **Supply and extract grilles** - The air is supplied and extracted from the ductwork to the rooms via white plastic grilles. Extract grilles are installed in the wet areas of the dwelling, and are positioned as close to the main source of moisture as possible. The inlet grilles, on the other hand, are installed in the dry rooms of the dwelling, and are positioned as far as possible away from any doors in the room to ensure that the air permeates the whole room.

- **Controls** - Control of the unit is achieved using a pulse-width modulator to control the speed of the DC fans. This operates manually by a two-way switching arrangement, which enables the occupants to boost the unit when required. In normal day-to-day operation, the unit is intended to operate continuously at 'normal' speed giving an air change rate of approximately 0.5 ac/h, with balanced supply and extract rates.

A4.2 Manufacturer B

This system was based around a DUCTEX HRV whole house ventilation system. A picture of the system unit is shown below.

The technical information available which relates to this system is as follows.

- **Central air unit** - The central air unit consists of an insulated steel box which is mounted in the loft. Housed within this box is the heat exchanger and the fans. A condensate drain tube runs from the central air unit to a suitable drainage point.

- **Fans** - There are two fans within the system, one for the fresh air supply, and one for the stale air exhaust. Fans are centrifugal with forward curved pressed steel blades. Motors are capacitative-start external rotor induction motors.

- **Heat exchanger** - Plastic cross flow heat exchanger. It is claimed that the heat exchanger has an average efficiency of 68% sensible heat recovery (BSRIA Test Number ID48430).

- **Ducting** - The ducting consists of 100 mm internal diameter flexible aluminium sections. This ductwork is light, can easily be formed into bends and offsets, and is fire and corrosion resistant. Ductwork situated in the loft is insulated on site with with 25 mm of mineral wool insulation with a plastic outer covering. Insulation is not required in the ductwork contained within the living areas of the house. A sound absorbing section of ductwork is installed in the duct run supplying the rooms with fresh air. This section is installed in the supply duct, as close as possible to the central air unit, and is designed to reduce noise levels in sensitive areas such as bedrooms where fan noise or noise entry from outside can be a nuisance.

- **Filters** - A number of filters are installed in the Rega system. An external air filter is located in the air intake air duct which brings air into the system from outside, to prevent the ingress of dust and insects which would otherwise have a detrimental effect on the heat exchanger. Washable and flexible filters are also present in each of the room grilles. These filters further improve the quality of the fresh air, and also help to balance the air flow to individual rooms.

- **Supply and extract grilles** - The air is supplied and extracted from the ductwork to the rooms via white plastic grilles which contain the washable and flexible filters. The extract grilles are installed in the wet areas of the dwelling, and are positioned as close to the main source of moisture as possible. The inlet grilles, on the other hand, are installed in the dry rooms of the dwelling, and are positioned as far as possible away from any doors in the room to ensure that the air permeates the whole room.

- **Controls** - Control is achieved by a triac control system which varies the speed of the system fans. This switch enables the occupants to adjust the volume of air supplied by the system.

APPENDIX 5

TENANT QUESTIONNAIRE AND ANALYSIS

5.1 RESEARCH FINDINGS

This section summaries the tenants responses to the questionnaire which was undertaken in January 1997. The questions put to the tenants during the interview are shown in italics, with the tenants responses noted under each of the questions. As the research involved small numbers of respondents, the actual number giving each response is given. However, these figures should be treated with care, as confidence on small samples is low.

It is also important to note that the weather for the previous couple of weeks leading up to the tenant questionnaires had been particularly cold. This may or may not have an influence in the responses obtained from the tenants.

Dwelling Details

Dwelling Type:

	Type A	Type B
Control	3	3
Experimental	3	2

The control and experimental dwellings are evenly split between the two dwelling types, Type A and Type B.

Dwelling Position:

	End terrace	Mid terrace
Control	4	2
Experimental	3	2.

The dwellings are also evenly split between end and mid terraced dwellings.

Anomalies with other dwellings in field trial:

One of the control dwellings (Type A), and one of the experimental dwellings (Type B), have a heat meter installed. Control house F (Type B) has a gas cooker, whilst control house E (Type B) did not receive any airtightness measures.

Residence

How many people live in this dwelling ?

House	Adults	Children
A (Control)	1	
B (Control)	1	
C (Control)	2	2
D (Control)	2	1
E (Control)	2	4
F (Control)	1	
H (MVHR)	1	1
I (MVHR)	2	3
J (MVHR)	3	1
K (MVHR)	2	
L (MVHR)	1	1

How long have you lived in this dwelling ?

House	Length of time in this dwelling
A (Control)	18 months
B (Control)	10 months
C (Control)	almost 4 years
D (Control)	10 months
E (Control)	2.5 years
F (Control)	7 months
H (MVHR)	a couple of years
I (MVHR)	about 6 years
J (MVHR)	18 months
K (MVHR)	13 months
L (MVHR)	10 months

The first dwellings to be refurbished were completed in December 95 (some 13 months ago) and the second phase was completed in February 1996 (some 11 months ago). From the table above, it can be seen that 6 out of the 11 tenants (3 control and 3 experimental), lived in the field trial dwellings before they were refurbished by Derwentside District Council.

Before you moved into this dwelling, what type of dwelling did you previously live in?

	Bungalow	Terrace	Semi	Flat	Other
Control	1	4	0	1	0
Experimental	2	3	0	0	0

The most common house type which the tenants previously lived in was a terraced house, with 7 out of 11 tenants living in this house type. 3 of the tenants previously lived in a bungalow, and one tenant previously lived in a flat.

How do you feel about this dwelling compared to your previous dwelling ?

The majority of the residents interviewed in both the control and experimental group preferred their refurbished dwelling to the previous dwelling that they stayed in. The tenants described the refurbished dwelling as being “ideal”, “much improved”, “100 times better than the previous dwelling”, and, “a lot better”.

Consultation about refurbishment works

How do you feel about the refurbishment work that has been carried out on the dwelling ?

In general, the majority of the tenants were happy about the refurbishment work that had been carried out on the dwellings. However, 4 of the tenants did complain about the front and back doors of their dwelling being draughty. Out of these 4 tenants, 3 mentioned that when it was snowing, snow could be seen coming into the house through either the front or back door. In addition, the tenants from house E stated that they no longer use the front door of their house because they cannot get the door open.

2 of the tenants also complained that the windows of their dwellings were draughty. One of these tenants occupies house E, which **did not** receive the airtightness work. This proves that the injection of expanding polyurethane foam around the windows of the filed trial dwellings has had a positive effect.

One tenant, house J, was not happy that she didn’t get a choice as to which type of heating systems were installed in her dwelling. The tenant feels that this is unfair, because the tenants taking part in the Council’s second refurbishment programme, can choose which type of primary and secondary heating system that they want to have installed.

Heating system

What type of heating system did you have in your previous dwelling ?

	Coal/Coke	Oil	Gas	Electric		Other
Control	1		0	5	0	0
Experimental	3		1	1	0	0

	Central	Single point
Control	6	0
Experimental	5	0

Almost half of the tenants had had a gas-fired heating system, 4 had had a coke/coal-fired system, and one had had an oil-fired system. All of the systems had been central heating systems.

How do you feel about the heating system installed in your dwelling ?

All of the tenants stated that they "liked" the heating system installed in their dwelling, and they appeared to be very happy with it. The heating system was classed by the tenants as being "ideal", "champion", and "brilliant".

In house J, although the tenant likes the gas central heating system, she feels that the sitting room of her house is a lot cooler than it was when she had coke central heating. She believes that this is down to the grilles from the MVHR system. However, it is believed that this is unfounded, and the real reason can be attributed to the change from a coke to a gas-fired central heating system.

Has anyone ever offered you advice on the operation of the heating system installed in your dwelling ?

	Yes	No
Control	4	2
Experimental	5	0

The majority of the tenants, 9 out of 11, stated that they had received some form of advice relating to the operation of the heating system. Only 2 tenants, from the control group, stated that they had received no advice.

If Yes, what form did it take ?

	Council		University	Council+University
Control	2	1	1	
Experimental	3	1	1	

Of the tenants receiving advice, the majority of the tenants, 7 out of 9, stated that it came from a council employee showing them what to do. The advice received from the council mainly related to how to light and switch on and off the boiler, not how to operate the heating system. The other 2 tenants received advice from LMU only.

These results are somewhat surprising. In total, only 4 tenants claim to have received advice from LMU, although it is known that all of the tenants did receive a tenant advice sheet from LMU, which contained information on the operation of their central heating system.

How well do you feel that you understand the operation of the heating system installed in your dwelling ?

	Fully	Partly	Not at all
Control	4	2	0
Experimental	4	1	0

8 out of 11 of the tenants (73%) believed that they fully understood the operation of their heating system. Only 3 tenants believed that they could operate the system but did not understand it. Nobody did not understand how to use the heating system.

How do you control your central heating system ?

In almost all of the dwellings, 9 out of 11, the central heating system is mainly controlled using the on/off switch on the boiler. The remaining 2 tenants use the timer as the main way of controlling the heating. In 6 of the dwellings, the tenants claim that they do not use the timer at all. The thermostat is used in all of the dwellings to regulate the internal temperature, and it is also used as an on/off device for the central heating system.

Ventilation system (MVHR tenants)

How do you feel about the MVHR system installed in your dwelling ?

All of the tenants are generally happy with the MVHR system, with the majority of them hardly noticing that the MVHR system is even there. However, two of the tenants (house L and J) did voice some complaints about the MVHR system.

The tenant of house L stated that they have noticed a slight draught from the supply grilles of the MVHR system in their daughters bedroom upstairs. In addition to this, they mentioned that the noise of the system was a bit of a problem.

The tenant from house J mentioned that although they liked the MVHR system, they did feel that the sitting room of the house was a lot cooler than it was before, and they felt that this was due to the MVHR supply grilles. However, as mentioned earlier, it is more likely that this difference can be attributed to the change from a coke to a gas-fired central heating system.

Has anyone ever offered you any guidance or advice on the operation of the MVHR system installed in your dwelling ?

	Yes	No
ADM system	0	4
REGA system	1	0

All of the tenants, apart from the tenant of house H (REGA unit), stated that they had either not received any advice on the operation of the MVHR system or that they could not remember if they had received any advice.

If Yes, what form did it take ?

The tenant from H mentioned that they received verbal advice from the MVHR manufacturer (REGA) when they came to correctly install the system. The advice given by the MVHR manufacturer related to the use of the MVHR speed controller.

How well do you feel that you understand the operation of the MVHR system that has been installed ?

	Fully	Partly	Not at all
ADM system	0	2	1
REGA system	0	1	1

3 of the tenants believe that they can operate the MVHR system but do not understand it, whilst 2 of the tenants (one ADM, and one REGA system) feel that they do not understand the operation of the MVHR system. None of the tenants claimed to fully understand the operation of the MVHR system.

Do you keep the MVHR unit on constantly ?

	Yes	No
ADM system	3	0
REGA system	2	0

All of the tenants claim to keep the MVHR unit switched on constantly. This can be backed up by physical data from the dataloggers.

Do you use the boost switch/speed controller on the MVHR unit ?

	Yes	No
ADM system	0	3
REGA system	1	1

The only tenant that uses the boost switch/speed controller on the MVHR unit is the tenant in house I (REGA unit). In houses J, K and L (ADM units), the boost switch has been left at the ‘normal’ position, whilst in house H (REGA unit), the speed controller has been left on at about 1/3 of their total speed..

If Yes, how often and why ?

The tenant in house I only uses the speed controller when they are doing a lot of cooking, in order to remove kitchen smells and condensation.

What do you think of the MVHR system when it is in operation ?

Again, most of the tenants don't notice that the system is there. The majority of them also feel that the MVHR systems "do work" because they remove condensation and kitchen smells from the dwellings. In addition, a number of the tenants feel that they no longer have to open the windows in their dwellings as much for ventilation.

Do you feel that the MVHR unit is successful ?

	Yes	No
ADM system	3	0
REGA system	2	0

All of the tenants felt that the MVHR unit is successful.

If Yes, why ?

Most of the tenants feel that the unit removes condensation and kitchen smells. The tenant of house K (ADM unit) also feels that their house is no longer "stuffy", and they have noticed that the MVHR system removes the smell from aerosols, which the tenant uses for model making.

How would you categorise your MVHR system ?

	Very noisy	Fairly noisy	Not noisy
ADM system	0	1	2
REGA system	0	0	2

Initially the tenants felt that the MVHR unit was noisy, until they got used to it. Now they don't even notice it. Only one tenant (house L - ADM unit) still categorised the MVHR system as being fairly noisy.

	Very draughty	Fairly draughty	Not draughty
ADM system	0	2	1
REGA system	0	1	1

3 of the tenants (houses I, J, and L) feel that the MVHR system is fairly draughty whilst the other 2 tenants feel that the units are not draughty.

It is worth noting, that since the questionnaire was conducted, it was found that the ADM systems were commissioned with the fans operating at too high a speed. This problem has been rectified, and should result in a reduction in both the noise and draughts from these units.

In your opinion, does your MVHR system adequately remove the following ?

	Kitchen smells	Cigarette smoke	Condensation from cooking	Condensation from bathing
ADM system	1	1	0	1
REGA system	1	1	2	2

Almost all the tenants feel that the MVHR system adequately removes condensation from cooking and bathing, kitchen smells, and from those that smoke, cigarette smoke. Only one tenant (house J - ADM unit) felt that the MVHR system removed none of the above.

The relatively low scores to the above question could be explained by the fact that the tenants hardly notice that the MVHR systems are even there, making it difficult for the tenants to perceive if the MVHR unit is removing anything.

Do you open your windows when the MVHR system is operating ?

	Yes	No
ADM system	3	0
REGA system	2	0

All of the tenants have opened their windows at some point when the MVHR system is operating.

If Yes, why, for how long and how often ?

The main reasons for doing so are: for fresh air and ventilation; to "air" the rooms; and, when it gets too warm (mainly during the summer). Generally the tenants of the dwellings open their windows a couple of times a week for a few hours.

Ventilation system (Mechanical extract fan tenants)

How do you feel about the extract fans installed in your dwelling ?

All of the tenants are generally happy with the extract fans installed in their dwelling. The extract fans have been classed by the tenants as being "good", "great", and "a good thing".

Has anyone ever offered you any guidance or advice on the operation of the extract fans installed in your dwelling ?

	Yes	No
Control	1	5

Only one tenant stated that they had received advice on the operation of the extract fans.

If Yes, what form did it take ?

The advice received by the tenant came verbally from LMU, as well as in the form of a tenant advice sheet. the advice given related to how to operate the extract fans.

How well do you feel that you understand the operation of the extract fans that have been installed ?

	Fully	Partly	Not at all
Control	6	0	0

All of the tenants feel that they fully understand the operation of the extract fans.

Do you keep the extract fans on constantly ?

	Yes	No
Control	4	2

Only 2 of the tenants (houses B and F) state that they do not keep their extract fans powered on constantly.

If No, when do you switch them off ?

In house B, the kitchen extract fan has been switched off because the tenant doesn’t do very much cooking, and believes that he doesn’t need the fan. In house F, the tenant has switched off the upstairs bathroom extract fan because the fan seems to run when not required (i.e. the fan is operating but there is no sign of condensation or steam in the room). The tenant in this house only switches the bathroom fan on when it is required.

What do you think of the extract fans when the are operating ?

All of the tenants are happy with the extract fans when they are operating because they remove kitchen smells and condensation. The extract fans have been described by the tenants as being “very effective”, “very good”, “handy”, and “great”.

Do you feel that the extract fans are successful ?

	Yes	No
Control	6	0

All of the tenants feel that the extract fans are successful.

If Yes, why ?

Most of the tenants feel that the extract fans are successful because they come on automatically, and remove condensation and kitchen smells.

How would you categorise the extract fans ?

	Very noisy	Fairly noisy	Not noisy
Control		3	3

Half of the tenants feel that the extract fans are fairly noisy, whilst the other half feel that they are not noisy.

In your opinion, does the extract fans adequately remove any of the following ?

	Kitchen smells	Cigarette smoke	Condensation from cooking	Condensation from bathing
Control	4	2	6	5

Almost all of the tenants feel that the extract fans adequately remove condensation from cooking and bathing, and kitchen smells. Only 2 out of the 5 tenants in the control dwellings that smoke, felt that the fans adequately removed cigarette smoke.

The relatively high scores noted above, compared to those obtained for the experimental dwellings, may be explained because it is obvious to the tenants in the control dwellings when the fans are operating (due to their noise), and subsequently removing condensation, smells, etc. In the experimental dwellings, tenant perception is generally lower, because there is no way in which the tenants can perceive the system operating to remove smells, etc.

Do you open your windows when the extract fans are operating ?

	Yes	No
Control	2	4

Only 2 of the tenants open their windows when the extract fans are operating. The rest of the tenants feel that they do not have to.

If Yes, why, for how long and how often ?

The 2 tenants only open their windows when the extract fans are on, wheat they are cooking to get rid of kitchen smells and condensation, or if there is a lot of steam when they are washing or bathing.

Window/door opening pattern

How often do you open your windows ?

The majority of the tenants frequently open their windows for a number of reasons. Only 3 of the tenants (two control, and one experimental) never or only very rarely open their windows.

For what reasons ?

The main reason is to "air" the rooms, but they are also opened to get rid of condensation, kitchen smells, and cigarette smoke.

In the last week, have you opened your bedroom windows at night ?

	Yes	No
Control	2	4
Experimental	1	4

The majority of the tenants, 8 out of 11, do not open their bedroom windows at night. Only 3 of the tenants (two control, and one experimental) do open their bedroom windows at night.

If Yes, how often and why ?

The bedroom windows are opened for fresh air and because it was too hot in the two control houses, whilst in the experimental house the bedroom window was opened only because it was too hot.

In the last week have you opened any of your other windows ?

	Yes	No
Control	4	2
Experimental	4	1

The majority of the tenants, 8 out of 11, have opened other windows in their house within the last week. Only 3 of the tenants (two control, and one experimental) have not opened any of their other windows within the last week.

If Yes, which ones and why ?

A number of different windows are opened in each of the dwellings mainly to “air” the rooms, but they are also opened to get rid of condensation, kitchen smells, and cigarette smoke.

Do you use the trickle ventilators ?

	Yes	No
Control	4	2
Experimental	2	3

6 out of 11 tenants stated that they do use the trickle ventilators in their dwelling. Out of these houses 4 of them are control dwellings, and 2 are experimental dwellings.

If Yes, which ones and why ?

In the control dwellings, the majority of the tenants have all of their trickle ventilators open all of the time mainly for ventilation. They are also sometimes used to get rid of condensation.

In the experimental dwellings the trickle ventilators are used less frequently. In house I they are used in the bedroom and living room to let in fresh air, whilst in house K they are used mainly in the summer, and rarely in the winter, for ventilation. It should be noted that the tenant in house K is a keen model maker who uses a lot of aerosols for painting, etc.

In the last week, have you opened the trickle ventilators on your bedroom windows at night ?

	Yes	No
Control	4	2
Experimental	0	5

Only 4 out of 11 tenants stated that they opened the trickle ventilators in their bedrooms within the last week, and all of these tenants live in control dwellings.

If Yes, how often and why ?

The bedroom trickle ventilators are open in these dwellings most of the time for ventilation.

In the last week, have you kept your bedroom door open at night when you are asleep?

	Yes	No

Control	3	3
Experimental	4	1

7 out of 11 of the tenants keep their bedroom door open at night when they are asleep. 3 of these tenants live in control dwellings, whilst 4 of the tenants live in experimental dwellings.

If Yes, by approximately how much ?

	Just open	Half open	Fully open
Control	0	1	2
Experimental	1	1	2

Out of the tenants who leave their door open at night, most of them leave it fully open.

Condensation and mould growth

Did you have any problems in your previous dwelling with condensation and mould ?

	Yes	No
Control	5	1
Experimental	1	4

6 of the tenants had experienced problems with condensation and mould in their previous dwelling. 5 out of the 6 who experienced these problems, live in control dwellings.

The difference between these two groups may be explained by different behaviour patterns, however, further research will be required to determine this.

If Yes, what sort of problems ?

	Condensation	Mould	Condensation & mould
Control	0	2	3
Experimental	0	0	1

Most of these tenants had problems with both condensation and mould in their previous dwelling.

Where did these problems occur ?

Most of these tenants had problems with condensation forming on the windows, and mould forming on the walls of their previous dwellings.

Have you had any problems with condensation and mould growth since the refurbishment work took place ?

	Yes	No
Control	3	3
Experimental	3	2

6 of the tenants stated that they were getting condensation on the windows of their dwelling after the refurbishment work had been undertaken. Out of these 6 tenants, 3 were from the control group and 3 were from the experimental group.

Only one of the tenants (house C) stated that they had had problems with mould and condensation in their dwelling since the refurbishment took place.

If Yes, what sort of problems ?

The condensation in the control dwellings was occurring when the tenants were drying clothes on the radiators in the house, when they were cooking, and if they were washing or bathing. In the experimental dwellings (house J and L), the condensation was mainly occurring on the kitchen window when the tenants were cooking. This was probably occurring because neither of these tenants use the boost switch on their MVHR system.

In house C, condensation and mould had occurred in the bathroom and downstairs cloakroom of the dwelling. However, the mould and condensation in these areas had been present before the tenants moved into the dwelling, and had been caused by a number of pipe bursts during the refurbishment work.

Have you taken any measures to rectify these problems ?

	Yes	No
Control	3	0
Experimental	1	2

4 out of the 6 tenants who reported problems with condensation have taken measures to rectify these problems.

If Yes, what measures have you taken ?

The measures taken by the tenants mainly involve wiping the windows, and opening the windows and the trickle vents when the condensation occurs. In house C, the council and the tenant washed down the walls where the mould had occurred with a fungicidal wash and bleach.

Occupancy

How many people are in the house during the day ?

House	No. of people in dwelling
A (Control)	Nobody
B (Control)	1
C (Control)	4
D (Control)	2
E (Control)	1
F (Control)	1
H (MVHR)	1
I (MVHR)	4
J (MVHR)	2
K (MVHR)	Nobody
L (MVHR)	2

On average, how long are they in for ?

House	Length of time in dwelling
A (Control)	Thur night to Sun tea time
B (Control)	Most of the day, every day
C (Control)	Most of the day, every day
D (Control)	Most of the day, every day
E (Control)	Most of the day, every day
F (Control)	Most of the day, every day
H (MVHR)	Half of the day, every day
I (MVHR)	Most of the day, every day
J (MVHR)	Half of the day, every day
K (MVHR)	Mornings/Evenings, every day
L (MVHR)	Most of the day, every day

Generally, how many people sleep in each room at night ?

House	Master bed	Bedroom 2	Bedroom 3
A (Control)	1		
B (Control)	1		
C (Control)	2	2	
D (Control)	3		
E (Control)	2	3	1
F (Control)	1		
H (MVHR)	1+1	1	
I (MVHR)	3	1	1
J (MVHR)	2	1	1
K (MVHR)	1	1	
L (MVHR)	2		

HEALTH

Have you suffered from any health problems in the last few months ?

	Yes	No
Control	0	6
Experimental	0	5

None of the tenants of the field trial dwellings have suffered any health problems in the last few months.

Does anyone in the house smoke ?

	Yes	No
Control	5	1
Experimental	4	1

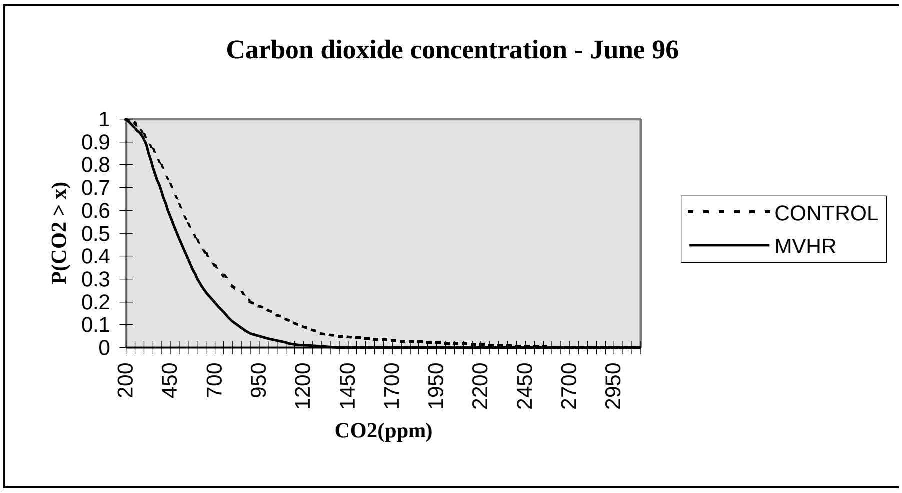
Nobody in the house smokes in only 2 of the field trial dwellings..

APPENDIX 6

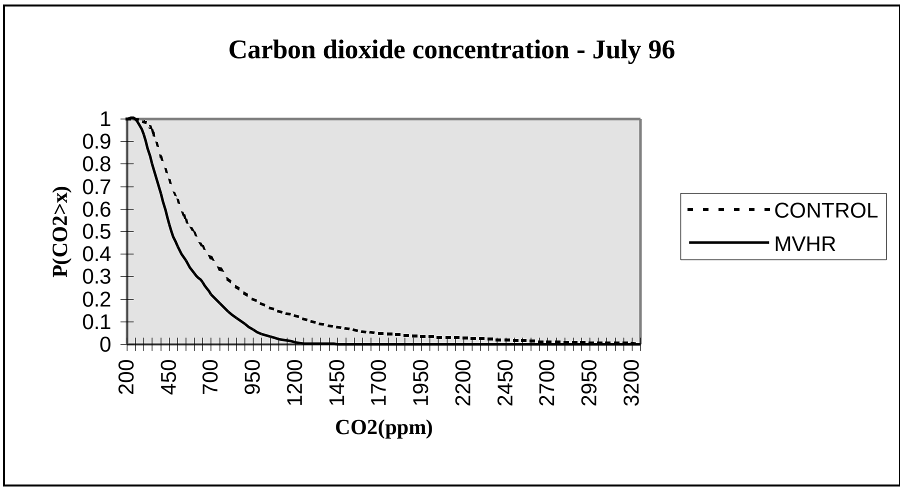
INDOOR AIR QUALITY ANALYSIS

A6.1 BEDROOM DATA ANALYSIS

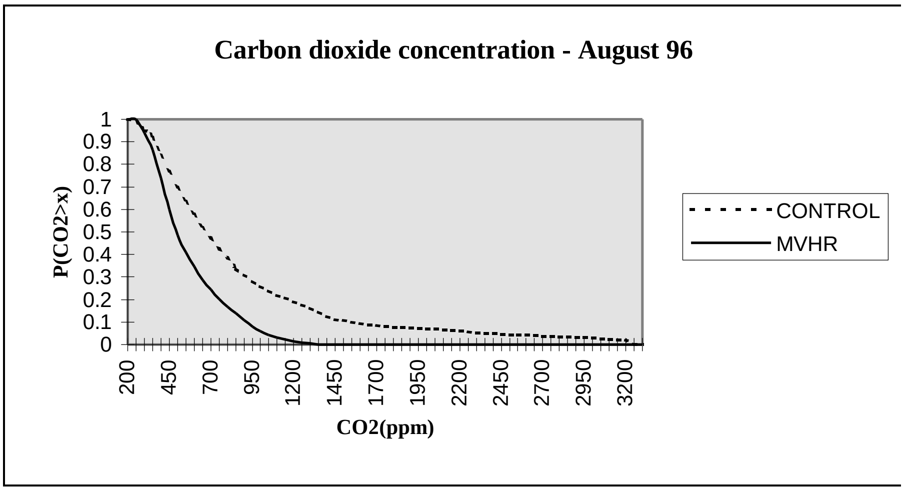
A6.1.1 Bedroom CO_2 concentration



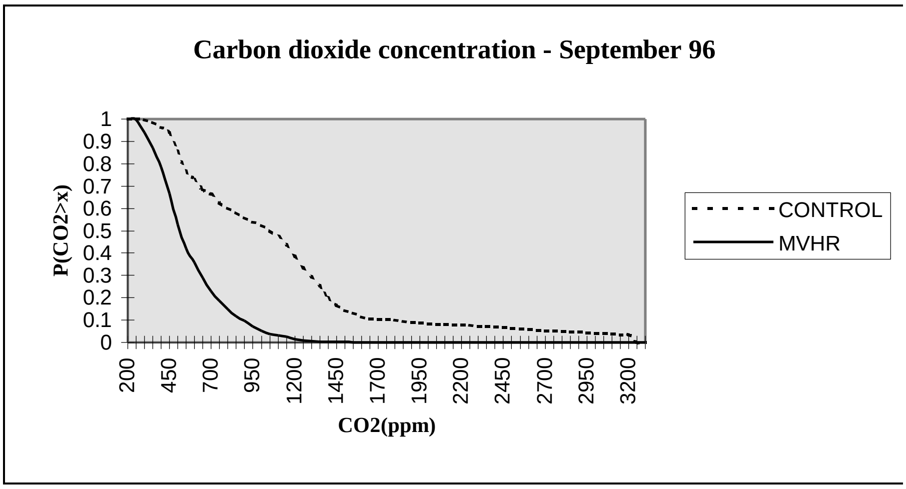
Graph 6.1



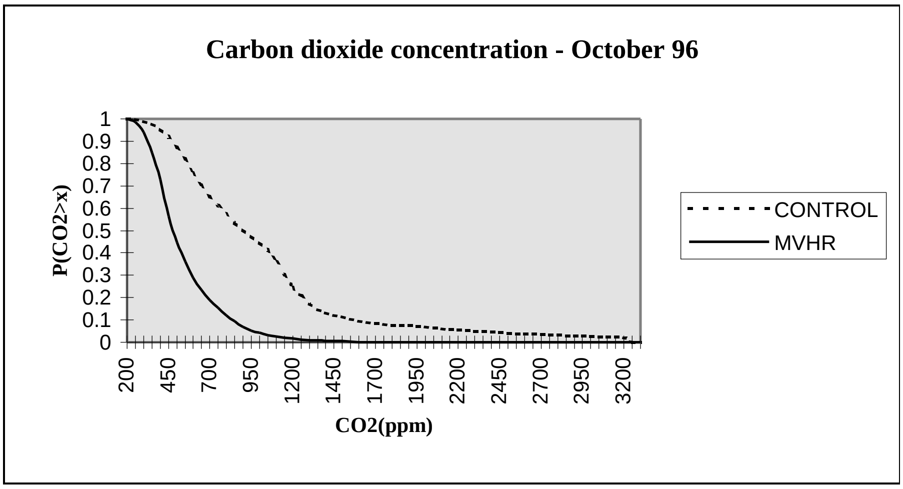
Graph 6.2



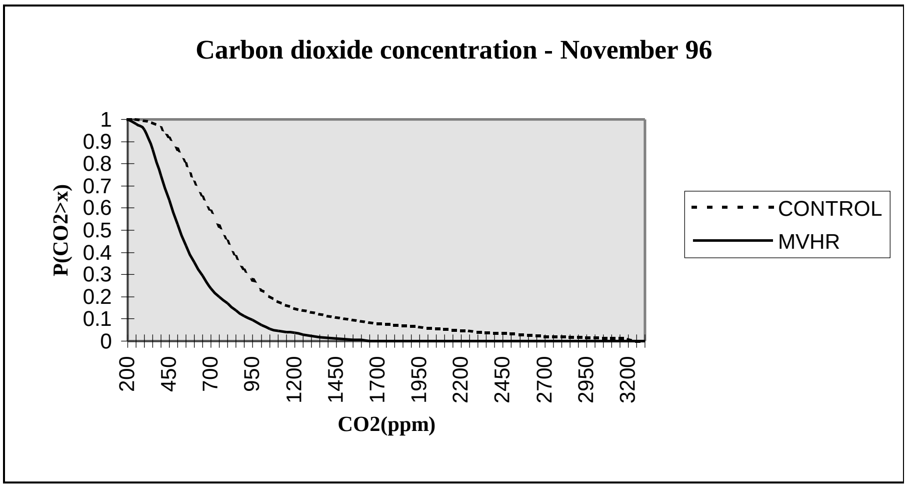
Graph 6.3



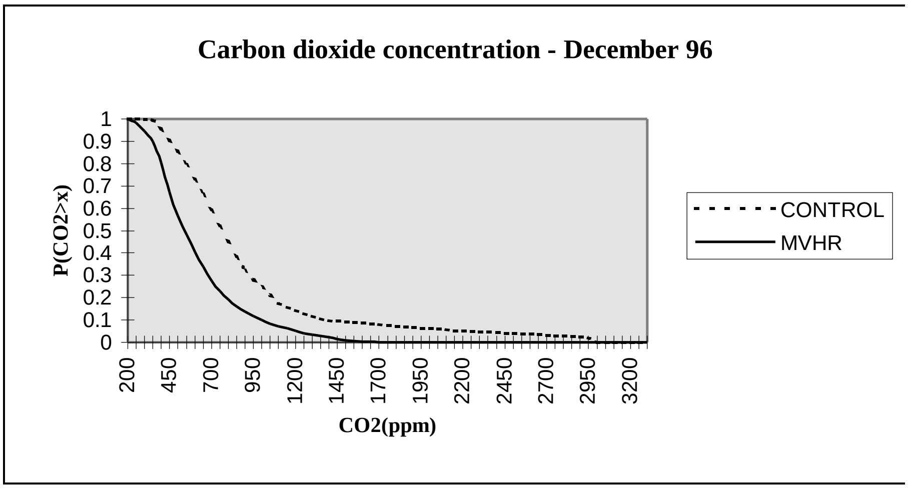
Graph 6.4



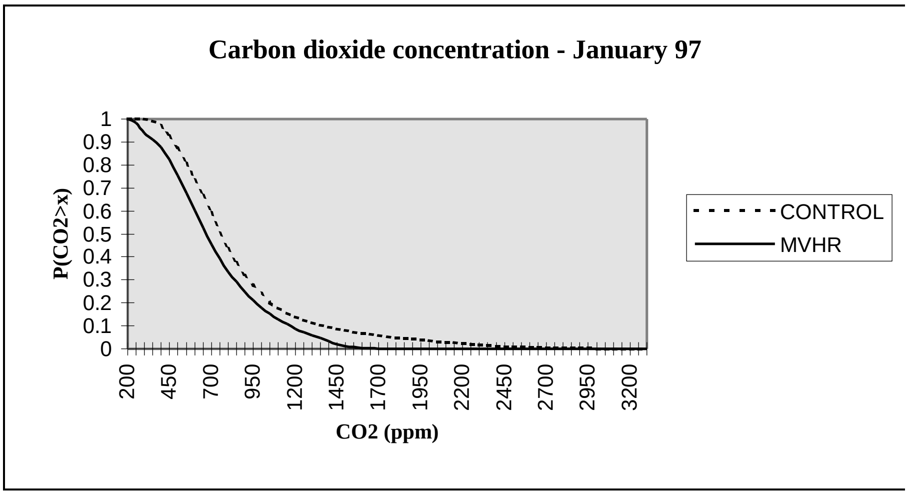
Graph 6.5



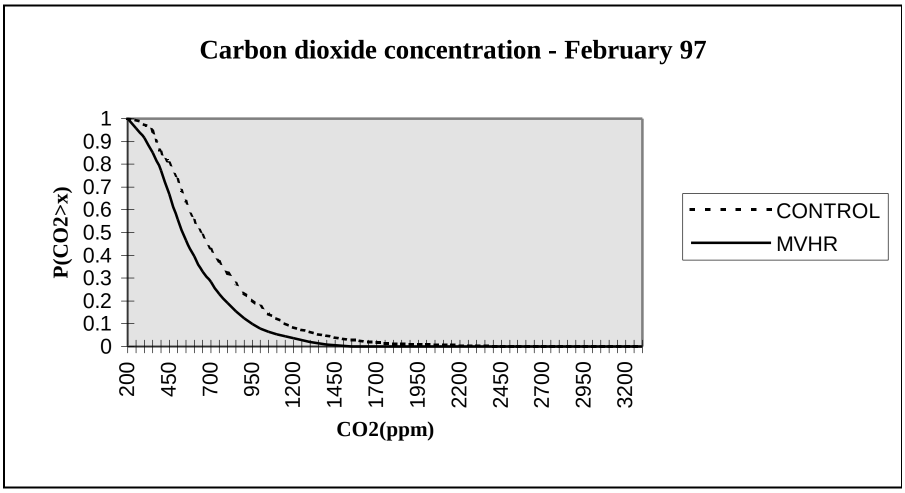
Graph 6.6



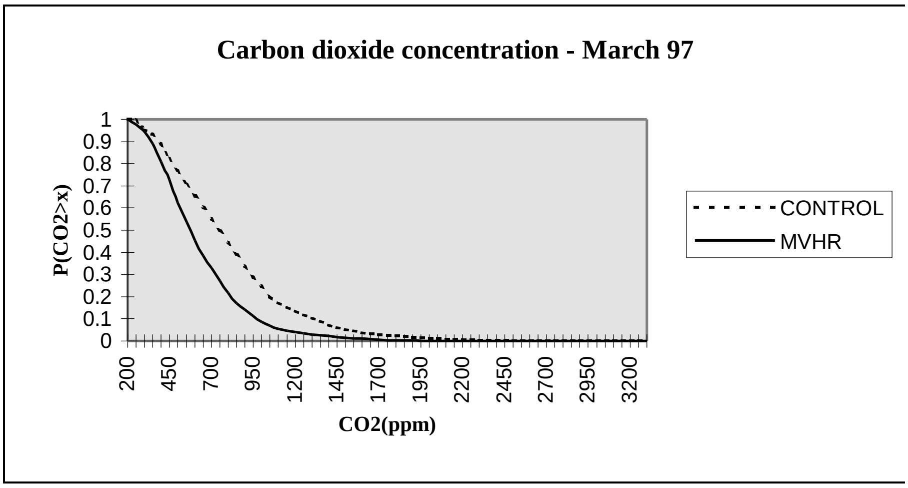
Graph 6.7



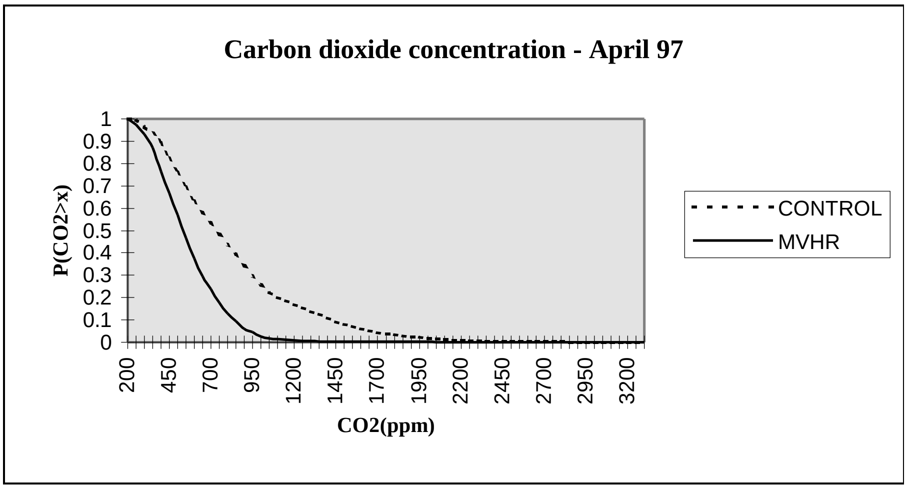
Graph 6.8



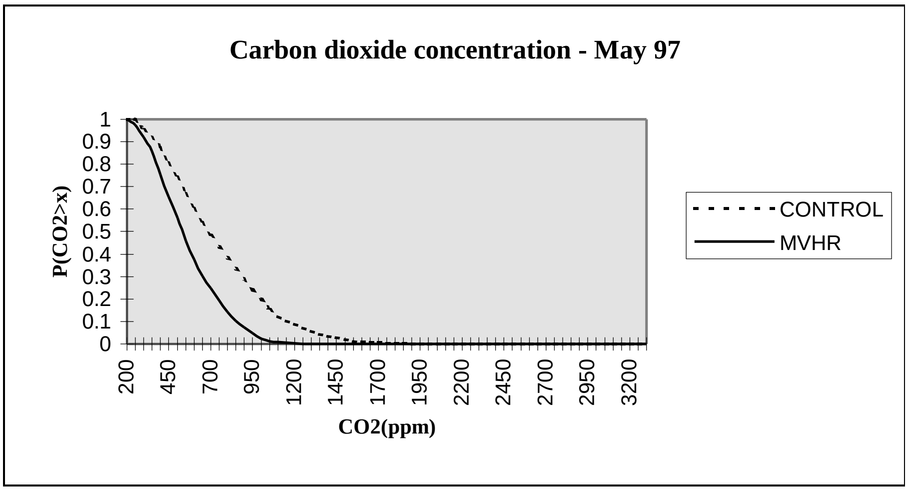
Graph 6.9



Graph 6.10

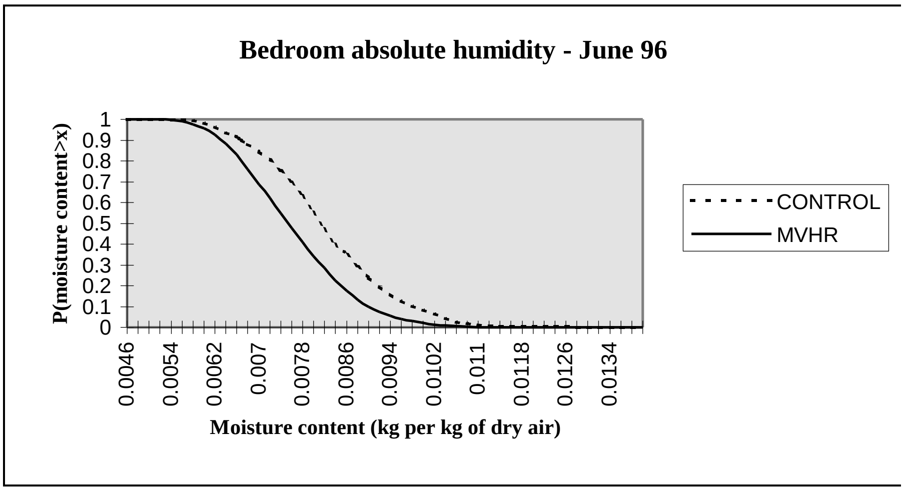


Graph 6.11

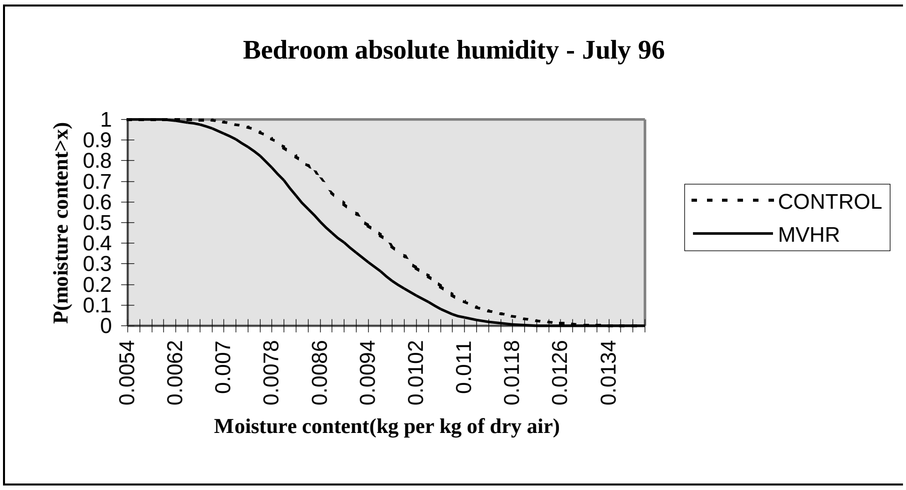

Carbon dioxide concentration - May 97
P(CO2>x)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
200
450
700
950
1200
1450
1700
1950
2200
2450
2700
2950
3200
CO2(ppm)
CONTROL
MVHR

Graph 6.12

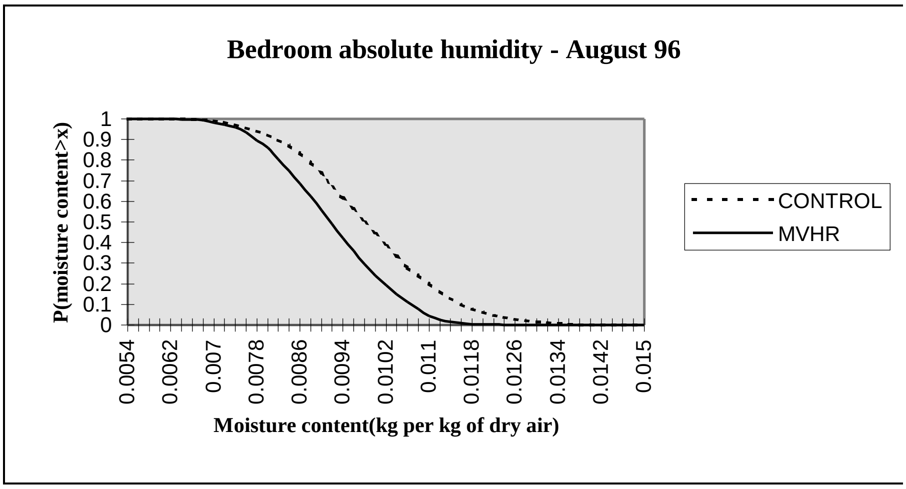
A6.1.2 Bedroom absolute humidity



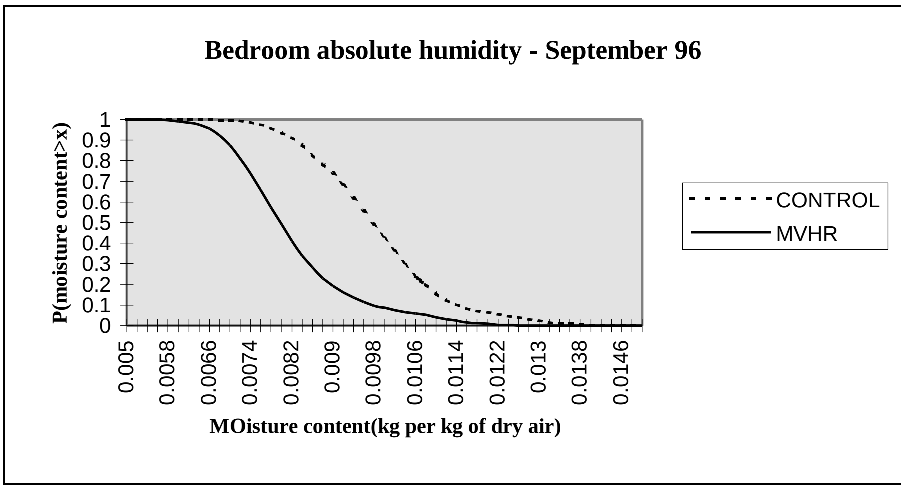
Graph 6.13



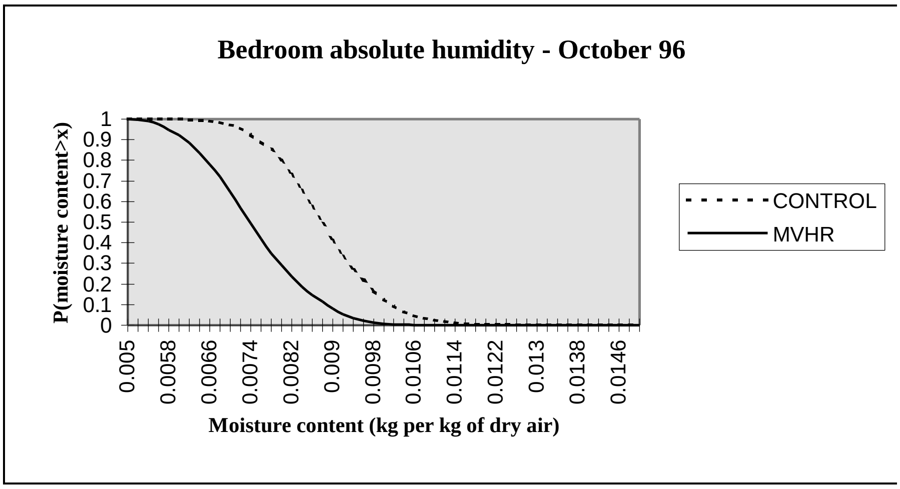
Graph 6.14



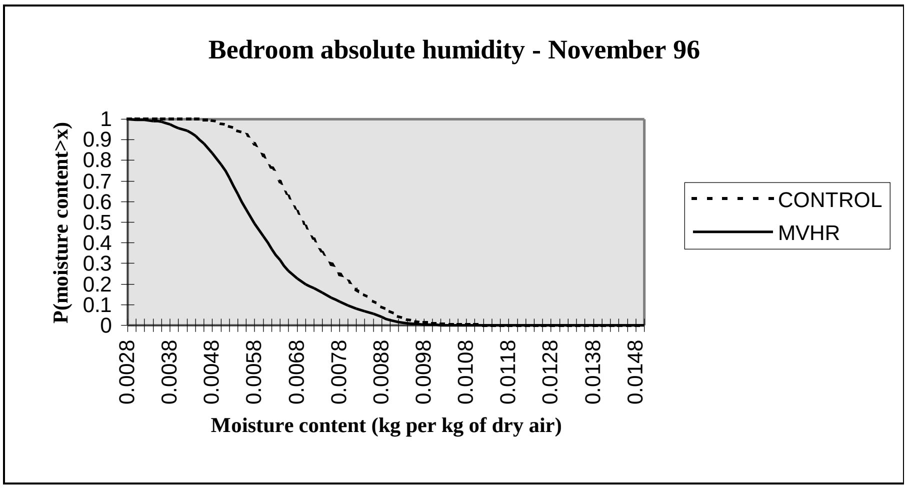
Graph 6.15



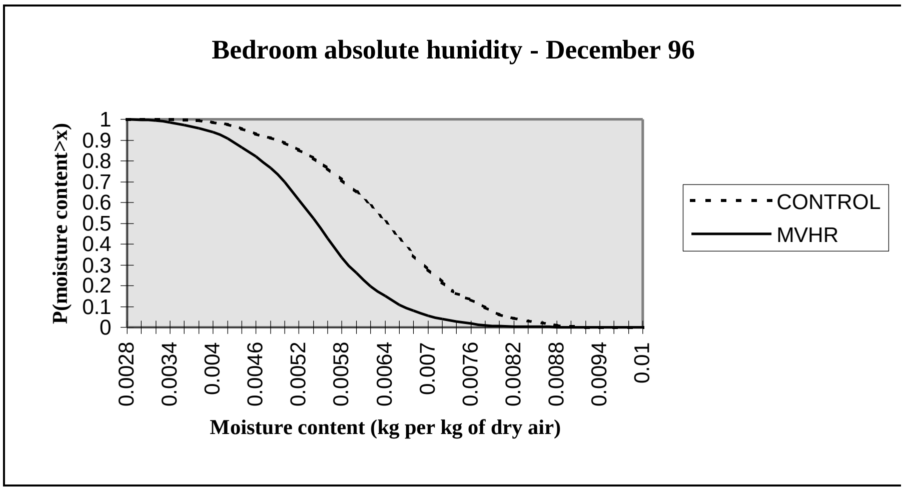
Graph 6.16



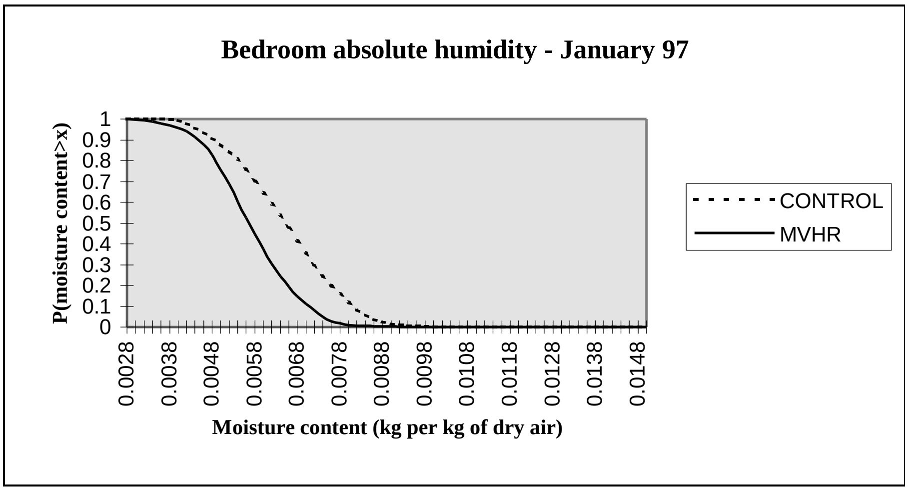
Graph 6.17



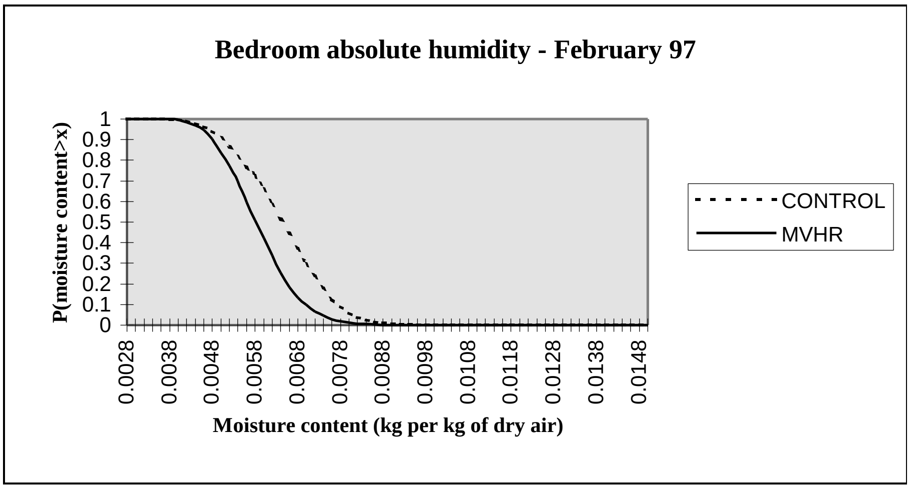
Graph 6.18



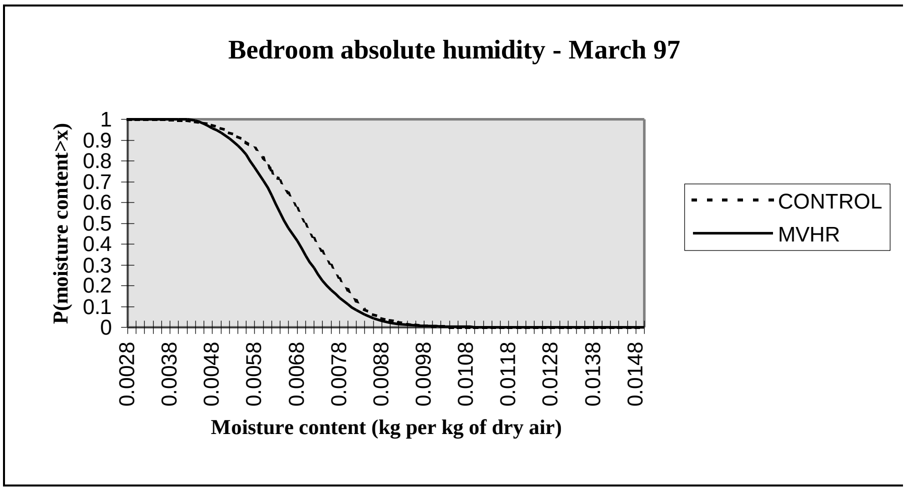
Graph 6.19



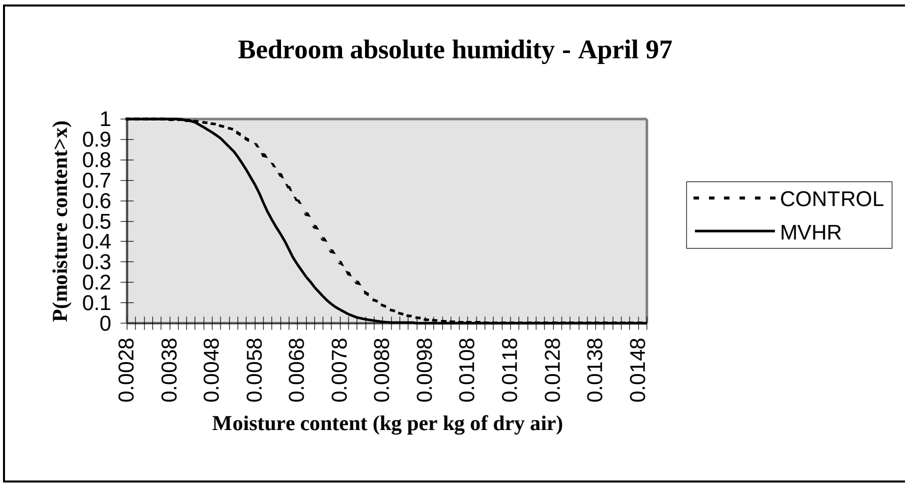
Graph 6.20



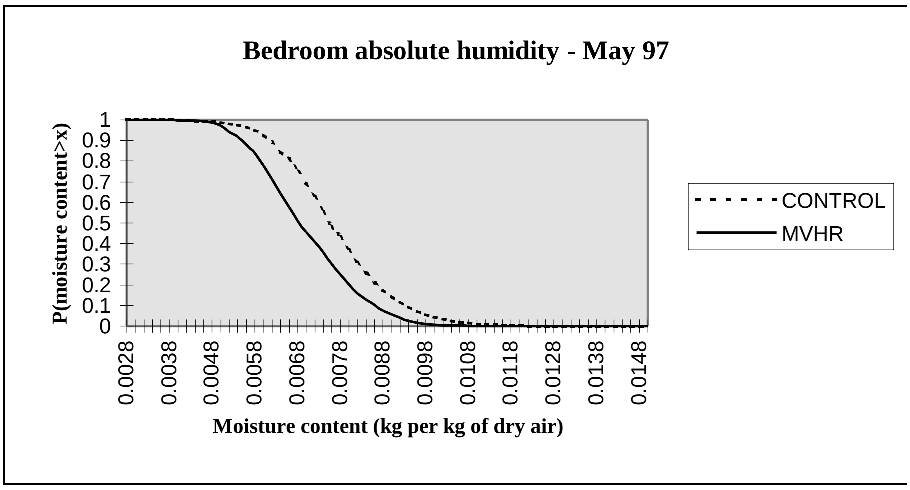
Graph 6.21



Graph 6.22

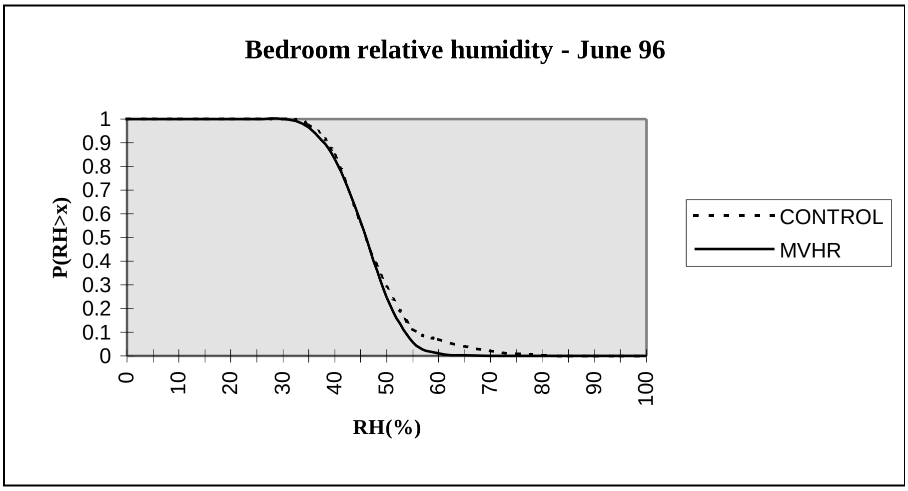


Graph 6.23

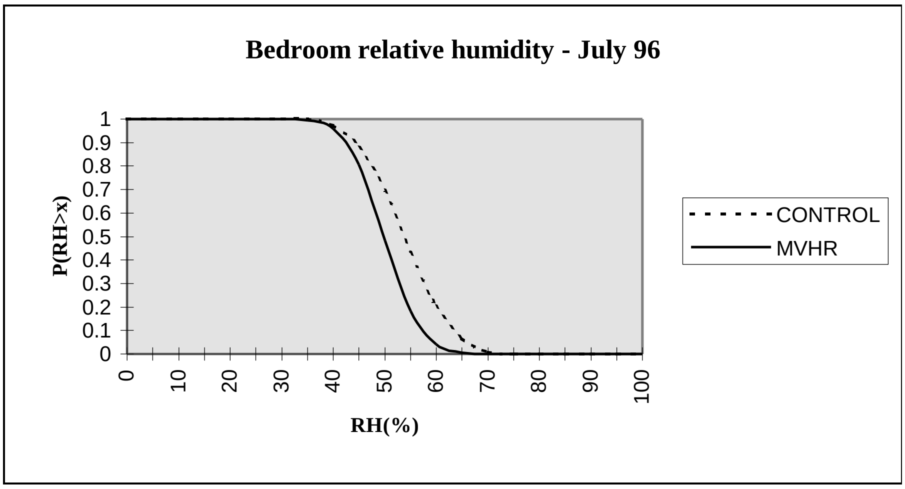


Graph 6.24

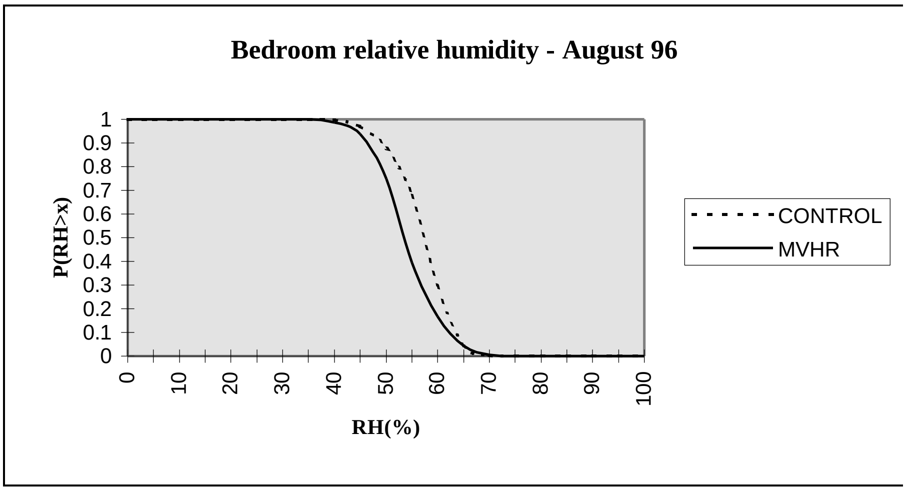
A6.1.3 Bedroom relative humidity



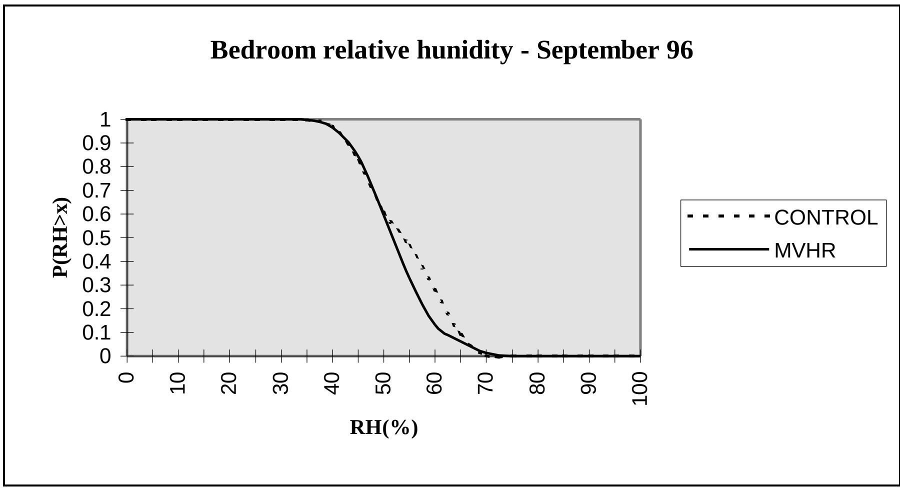
Graph 6.25



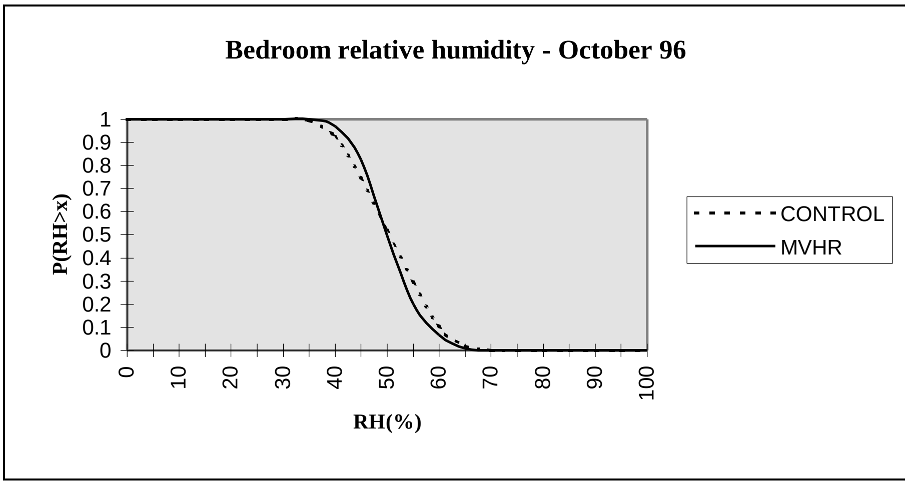
Graph 6.26



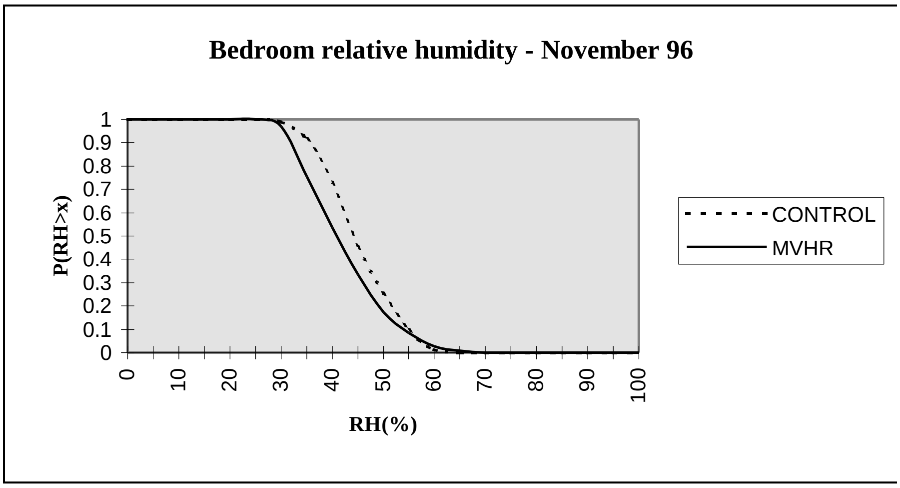
Graph 6.27



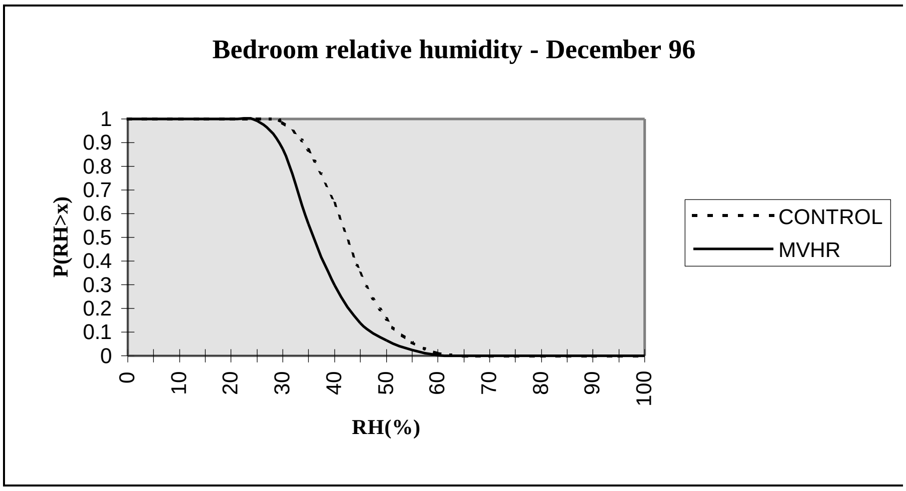
Graph 6.28



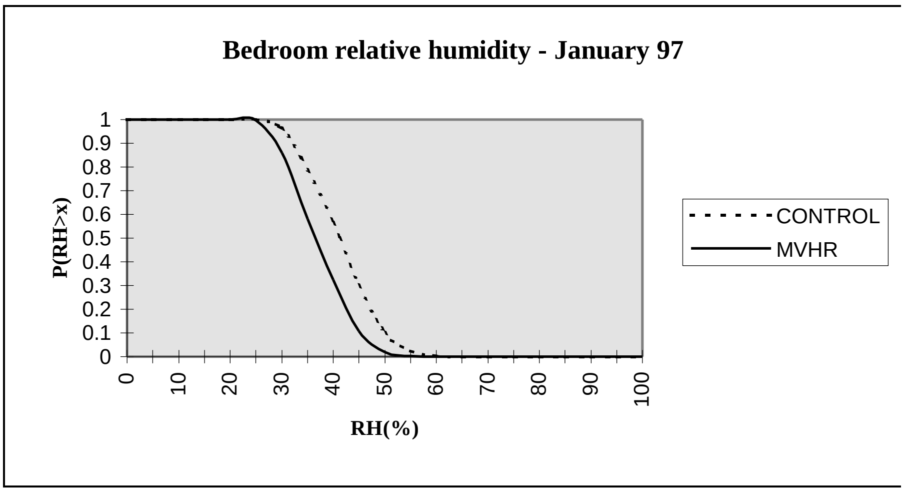
Graph 6.29



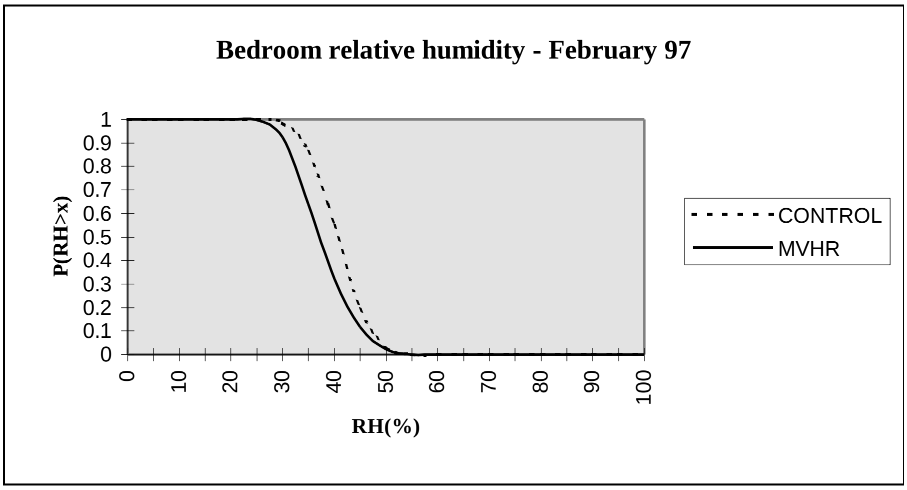
Graph 6.30



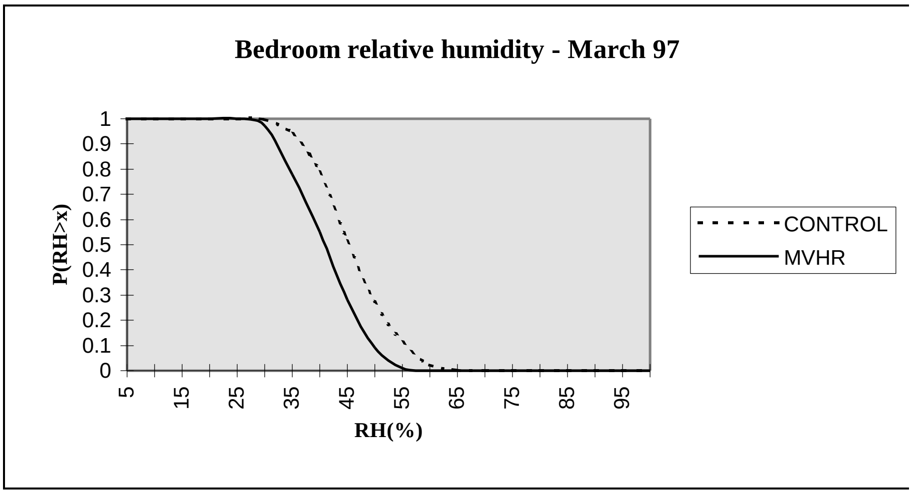
Graph 6.31



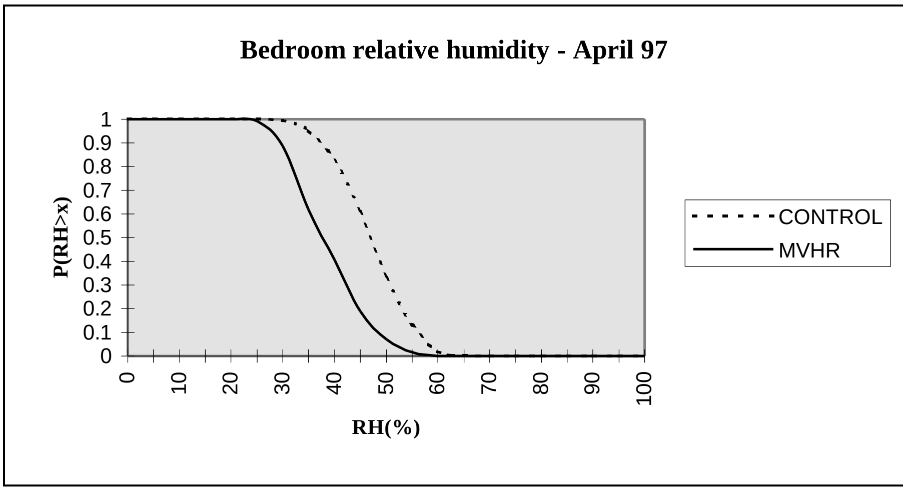
Graph 6.32



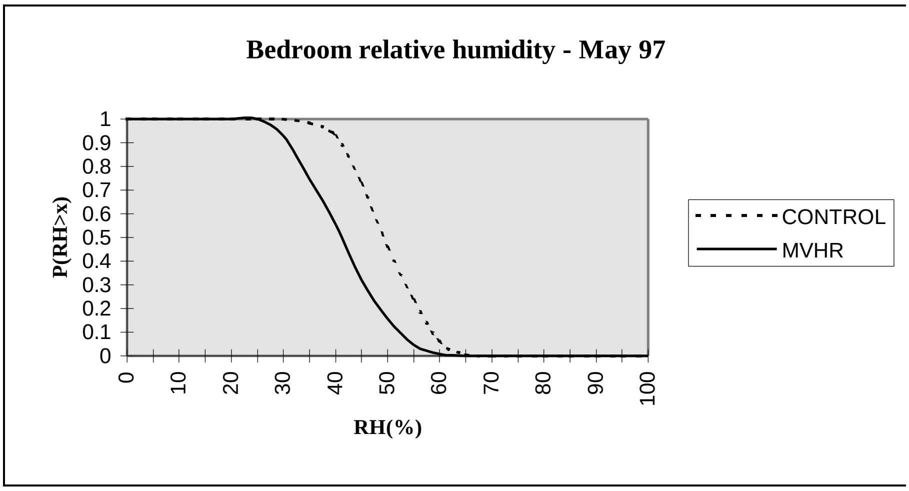
Graph 6.33



Graph 6.34



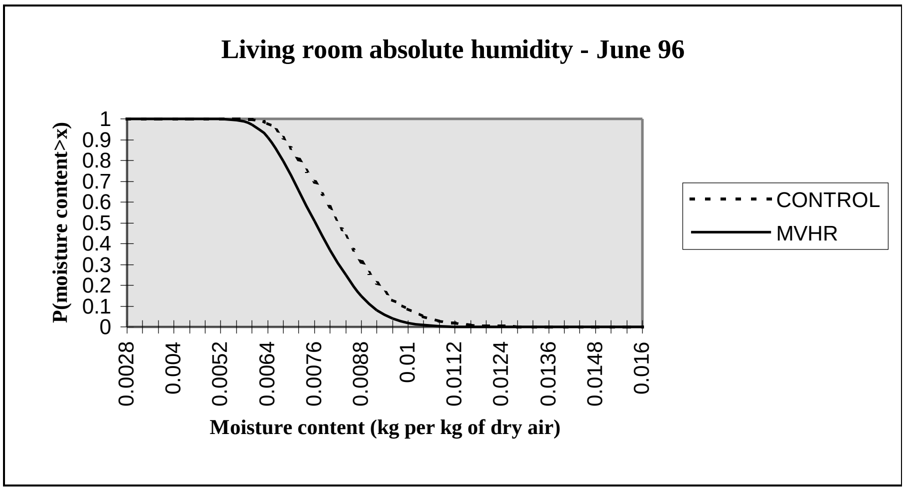
Graph 6.35


Bedroom relative humidity - May 97
P(RH>x)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
RH(%)
CONTROL
MVHR

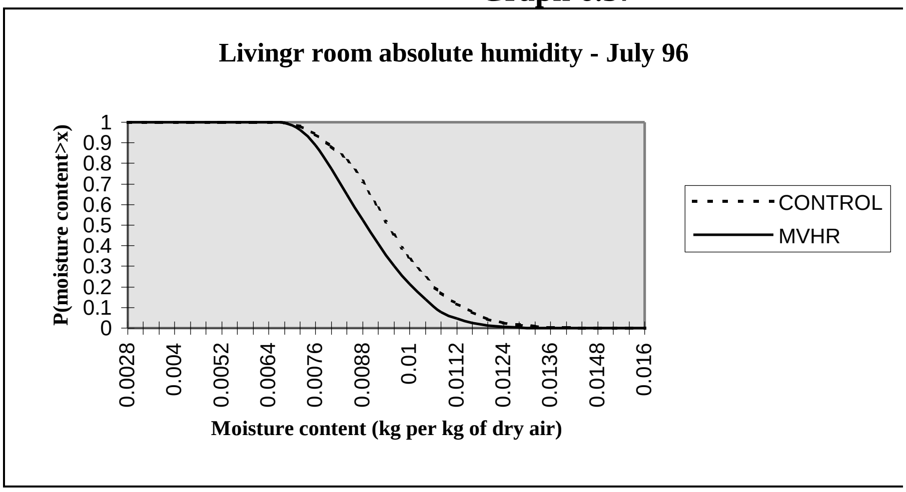
Graph 6.36

A6.2 LIVING ROOM DATA ANALYSIS

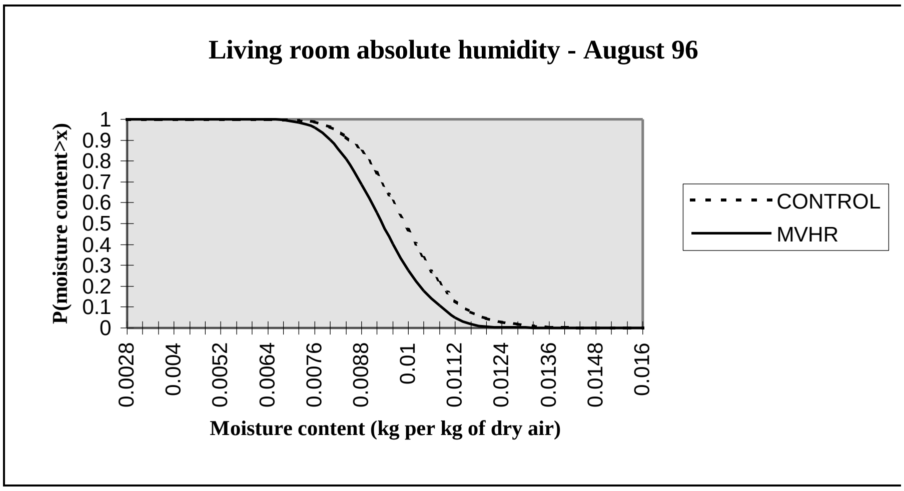
A6.2.1 Living room absolute humidity



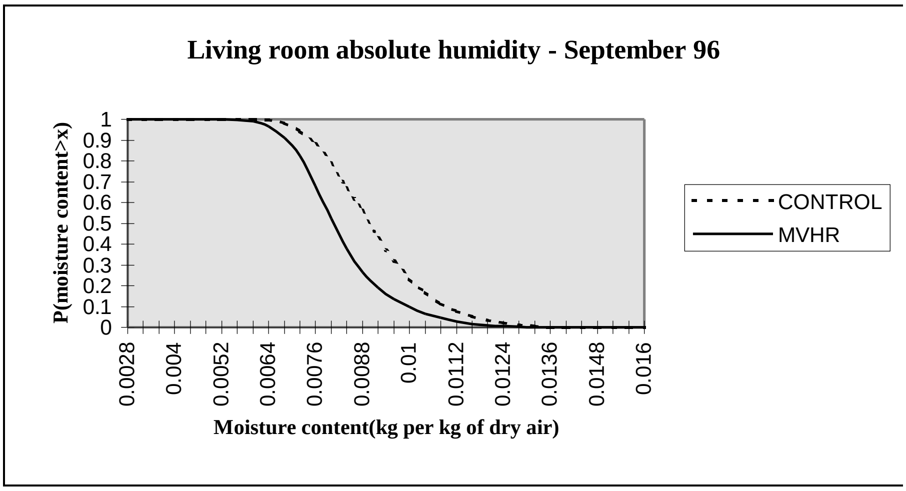
Graph 6.37



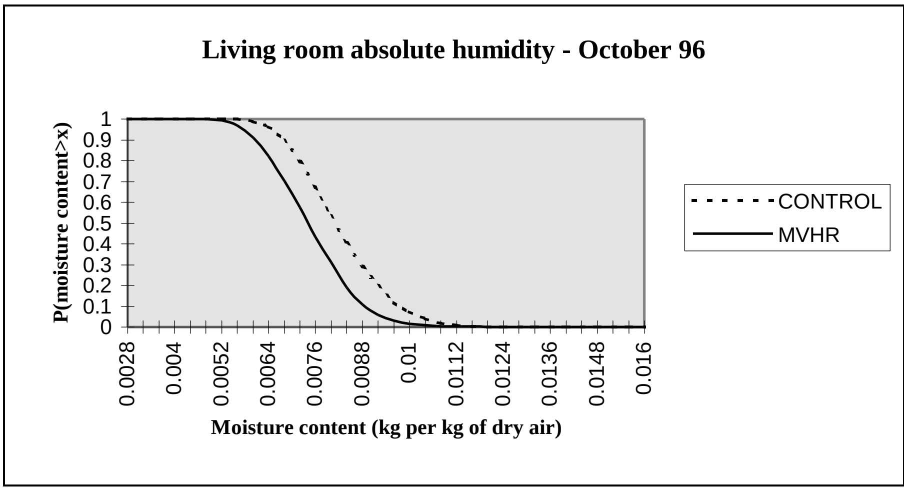
Graph 6.38



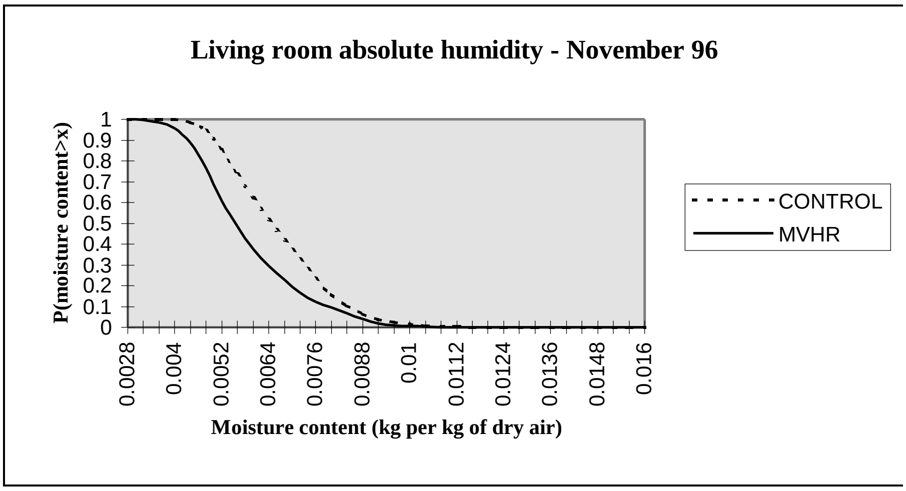
Graph 6.39



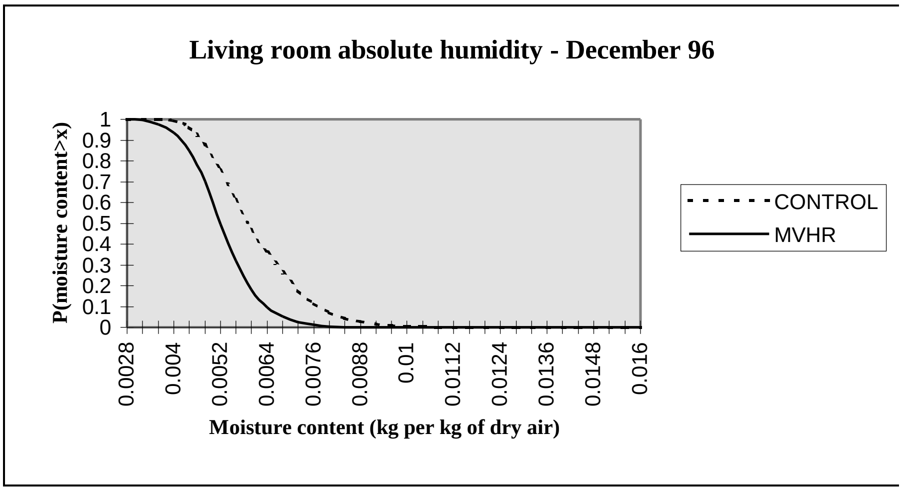
Graph 6.40



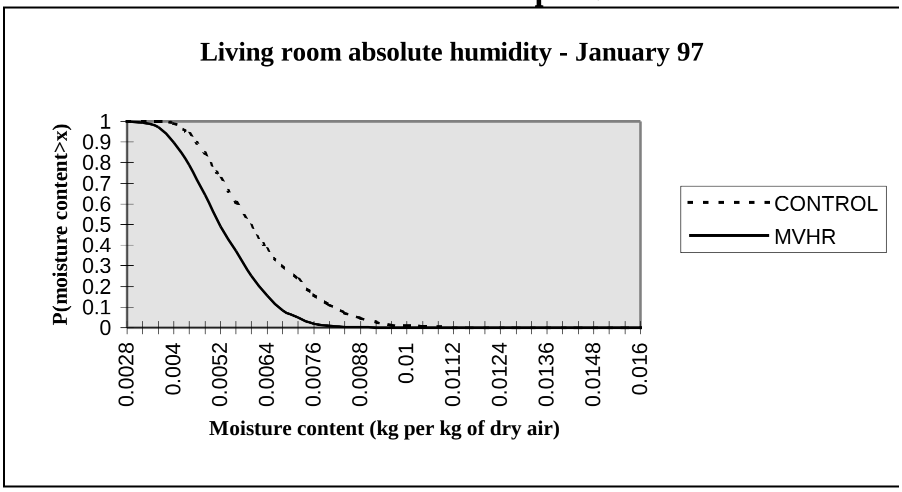
Graph 6.41



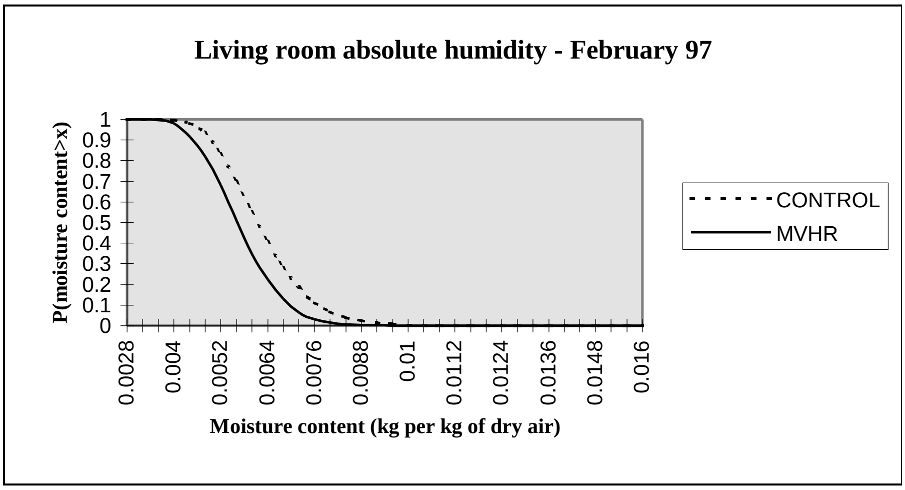
Graph 6.42



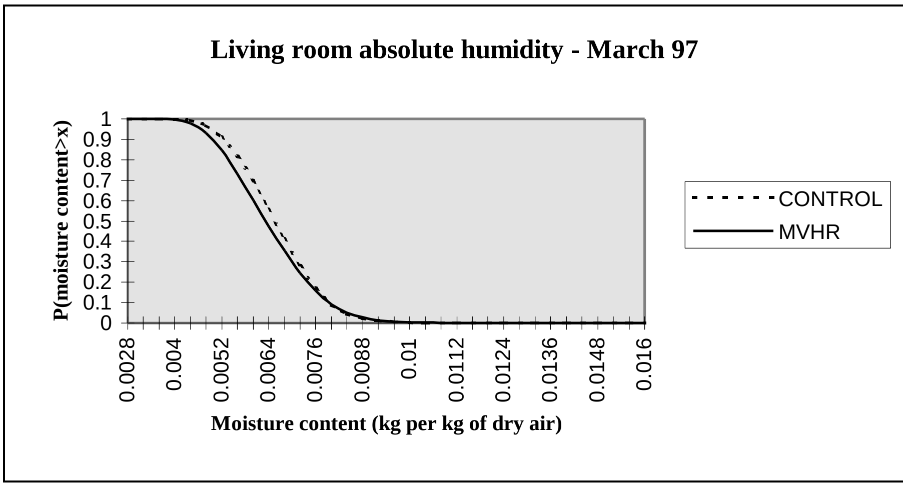
Graph 6.43



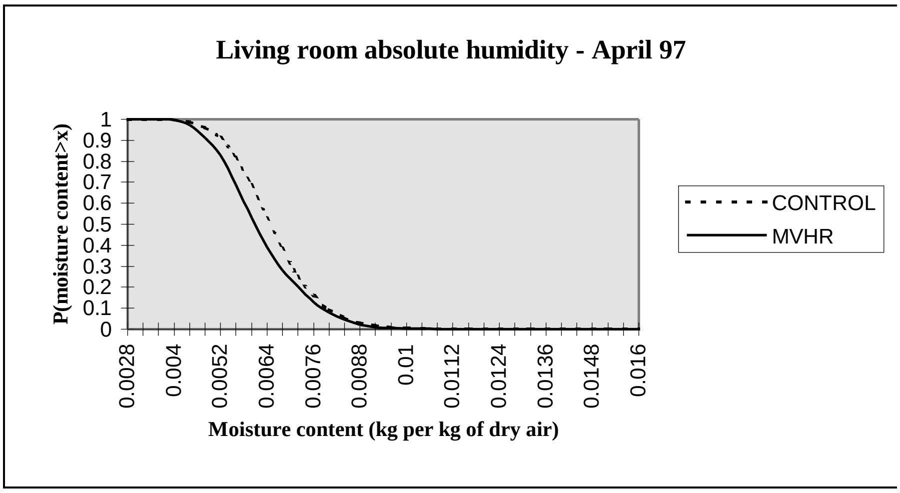
Graph 6.44



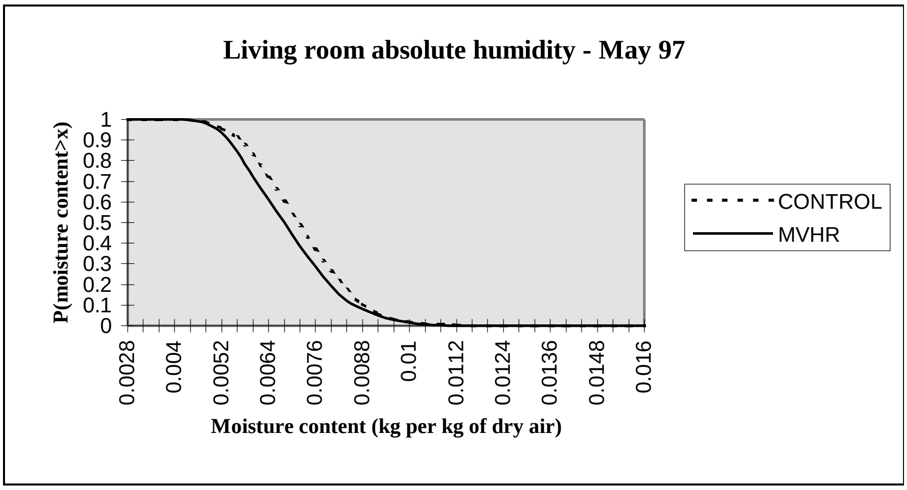
Graph 6.45



Graph 6.46

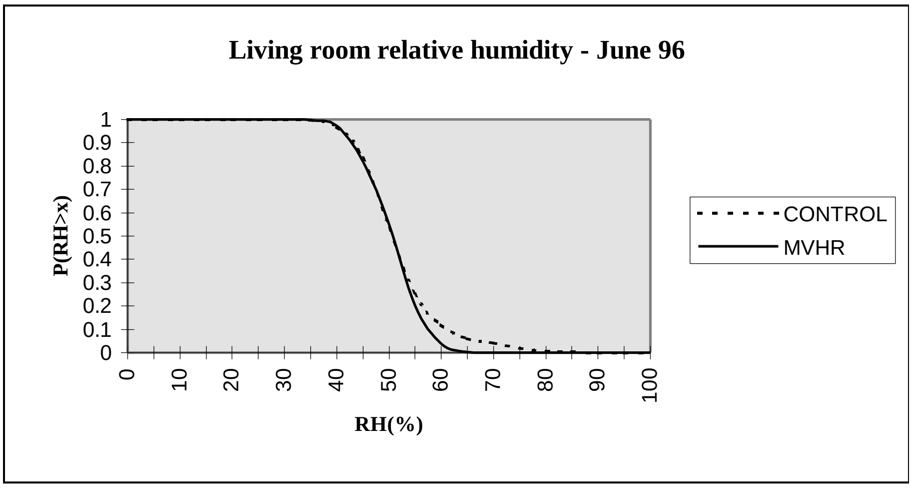


Graph 6.47

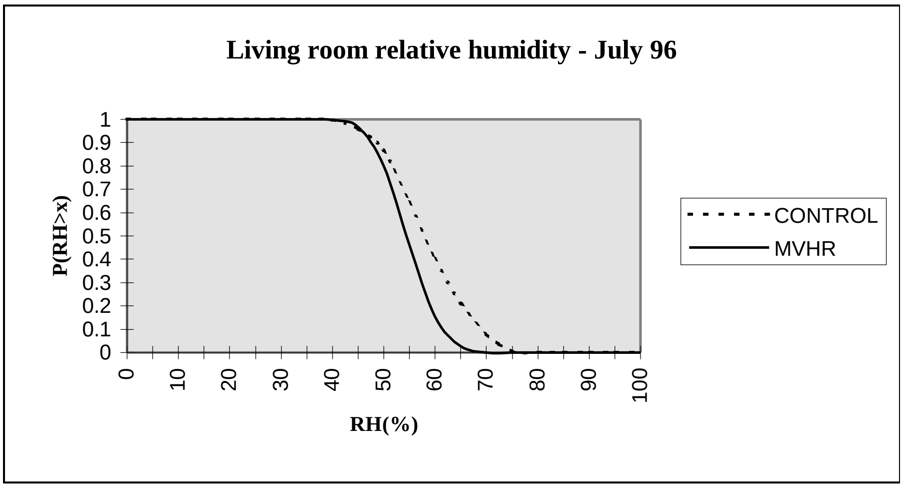

Living room absolute humidity - May 97
P(moisture content>x)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0028
0.004
0.0052
0.0064
0.0076
0.0088
0.01
0.0112
0.0124
0.0136
0.0148
0.016
Moisture content (kg per kg of dry air)
CONTROL
MVHR

Graph 6.48

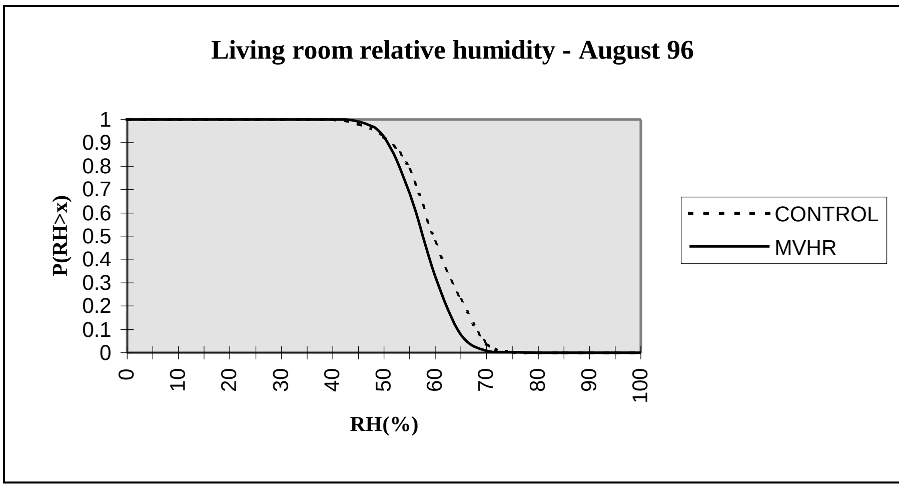
A6.2.2 Living room relative humidity



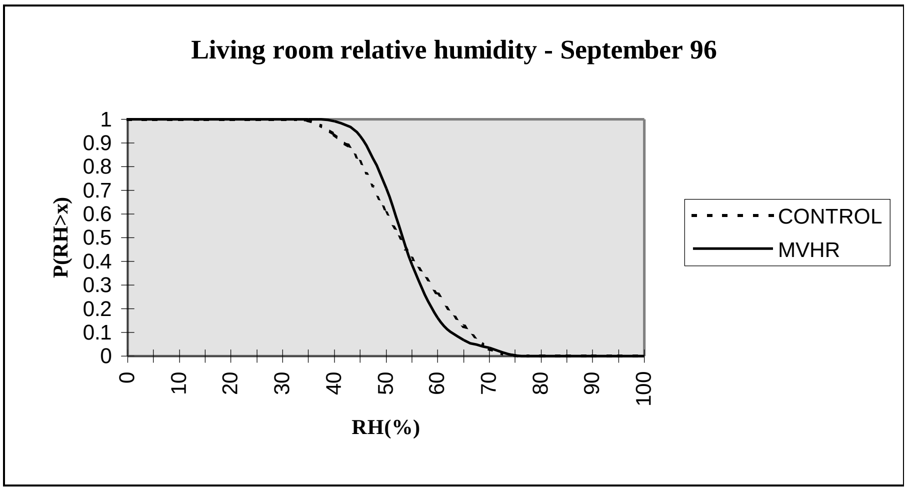
Graph 6.49



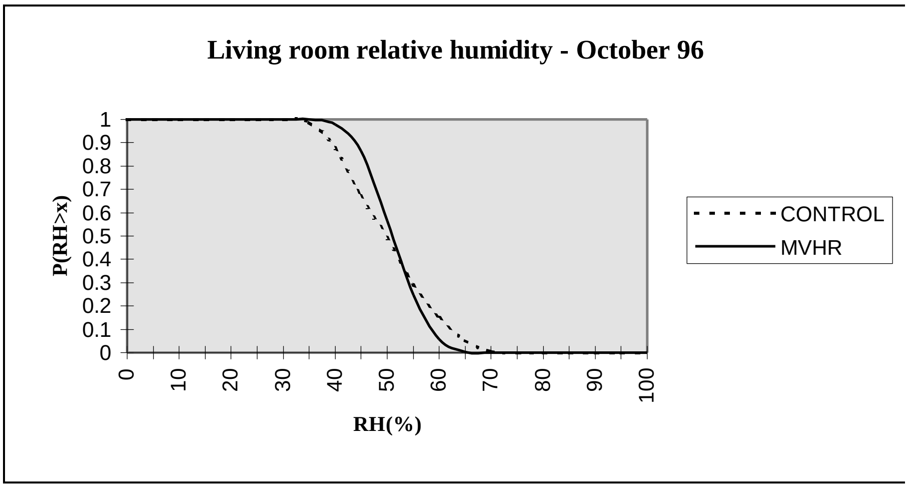
Graph 6.50



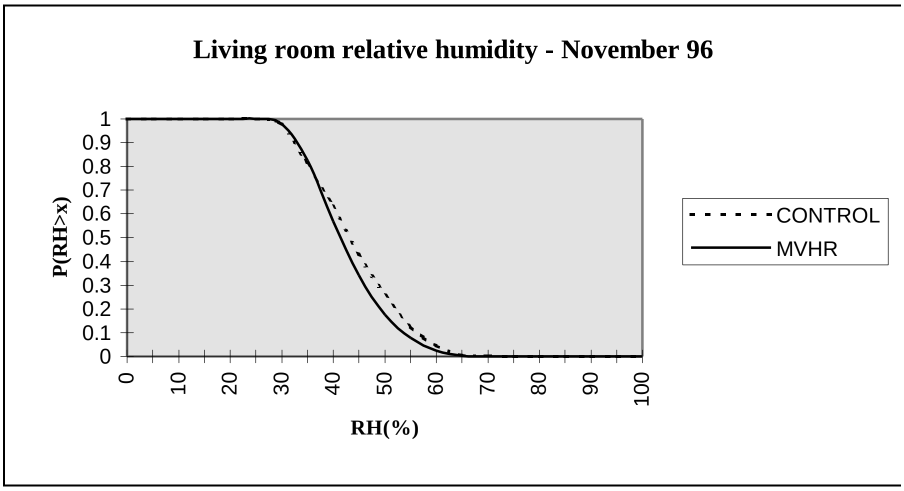
Graph 6.51



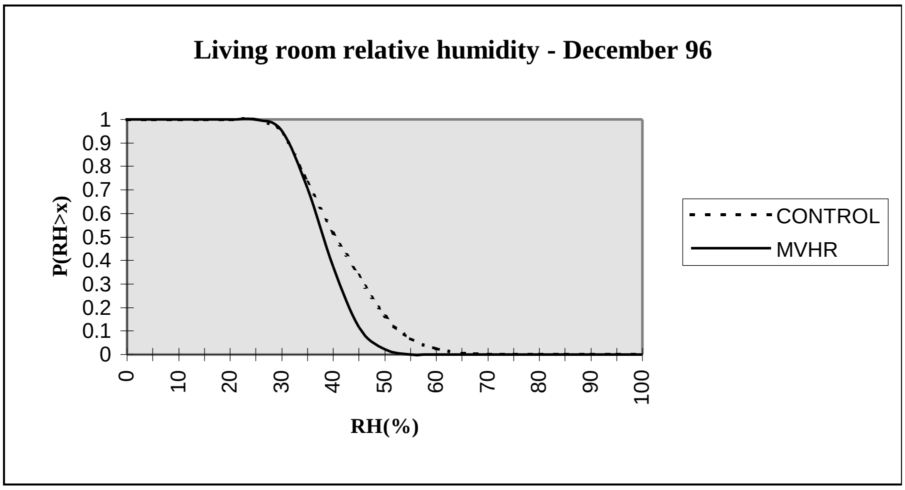
Graph 6.52



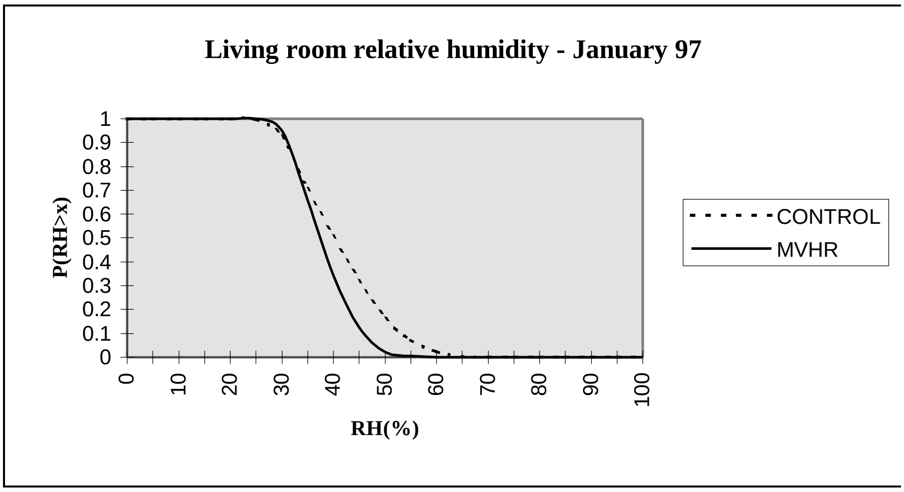
Graph 6.53



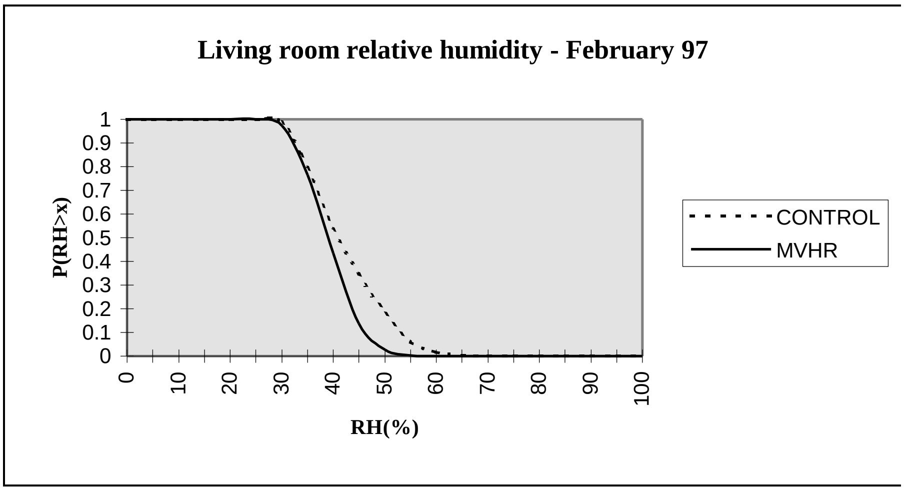
Graph 6.54



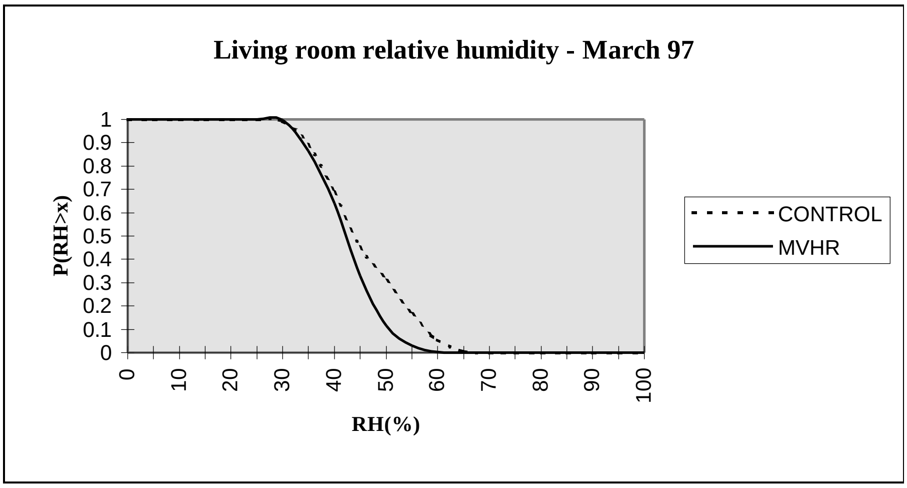
Graph 6.55



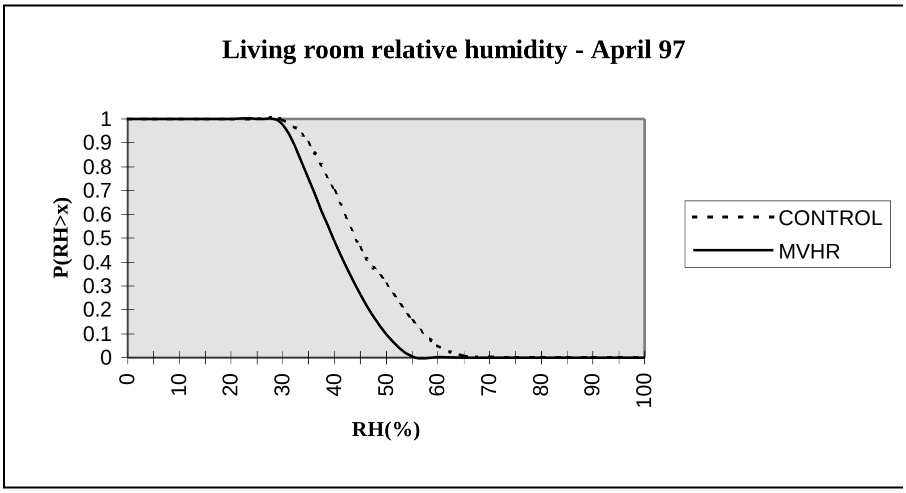
Graph 6.56



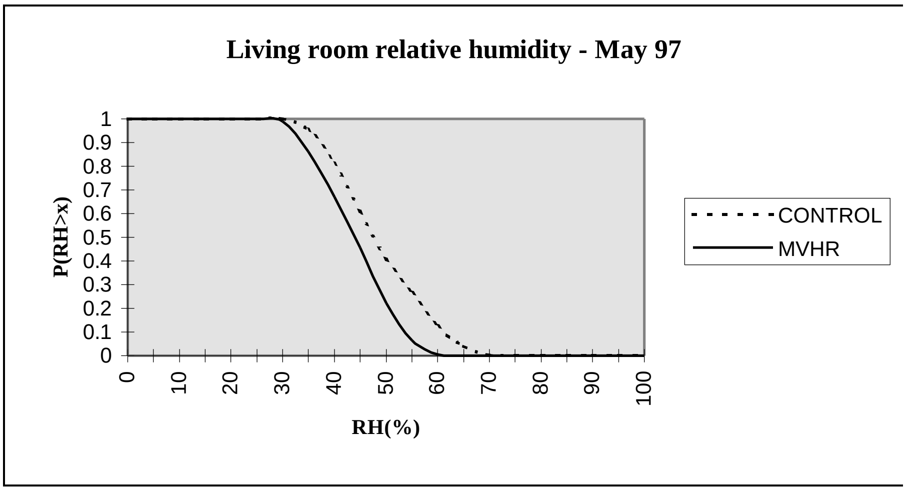
Graph 6.57



Graph 6.58



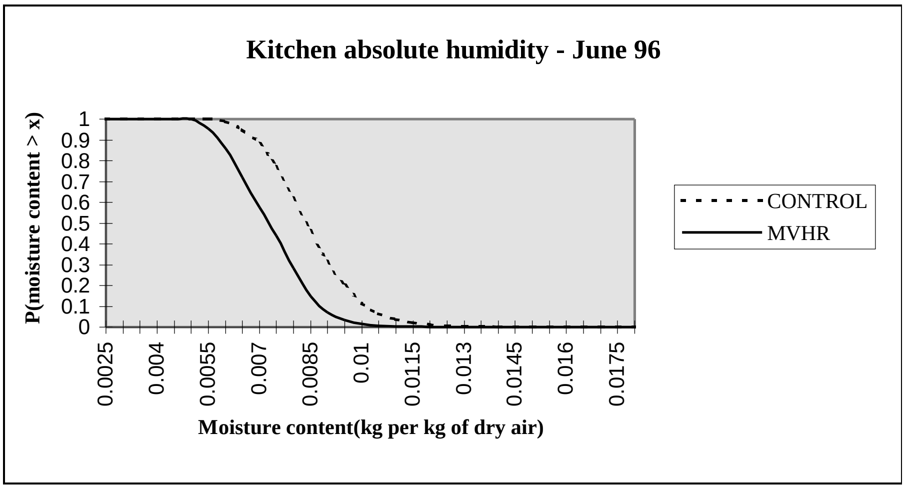
Graph 6.59



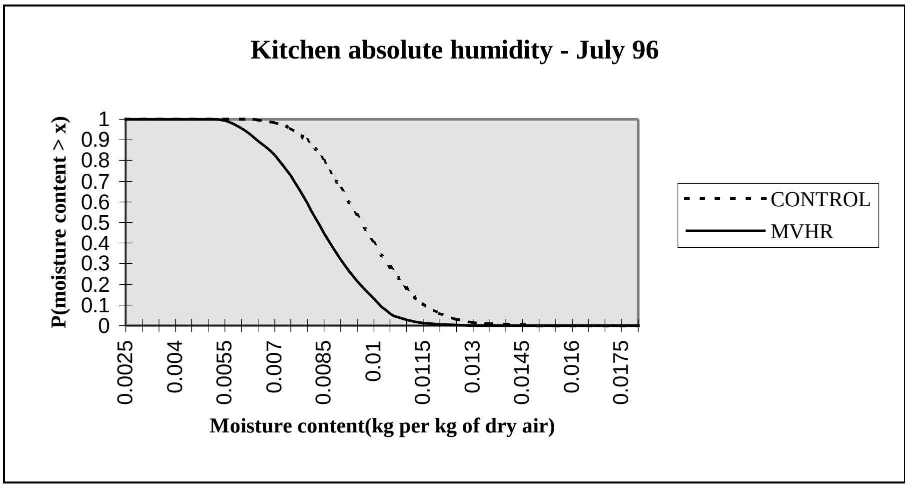
Graph 6.60

A6.3 KITCHEN DATA ANALYSIS

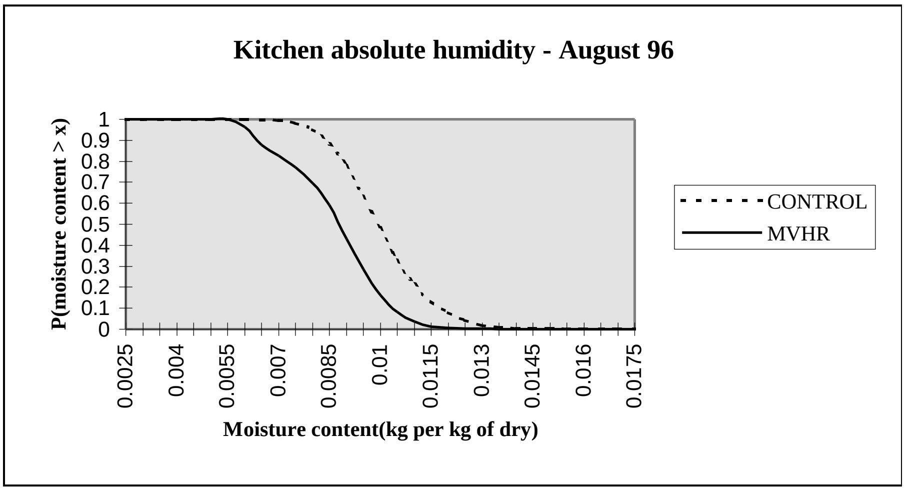
A6.3.1 Kitchen absolute humidity



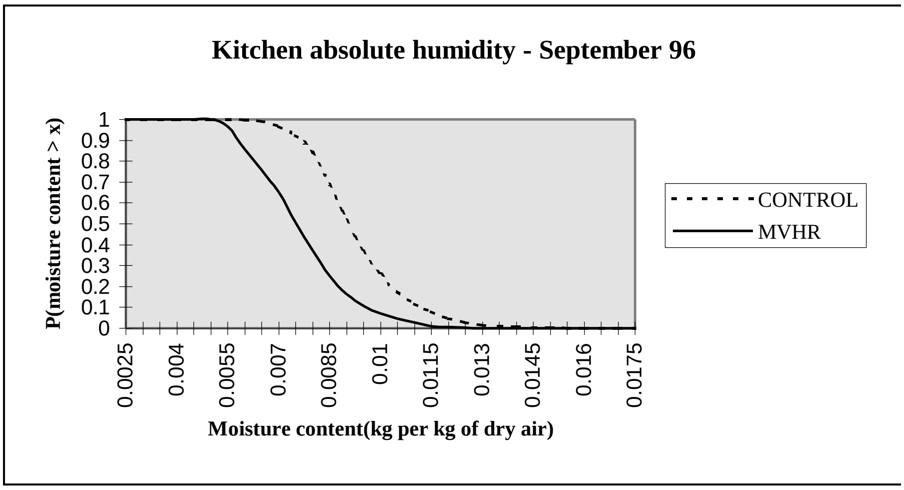
Graph 6.61



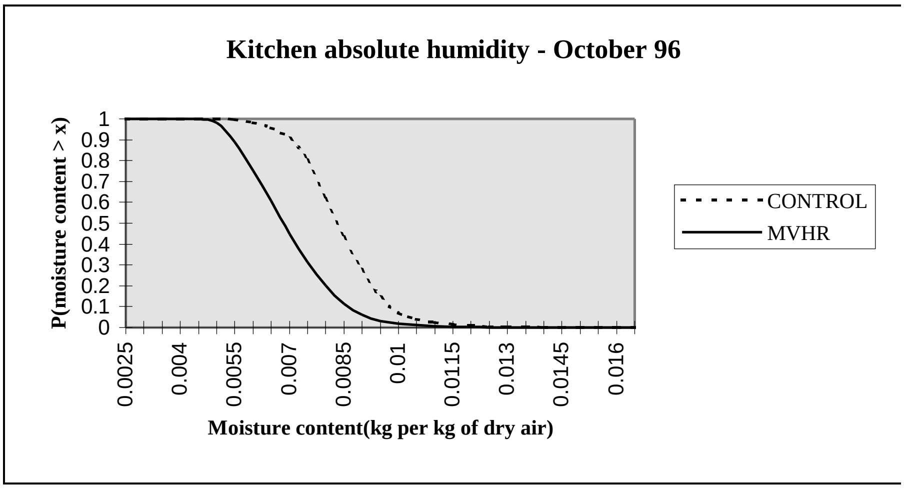
Graph 6.62



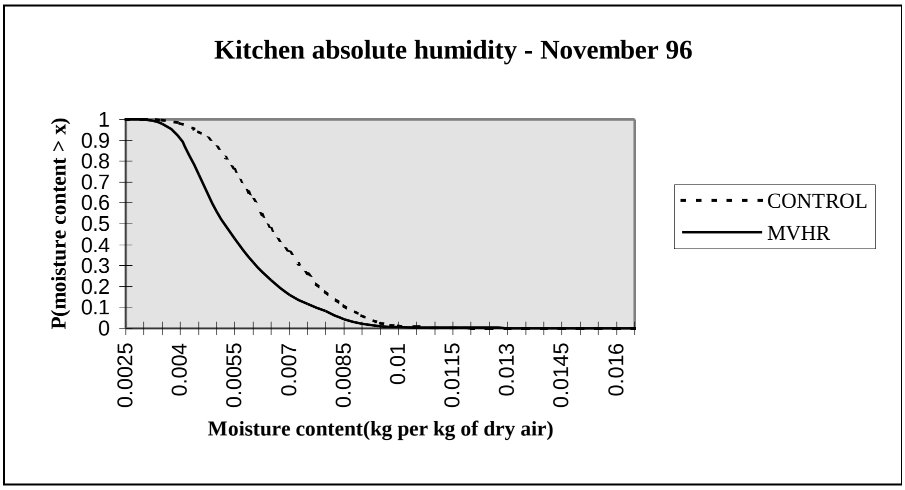
Graph 6.63



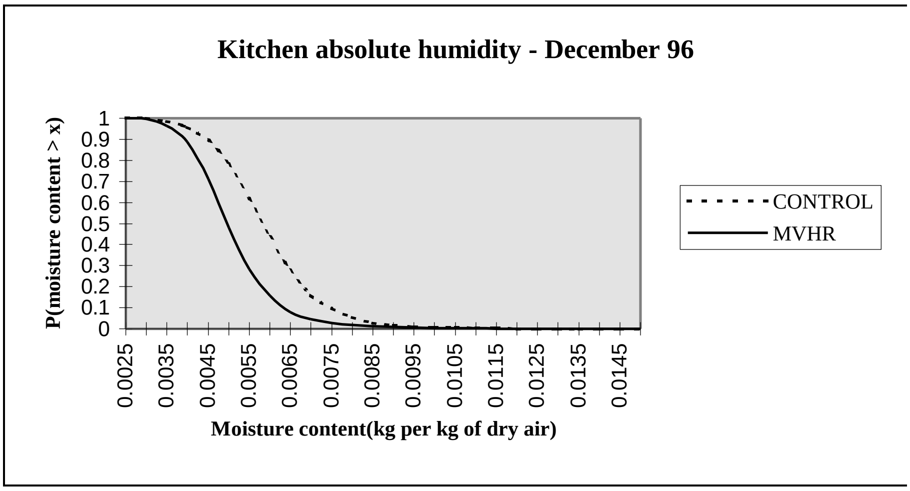
Graph 6.64



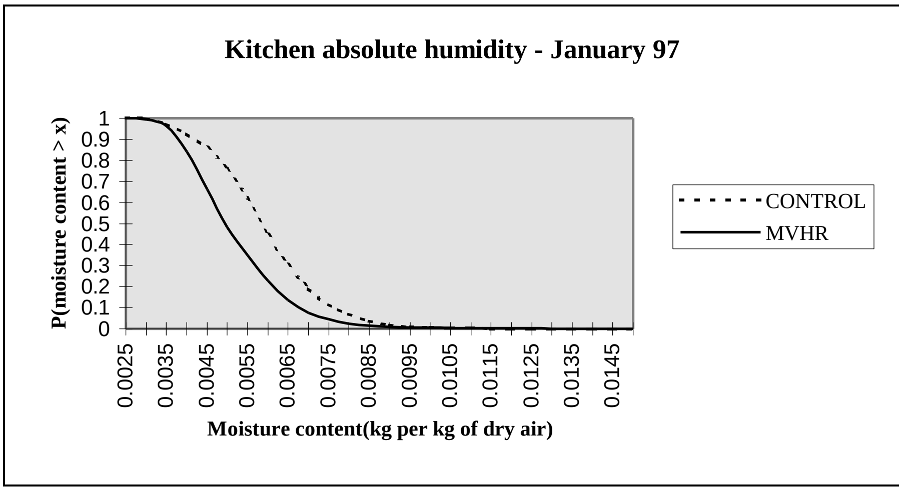
Graph 6.65



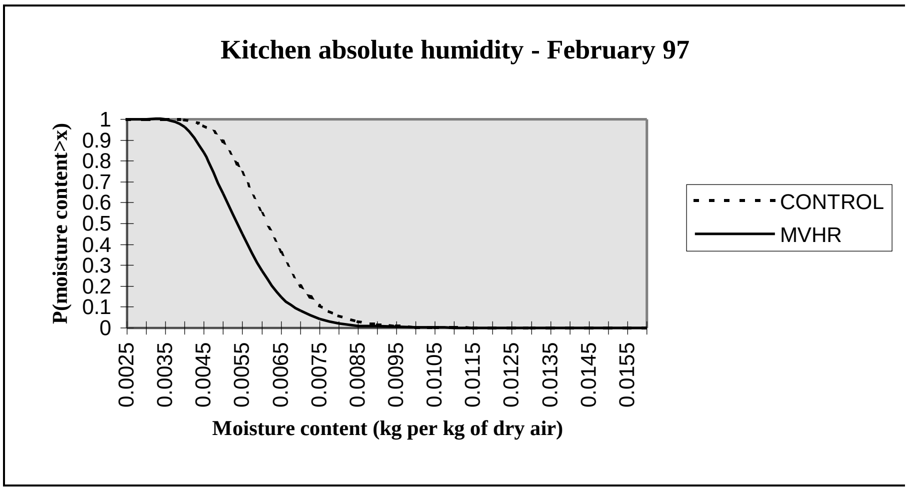
Graph 6.66



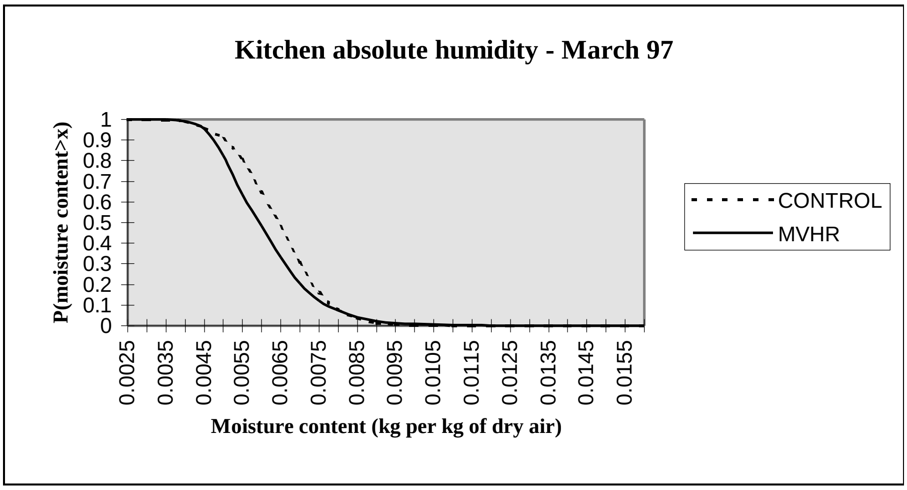
Graph 6.67



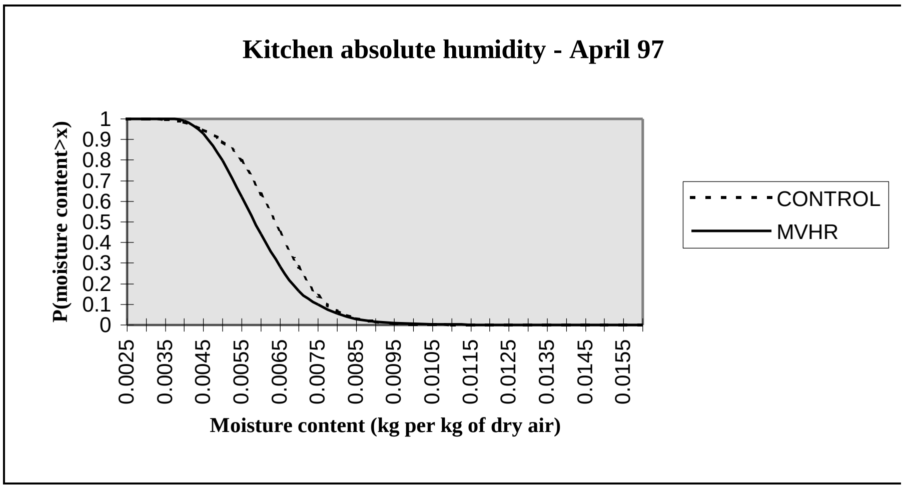
Graph 6.68



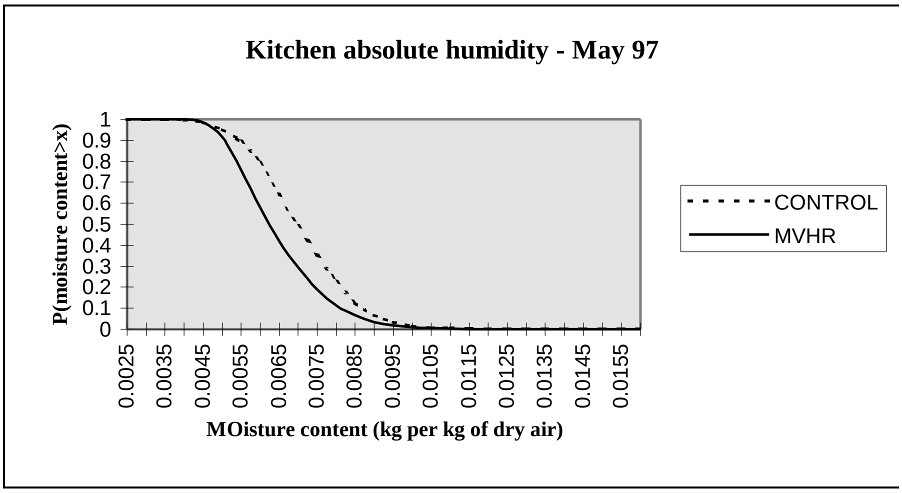
Graph 6.69



Graph 6.70



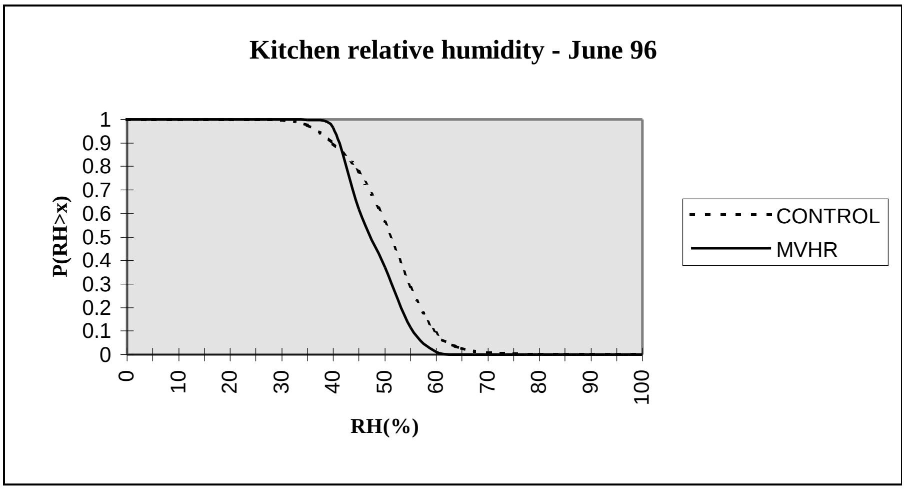
Graph 6.71



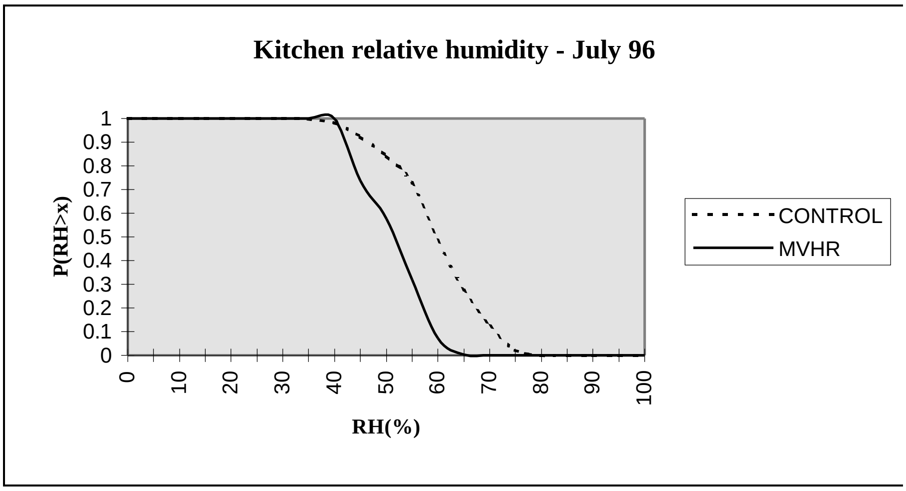
Kitchen absolute humidity - May 97
P(moisture content>x)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0025
0.0035
0.0045
0.0055
0.0065
0.0075
0.0085
0.0095
0.0105
0.0115
0.0125
0.0135
0.0145
0.0155
MOisture content (kg per kg of dry air)
CONTROL
MVHR

Graph 6.72

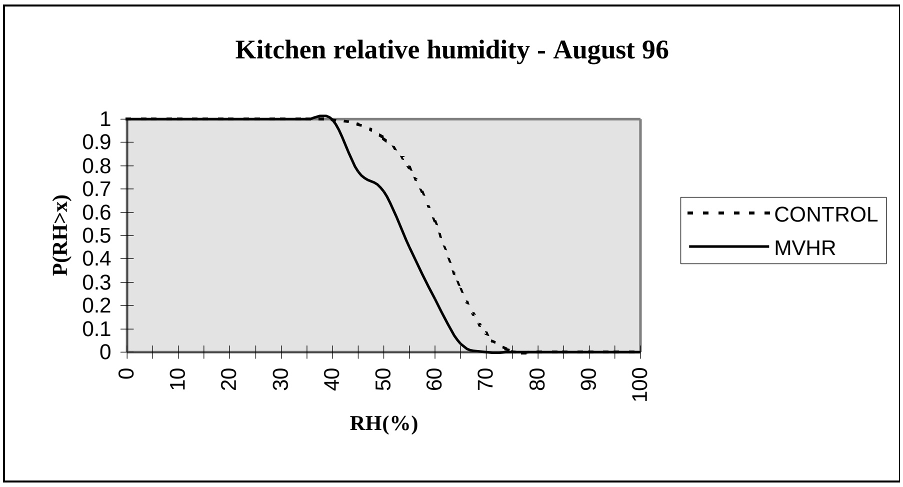
A6.3.2 Kitchen relative humidity



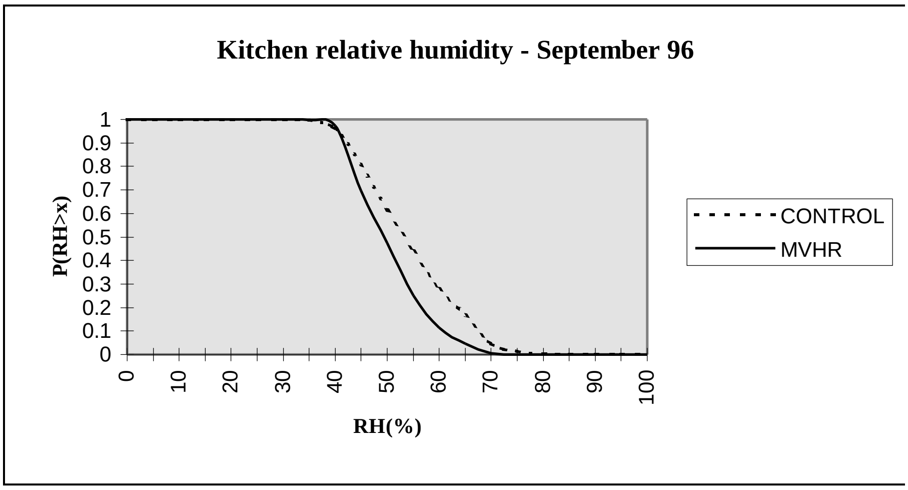
Graph 6.73



Graph 6.74



Graph 6.75



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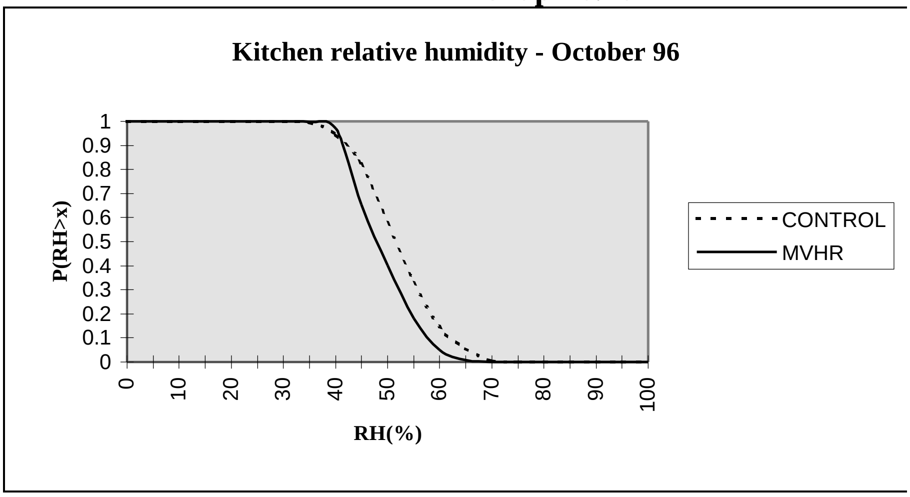

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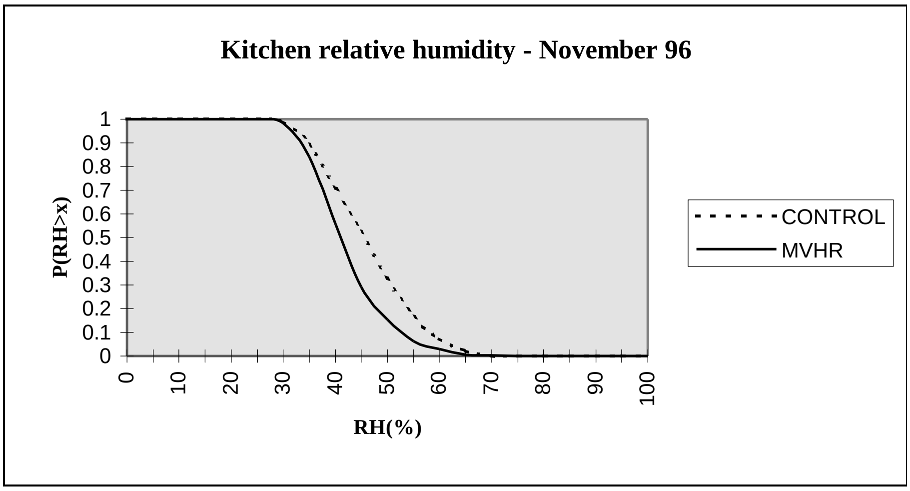

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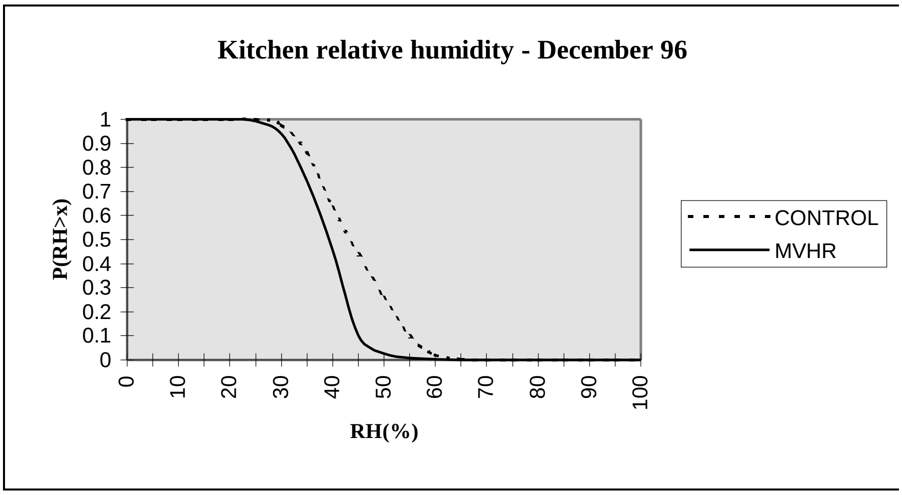

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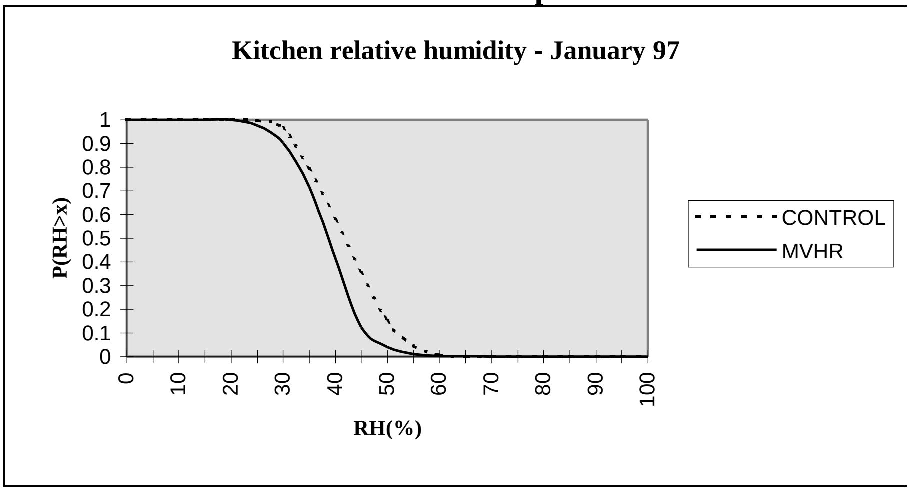
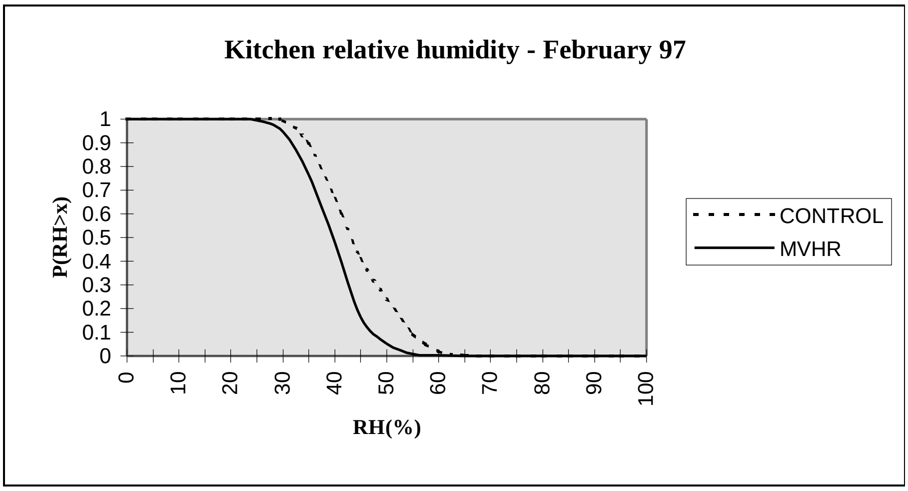
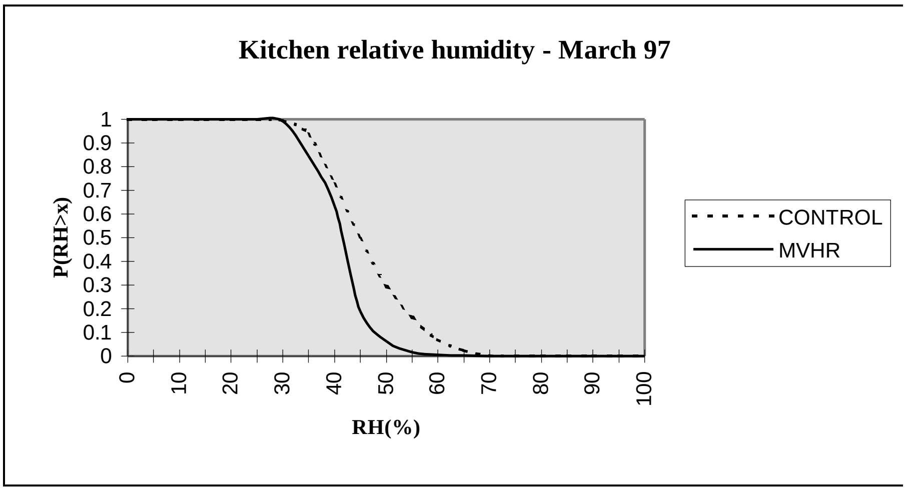


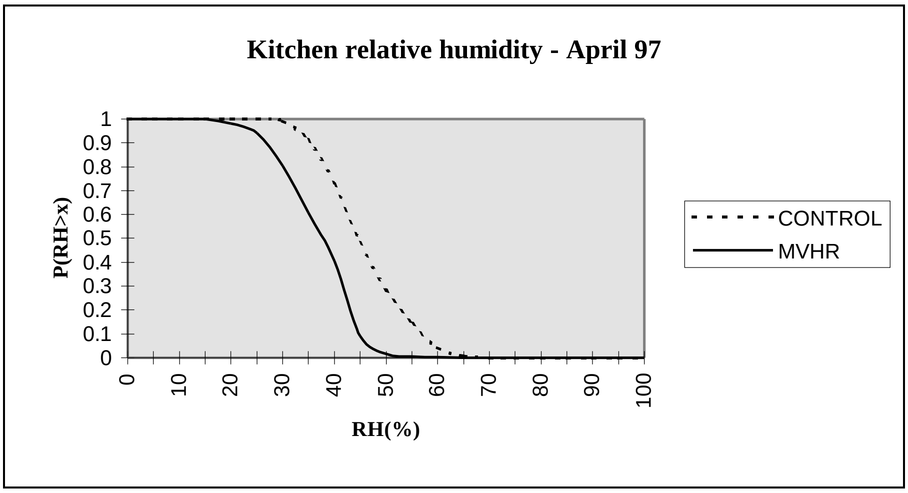
Graph 6.80



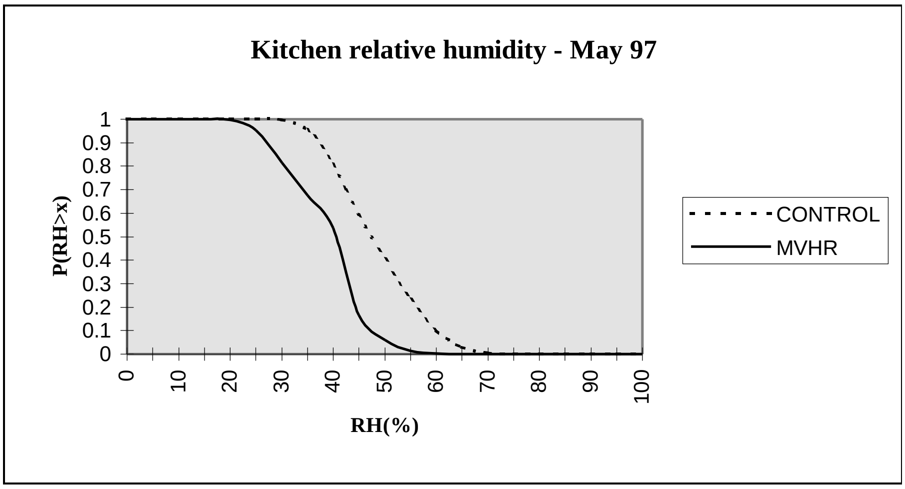
Graph 6.81



Graph 6.82



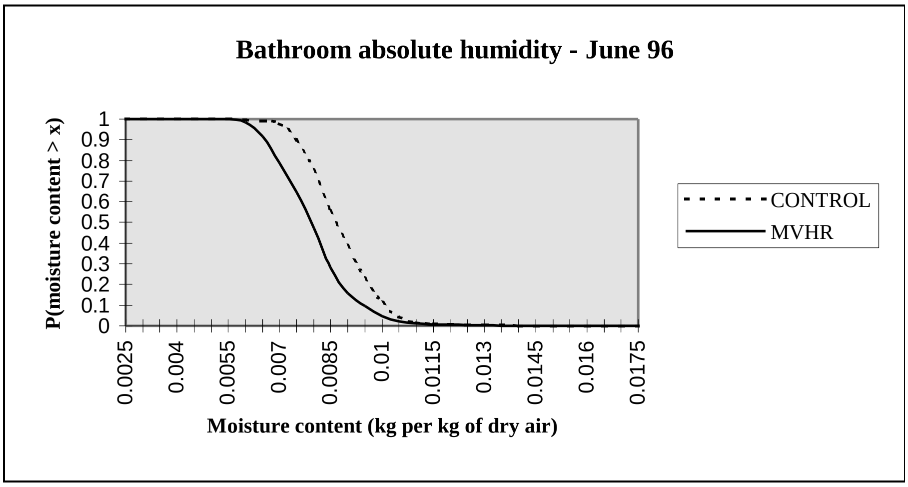
Graph 6.83



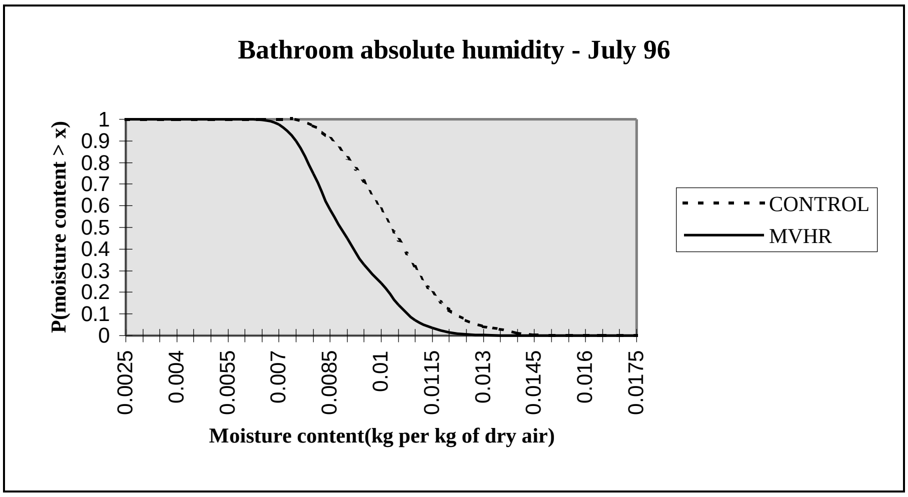
Graph 6.84

A6.4 BATHROOM DATA ANALYSIS

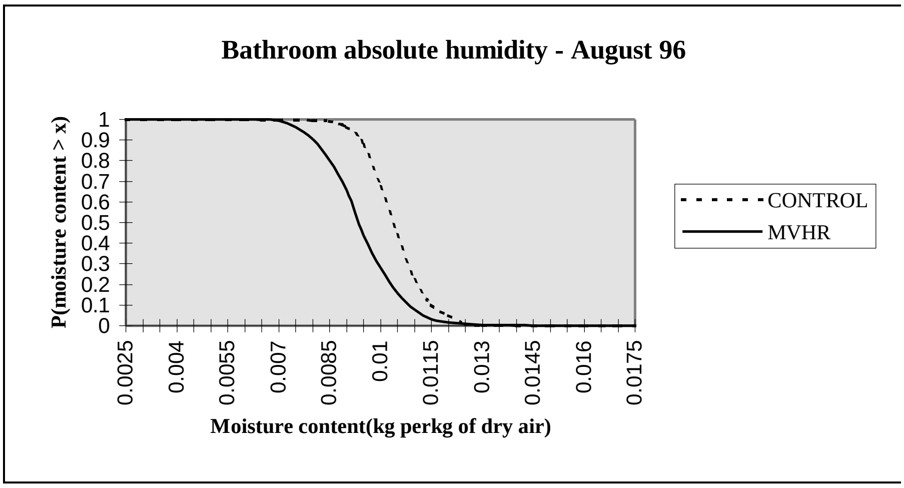
A6.4.1 Bathroom absolute humidity



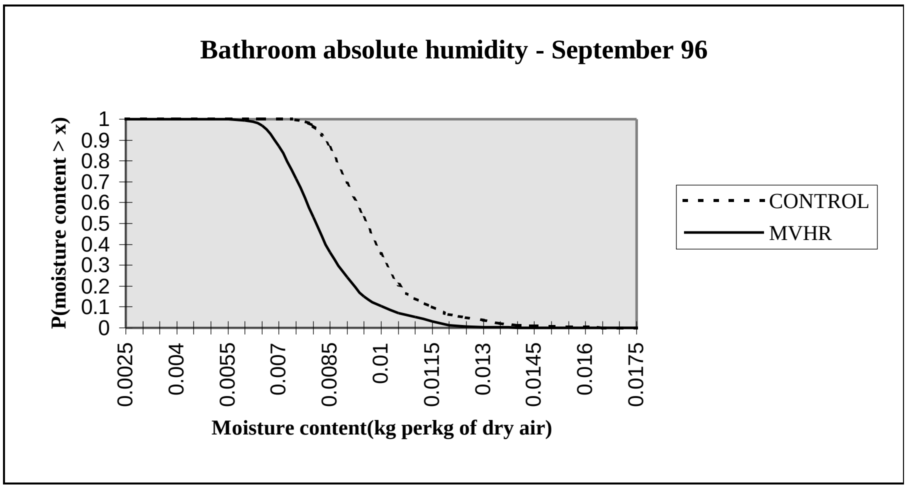
Graph 6.85



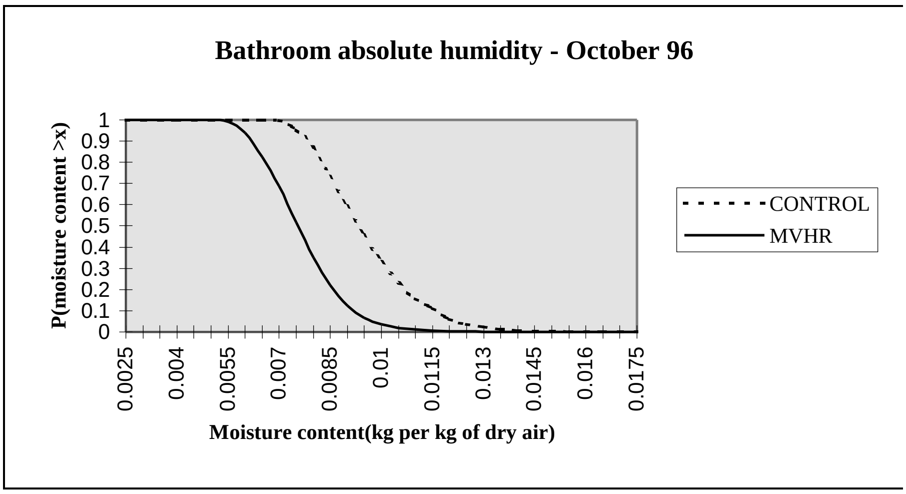
Graph 6.86



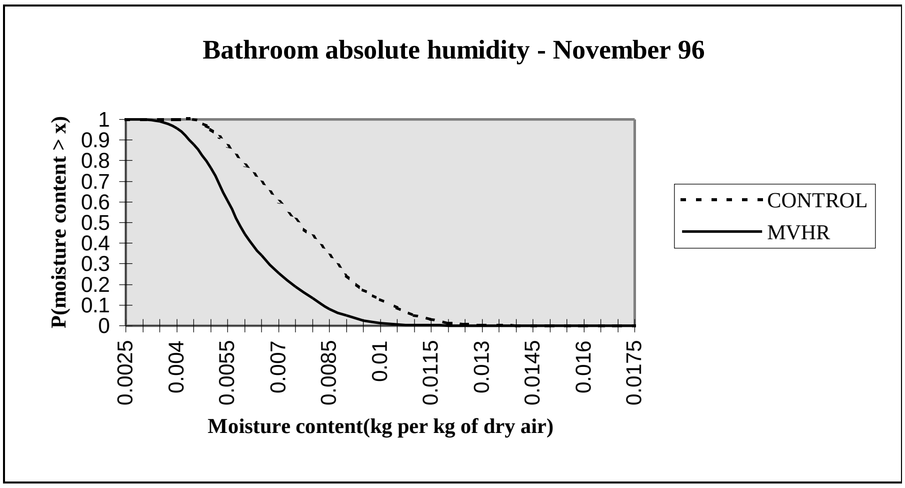
Graph 6.87



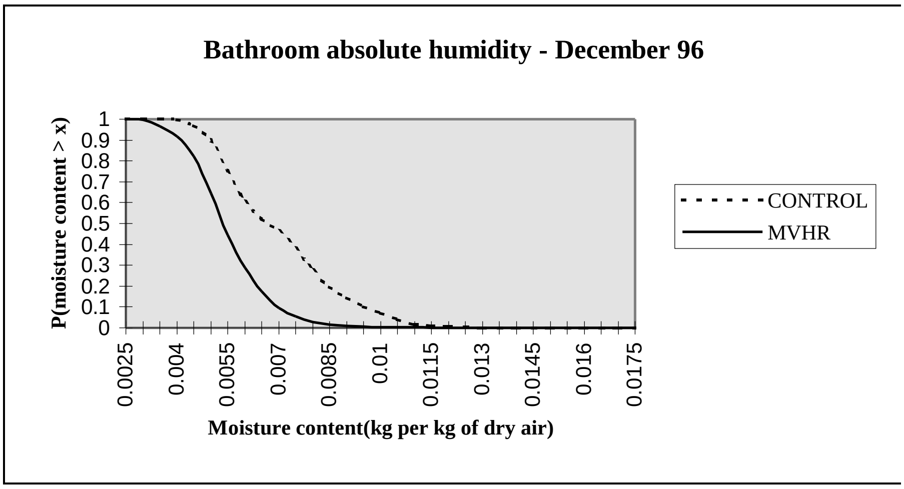
Graph 6.88



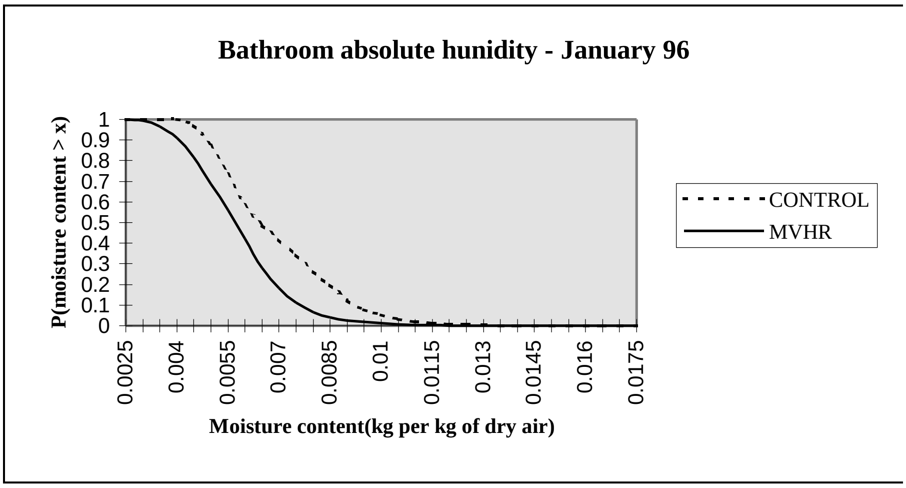
Graph 6.89



Graph 6.90



Graph 6.91



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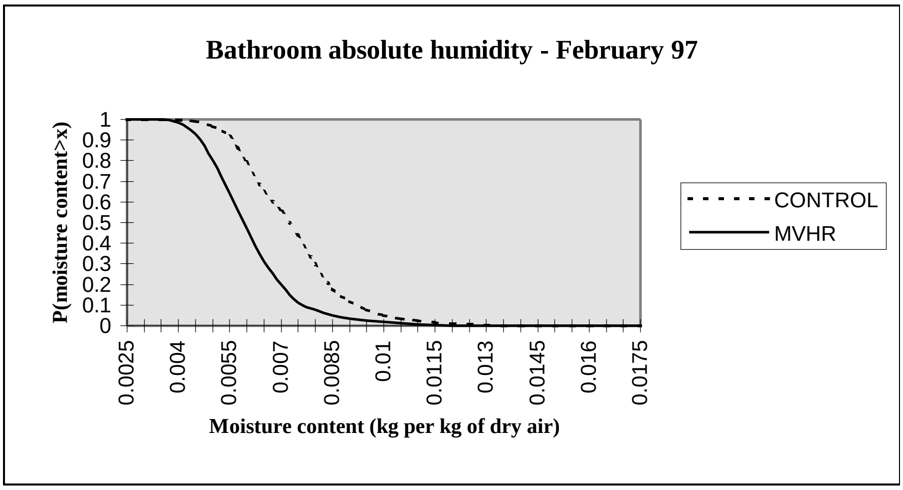
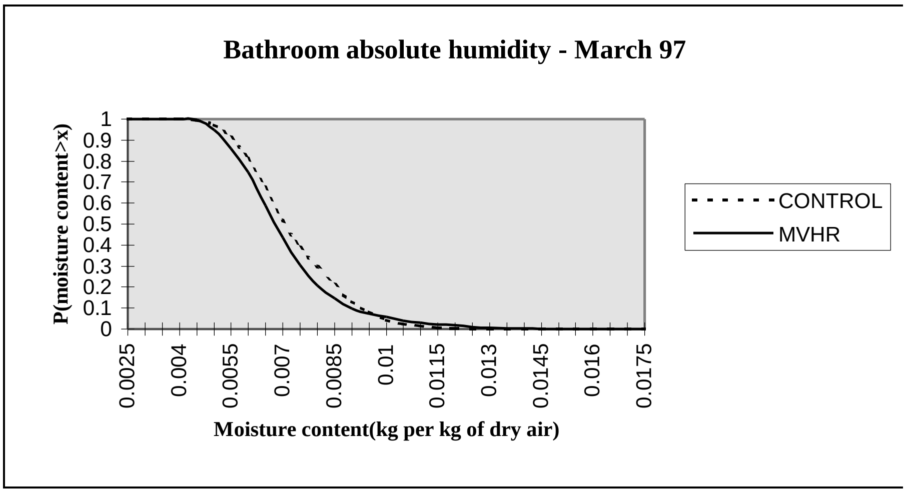
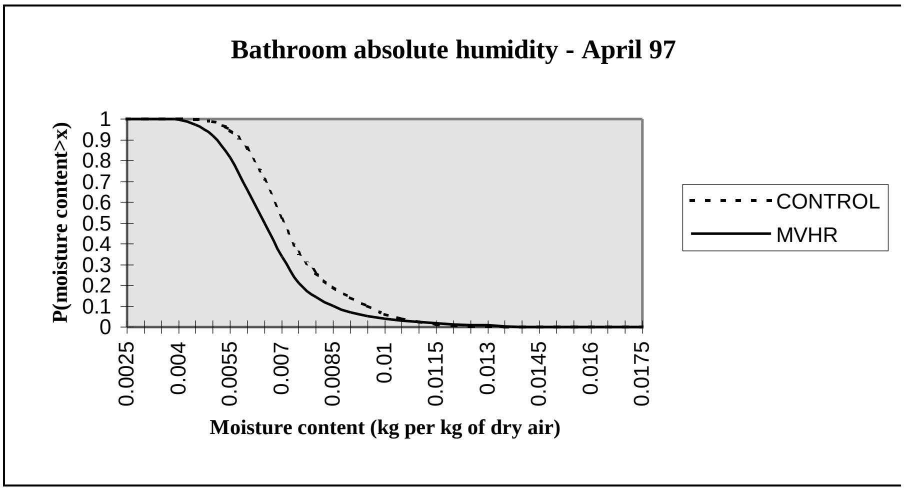


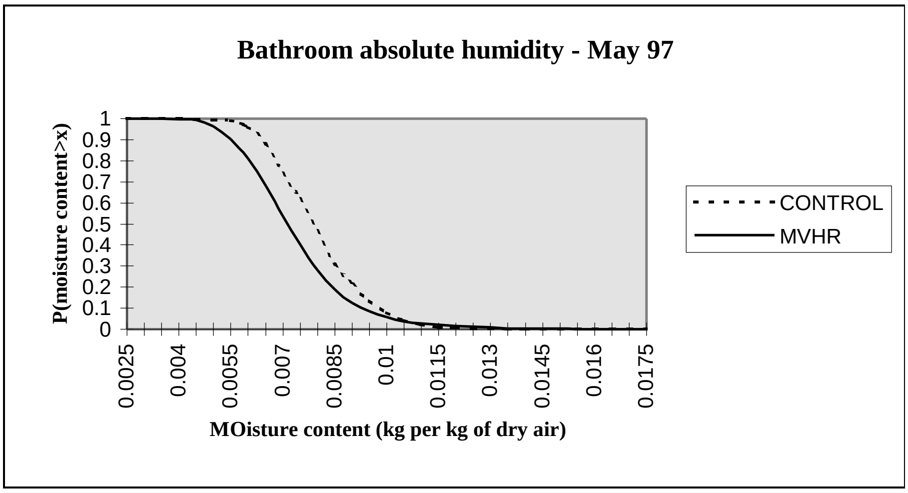
Graph 6.93



Graph 6.94



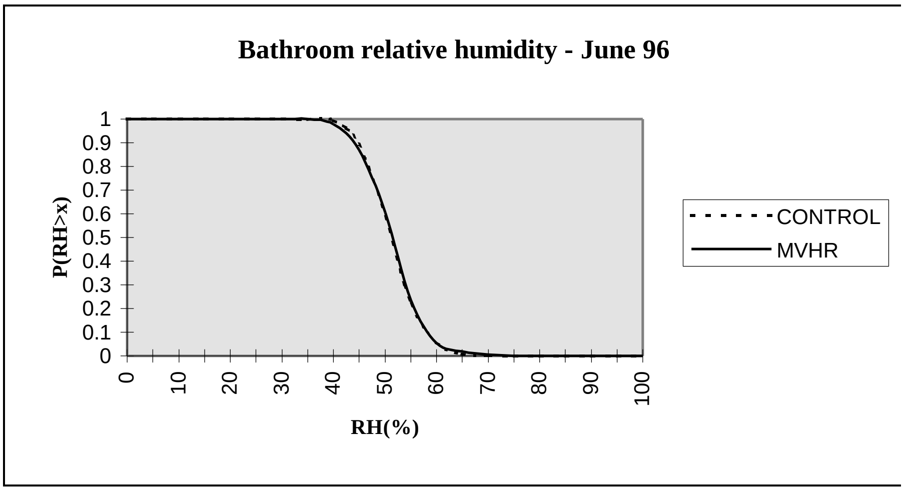
Graph 6.95



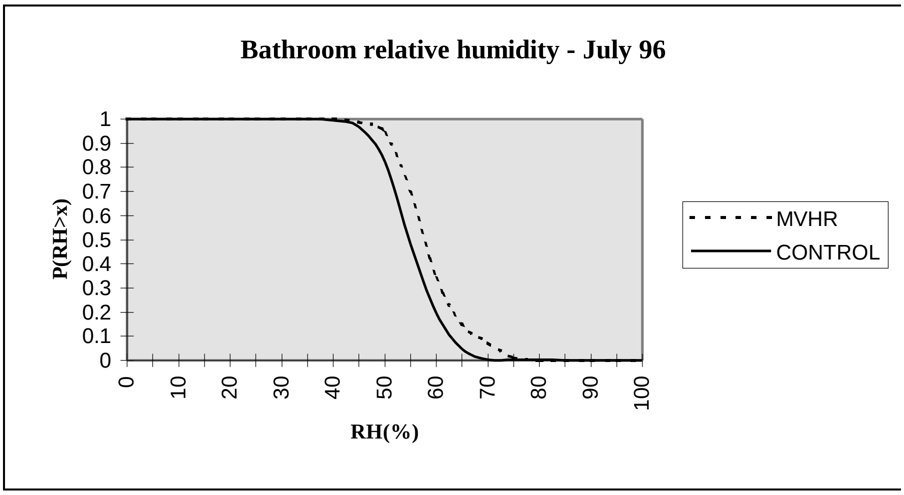
Bathroom absolute humidity - May 97
P(moisture content>x)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0.0025
0.004
0.0055
0.007
0.0085
0.01
0.0115
0.013
0.0145
0.016
0.0175
MOisture content (kg per kg of dry air)
CONTROL
MVHR

Graph 6.96

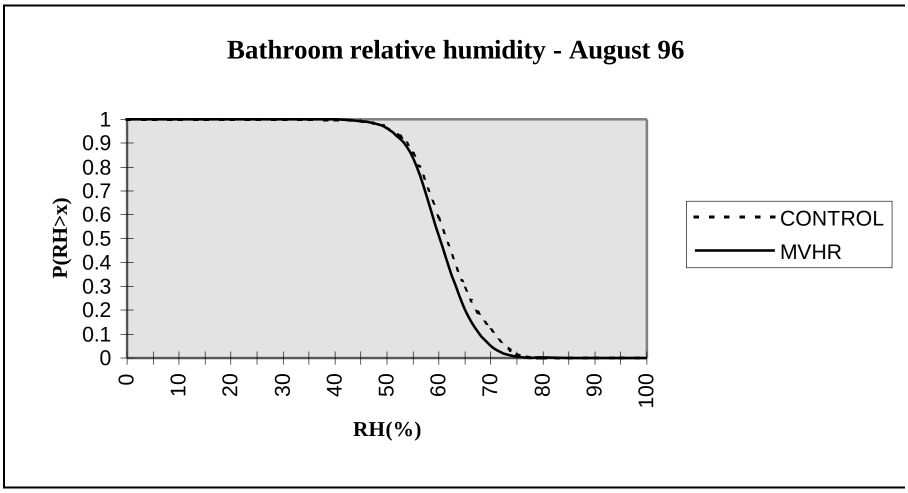
A6.4.2 Bathroom relative humidity



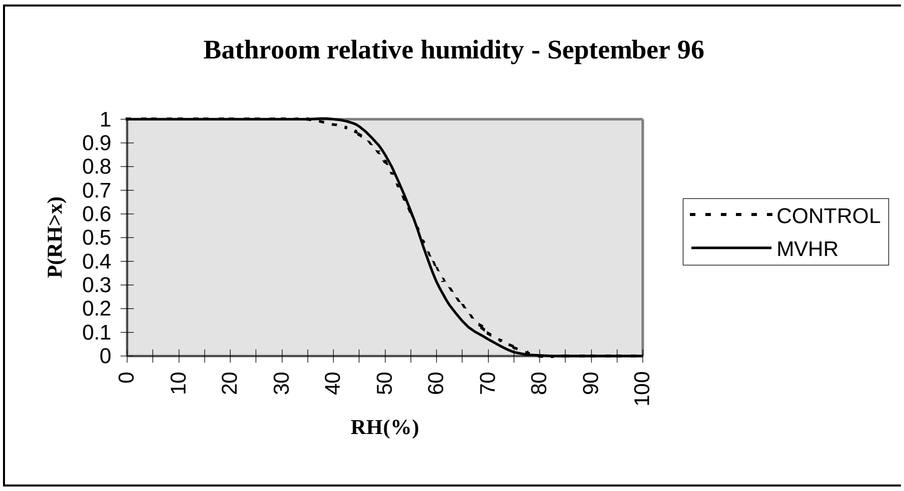
Graph 6.97



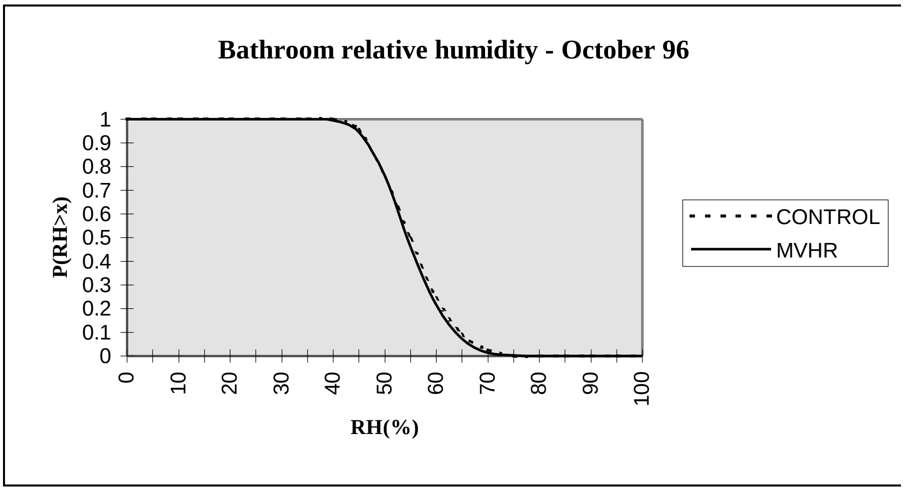
Graph 6.98



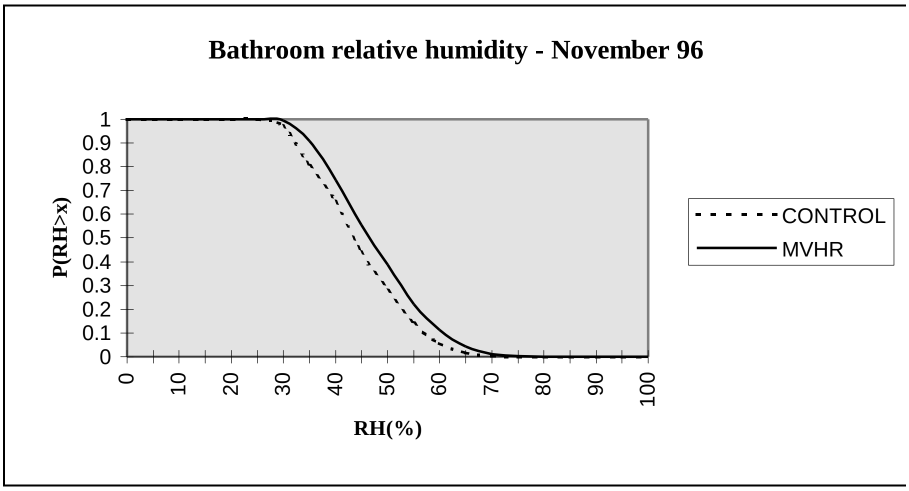
Graph 6.99



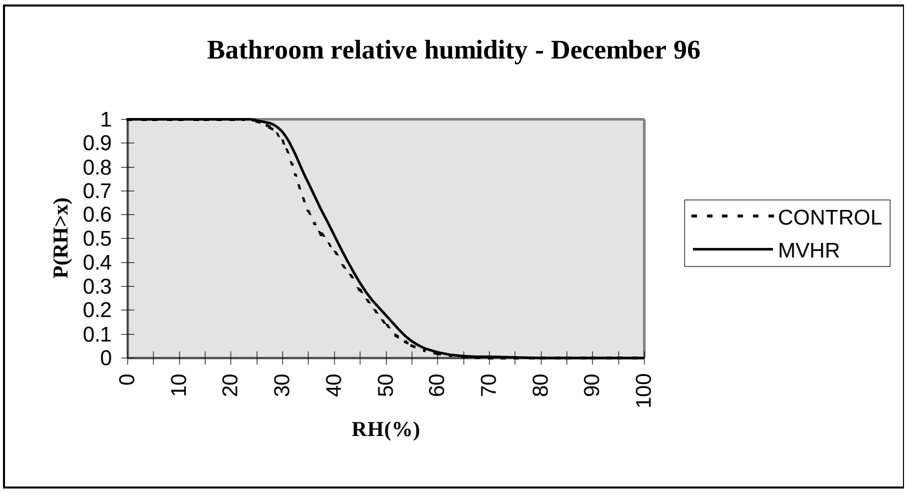
Graph 6.100



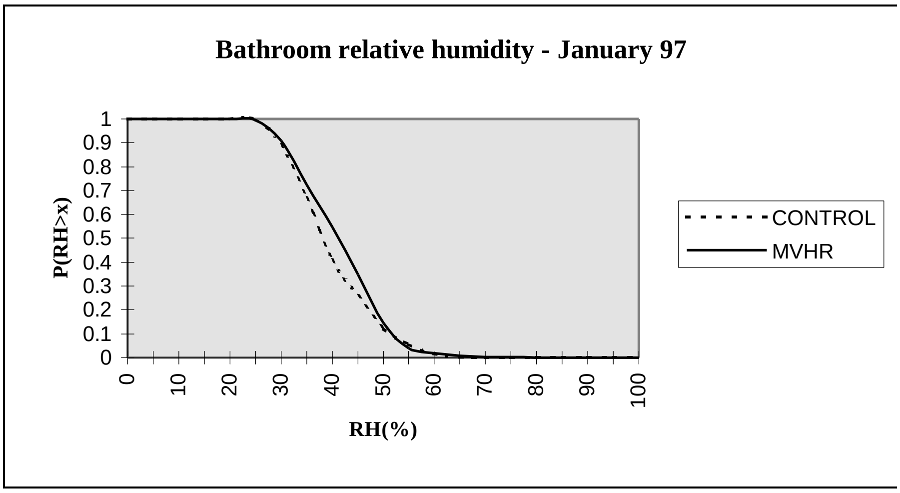
Graph 6.101



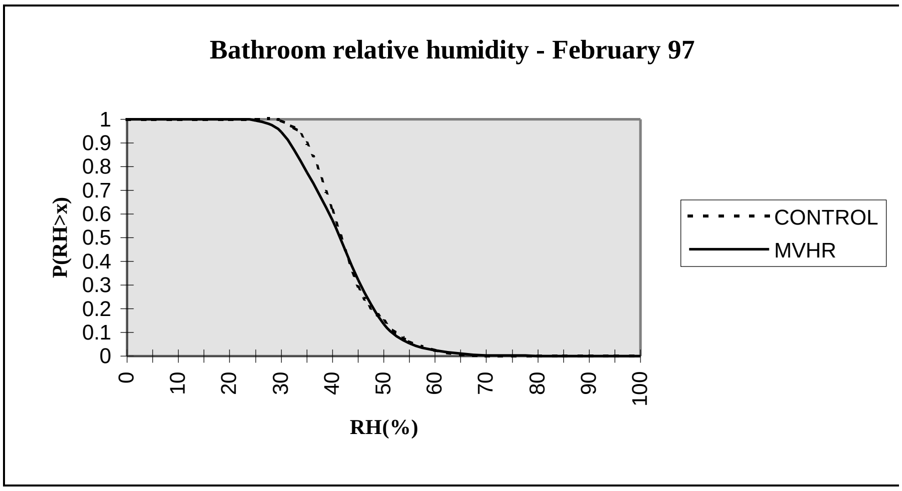
Graph 6.102



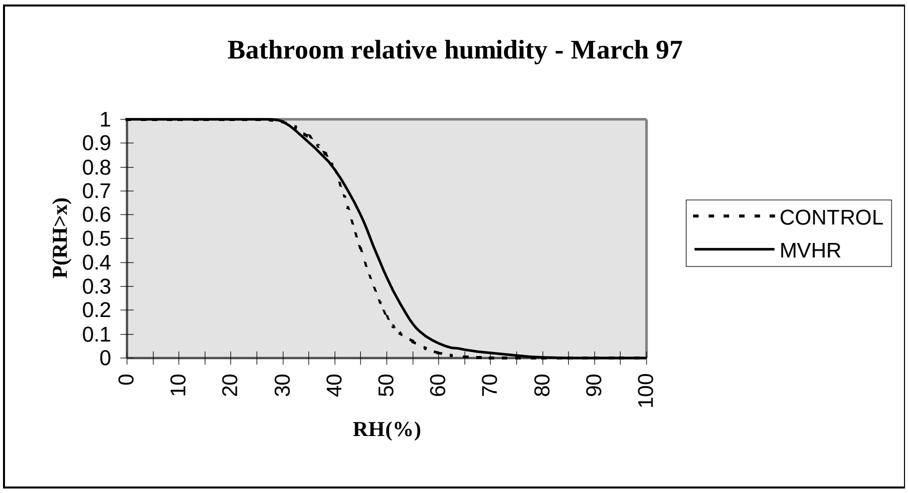
Graph 6.103



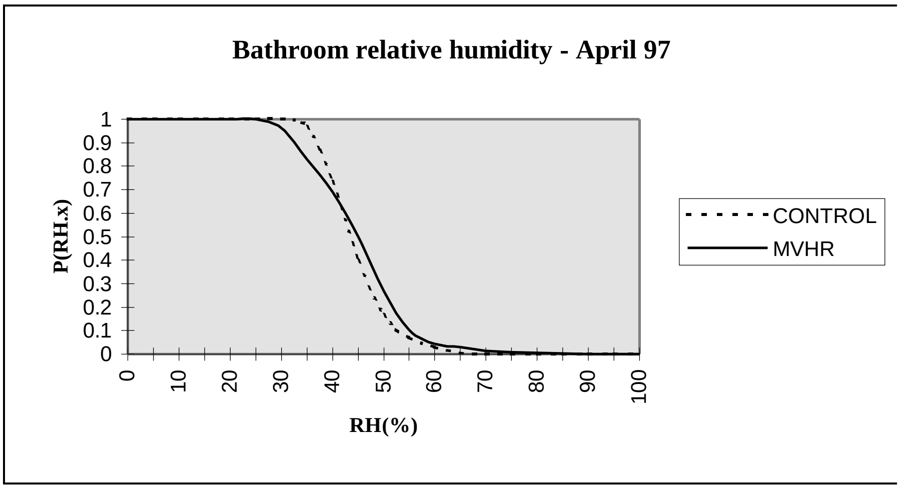
Graph 6.104



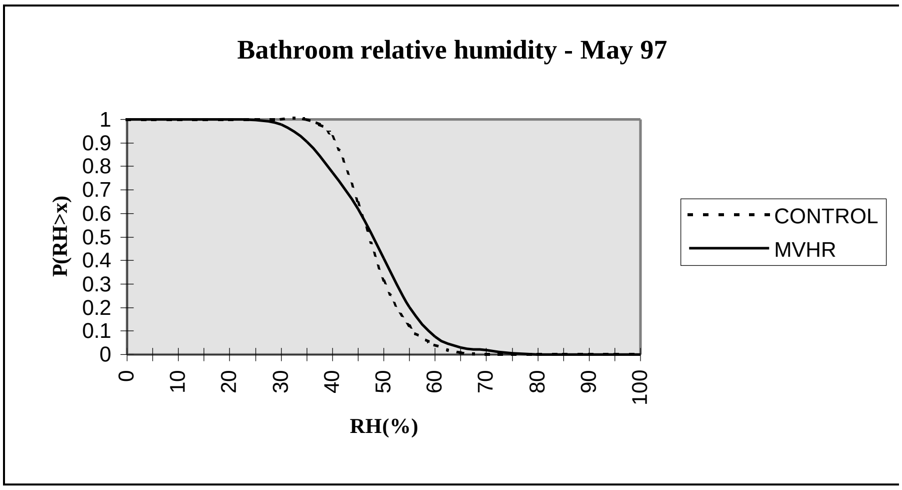
Graph 6.105



Graph 6.106



Graph 6.107



Bathroom relative humidity - May 97
P(RH>x)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
RH(%)
CONTROL
MVHR

Graph 6.108

APPENDIX 7

SUMMARY OF WEATHER AT DERWENTSIDE, 1996-7

The purpose of this appendix is to present a summary of the weather data collected at the field trial site over the year from May 1996 to June 1997. This data is presented in the form of a table and graph of monthly means of air temperature, relative humidity, solar radiation on a horizontal surface, and wind speed measured approximately 1 m above ridge height.

Monthly mean weather data	air temp °C	humidity %RH	horizontal solar W/m^2	wind speed m/s
May				
June	13.0	70		
July	14.9	74	145	2.0
August	15.1	81	170	2.1
September	12.1	85	98	2.2
October	10.3	87	67	2.9
November	4.7	89	56	3.3
December	3.0	91	36	2.6
January	3.3	92	36	1.7
February	5.7	86	64	4.4
March	7.4	83	118	3.6
April	8.0	80	138	2.8
May	9.4	85	173	2.1
June				
Annual means	8.9	84	≈110	≈2.7
Heating season means	7.1	87	87	2.8

Table A7.1

The data illustrate a climate which is broadly typical of the UK, with temperatures approximately 1°C lower than would be expected in the South-East of England. Annual averages for solar radiation and wind speed have had to be approximated, owing to missing data at the beginning of the period covered. The heating season at Eshwinning appears to be longer than in more sheltered parts of the UK, and in the above table, has been assumed to run from September to the end of May inclusive (months with mean outside temperatures of 13°C or greater).

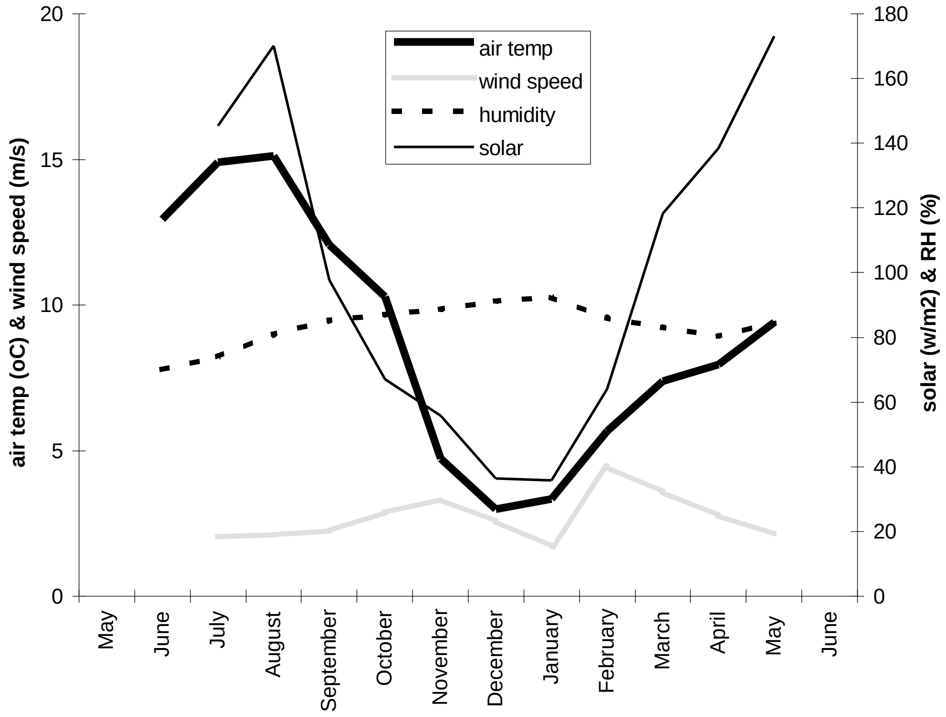


Fig A7.1 Monthly mean weather data from Eshwinning

APPENDIX 8

TENANT ADVICE SHEETS

This appendix contains advice sheets that were distributed to tenants of the field trial houses in May 1996, shortly after the completion of the refurbishment works. One sheet covered the nature of the field trial. An important function of this sheet was to enable field trial tenants to recognise Leeds Metropolitan University personnel. A second sheet covered the operation of the heating system - it must be remembered that field trial had not previously had central heating, and that some tenants would have been unfamiliar with basic concepts. Finally, three separate sheets were prepared on the subject of ventilation, so that advice could be tailored to the specific system in each house. Some of the details in the advice sheets have been omitted from this appendix, but otherwise the sheets are as distributed to tenants.

A FIELD TRIAL OF MECHANICAL VENTILATION WITH HEAT RECOVERY IN LOCAL AUTHORITY LOW-RISE HOUSING

This note is to inform you about the Field Trial Project which you are involved in.

COLLABORATING ORGANISATIONS

A number of organisations have collaborated on the field trial project forming a small team (the club). These include: National Power PLC; Neighbourhood Energy Action (N.E.A.): Derwentside District Council; and Rega and ADM, the two manufacturers of the mechanical ventilation and heat recovery units. Monitoring of the field trial will be conducted by the Centre for the Built Environment at Leeds Metropolitan University.

AIM OF THE FIELD TRIAL PROJECT

The aim of the project is to assess the effectiveness of whole house Mechanical Ventilation with Heat Recovery (MVHR). which is installed as part of a comprehensive energy efficiency and environmental improvement package in existing housing in terms of energy conservation, thermal comfort, and internal air quality.

DURATION OF THE PROJECT

The project will be monitored from the beginning of May 1996 until the end of July 1997.

MONITORING PERSONNEL

The personnel from Leeds Metropolitan University involved in monitoring the project are as follows:

The two people who you will come into regular contact with are David Johnston and Myke Duncan. They will be installing the monitoring equipment in your dwelling. David Johnston will also be in Eshwinning once a month to answer any queries that you have, take electric and gas meter readings and make any payments.

PAYMENTS TO THE TENANTS

A payment of £10 cash will be made once a month (starting in April) for the duration of the project. This Payment is intended to compensate for any inconvenience caused during the monitoring period.

USEFUL TELEPHONE No.'s / CONTACT No.'s

Leeds Metropolitan University
Contact: David Johnston
Tel: 0113 283 2600 Ext: (omitted)

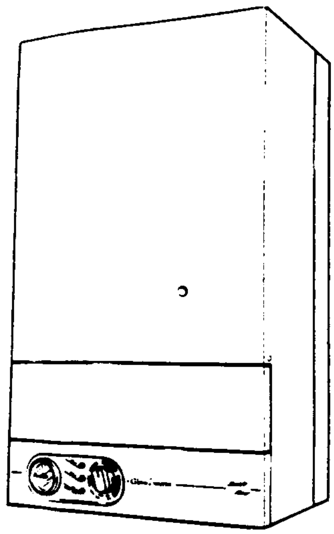
Derwentside District Council
Contact: Mary Allanson
Tel: 01207 (omitted)

TENANT ADVICE

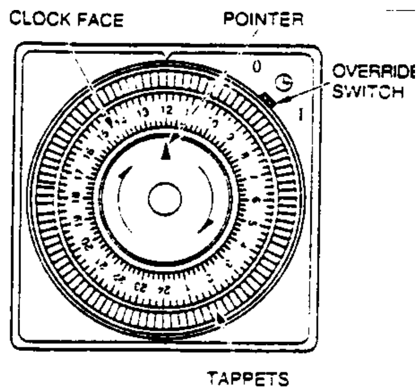
You are living in an energy efficient house. Your house has received an energy efficiency package from Derwentsitde DSO which has consisted of the installation of: blown-fibre cavity wall insulation; new single-glazed wooden framed windows with trickle ventilators; a gas-fired central heating system; and, the replacement of existing external doors and frames. In addition to this package, the house has also received a comprehensive airtightness package from Leeds Metrpolitan University. This has involved the injection of polyurethane expanding foam into the space between the plasterboard lining and the blockwork inner leaf of the dwelling's external walls. This process has improved the airtightness of your dwelling by about a half.

HEATING SYSTEM

A gas central heating system has been installed in your house. The boiler for this system is situated in the upstairs cupboard and is of a special type called a combination boiler. Combination boilers incorporate a central heating boiler with an instantaneous water heater. The boiler heats water direct from the mains on demand, thus removing the need for separate water storage.



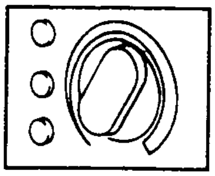
The boiler is connected to a number of radiators in the house. All of the radiators can be controlled by the manual radiator valve, situated on the bottom corner of the radiator. Individual radiators can be switched off by fully closing these valves.



The central heating system can be controlled in a number of ways. In the downstairs hallway there is a room thermostat situated on the wall. The thermostat is used to manually set the required temperature in this area of the dwelling. A comfortable set point temperature will be around 20 - 21°C, but this is entirely up to yourself. When the central heating system is turned on, the thermostat senses the temperature in the hallway, and turns the central heating system on or off accordingly. The central heating system will continue to operate until the set-point temperature on the thermostat is reached.

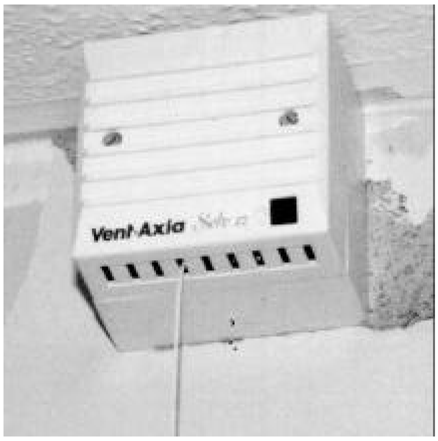
In the upstairs cupboard there is an electro/mechanical programmer situated on the boiler unit. This is used to turn the central heating system on or off at pre-set times. The programmer consists of a number of moving tappets on a circular clock face, with each of the tappets representing a 15 minute segment. Operation of the programmer is achieved by switching the clock face switch to ⊗. Pushing the tappets outwards in this mode sets the time ‘off’ whilst pushing the tappets inwards switches the time ‘on’. The programmer can be overridden by switching the time clock to **0** (off) or to **1** (continuous). The switch has to be repositioned to ⊗ to resume programmed working.

The temperature of the water flowing around in the central heating system can be set using the central heating temperature control knob on the boiler. The required temperature can be set by adjusting this knob to the desired value.



A FIELD TRIAL OF MECHANICAL VENTILATION WITH HEAT RECOVERY IN LOCAL AUTHORITY LOW-RISE HOUSING

VENTILATION SYSTEM



Your house has been fitted with a number of mechanical extract fans. These fans are situated in the high moisture producing areas of the dwelling, i.e. the kitchen, and the downstairs and upstairs bathrooms. Control of these fans is achieved manually, by pulling the cord from the small Vent Axia box shown opposite downward. The extract fans situated in the bathrooms are controlled by a humidistat sensor as well as the manual control. This means that when the set-point on the humidistat sensor is reached, the extract fans will switch on automatically, and then switch off automatically when the humidity level has reduced sufficiently.

Further ventilation of your dwelling can be achieved by opening the trickle ventilators which are situated on all of the dwellings windows.

MEASURING YOUR ENERGY USE

Leeds Metropolitan University would like to measure the energy that you use in your house over the next year. We would like to find out how much gas and electricity you consume over a year, and how much of it is used for each purpose - room heating, water heating, cooking, extract fans, lights and appliances. We would also like to know how warm you keep your house, what levels of humidity are achieved, and the levels of CO2 produced in the main bedroom. To do all of this, we have installed a number of sensors in your rooms, an extra gas meter, and two extra electric meters. The information obtained from this equipment will form the basis of a scientific report. **We will keep this information strictly confidential, and your name and address will not be mentioned in any publication.**

Thank you for your co-operation.

A FIELD TRIAL OF MECHANICAL VENTILATION WITH HEAT RECOVERY IN LOCAL AUTHORITY LOW-RISE HOUSING

VENTILATION SYSTEM

Your house has been fitted with a mechanical ventilation and heat recovery (MVHR) system donated by Manufacturer A. This system is designed to operate continuously, i.e.24 hours per day, and controls the ventilation rate within your dwelling. The main unit is installed in your loft, and operates by extracting warm moist air from the 'wet' areas of the dwelling, such as the bathroom and the kitchen, whilst fresh air is supplied to the living and bedrooms of the dwellings. Both of these air flows are ducted through the heat exchanger unit, where heat from the outgoing air is transferred to the incoming fresh air. This process provides positive ventilation at a controlled rate, and reduces the ventilation heat loss from the dwelling.

Control of the MVHR system is achieved manually using a two-way switch situated in the kitchen. This switch controls the speed of the fans contained within the MVHR unit. The faster the speed of the fans, the larger the volume of air that enters the rooms of your dwelling. In normal day-to-day operation, the switch should be set at the NORMAL position, in which the air in the dwelling is changed approximately every two hours. During cooking, washing and bathing, the unit can be switched to the BOOST setting. The BOOST setting increases the ventilation rate through the property and will remove cooking smells and excessive moisture in your bathroom and kitchen.

The MVHR system operates most effectively when all of the windows and doors in the dwelling are kept closed. However, during the summer months additional ventilation can be provided by using the trickle ventilators installed in all of the windows or by opening the windows.

MEASURING YOUR ENERGY USE

Leeds Metropolitan University would like to measure the energy that you use in your house over the next year. We would like to find out how much gas and electricity you consume over a year, and how much of it is used for each purpose - room heating, water heating, cooking, MVHR system, lights and appliances. We would also like to know how warm you keep your house, what levels of humidity are achieved, and the levels of CO_2 produced in the main bedroom. To do all of this, we have installed a number of sensors in your rooms, an extra gas meter, and two extra electric meters. The information obtained from this equipment will form the basis of a scientific report. **We will keep this information strictly confidential, and your name and address will not be mentioned in any publication.**

Thank you for your co-operation.

A FIELD TRIAL OF MECHANICAL VENTILATION WITH HEAT RECOVERY IN LOCAL AUTHORITY LOW-RISE HOUSING

VENTILATION SYSTEM

Your house has been fitted with a mechanical ventilation and heat recovery (MVHR) system donated by Manufacturer B. This system is designed to operate continuously, i.e.24 hours per day, and controls the ventilation rate within your dwelling. The main unit is installed in your loft, and operates by extracting warm moist air from the 'wet' areas of the dwelling, such as the bathroom and the kitchen, whilst fresh air is supplied to the living and bedrooms of the dwellings. Both of these air flows are ducted through the heat exchanger unit, where heat from the outgoing air is transferred to the incoming fresh air. This process provides positive ventilation at a controlled rate, and reduces the ventilation heat loss from the dwelling.

Control of the MVHR system is achieved manually using the control switch situated in the kitchen. This switch controls the speed of the fans contained within the MVHR unit. The faster the speed of the fans, the larger the volume of air that enters the rooms of your dwelling. By turning the control switch clockwise the volume of air entering the room increases, whilst turning the switch anti-clockwise reduces the volume of air entering the room. During cooking, washing and bathing, cooking smells and excessive levels of moisture can be removed from the kitchen and bathroom by turning the control switch fully on.

The MVHR system operates most effectively when all of the windows and doors in the dwelling are kept closed. However, during the summer months additional ventilation can be provided by using the trickle ventilators installed in all of the windows or by opening the windows.

MEASURING YOUR ENERGY USE

Leeds Metropolitan University would like to measure the energy that you use in your house over the next year. We would like to find out how much gas and electricity you consume over a year, and how much of it is used for each purpose - room heating, water heating, cooking, MVHR system, lights and appliances. We would also like to know how warm you keep your house, what levels of humidity are achieved, and the levels of CO_2 produced in the main bedroom. To do all of this, we have installed a number of sensors in your rooms, an extra gas meter, and two extra electric meters. The information obtained from this equipment will form the basis of a scientific report. **We will keep this information strictly confidential, and your name and address will not be mentioned in any publication.**

Thank you for your co-operation.

APPENDIX 9

BRE PROTOCOL FOR THE COLLECTION OF DUST SAMPLES FROM THE INDOOR ENVIRONMENT

PROTOCOL FOR THE COLLECTION OF DUST FOR ENUMERATION OF HOUSE DUST MITES OR ANALYSIS OF THE ANTIGEN (DER Pl) IN THE INDOOR ENVIRONMENT

1. Personnel

To minimise variations between samples the same person should collect all samples.

2. Equipment

Goblin R1000 fitted with a modified Culter sampler head. For sampling carpet material a rectangular orifice should be used but for sampling soft-furnishings and mattresses a round orifice should be used.

The filter material should be of cellulosic material with a suitable weave to trap the mites (Kleenex tissue code number 4472 [Kimberly-Clark Ltd] is a suitable product). Sufficient cellulosic material from the same batch should be obtained to make all the filters required for the entire sampling programme.

A countdown timer capable of measuring time intervals between 10sec and 10 minutes.

3. Safety

The wearing of a particle filter mask and disposable rubber gloves for taking and decanting mattress samples on site is required (3M mask code 8810 are recommended, the normal Martindale type face mask is not suitable). Because of the fine nature of the material from the mattress, deposits of what appears to be dead skin scales and probably mites frequently build up on the internal surface of the head as well as on the filter and needs careful brushing into the receptacle. During this operation some of the material becomes airborne and therefore the operator may be exposed to an increase level of allergen than normal. The wearing of a particle filter mask and disposable rubber gloves for taking and handling the other samples may be advisable.

4. Methodology

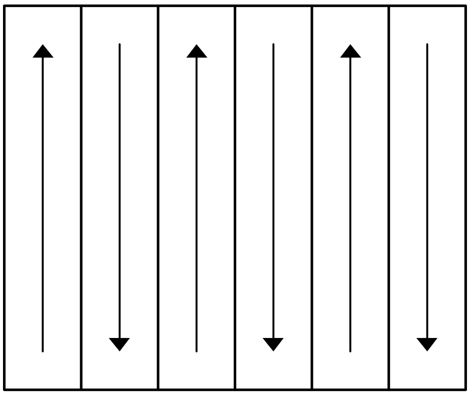
- An area of carpet should be selected to provide a 10,000 cm^2 sample area (normally lm x lm), in the living room, the area in front of the sofa or main seating area should be selected. A template should be used and sufficient measurements be taken from the template to walls, doors, windows, etc. to ensure that the template can be accurately relocated at a later date. In the bedroom the area adjacent to but not underneath the bed should be selected. If possible the template should be located so that its midpoint coincides with that of the smaller area sampled on the bed.

- For mattresses a template measuring 35 x 35 cm should be used. The template is located on the side of the mattress next to the area of carpet being sampled and placed 60 cm from the top of the mattress (headboard end) and 15 cm in from the edge of the bed.

- For soft-furnishings a similar sized template is employed (35 x 35 cm) and is placed on one seating unit, located centrally to each of the four sides.

- A clean cellulosic filter should be placed in the modified Cutler sampler and carpets are to be sampled for 3 minutes, while for soft-furnishings and mattresses a sampling rate of 1 minute should be used. The sampler should cover the area in a "stepped zig-zag" pattem.

i.e.



Each box represents one pass of the sampler head, in the direction as indicated. The direction of travel of the sampler is left to right.

The operator should attempt to standardise the speed of travel of the sampler aiming to vacuum the entire area of carpet between 3 and 5 times and for soft-furnishings and mattresses between 2 and 3 times.

- The cellulosic filter and collected dust should be decanted into a clean sealable receptacle (ie a resealable plastic bag).

- Before installing the next filter**,** the sampler head should be cleaned using a dry soft brush (a no. 8 sable artists brush is ideal) and flushed by drawing air through the head for 5 seconds.

- The same area of carpet, soft-furnishing and mattress should be sampled on each of the visits to the property. A small piece of thread should be attached to the top left hand comer of the mattress to ensure that the same face and orientation of the mattress is monitored. Similar marking of the seating unit should be considered if there is more than one possible upper surface.

- A location map of the sampler location and major items (i.e. sofa or chairs) in the room should be made.

- Any change to the room either in terms of re-organisation or replacement of furnishings or carpets should be noted.

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