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Solving mould and condensation problems: A dehumidifier trial in a suburban house in Britain

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ABSTRACT

High humidity can lead to condensation and mould formation if a house is well sealed and indoor temperatures fall significantly during the night. Solutions that have been offered are to keep heaters on throughout the night, to increase the thickness of insulation, or to install heat-exchange ventilators. These solutions are expensive. The cultural practice of heating homes to around 20 °C during the day and evening has been challenged, but lack of heating will not prevent natural temperature swings. A more direct solution is to remove the moisture from the air using a dehumidifier. This study reports a controlled 28-night trial of a dehumidifier in a suburban UK home in winter. The machine drew an average of 680 ml of water out of the air each night and consumed around 1 kW of electrical energy per night, with a high correlation between volume of water collected and energy consumed. Occupants reported that the previously severe condensation problem was solved, and measurements showed that the latent heat of the collected moisture also increased the ambient temperature. The estimated cost of running the machine for half the nights of the year is €28, an order of magnitude cheaper than other solutions.

1. Introduction

High humidity, leading to condensation and mould, is a significant problem in homes, as a number of recent papers in this journal indicate (e.g. [1–7]). It has been identified as deleterious to health in countries as meteorologically diverse as the UK [8,9], Finland [10], Sweden [11] and New Zealand [12,13]. Condensation forms on indoor surfaces when their temperature falls below the dew point, which varies according to the relative humidity of the air before the drop in temperature and the initial air temperature. For the typical range of relative humidity and air temperature likely to be found in homes, the drop in temperature that will trigger condensation is around 1–5 °C (See Table 1.). For example, if a room is heated to 20 °C during the day and has a relative humidity of 75% at this temperature, condensation will form on surfaces that fall in temperature to 15 °C during the night. A room that was colder initially, say 13 °C, will not suffer condensation until temperatures fall to 8 °C. For higher initial humidity, say of 90%, condensation will form in both cases with a temperature drop of just 2 °C.

Mould formation is therefore a potential problem for any dwelling in which relatively high daytime indoor temperature is followed by a temperature drop at night. It is exacerbated by lack of air exchange between indoors and outdoors, a characteristic of modern homes with air-sealed window and door frames. Theoretically, residents of such homes could avoid condensation by keeping rooms at a constant, steady, low temperature, but this is impossible in practice. On a sunny day in winter the temperature of an unheated room can rise to 20 °C or more, but will then fall steeply in the evening, unless the home is exceptionally well insulated, preferably with external wall insulation that keeps the dew point outside the building fabric. Cooking and other human activities can also raise indoor temperatures during the day, often with attendant rises in humidity.

German building regulations for both new homes and thermal refits use the standard of year-round indoor temperature of 19 °C or greater. The regulations set the maximum permissible heat energy consumption to keep the interiors of homes at this temperature. British standards are maintained by the Chartered Institution of Building Services Engineers, and include a more flexible approach that now acknowledges 'the thermal adaptive approach', whereby provision should be made for inhabitants' felt needs for deviations from the standard norms, particularly in low energy, sustainable buildings [14].

Some recent studies have criticized the growing acceptance of the need to maintain high indoor temperatures in winter, seeing this as a cultural trend rather than a physiological necessity ([15,16], and see [17]), though this has been challenged (e.g. [18]). But even if householders do prefer lower temperatures, it is difficult to avoid the swings in temperature that lead to the dew point being reached.

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Table 1
Temperature required for condensation to form, given initial air temperature and relative humidity.

Starting air temperature (°C)	% Relative humidity						
	100	95	90	85	80	75	70
24	24	23	22	21	20	19	18
21	21	20	19	18	17	16	15
20	20	19	19	18	17	15	14
18	18	17	17	16	15	14	13
16	16	14	14	13	12	11	10
13	13	12	11	10	9	8	7
10	10	9	8	7	7	6	4
7	7	6	6	4	4	3	2
4	4	4	3	2	1	0	
2	2	1	0				
0	0						

Condensation may be visible on windows but is usually invisible on walls, ceilings, books, and clothes in wardrobes, where it provides a luxuriant environment for moulds to grow. Moulds take nutrient from the organic matter they rest on, causing deterioration of fabrics, décor and structural materials. While it is difficult to state confidently the direct causal links between mould and ill health [19], there is a high correlation between the two [10,12,20], and health literature tends to take a precautionary approach. High concentrations of house dust mites, which do exacerbate respiratory illness, are also associated with high humidity and condensation [8].

Hence there needs to be caution around discussion of cultural or individual preferences for indoor temperatures below the norm of around 20 °C. Choosing lower indoor temperatures could inadvertently endanger the health of household members, in addition to causing ugly and destructive growths of mould on clothes, décor and building structure.

2. Mould, insulation and the building regulations

In the wake the oil crisis of 1973 many countries in temperate and frigid zones introduced thermal retention requirements for new buildings, particularly dwellings. In more recent years the threat of climate change has combined with increasing concerns for fuel security, leading these countries to steadily tighten building regulations for energy efficiency, including both insulation and the fuel efficiency of heating systems [21,22]. This applies to both new builds, and renovations to existing buildings. Meanwhile technology and building methods have developed, so that it is now possible to build a house which consumes no more than 15 kWh of heating energy per square metre of floor space per year (kWh/m^{2}a). This so-called 'passive-house' standard is also being achieved in renovations of old apartment blocks (see examples at http://passiv.de/), though renovating to this standard is prohibitively expensive. By contrast, dwellings built prior to the 1980s typically consume 200–450 kWh/m^{2}a for space heating [23].

One of the most advanced countries in thermal retention regulations is Germany. Through its *Energieeinsparverordung* (Energy Saving Regulations) the maximum permissible heat energy consumption of buildings was reduced by 30% in 2002 and a further 30% in October 2009, and is due for a further 30% tightening in 2012. The maximum permissible heat energy consumption depends on the geometry of the building, with the typical range for thermal refits now around 70–100 kWh/m^{2}a. Federal subsidies are available for renovations which go a further 10% below the minimum requirement. Renovations to this standard may well provide steady room temperatures throughout the night without the consumption of much heat energy, and therefore reduce condensation and mould formation, but they are extremely expensive. They are now under challenge from within the German government, and in September 2009 the Conservative (CDU/CSU) caucus of the federal government put forward a new proposal to slacken the renovation standards radically, to 130 kWh/m^{2}a [24].

One of the features of modern insulation is draft-proofing, whereby the building is completely sealed so there is no leakage of warm air to the outside. This contributes to problems with moisture and therefore mould formation, as condensation occurs when the inside temperature falls at night if there is not a free exchange of air with the outdoors. More advanced renovations solve this problem in two main ways. Firstly, using very thick loft, floor and external wall insulation, together with triple-glazed windows, the thermal resistance ('R') of the building envelope is increased (the 'U'-value is decreased) to such an extent that there is very little cooling indoors at night.

A more sophisticated solution is to install a heat-exchange ventilator system, in which 'fresh' incoming air is heated by 'stale' outgoing air in a capillary system [5]. This provides a constant interchange of air between indoors and outdoors without wasting heat. A particular advantage of such a system is that it can remove the need for theoretical modelling of indoor humidity with variables such as amount and type of cooking, showering and bathing, number of occupants, amount of activity in the home, as it simply replaces indoor air with outdoor air.

But both these solutions are expensive, particularly the latter. Empirical studies show that simply applying an 8 cm layer of external wall insulation to an old apartment block can reduce heat energy consumption by over 100 kWh/m^{2}a and provide a comfortable indoor environment, for as little as €4000 per apartment [25]. With 20 cm thick wall insulation, window replacement and heat-exchange ventilators, the price rises to around €36,000 per apartment, a 9-fold increase. However the fuel saving is only increased by a factor of 3. The cost, therefore, of each kWh of heat energy saved is three times as high for the more sophisticated solution.

While the absolute costs of renovation vary widely depending on type of building, economies of scale, and choice of renovation firm, these ratios are typical for thermal renovation standards in continental Europe [26,27].

In short, saving heat energy by sealing the building can lead to condensation and mould, which can be alleviated by more comprehensive insulation and heat-exchange ventilation systems, but these solutions are both expensive and economically inefficient in terms of money invested per unit of energy saved.

The problem, however, is not that some homes are too cold, but that they are too moist. A more direct solution is to aim simply to take the moisture out of the air. Hence it was decided to conduct a controlled experiment, in an air-sealed, modestly insulated home with a condensation and mould problem, to see whether a dehumidifier would solve the problem.

3. Dehumidifier trials to date

While dehumidifiers are a widely known device and can be readily purchased, there has been little systematic study of how best to use them in the home. Galbraith et al. [28] conducted laboratory and field experiments with dehumidifiers of three different water extraction rates, to determine their effectiveness in combating condensation and mould formation. They found that smaller models acted as little more than low wattage heaters, while larger models improved living conditions in the bedrooms where they operated. However, residents found the noise of the machines a problem, and often failed to operate them at night, when they would do most good.

Hyndman et al. [8] conducted a randomized trial, over a year, to examine the effects of dehumidifiers on reduction of house mites in the bedrooms of allergy sufferers. 76 homes were either allocated a dehumidifier, given a behavioural program, or designated a control group. Measurements of relative humidity and house dust mite count were made four times throughout the year. Humidity was found to be lower in the bedrooms with the dehumidifiers (no doubt because they were running when the measurements were made), but the house dust mite count was lower in all three groups. However, because the dehumidifiers were noisy, they were seldom run at night, which is the time when temperature is falling, humidity is increasing, and therefore condensation is occurring. Running the machines during the day is of little use if the aim is to achieve constant conditions of low humidity. Htut [29] and Cunningham [30] found it was necessary to maintain constant low humidity for at least 5 months, to have a significant impact on mould formation.

In a further trial reported by Custovic et al. [31], the dehumidifiers used were not powerful enough to reduce humidity significantly.

A clear lesson from these studies is that for dehumidifiers to be effective, ways need to be found to operate them through the night, even though they are noisy. They need to be sited well away from bedrooms, to reduce noise, but with internal doors left open, to permit exchange of air between rooms. The dwelling needs to be well sealed, and there needs to be free internal exchange of air between all the rooms, so that removing the moisture from the air at one point will have a knock-on effect throughout the building over a period of hours. What has not been tried is a controlled experiment, using these principles, structured so as to apply them within a dwelling of a particular size and layout. This is what the present study attempted. A structure of trial is developed which is offered for wider use in a range of different types of dwelling and household.

4. A house with a mould problem

The dwelling chosen for the trial was a three bedroom semidetached house in Cambridge, UK. It had been built in 1930 as part of a council estate, and was sold to its tenants in the 1980s and to the present owner in 2002. It is a two-story dwelling, with 75 m^2 of living space plus a converted loft of 20 m^2. It has three bedrooms, two reception rooms, a small kitchen, a bathroom, and a separate toilet. There are three adult occupants. All the windows have PVC double-glazing, as do the front and back doors, which were recently installed and are of high thermal resistance. The walls are solid brick, 25 cm in thickness, with no extra external or internal insulation. There is a 15 cm layer of insulation in the ceiling of the upper storey, i.e. under the floor of the loft, plus 6 cm of roof insulation. The floor to ceiling height is 2.5 m. The ground floor rooms have polished wood floors and no under-floor insulation.

There is a central heating system with a combi-boiler, providing individually adjustable radiators to all the rooms plus the stairwell. The boiler also allows adjustment of the heating system water temperature and has an easily adjustable on–off timer. On most winter days the occupants set the heating to run from 6 am to 8.30 am, when the last person leaves for work, and again from 5.30 pm to 9.00 pm. They adjust the heating system temperature upwards on exceptionally cold days, and regularly adjust individual radiators so that only rooms currently occupied are heated. The annual gas bill for the home is around €460, and this includes water heating. As there is a standing charge of €120 per year, gas usage equates to about 7740 kWh per year, or 100 kWh/m^2a. The space-heating portion of this probably comes to no more than 75 kWh/m^2a. There are no other devices used to heat rooms.

The house suffers a problem, in winter, of heavy condensation on the windows in the morning, and mould growing on parts of the north-facing walls and a section of shaded south-facing wall. This is almost certainly due to the condensation of moisture in the air during the night as the indoor air temperature falls and the relative humidity consequently rises. The solutions which had been suggested were (a) to apply 8–10 cm of external wall insulation so that the indoor temperature drop is not so extreme at night, or (b) to keep the central heating running all night during winter months.

Both of these options are expensive. A quote from a home insulation firm put the first at around €17,000. This would reduce heating bills, but even if it halved the gas consumption for space heating, it would save only €126 per year and would therefore take 113 years to pay for itself. Assuming the insulation lasted 25 years and there were no interest or opportunity costs on the €17,000, the net cost of the measure would amount to at least €540 per year. Interest and opportunity costs of 4% per annum would raise this to about €840 per year. The second option would be cheaper, possibly increasing the gas bill by around €240 per year.

A third option was to use a dehumidifier to extract the moisture from the air at night, thus lowering the relative humidity and consequently preventing condensation as the indoor temperature fell during the night.

5. The dehumidifier trial

A dehumidifier was operated for 28 consecutive nights in winter, from 20 November to 17 December 2008. The machine was purchased from the firm B&Q for €120.00. As the household wanted to keep running costs to a minimum, a model was chosen with a timer and a target humidity setting which prevented its water collecting mechanism cutting in until a selected relative humidity was reached. The setting selected was 60%. The machine was set each evening to switch on at 3.00 am and was turned off manually by the experiment leader (an occupant who is also an engineer) at around 7.00 am. Measurements were taken each evening, and the following morning, of indoor and outdoor temperature, and indoor humidity. The volume of water collected by the machine was measured each morning, to the nearest 10 ml. The experiment leader checked all the windows in the house each morning for condensation, and a score was given on a scale of 0–5 for the amount of condensation found. This was somewhat subjective, but with 12 windows in the house, all at different distances from the dehumidifier, it was impossible to devise a robustly quantitative method of measurement. A score of '0' meant that no condensation was found, while a '5' would indicate condensation as widespread and heavy as on the worst mornings before the dehumidifier was purchased.

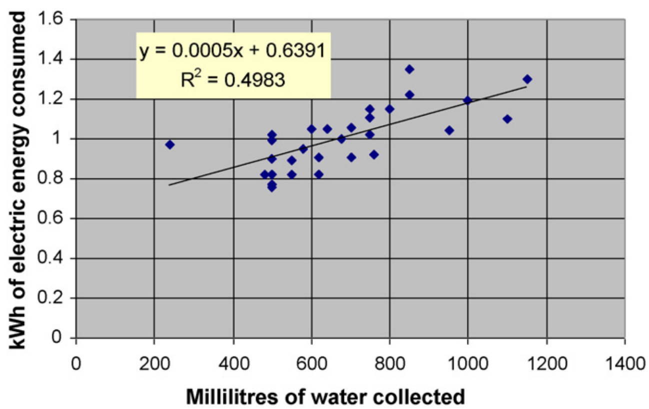
A power meter was also purchased, for €12.00, from the electrical store Maplin. Each morning the power usage of the dehumidifier was noted.

All the results were recorded by hand on a chart and later entered into a spreadsheet for processing (see Appendix A).

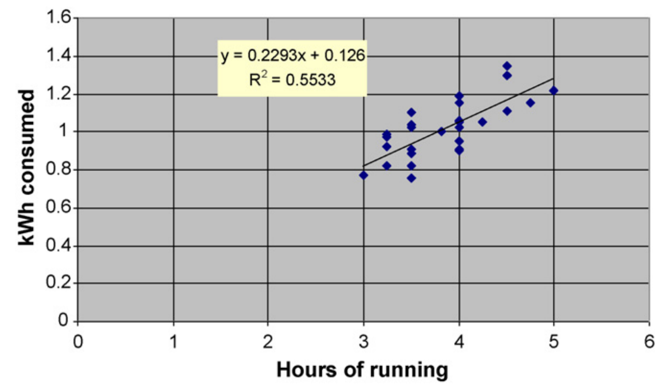
Because of the noise problem, the dehumidifier was placed in the dining room, as far away as possible from the bedrooms. All the internal doors were left open so that air could circulate within the house, but the trapdoor to the loft was kept shut. Since most of the condensation had been in the ground floor rooms, this also put the machine where it would do most good. Residents reported some disturbance while the machine was running, but not severe enough to significantly affect their sleep.

6. Results

In subjective terms the householders were very pleased with the dehumidifier's performance, and continued to use it after the 28-day experiment was completed. The condensation on the windows was almost completely gone, with measurements ranging from 0 to 2, average 0.4. Residents reported that the downstairs rooms felt dry in the mornings and noticeably warmer than previously. Householders also found the dehumidifier useful for drying laundry



Graph 1. kWh per ml of water collected.



Graph 2. kWh used against hours of running.

indoors during the day, providing they shut the doors to the room where the dehumidifier and laundry were positioned.

The volume of water collected each night ranged from 480 to 1150 ml, with an average of 678 ml. The dehumidifier consumed an average of 1.00 kWh each night, at a cost of 15.02 eurocents per kWh. Running the machine for half the nights of the year would therefore increase the electricity bill by about €28 per year.

There was a significant correlation between volume of water collected and kWh of electrical energy consumed (R^2 = 0.4983, see Graph 1), but energy consumption never fell below 0.82 kWh per night, so it is unlikely that the cost would be significantly lower on drier or warmer nights in spring and autumn. Nevertheless, a cost of €28 per year compares very favorably with €240 per year for running the central heating during the night, and €540–€840 per year for external wall insulation.

Using the dehumidifier rather than the heating system at night equates to an energy saving of around 8 kWh per night, since running the heating through the night would consume around 9 kWh, compared to the dehumidifier's consumption of 1 kWh. If the heating system were timed and set to half its normal running time, the saving would still be in the order of 3.5 kWh per night. Over the 6 months of cold weather this would amount to a saving of some 630 kWh. This equates to around 130 kg of saved CO_2 emissions per year.

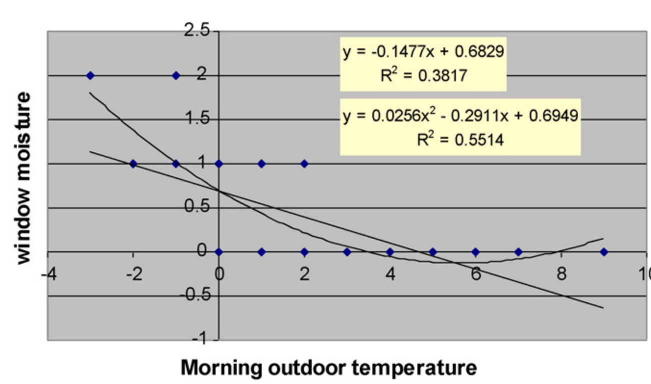
A further feature of Graph 1 is the equation of its regression line: $y = 0.0005x + 0.6391$ (where y = kWh, x = ml). The figure 0.6391 (kWh) is a likely measure of the energy required to run the machine for some 3.5 h regardless of the actual humidity and the target humidity.

A further result contributing to the comfort of occupants was the significant heating effect of the dehumidifier. The average morning indoor temperature in the dining room was 16.4 °C, compared to an average outdoor morning temperature of 2.0 °C. The evening indoor and outdoor average temperatures were 17.9 °C and 3.4 °C, respectively. Since the dining room enjoys no heating benefit from human presence at night and is separated from the outdoors by only the back door and a large window without a curtain, it is significant that the dehumidifier maintained such a large differential between indoor and outdoor temperatures. This heating effect is explained by the latent heat of condensation being given off by water vapour as it condenses, in the dehumidifier, to form liquid water, at the rate of 6.75×10^{-4} kWh/g. Since 1 ml of water has a mass of approximately 1 g, and an average of 678 ml of water was collected per night, the 'free' heat generated in this way averaged 0.46 kWh. In other words, almost half the electrical energy consumed by the dehumidifier, as it removed water from the air, was given back as heat.

Also of interest was the significant correlation between energy consumed, and total length of time the dehumidifier was operating. This was not a 1:1 correlation (instead R^2 = 0.5533, see Graph 2), as very little energy is consumed while the machine is in its 'coasting' mode, i.e. when the target humidity has been reached. In this mode only a small fan is running, to keep air circulating through the machine so that humidity can be monitored. Maximum power is used while its pump mechanism is operating, i.e. when the humidity of the air is higher than the target humidity. Hence it is not especially wasteful to leave such a machine on when the target humidity has been reached. Indeed, this cannot be avoided if the machine is to run through the night. The important consideration, however, is that this economy only applies to machines with a mechanism which stops the pump when the target humidity is reached.

A further feature of interest was the significant inverse correlation between the outdoor temperature in the morning, and the estimated wetness of the windows (see Graph 3). Generally, the colder the morning outdoor temperature, the greater the wetness. It is not clear why this should be so. One possible explanation is that a very low outdoor morning temperature is evidence of an early drop in temperature during the night, in which case condensation could have begun to form on the windows before the dehumidifier switched on. This theory could be tested by running the dehumidifier for the whole night, i.e. from 10.30 pm to 7.00 am. This would increase the electrical energy consumption by only a small amount if, for most of the extra time, the machine was merely coasting.

An alternative explanation is that there were local pockets of cooling indoors alongside the window surfaces, so that in these regions the relative humidity was higher than the average in the rooms. As Graph 3 shows, no condensation formed when the out-



Graph 3. Surface wetness and morning outdoor temperature.

door temperature stayed above 2 °C. Since the humidity sensor was on the dehumidifier itself, some metres from the nearest window, its pump would have been switching off while these local regions still had high humidity. This could be tested by putting local temperature sensors on the indoor window surfaces. Its solution would then be in more effective circulation of air within the room – i.e. installing small fans – or in setting the target humidity lower. The former solution would probably be the cheaper, but least convenient.

Further regression analyses were run between the datasets for temperature differences morning and evening, and indoor and outdoor; humidity changes; water volume collected; electrical energy used; and the householders' perception of dryness of windows. However the only significant correlations were those noted above. The most significant factor affecting energy use is the amount of water collected, which is directly related to the amount of water needing to be extracted from the air. Every litre of water collected increases the energy consumption by half a kWh. The second most significant factor is the length of time the machine is running. Every extra hour increases the energy consumption by just over 0.2 kWh – but this might not apply when it is in coasting mode, i.e. while collecting no water.

7. Conclusions

Using a dehumidifier proved to be a very cheap way to solve the problem of condensation, presumably leading to far less mould formation. The estimated cost is €28 per year plus the interest and opportunity cost on the initial outlay of €120 for the dehumidifier. Depending on a householder's personal discount rate, and assuming the machine lasts 10 years, this would amount to a total annual expense of around €48. This might rise to €60 if the target humidity were set lower. This still compares very favorably with €240 per year for leaving the heating on all night, and €540–€840 per year for external wall insulation. Further, since the problem is moisture not temperature, the more direct and dependable solution is to use technology designed to remove moisture rather than to keep the temperature steady.

Using a dehumidifier also offers considerable energy saving compared to using a home's heating system to achieve the same goal, i.e. of reducing condensation and mould formation and growth. As we saw, it reduces energy consumption by at least 3.5 kWh per night, or 630 kWh for the 6 cold months of the year, resulting an annual saving of CO_2 emissions of 130 kg, or one-eighth of a tonne.

Some of the factors discussed above lead to the suggestion of developing a 'smart' dehumidifier system, to reduce running costs to a minimum while achieving optimal moisture reduction. This would include temperature sensors on the indoor window surfaces. When the temperature here fell below a specified minimum, the target humidity would automatically reset to a lower level. Hence the pump would switch on until that new target was reached.

However for general use an important issue is the type of dehumidifier purchased. There are considerable economies in using a model with a timer to switch it on in the middle of the night, and a sensor to turn the pump on and off according to whether or not the target humidity has been exceeded. The more important of these is the sensor, as the power meter indicated a usage of 230 W when this was running, and less than 30 W in the coasting mode.

A further important feature of the dehumidifier chosen for the experiment was its target humidity setting. The machine ran in full operational mode until this target was reached, then its compressor switched off while its fan continued to draw air through its sensors. This aided the circulation of dehumidified air around the house, and also triggered the compressor to switch on again when air passed through with a higher humidity than the target. Since the compressor normally ran for much less than the whole period the machine was turned on, it was clear that most of the air in the house was kept at or below the target humidity for most of the night. If this had not been the case, a more powerful machine would have had to be used. It was more straightforward doing the experiment this way, than attempting to model the likely humidity and using theoretical criteria for judging what would be required to lower it, since there are wide day-to-day variations in the factors causing high humidity in households.

Equally important is the need for householders to be trained in the machine's use. A condensation problem requires nighttime running, not daytime. All the windows must be shut, and air leakage sealed off, while internal doors must be kept open. Where possible, curtains should be left open at night so as to permit circulation of air around the inside surfaces of the glass. The water catcher has to be emptied every morning or it will quickly fill up and switch the machine off – though there is a provision for an overflow tube if, for example, the machine is to be left running in an empty house over a weekend. The placement of the machine within the house is of crucial importance, as the noise it makes at night must not drive occupants to switch it off, yet the further away from the bedrooms it stands, the less benefit they will gain from it.

Most importantly, there is no significant gain in running a dehumidifier during the daytime to try to solve a condensation problem. It is even more unproductive to do so with a window open. Studies such as that of Hyndman et al. [8], in which dehumidifiers were run in bedrooms during the day and then switched off at night, seem to be based on a faulty understanding of the physics of humidity and water vapour condensation.

There is scope for a larger scale trial of the type reported here. It would be interesting to see whether a large number of households with mould and moisture problems could be provided with a dehumidifier and trained in its use, using the structure trialed here. Hence this paper offers a structure and method which others could repeat. The hypothesis arising from this one trial is that in the long term, dehumidifiers, used sensibly, can solve condensation, mould, and morning chill problems far cheaper and more fuel-efficiently than using heating fuel or excessive insulation to keep the indoor temperature steady throughout the night.

Appendix A. Appendix 1 Dehumidifier data for Cambridge 3 bedroom house.

Evening date	Evening room relative humidity	Evening room temperature	Evening outdoor temperature	Morning date	Morning room relative humidity	Morning room temperature	Morning outdoor temperature	Water volume collected (ml)	window wetness 0 = bone-dry; 5 = very wet	kWh consumed	Hours of running
20/11/2008	80	17	15	21/11/2008	70	16	9	1100	0	1.1	3.5
21/11/2008	65	19	1	22/11/2008	65	15	1	700	1	0.91	3.5
22/11/2008	70	20	−1	23/11/2008	60	17	0	850	1	1.22	5
23/11/2008	75	17	3	24/11/2008	65	17	3	580	0	0.95	4
24/11/2008	65	18	5	25/11/2008	60	17	2	700	0	1.06	4
25/11/2008	75	16	2	26/11/2008	65	15	3	500	0	0.76	3.5
26/11/2008	70	18	6	27/11/2008	60	18	6	1150	0	1.3	4.5
27/11/2008	65	20	8	28/11/2008	60	18	5	760	0	0.92	3.25
28/11/2008	70	20	4	29/11/2008	65	15	1	620	1	0.82	3.25
29/11/2008	65	22	2	30/11/2008	65	15	3	800	0	1.15	4
30/11/2008	75	19	7	01/12/2008	60	17	1	950	1	1.04	3.5
01/12/2008	65	18	4	02/12/2008	60	16	−1	620	1	0.91	4
02/12/2008	65	17	−1	03/12/2008	60	16	−1	640	2	1.05	4.25
03/12/2008	65	16	0	04/12/2008	65	14	2	500	0	0.82	3.5
04/12/2008	75	18	3	05/12/2008	60	17	0	550	0	0.82	3.5
05/12/2008	70	17	4	06/12/2008	65	16	2	850	0	1.35	4.5
06/12/2008	70	17	1	07/12/2008	60	16	−2	500	1	0.9	4
07/12/2008	70	16	0	08/12/2008	60	17	2	600	0	1.05	4
08/12/2008	75	16	4	09/12/2008	65	15	0	500	0	0.77	3
09/12/2008	65	18	−1	10/12/2008	60	17	0	480	0	0.82	3.5
10/12/2008	70	17	2	11/12/2008	65	16	1	240	0	0.97	3.25
11/12/2008	60	20	−1	12/12/2008	65	16	−3	500	2	0.99	3.25
12/12/2008	70	17	7	13/12/2008	65	15	4	500	0	1.02	3.5
13/12/2008	70	19	5	14/12/2008	60	17	2	1000	1	1.19	4
14/12/2008	70	16	3	15/12/2008	65	16	3	750	0	1.02	4
15/12/2008	70	17	4	16/12/2008	60	17	2	750	0	1.15	4.75
16/12/2008	65	17	5	17/12/2008	60	17	3	750	0	1.11	4.5
17/12/2008	70	18	5	18/12/2008	60	20	7	550	0	0.89	3.5
Averages	69.3	17.9	3.4		62.5	16.4	2.0	678.2	0.4	1.00	3.8

References

[1] M. Abuku, H. Janssen, S. Roels, Impact of wide-driven rain on historic brick wall buildings in a moderately cold and humid climate: numerical analyses of mould growth risk, indoor climate and energy consumption, Energy and Buildings 41 (1) (2009) 101–110.

[2] M. Adamski, Ventilation system with spiral recuperator, Energy and Buildings 42 (5) (2010) 674–677.

[3] A.E. Ben-Nakhi, Development of an integrated dynamic thermal bridging assessment environment, Energy and Buildings 35 (4) (2003) 375–382.

[4] H. Janssen, S. Roels, Qualitative and quantitative assessment of interior moisture buffering by enclosures, Energy and Buildings 41 (4) (2009) 382–394.

[5] J. Kragh, J. Rose, T.R. Nielsen, S. Svendsen, New counter flow heat exchanger designed for ventilation systems in cold climates, Energy and Buildings 39 (11) (2007) 1151–1158.

[6] F. Lucas, L. Adelard, F. Garde, H. Boyer, Study of moisture in buildings for hot humid climates, Energy and Buildings 34 (4) (2002) 345–355.

[7] F. Wang, H. Yoshida, H. Kitagawa, K. Matsumoto, K. Goto, New counter flow heat exchanger designed for ventilation systems in cold climates, Energy and Buildings 39 (11) (2005) 1151–1158.

[8] S.J. Hyndman, L.M. Vickers, T. Htut, J.W. Maunder, A. Peock, T.W. Higenbottam, A randomized trial of dehumidification in the control of house dust mites, Clinical and Experimental Allergy: Journal of the British Society for Allergy and Clinical Immunology 30 (8) (2000) 1172–1180.

[9] J. Singh, Review: occupational exposure to moulds in buildings, Indoor and Built Environment 10 (3–4) (2001) 172–178.

[10] O.M. Koskinen, T.M. Husman, T.M. Meklin, A.N. Nevalainen, The relationship between moisture or mould observations in houses and the state of health of their occupants, European Respiratory Journal 14 (1999) 1363–1367.

[11] L.H. Engman, C.-G. Bornehag, J. Sundell, 'How valid are parents' questionnaire responses regarding building characteristics, mouldy odour, and signs of moisture problems in Swedish homes? Scandinavia Journal of Public Health 35 (2) (2007) 125–132.

[12] P. Howden-Chapman, K. Saville-Smith, J. Crane, N. Wilson, Risk factors for mold in housing: a national survey, Indoor Air 15 (6) (2005) 469–476.

[13] C.R. Lloyd, M.F. Callau, T. Bishop, I.J. Smith, The efficacy of an energy efficient upgrade programme in New Zealand, Energy and Buildings 40 (7) (2008) 1228–1239.

[14] CIBSE (Chartered Institution of Building Services Engineers), Guide A: Environmental Design: Category: Heating: Air Conditioning and Refrigeration, seventh ed., CIBSE, London, 2007.

[15] H. Chappells, E. Shove, The Environment and the Home: Draft Paper for Environment and Human Behaviour Seminar 23rd June 2003, Policy Studies Institute, London, 2003.

[16] S. Darby, R. White, Thermal comfort: background document C for the 40% house report, Environmental Change Institute, University of Oxford, 2005. Available from: http://www.eci.ox.ac.uk/research/energy/downloads/40house/background_doc_c.pdf (accessed 18.05.09).

[17] R. Critchley, J. Gilbertson, M. Grimsley, G. Green, Warm Front Study Group, Living in cold homes after heating improvements: evidence from Warm-Front, England's Home Energy Efficiency Scheme, Applied Energy 84 (2007) 147–158.

[18] J. Cupples, V. Goat, J. Pearce, "Put on a jacket, you was": cultural identities, home heating, and air pollution in Christchurch, New Zealand, Environment and Planning A 39 (2007) 2883–2898.

[19] H.A. Kolstad, C. Brauer, M. Iversen, T. Sigsgaard, S. Mikkelsen, Do indoor molds in nonindustrial environments threaten workers' health? A review of the epidemiologic evidence, Epidemiologic Reviews 24 (2) (2002) 203–217.

[20] G. Karevold, E. Kvestad, P. Nafstad, K.J. Kvaerner, Respiratory infections in schoolchildren: co-morbidity and risk factors, Archives of Disease in Childhood 91 (5) (2006) 391–395.

[21] P. de T'Serclaes, Financing Energy Efficient Homes: Existing Policy Responses to Financial Barriers, International Energy Agency, Paris, 2007.

[22] IEA (International Energy Agency), Promoting Energy Efficiency Investments: Case Studies in the Residential Sector, International Energy Agency, Paris, 2008.

[23] A. Schuler, C. Weber, U. Fahl, Energy consumption for space heating of West-German households: empirical evidence, scenario projections and policy implications, Energy Policy 28 (2000) 877–894.

[24] J. Pfeiffer, G. Nüsslein, Thesenpapier: Energiepolitische Herausforderung für die 17. Legislaturperiode, CDU/CSU-Bundestagsfraktion, Bundestag, Berlin, 2009.

[25] A. Enseling, E. Hinz, Energetische Gebäudesanierung und Wirtschaftlichkeit-Eine Untersuchung am Beispiel des 'Brunckviertels' in Ludwigshafen, Institut Wohnen und Umselt GmbH, Darmstadt, 2006.

[26] M. Jakob, Marginal costs and co-benefits of energy efficiency investments: the case of the Swiss residential sector, Energy Policy 34 (2006) 172–187.

[27] R. Galvin, Thermal upgrades of existing homes in Germany: the building code, subsidies, and economic efficiency, Energy and Buildings 42 (6) (2010) 834–844.

[28] G. Galbraith, C.H. Sanders, C. Allison, Portable dehumidifiers for the control of condensation in housing, Building Services Engineering Research and Technology 7 (1) (1986) 1–10.

[29] T. Htut, Airborne house dust mite allergen: are short-duration avoidance measures helpful? Indoor Environment 3 (1994) 48–53.

[30] M.J. Cunningham, Controlling dust mites psychometrically: a review for building scientists and engineers, Indoor Air 6 (1996) 249–258.

[31] A. Custovic, S.C.O. Taggart, J.H. Kennaugh, A. Woodcock, Portable dehumidifiers in the control of house dust mites and mite allergens, Clinical and Experimental Allergy 25 (1995) 312–316.