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Prevention of Winter Mould Growth in Housing

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Abstract: This paper reports on a study that researched the possibility of building passive designs to prevent mould growth in housing in humid and mild winter climatic zones without permanent thermal active controls. This study also investigated indoor relative humidity related to insulation, window cross ventilation, exhaust fan ventilation and temporary heating. The study found that for controlling mould growth on indoor surfaces there are two options available for different climatic conditions and housing designs: a conventional method for buildings designed for permanent thermal active controls and a newer method using passive building design and passive controls to keep the indoor relative humidity under 80%. Implications from the study include the passive prevention of winter mould growth in houses without permanent active thermal controls, insulation levels and thermal resistance, appropriate insulation levels to prevent mould growth, winter daytime cross ventilation, temporary exhaust fan ventilation and temporary heating and their impacts on decreasing mean indoor relative humidity levels and the relative humidity of air near ceilings. Educating occupants on how to 'drive' their passive designed house is also critical to prevent mould growth problems.

Keywords: Housing; Mould growth; Building passive design; Passive control strategies

Introduction

The process of mould growth on indoor surfaces generally includes gemmation, growth, and sporulation. Basic requirements for the growth of mould on indoor surfaces are mould spores, oxygen, fat and dust on the surfaces, available temperature and moisture (either on the surfaces themselves or as high relative humidity). If these conditions are available in a building, mould growth can occur on the indoor surfaces. The key factor of moisture is related closely to the building's passive design and active control.

Condensation leading to wet indoor surfaces can cause mould growth problems, but this is not the only condition that encourages mould growth. In fact, mould growth is likely on almost any building material if the equilibrium relative humidity of the material exceeds 75-80% (Block, 1993; Coppock, 1951; Pasanen, 1992). The International Energy Agency (IEA) in 1991 proposed an average relative humidity of 80% as the critical threshold. The ASHRAE Handbook of Fundamental (1993) adopted it in 21.7 Concealed Condensation, Chapter 21 Thermal Insulation and Vapour Retards Applications (ASHRAE, 1993). Relative humidity of 60% is the threshold for mould to survive and grow after incubation. Gemmation of mould spores needs higher relative humidity and time. Thresholds of mould gemmation related to different relative humidity and time (Hens, 2000) are shown in Table 1.

Table 1. Threshold of relative humidity and time for mould gemmation

Substrate	Threshold RH	Time
Porous	100 %	1 day
Non-porous, dust and fat coved	89%	7 day
	80%	30 days

(Source: H.L.S.C. Hens, Minimising Fungal Defacement, 2000)

This study introduces a new concept and explores the possibility of passively preventing mould growth in a house without permanent thermal active controls, particularly in a climate with mild, humid winters. Data used for this study were based on a field study of Auckland houses with and without mould growth problems during the mild, wet winter period. Auckland has a somewhat higher vapour pressure than the other main cities in New Zealand, and the Auckland monthly mean relative humidity is very high, especially during winter. Generally, the Auckland summer is comfortable and relatively dry. Temperatures in the winter months can be lower than the comfort zone but rarely below 5 °C (Hessell, 1988) and most Auckland houses are designed for the use of temporary rather than permanent heating. Visible mould growth on indoor surfaces during the winter is a common problem in aged residential houses that lack sufficient insulation.

Control of Indoor Relative Humidity under the Threshold of Mould Gemmation

A field study to measure the indoor microclimate condition of an old house with mould growth problems and a brand new house without mould growth problems was conducted in Auckland, New

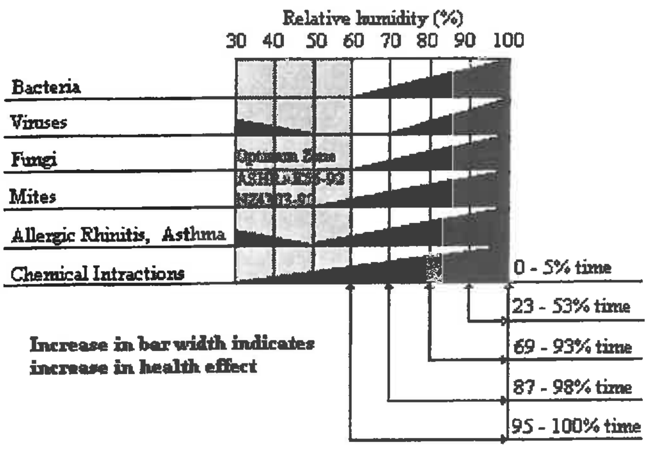

Figure 1. Indoor relative humidity near ceiling of an old house with mould growth.

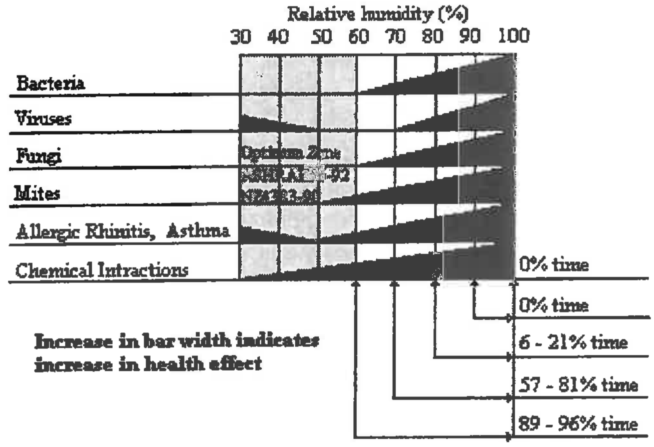

Figure 2. Indoor relative humidity near ceiling of new two-storey house without mould growth.

Zealand, during the winter of 2001 (Su, 2002). Temperatures and the relative humidity of air near ceilings and floors of the rooms in the two houses were measured by the data loggers at 10-minute intervals, 24 hours a day for 6 weeks during the winter months. Figure 1 shows the ranges of relative humidity of air near the ceiling of a bedroom in the old house and their percentages of time in the field study period, drawn against the ranges of relative humidity for indoor health effects. A heater was used temporarily in the bedroom during the field study. Windows were not opened for cross ventilation during the study, both for security reasons and because of rain protection problems with the windows in the double bedroom. Figure 2 shows the ranges of relative humidity of air near the ceiling of a bedroom in the new house and their percentages of time in the field study period, drawn against the ranges of relative humidity for indoor health effects. No heating was used in the new house during the study. The windows had adjustable security fittings and a rain protection area at the bottom, and were thus able to be opened for cross ventilation during the day. For both houses, for over 90% of the testing time, the indoor relative humidity was higher than 60%, the threshold for mould to survive and grow, but visible mould occurred on the underside surface of the ceiling only in the old house. The significant difference between the two houses was the percentage of time when indoor relative humidity was over 80% - the threshold for mould gemmation. The field study data, in addition to the known conditions for mould growth, indicate that it is possible to prevent mould growth on indoor surfaces by keeping the relative air humidity of air near indoor surfaces under 80%, the threshold for mould gemmation, by building passive designs without using permanent thermal active controls, even when indoor relative humidity is higher than 60% most of the time.

Insulation to Control Air Temperature and Relative Humidity near Indoor Surfaces

Sufficient insulation within the building envelope in relation to the local winter climate conditions is one of the key factors in controlling indoor air relative humidity level to prevent mould gemmation on internal surfaces. Mean indoor relative humidity is not directly related to mould growth on indoor surfaces. When the indoor mean relative humidity is lower than 80%, the relative humidity of air near indoor surfaces can still be higher than 80%, as indoor surfaces with a lower temperature can decrease the temperature of nearby air and therefore increase its relative humidity through heat exchange. Indoor surface temperature is strongly affected by the insulation level of the house envelope during the winter.

There is a significant difference in the distribution of indoor air relative humidity near indoor surfaces, between the houses with and without ceiling insulation. Figures 3 and 4 show the five-day distribution samples of temperature and relative humidity of the new house with insulation and without mould growth problems, and the new house without insulation and with mould growth problems. For a house with sufficient ceiling insulation, the air temperatures near the ceiling are normally higher than the air temperature near the floor as the warm air moves up, and the mean air relative humidity near the ceiling is normally lower than the air relative humidity near the floor (see Figure 3). For a house without ceiling insulation, the air temperatures near the ceiling can be lower than the air temperature near the floor during the night, as the ceiling underside surface temperature is decreased by the heat loss of long wave radiation to the cold sky (see Figure 4). As the mean indoor temperature during the night is lower than in daytime, the lower air temperature near the ceiling can cause

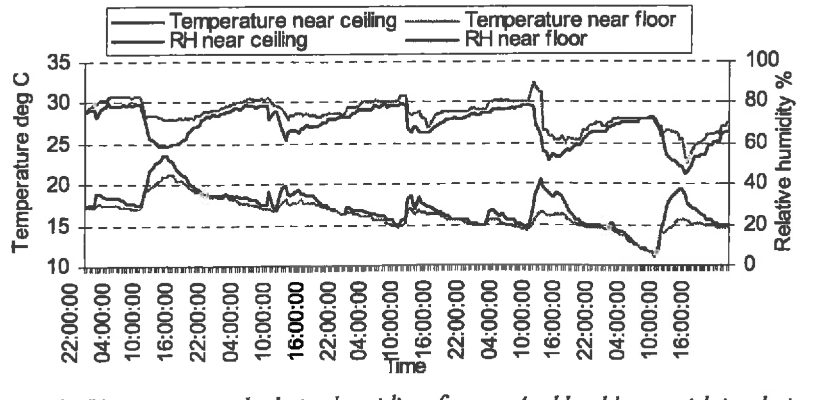

Figure 3. Temperature and relative humidity of a new Auckland house with insulation.

the higher relative humidity to encourage mould gemmation on the ceiling. For a house with sufficient ceiling insulation, if visible mould appears on the underside surface of the ceiling, there should also be mould growth on other surfaces near the floor, such as furniture, shoes, etc. For a house without insulation, this issue is more complex.

Prevention of Indoor Relative Humidity over the Threshold of Mould Gemmation

Table 2 shows the data from a second, more recent field study conducted in 2005. The same two-storey Auckland townhouse used for the field study in 2001 (Su, 2002) was measured again for this field study in 2005. There were no mould growth problems in the two-storey town house from 2001 to 2005. Relative humidity and temperature in roof spaces, bedrooms, living room with occupants on the south and north sides, both upstairs and downstairs and the shaded outdoor space, were measured at 10-minute intervals 24 hours a day for 30 days during the winter. During this field study, no heaters were used in the house and the occupants had a normal daily life. On rainless days, the windows were always open normally for natural cross ventilation. When it was raining, they were kept partially open with a small gap at the bottom for natural ventilation. Windows were closed during the night. The relative humidity of the air near the floor in the downstairs bedroom on the sunless south side of the house during the winter was higher than 80% for 9% of the 30-day field study. If 9% was used as the mean time during the winter months from June to August (90 days) or the typically wet five months from April to August (150 days), there would be a total of 8.1 days in the three winter months and 13.5 days in the typically wet five months when the relative humidity of the air near the floor of the bedroom was higher than 80%. This is less than the 30-day threshold for mould gemmation. If the time when the relative humidity of the air near indoor surfaces is higher than 80%, can be kept below the threshold for mould gemmation, mould growth on indoor surfaces can still be prevented by passive house design.

Ventilation to Remove Indoor Extra Moisture

Daytime winter window cross ventilation is important and necessary to remove the extra moisture produced by occupants' daily activities and the extra moisture produced by occupants and temporary heating during the night. The period of daytime that is best for window cross-ventilation is when the relative humidity of outdoor space is lower than that of indoor space and the temperature of outdoor space is close to or higher than that of indoor space. Figure 5 shows a five-day sample of indoor mean relative humidity and outdoor relative humidity from the two-storey Auckland townhouse during the field study in 2005. To reduce mean indoor relative humidity, the windows should be adjustable for partial opening allowing appropriate air change rate from cross ventilation during winter daytime, but without causing security and rain protection problems when the occupants are out of the home. The indoor potential air change rate of a house from cross ventilation through appropriate opened areas of windows can be estimated according to the local wind frequency data during winter daytime and wind pressure coefficients. For a given air

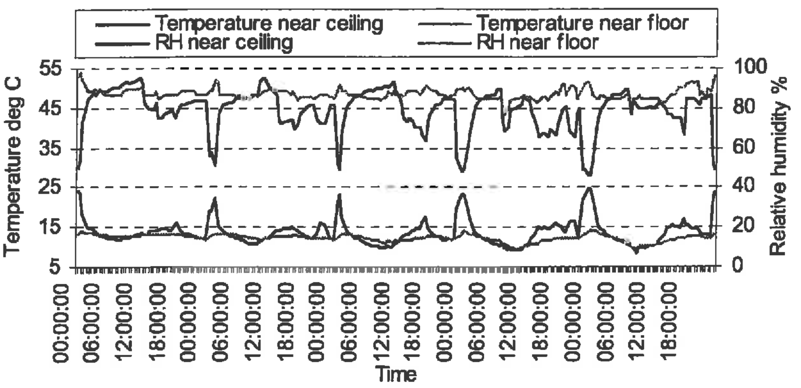

Figure 4. Temperature and relative humidity of an agedly Auckland house without insulation.

Table 2. Relative humidity ranges and percentage of time of the new two-storey house, 2005

Relative Humidity Ranges	>50%	>60%	>70%	>80%	>90%	=100%	Mean RH
Outdoor	100%	95%	82%	69%	54%	42%	88%
North roof space	89%	79%	64%	39%	3%	0%	72%
South roof space	94%	84%	62%	45%	5%	0%	74%
North upstairs double bedroom ceiling	95%	78%	40%	0.5%	0%	0%	66%
North upstairs double bedroom floor	99.5%	87%	66%	0.5%	0%	0%	67%
North downstairs living room ceiling	97%	73%	7%	0.5%	0%	0%	63%
North downstairs living room floor	99.5%	95%	56%	4%	0%	0%	71%
South upstairs bedroom ceiling	99.5%	92%	39%	0%	0%	0%	68%
South upstairs bedroom floor	100%	99.5%	71%	0%	0%	0%	72%
South downstairs bedroom ceiling	100%	99.5%	72%	0%	0%	0%	72%
South downstairs bedroom floor	100%	99%	82%	9%	0%	0%	75%

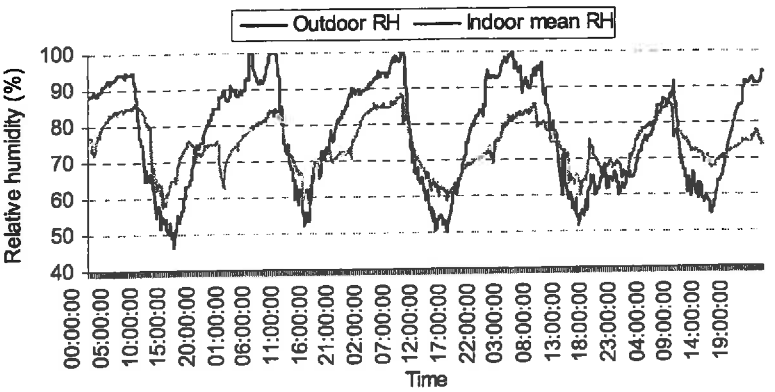

Figure 5. Outdoor and indoor relative humidity of the two-storey house in 2005.

change rate, air speeds at different levels and areas of the indoor space can be controlled or guided by the position of the open area and type of window, which affects the distribution of air relative humidity and indoor thermal comfort conditions e.g. a top-hung window can guide wind to the upper level of rooms but not to floor level (Su, 2002; Su, 2003). Winter cross ventilation from windows is not totally controlled by passive house design but also depends on the occupants.

Exhaust fans are commonly installed in bathrooms and kitchens to remove extra moisture from cooking and showers and to control indoor mean relative humidity level. Figure 6 shows the distribution of relative humidity in a bathroom within the master bedroom of the two-storey townhouse during a period of winter night time from 7 pm to 1 am in July 2005, while the occupant took a 15-minute shower from 8 pm to 8:15 pm and the exhaust fan was used from 7 pm to 9:50 pm. When the occupant started to take a shower, the relative humidity near the ceiling above the shower and near the centre of the bathroom increased sharply but the relative humidity near the floor did not increase. After the shower, it took at least 3 – 5 times the length of the shower to decrease the relative humidity near the ceiling of the bathroom to the accepted level by using the exhaust fan. It took a longer time to decrease the relative humidity near the ceiling above the shower to an acceptable level. It was necessary, to remove the extra moisture out of the bathroom and reduce the relative humidity near the ceiling to the accepted level, to continually run the exhaust fan for an extra period of time after the occupant had finished the shower. The best and most efficient place to install an exhaust fan is right above the shower. An exhaust fan can efficiently remove the extra moisture out of the bathroom without increasing the relative humidity of indoor space next to the bathroom when the bathroom door is closed (see Figure 7).

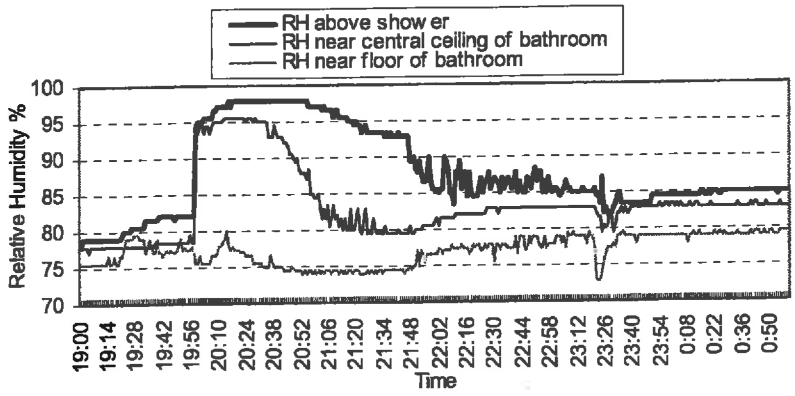

Figure 6. Variation of relative humidity in bathroom within double bedroom of two-storey house.

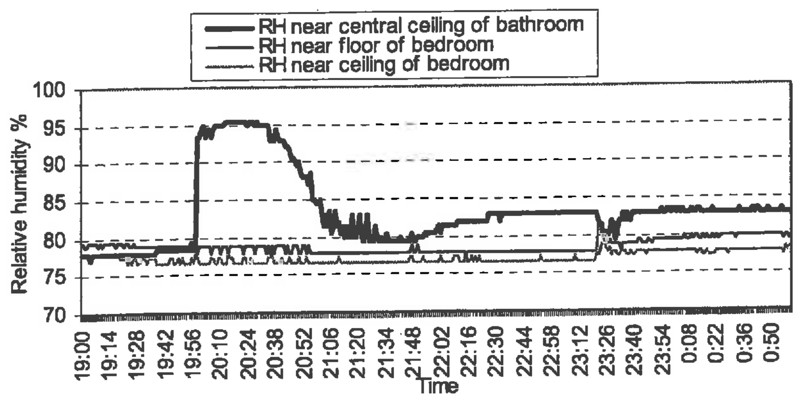

Figure 7. Variation of relative humidity in bathroom and master bedroom of two-storey house.

Temporary Heating to Decrease Indoor Relative Humidity

Temporary heating cannot only improve indoor thermal comfort conditions, but can also significantly decrease the relative humidity near the ceiling and the mean indoor relative humidity. Figure 8 shows the variation of temperature and relative humidity in a bedroom of the old Auckland house used for the field study in 2001. When an oil heater was used in the bedroom, air temperatures near the ceiling apparently increased, and the relative humidity decreased sharply. The air temperature near the floor did not increase much in response to the heating, and the relative humidity near the floor slightly increased. The indoor mean relative humidity significantly decreased when the heater was used.

Conclusions

For controlling mould growth on indoor surfaces there are two options available for different climatic conditions and housing designs. A conventional method for buildings designed for permanent thermal active controls, is to keep the indoor relative humidity under 60%, the threshold for mould to survive and grow. For indoor air quality, current international standards (ANSI/ASHRAE, 1992; ASHRAE, 1993) require indoor relative humidity to be under 60% to minimize mould growth in a building with permanent thermal active controls. It is difficult and not

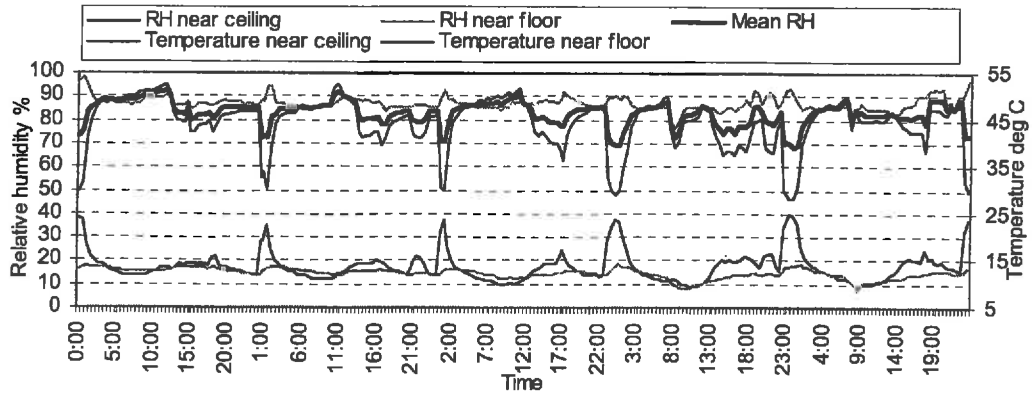

Figure 8. Indoor microclimate with temporary heating in a bedroom of the old house from the 2001 field study.

energy-efficient for a house that is not designed to use permanent heating, to keep indoor relative humidity under 60%. Another option is to use passive building design and passive controls to keep the indoor relative humidity under 80%, the threshold of mould gemmation, for a building that is not designed for permanent active controls. If mould spores never start gemmation, mould never grows on indoor surfaces.

Although the data used for this study were based on the local houses and climate conditions in New Zealand, the findings from the study have demonstrated the possibility of passive prevention of winter mould growth in housing without permanent thermal active controls, particularly in other parts of the world with climates with mild, humid winters. This mould control strategy could also be applied in other locations in the world with similar climatic conditions. To prevent winter mould growth passively in a house without permanent active thermal control, the first step is to keep the relative humidity of air near indoor surfaces under 80%, the threshold for mould gemmation. If the relative humidity of air near indoor surfaces cannot be kept under 80% all the time, the total time when the relative humidity of air near indoor surfaces is over 80% during the winter, must be less than 30 days to prevent mould gemmation.

The insulation level and thermal resistance of the house envelope is critical for controlling the relative humidity of the air near indoor surfaces. The appropriate insulation level of a house to prevent mould growth should be decided and included in the design according to the local winter climate conditions in order to keep air relative humidity under the threshold of mould gemmation near indoor surfaces. A field study of local houses without mould growth can be a realistic and reliable way to find out whether the current insulation level for thermal or energy efficiency purposes is sufficient to prevent mould growth on indoor surfaces. For passive mould control, indoor psychrometric conditions of local houses without mould growth problems are critically important. Indoor psychrometric conditions from field studies in the local climate and related to real local house designs and building materials can be used as the design criteria for a new house to prevent mould growth.

Window winter daytime cross ventilation, temporary exhaust fan ventilation and temporary heating can decrease mean indoor relative humidity levels and the relative humidity of air near the ceiling significantly, but they are not directly related to nor totally controlled by the passive building design and also depend on the occupants. Educating occupants on how to 'drive' their passive designed house is also critical to prevent successfully mould growth problems.

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