VENTILATION AND MOISTURE SOURCES IN APARTMENTS

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ABSTRACT

Moisture related problems, growth of fungi and an abundance of house dust mites harm the health. Suggested alleviating measures include increased ventilation, the use of biocides, improved moisture and temperature insulation, or reduction of humidity sources. This study was done to investigate the importance of user behavior; ventilation and construction details for humidity related problems. In a cross sectional study in Danish apartment’s air exchange rate, relative humidity and temperature of room air was logged during winter with average daily outside temperatures in the range –5 to 8 °C. Information on user behavior was obtained by questionnaires. A mass balance model based on humidity in room air, temperature and air change rate was used to show that moisture production is significant related to air change rates. Laundry drying was significant for humidity of room air. No significant relation between air change rates and humidity was found in the study.

INDEX TERMS

Moisture, Moisture source, Ventilation, User behavior

INTRODUCTION

High humidity in homes has been associated with increased prevalence of symptoms and serious diseases like asthma among occupants - in particular among children. Increased moisture levels in a microenvironment have been shown to increase the prevalence of both fungi and house dust mites (Cunningham 1999). Therefore the increased growth of moulds and proliferation of house dust mites in moist rooms may partly explain the health impacts (Jaakkola et al. 1993). Moulds are problematic since their spores and other elements may contain allergy causing agents and some extremely toxic substances. House dust mites are the most important source of inhalation allergens in homes.

Fungi require substrates containing water and organic matter that can supply them with nutrition and moisture for growing. Fairly high water activity of their substrates is required. Most construction products should at least have water activities comparable to equilibrium with an air humidity of 70-75 % RH to be seriously infested with fungi. This may be the case where indoor surfaces are cold locally or the indoor humidity is very high. The construction products may also be wetted from water leaks, flooding, diffusive transport of water or splashes from activities like bathing. At low (70 %) water activities growth is slow and develops over months or years. At higher activities significant growth can develop in a few weeks (Nielsen et al. 2000).

House dust mites require certain temperatures and high humidity in their microenvironment. They feed on human skin scales found abundantly in most homes and thrive from elevated moisture contents. It is difficult to re-move mites from protected environments such as mattresses, wall-to-wall carpets or textured upholstered furniture. Normal cleaning procedures

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are more likely to remove mites from smooth surfaces. The mites move around and in infested rooms they are found on most surfaces (Korsgaard 1983).

When moisture sources in the home are small, increased ventilation may reduce indoor humidity and hereby eliminate fungi and mites. However, the strength of the moisture sources is crucial for the ability of ventilation to control the moisture content of indoor air. Problems caused by high relative humidity at cold surfaces are only in some cases controllable by ventilation. Problems caused by direct wetting of materials can not be handled by ventilation. Furthermore it is important to consider the behavior of occupants of apartments when they try to control moisture sources and ventilation (Gunnarsen and Afshari 2000).

Many ventilation engineers consider increased ventilation to be the best way to reduce the moisture content of the air in apartments. New ventilation systems may therefore be installed in many places. Increased energy consumption is often an unwanted effect of increased ventilation. Other factors such as user behavior and moisture generating appliances may however have an equally important impact on moisture content.

The purpose of the present study was to investigate the importance of ventilation, user behavior and characteristics of moisture sources in apartments for the moisture content in apartment air.

METHODS
Using non-destructive methods, 87 apartments representing the typical range for rented apartments in Denmark were investigated. Occupants of a random sample of approximately 600 rented apartments drawn from the government register of houses were invited to participate. Approximately one out of six accepted to participate. Two trained assistants made a pre-announced visit to the apartments in the winter months January to March 1999. They set up small data loggers that monitored temperature and humidity, they placed small sources of tracer gas and passive samplers for air change measurements and they registered surface materials and other information about the apartments. A questionnaire concerning behavior was introduced and returned by occupants by mail after one week together with the monitoring equipment.

Estimation of moisture production in apartments
Moisture production $G$ (kg/h) in the apartments was estimated with the expression

$$G = \frac{x_i - x_o}{1 + x_i - x_o} n V \rho_a$$

where $x_i$ (kg/kg) and $x_o$ (kg/kg) is the absolute humidity of the indoor air and the outdoor air, respectively, $n$ (h$^{-1}$) is the air change rate, $V$ (m$^3$) is the volume of the apartment and $\rho_a$ (kg/m$^3$) is density of the indoor air. Eq. (1) is based on the mass balance of a ventilated room. The density of the indoor air was calculated for dry air as a function of temperature using the perfect gas equation of state.

Absolute humidity of indoor air was calculated from the average relative humidity and the average air temperature measured in each apartment during the period of air change rate measurement. Absolute humidity of outdoor air was approximated using measurements of outdoor relative humidity and temperature averaged over a time interval corresponding to the
period of air change rate measurements relevant to each apartment. Outdoor relative humidity and outdoor air temperature was measured at Danish Building and Urban Research.

RESULTS
Table 1 shows mean values and standard deviations of the descriptive data for the 87 apartments. The size of most apartments and the number of people in each apartment were rather small. The air change rates however were approximately twice the rates found in a similar study in new single family houses (Bergsøe 1994).

Table 1. Descriptive data for the 87 apartments. Mean values and standard deviation (in brackets) are shown.

<table>
<thead>
<tr>
<th>Description</th>
<th>Mean Value</th>
<th>Standard Deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area of apartment</td>
<td>42.6 m²</td>
<td>(15 m²)</td>
</tr>
<tr>
<td>Temperature outside</td>
<td>2.2 °C</td>
<td>(4.3 °C)</td>
</tr>
<tr>
<td>Volume of apartment</td>
<td>139 m³</td>
<td>(50 m³)</td>
</tr>
<tr>
<td>Temperature in bedroom</td>
<td>18.8 °C</td>
<td>(1.9 °C)</td>
</tr>
<tr>
<td>Relative hum. outside</td>
<td>93 %RH</td>
<td>(9 %RH)</td>
</tr>
<tr>
<td>Relative hum. in bedroom</td>
<td>41 %RH</td>
<td>(9 %RH)</td>
</tr>
<tr>
<td>Number of people in apartment</td>
<td>1.81</td>
<td>(1.1)</td>
</tr>
<tr>
<td>Outside air change in apartment</td>
<td>0.71 h⁻¹</td>
<td>(0.4 h⁻¹)</td>
</tr>
<tr>
<td>Outside air change in bedroom</td>
<td>1.1 h⁻¹</td>
<td>(0.8 h⁻¹)</td>
</tr>
</tbody>
</table>

Figure 1 shows calculated values of absolute humidity as a function of the measured air change rate for 73 apartments. The figure shows no direct relation between absolute humidity and air change rate. Even at low air change rates absolute humidity does not seem to be elevated compared to higher air change rates.

This somewhat surprising finding is the reason for the calculation of average moisture production for the monitoring period of 5-8 days for each apartment.

Figure 1. Calculated absolute humidity based on measured relative humidity and temperature in 73 bedrooms in relation to measured outside air exchange rates.

Figure 2 shows the calculated moisture production as a function of the measured air change rate. The moisture production was calculated using Eq. (1). Also shown in Figure 2 is a regression line based the moisture production in apartments with a measured air change less
than 1 h\(^{-1}\). Statistical testing at a 5 % significance level showed that the regression line had a slope larger than zero.

Figure 2. Moisture production as a function of measured air change rate. The moisture production was calculated using Eq. (1).

Figure 3 shows average absolute humidity in bedrooms in three categories based on the questionnaire response of the occupants to a question on how often they dried laundry inside their apartment. Occupants who dry laundry on a daily basis in the apartment have significantly higher (p<0.05) absolute humidity in their apartments than the two other categories have.

Figure 3. Impact of laundry drying on absolute humidity in the apartments. Lines represent standard deviation on the mean measurements.

Other important findings from the study include that visual inspection resulted in suspected mould growth in 22 % of the apartments. Significant growth was found in 13 % of the investigated dwellings, mainly in bathrooms and kitchens. House dust mites were found in 57 % of the bedrooms. The concentration of mites was higher on floors than on mattresses. Floors with wall-to-wall carpets had far more mites per square meter than other floor types. Significant correlation was found between absolute humidity in bedroom air and mites on mattresses.
DISCUSSION
The lack of impact on absolute moisture in room air of the air change rate has been tested for being a chance finding based on the rather large uncertainty on measurements of air change rates and relative humidity. No impact would be expected at the higher air change rates above 1 h\(^{-1}\). But the majority of observations of humidity that took place in apartments with lower air change rates would be expected to be influenced by air change rates if moisture production varied randomly according to a normal distribution with mean and standard deviation according to findings in this study.

The significant slope of the regression line in Figure 2 indicates that user behaviour as regards moisture production could be influenced by the existing air change rate when the air change rate is lower than 1 h\(^{-1}\).

The brief questionnaire used in this study did not address other possible moisture producing activities than laundry drying. It is however well possible that other activities like bathing, cooking, washing and ironing could have similar impact on air humidity.

Possible explanations for the seemingly proportional relation between moisture production and air change rate include:

1. Occupants modify moisture-producing activities in apartments with low air change rates.
2. Occupants modify air change rates in relation to their moisture production.
3. Important sources of moisture have a direct dependency on air change rates or air humidity.

It is not possible to choose one best candidate among these explanations. It is more likely that they all have some influence on the found relation between air change and moisture production.

Many people may open windows or turn on some kind of exhaust ventilation when they produce much moisture. This may be the case when they use a stem iron, cook pasta, dry clothes or have many people in a room. It is also likely that encountered moisture problems at low ventilation rates will teach occupants how to reduce moisture production. Finally it is quite likely that many drying processes and other moisture sources will slow down at low ventilation rates.

The inherent feedback in the mass balance system of moisture in room air may compromise any strategy seeing only increased ventilation as a solution to moisture problems. Moisture problems are more likely to be reduced by a joint effort towards both ventilation systems, user behavior and source control.

CONCLUSIONS AND IMPLICATIONS
Air change rate and absolute humidity in room air do not seem to be correlated in Danish apartments.

- In apartments with low air change rates the moisture production is lower than it is in apartments with higher air change rates.
- Laundry drying in apartments and possibly other aspects of user behavior has significant impact on the absolute humidity in the apartments.
• Increased air change rates, improved user behavior and source control should all be applied to reduce moisture related problems in apartments.

ACKNOWLEDGEMENT
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REFERENCES