Mould growth control in cold attics through adaptive ventilation

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KEYWORDS: Adaptive ventilation, mould growth, moisture problems.

SUMMARY:
This paper presents results from numerical simulations and field measurements which indicate a significant potential to reduce mould growth in cold attic spaces by sealing the attic and fitting it with a system for adaptive ventilation.

1. Introduction

Problems with high humidity levels and mould growth in cold attics have been increasing over the last few years. A recent Swedish study showed that as many as up to 60 – 80 % of the single-family houses in Västra Götaland (largely, the Gothenburg region) are showing significant mould growth and thereby risk developing serious moisture problems. The high humidity levels are to a large extent a consequence of the increasing demand on energy efficiency. Houses are frequently retrofitted with additional attic insulation, which leads to a colder attic space and hence a higher humidity. Furthermore, furnace heating is often replaced in favour of heat pumps or district heat. This may alter the air-pressure balance of the house, resulting in an increased thermal pressure on the ceiling with subsequent air-leakage up to the attic.

Current theories and models for the growth rate of mould fungi at different climate conditions indicate a potential for significantly reducing the risk for mould problems by lowering the relative humidity by moderate amounts during critical seasons. For cold attics, the humidity reduction necessary is not greater than what should be possible to obtain with optimised ventilation.

1.1 Ventilation and air infiltration

An important moisture source influencing the attic hygrothermal condition is the water vapour in the surrounding air. The air is carrying both moisture from the indoor environment through air leakages of the attic floor and from the ventilation of the attic itself. High relative humidity during long periods is very often found in cold attics. This can lead to mould growth on the roof underlay often made of plywood or wood.
Leaks of indoor air up to the attic through the attic floor, and the under cooling of the roof due to sky radiation, increase the problem. The moist air might condensate at the underlay and small droplets of liquid water can build up. The water will then be absorbed and accumulated in the surface area. High moisture content can even lead to rot.

The advice given to the building sector in Sweden is to have a not too high or not too low ventilation rate of the attic. A too high ventilation rate, in combination with under cooling, results in high relative humidity. Too low ventilation is also risky in case of construction damp or leaky attic floor. The optimal air exchange rate varies with the outdoor climate, and fixed ventilation through open eaves and/or gable and ridge vents are not always the best choice.

1.2 Controlled and adaptive ventilation

To get optimised ventilation, whatever type of external climate, attic insulation, airtightness etc. ventilation must be controlled and adopted to the present situation. By using sensor technology, mechanical ventilation and making the attic as air tight as possible, this can be achieved, cf. FIG. 2. A basic system would comprise mechanical fans and dampers controlled by attic and outdoor climate sensors installed in a sealed attic without vents. The ventilation system runs only when the outdoor air has a potential to dry out the attic.

![Controlled ventilation of a cold attic](image)

FIG. 2: Controlled ventilation of a cold attic.

2. Simulations

2.1 HAM-Simulation

The state-of-the-art simulation model HAM-Tools has been used in the calculation of the hygrothermal conditions of the attic. The model has been validated for attics (Sasic, 2004) and (Samuelsson 1995). It has also been validated in the EU-project, HAMSTAD, (Hagentoft et.al. 2004).

It is quite complicated to model a real building and a real attic. There are many variables coupled to climate, materials, and geometry etc. that must be known. To handle this, a number of assumptions must be made. Parameter variations in the simulation can give us an idea of the performance of a building or a component.

The presented simulation results do not account for the positive pressure created by the ventilation fan. If this is accounted for we can expect an improved moisture situation since the leakage of indoor air through the attic floor will be lowered.
2.2 Modelled building and parameter cases

The slope of the roof is 28°. The thickness of the mineral wool insulation on the attic floor is 0.4 m. A vapour barrier, 0.2 mm polyethylene sheet, is placed below the insulation. The roof structure consists of, from the inside, 22 mm of wood, a bitumen felt and concrete tiles. The building is located in the Göteborg region. The indoor relative humidity is 30% for an average outdoor temperature of -10 °C and it is linearly increasing to RH=60% at the outdoor temperature of 20 °C. On an average this will correspond to an indoor moisture supply of 3 g/m$^3$.

The interior volume of the living space in the building is 396 m$^3$, and the part of the building envelope exposed to the exterior is 338 m$^2$. The air leakage characteristics for the base case building envelope is correlated to a pressure test at 50 Pa, and it gives an air exchange rate of 3 l/h. The air tightness of the attic floor is denoted: Leaky, Medium tight and Tight, corresponding to an air leakage of 75, 24 or 0 m$^3$/h at 50 Pa. For the Leaky case, the air tightness of the building envelope is equal distributed, while for the Medium tight case the attic floor is four times tighter than the other envelope parts.

The air volume of the attic is approx. 80 m$^3$ and the roof area exposed outwards is 189 m$^2$. The area of the attic floor is 74.8 m$^2$.

**TABLE 1: Parameter cases for the modelling. The air exchange rates refer to pressure test at 50 Pa.**

<table>
<thead>
<tr>
<th>Ventilation system</th>
<th>Attic floor tightness</th>
<th>Airtightness of the attic</th>
<th>Attic ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exhaust (E)</td>
<td>Leaky</td>
<td>Regular</td>
<td>Normal</td>
</tr>
<tr>
<td></td>
<td>0.85 l/h Vol. building</td>
<td>130 l/h Vol. attic</td>
<td></td>
</tr>
<tr>
<td>Balanced (B)</td>
<td>Medium tight</td>
<td>Sealed</td>
<td>Controlled</td>
</tr>
<tr>
<td></td>
<td>0.27 l/h Vol. building</td>
<td>7 l/h Vol. attic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Tight</td>
<td>Well sealed</td>
<td></td>
</tr>
<tr>
<td></td>
<td>0 l/h Vol. building</td>
<td>1 l/h Vol. attic</td>
<td></td>
</tr>
</tbody>
</table>

The air tightness for the base case attic corresponds to 130 air exchanges per hour at 50 Pa. This corresponds to an effective leakage area of 0,55 m$^2$ (=0,74x0,74m), assuming that Dicks law is valid.

In the case of controlled ventilation there are no intentional ventilation gaps or ducts, and the construction is tightened. Three levels of air tightness are studied, corresponding to 7, 1 and 0 air exchanges per hour at 50 Pa. The case with 7 l/h corresponds to an effective leakage area of 0,03 m$^2$ (=0,17x0,17m), or a 1 mm wide gap along both eves of the attic.

The air pressure inside the building is calculated from a mass balance where the air flow rates are based on stack effects, wind pressure, and the working curves for the mechanical ventilation components. The ventilation inside the house is 0,6 air exchanges per hour both for the case with exhaust ventilation system and the balanced ventilation system. The installation of the balanced ventilation system gives an under pressure inside the building of 1 Pa. For the exhaust ventilation system the corresponding number lies in the range 4-5 Pa. These numbers do not account for temperature or wind effects. The modelled air flows in the case of balance ventilation show that 75% of the supply air comes from intentional openings and 25% from air leakages of the building envelope.

The controlled ventilation of the attic results in 1 air exchanges per hour. For perfectly tight attic (excluding the intentional air outlet) the over pressure inside the attic is 10 Pa.

For the case with an air leakage through the attic floor of 75 m$^3$/h and the air tightness case corresponding to 7 l/h at 50 Pa, a slight overpressure of 1-2 Pa will be generated between the attic and the inside of the building.

Table 1 shows the parameter cases that are studied. However, all possible combinations are not considered.

For a few cases, and extra air tight building has been modelled as well, corresponding to 1 air exchanges per hour at 50 Pa. Some cases with an increased controlled attic ventilation of 5 l/h have also been added to the parameter cases.
2.3 Air flow through the attic floor

Table 2 shows the calculated annual average air flow rates through the attic floor.

**TABLE. 2: Calculated air flow through the attic floor as annual average flow rates (m³/h). For the case of controlled attic ventilation the attic is sealed.**

<table>
<thead>
<tr>
<th>Attic ventilation</th>
<th>Exhaust ventilation</th>
<th>Balanced ventilation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal/Leaky attic</td>
<td>3.1</td>
<td>47.0</td>
</tr>
<tr>
<td>Normal/Medium tight attic</td>
<td>2.7</td>
<td>17.5</td>
</tr>
<tr>
<td>Controlled/Leaky attic floor</td>
<td>2.8</td>
<td>40.6</td>
</tr>
<tr>
<td>Controlled/Medium tight att</td>
<td>2.6</td>
<td>16.7</td>
</tr>
</tbody>
</table>

2.4 Calculated temperature and relative humidity

Table 3 and 4 below give the number of weeks in three different hygrothermal intervals for a house with a balanced and exhaust ventilation system.

2.5 Mould risk

A fundamental uncertainty lies in how to evaluate the calculations results for the temperature and the relative humidity. What we really want to do is to estimate the probability or risk for mould growth in the attic. There are several studies on this subject, for instance (Adan, 1994). However, there is no standardised or widely accepted method for the evaluation of the mould growth risk. Here, we will base the risk on the method developed by Viitanen (2001) and Hukka & Viitanen (1999). He introduces mould index, in a scale from 0 to 6, where 0 means no growth of mould and 6 means very heavy and tight growth.

As a measure of the mould risk, a mould growth potential \( m \) has been used in this paper for the field measurements, which is simply the relative humidity divided by the critical relative humidity for mould growth to start according to Hukka & Viitanen (1999):

\[
m = \frac{RH}{RH_{crit}}
\]

\[
RH_{crit} = \begin{cases} 
-0.00267T^3 + 0.1607T^2 - 3.13T + 100.0, & T \leq 20^\circ C \\
80\%, & T > 20^\circ C 
\end{cases}
\]

(1) (2)

Theoretically, mould growth is possible only when \( m > 1 \). Hence, the development over time of \( m \) may be used to illustrate the development of the mould risk. By comparing this parameter for the tests attics with corresponding results from reference cases, the effect of the adaptive ventilation may be estimated.

2.6 Mould index simulations

A theoretical model for mould index calculations has been suggested by (Hukka, Viitanen 1999), and it will be used below.

**TABLE. 3: Number of weeks in given RH and temperature intervals and the maximum mould index during one simulated year. The building has a balanced ventilation system.**

<table>
<thead>
<tr>
<th>Building</th>
<th>Ceiling floor</th>
<th>Attic</th>
<th>Attic ventilation/controlled</th>
<th>No of weeks 0-5 °C above 90% RH</th>
<th>No of weeks 5-15 °C above 80% RH</th>
<th>Mould index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Regular</td>
<td>No</td>
<td>12/6/3</td>
<td>3.24</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Tight</td>
<td>Regular</td>
<td>No</td>
<td>11/5/3</td>
<td>1.35</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Sealed</td>
<td>Yes</td>
<td>12/4/0</td>
<td>3.02</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Sealed</td>
<td>Yes/extra strong fan</td>
<td>4/0/0</td>
<td>0.06</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Well sealed</td>
<td>Yes</td>
<td>8/2/0</td>
<td>1.03</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Well sealed</td>
<td>Yes/extra strong fan</td>
<td>1/0/0</td>
<td>0.02</td>
<td></td>
</tr>
<tr>
<td>Normal</td>
<td>Tight</td>
<td>Sealed</td>
<td>Yes</td>
<td>0/0/0</td>
<td>0</td>
<td></td>
</tr>
</tbody>
</table>
FIG. 3: Variation of the mould index in time (from summer to next summer). The base case with a medium tight attic floor is considered. The building has a balanced ventilation system.

TABLE 4: Number of weeks in given RH and temperature interval for the roof underlay, and the maximum mould index during one simulated year. The building has an exhaust ventilation system.

<table>
<thead>
<tr>
<th>Building</th>
<th>Ceiling floor</th>
<th>Attic</th>
<th>Attic ventilation/controlled</th>
<th>No of weeks 0-5 °C above 90% RH</th>
<th>No of weeks 5-15 °C above 80% RH</th>
<th>No of weeks Above 15 °C and 70% RH</th>
<th>Mould index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Normal</td>
<td>Leaky</td>
<td>Regular</td>
<td>No</td>
<td>11/5/1</td>
<td></td>
<td></td>
<td>2.63</td>
</tr>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Regular</td>
<td>No</td>
<td>12/5/3</td>
<td></td>
<td></td>
<td>2.81</td>
</tr>
<tr>
<td>Normal</td>
<td>Leaky</td>
<td>Sealed</td>
<td>Yes</td>
<td>5/1/0</td>
<td></td>
<td></td>
<td>0.05</td>
</tr>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Sealed</td>
<td>Yes</td>
<td>1/1/0</td>
<td></td>
<td></td>
<td>0.04</td>
</tr>
<tr>
<td>Normal</td>
<td>Medium tight</td>
<td>Sealed</td>
<td>Yes/extra strong fan</td>
<td>1/0/0</td>
<td></td>
<td></td>
<td>0.02</td>
</tr>
<tr>
<td>Extra tight</td>
<td>Medium tight</td>
<td>Well sealed</td>
<td>Yes</td>
<td>0/0/0</td>
<td></td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>

3. Field tests

Adaptive ventilation systems in accordance with fig. 2 were installed in the cold attics of two houses in December 2006 and January 2007, respectively. Temperature and relative humidity of attic and outside air have been recorded since. The indoor sensors for temperature and relative humidity were placed approximately halfways up the inside roof at the centre of the attic. The external sensors were placed on the northern gables, below the roof overhang, protected from rain and direct sunlight.

TABLE 5: Field test cases.

<table>
<thead>
<tr>
<th>House</th>
<th>Location</th>
<th>Test object</th>
<th>Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Gothenburg</td>
<td>Ridge attic</td>
<td>Previous measurements since 2005.</td>
</tr>
<tr>
<td>2</td>
<td>Stockholm</td>
<td>North side attic</td>
<td>Previous measurements since 2006 and simultaneous measurements on naturally ventilated south side attic.</td>
</tr>
</tbody>
</table>
3.1 Case 1 – Gothenburg

The adaptive ventilation system was installed on Dec. 21, 2006. Prior to this, the owner of the house had been recording the climate on the attic since the beginning of 2005. These old measurements were used as a reference for evaluating the effect of the adaptive ventilation, fig. 5.

It is seen that the mould risk with natural ventilation during 2005 – 2006 is more or less the same, and that the mould risk during 2007 is slightly smaller. One exception, though, is the period centred around day 70. This represents the end of March 2007, when the weather was extraordinarily beautiful for a number of weeks resulting in a significant heating of the roof. On the whole, though, a positive effect from the adaptive ventilation is seen.

![Mould growth potential chart](image)

**FIG. 5:** Comparison of mould growth potential with natural ventilation (2005 – 2006) and adaptive ventilation (2007).
3.2 Case 2 – Stockholm

The adaptive ventilation was installed on the north side attic on Jan. 4, 2007. Prior to this, the owner of the house had been recording the climate since 2006—on the north attic as well as on the south attic. The measurements on the naturally ventilated south attic continued also during 2007. Hence, it was possible to compare the results both with the same attic from previous year, fig. 6, and with the simultaneous measurements on the south attic, fig. 7.

**FIG. 6**: Comparison of mould growth potential with natural ventilation (2006) and adaptive ventilation (2007)

**FIG. 7**: Comparison of mould growth potential between north and south side attics. Adaptive ventilation was installed on the north attics on Jan. 4, 2007. The south attic is naturally ventilated the whole period.
It is obvious that the mould growth potential on the north attic is smaller with adaptive ventilation than with natural ventilation, fig 6. It is also interesting to note that, with natural ventilation, the mould risk was higher in the north attic than in the south, cf. the year 2006 in fig. 7. In fact, this was the reason for the house owner to install the measurement equipment: mould growth was observed in the north attic but not in the south. After installation of the adaptive installation system, however, the situation is turned around (cf. year 2007 in fig. 7). The mould risk is now lower in the north attic.

4. Discussion

Advanced numerical simulations have shown that the risk for mould growth can be substantially reduced, and even eliminated, if the cold attic is sealed and fitted with adaptive ventilation. Ideally, the construction is well built and air-tight, but leaks can to some extent be compensated with an increased ventilation rate. Field tests and extensive measurements over complete annual cycles confirm the simulations.

5. References


