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ScienceDirect

Procedia Engineering 146 (2016) 2 – 7

Procedia Engineering

www.elsevier.com/locate/procedia

8th International Cold Climate HVAC 2015 Conference, CCHVAC 2015

Drying potential of cold attic using natural and controlled ventilation in different Swedish climates

Carl-Eric Hagentoft*, Angela S Kalagasidis

Department of Civil and Environmental Engineering, Chalmers University of Technology, Göteborg, Sweden

Abstract

Problems with high humidity levels and mold growth in cold attics have been increasing over the last few years. 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. Replacing furnace heating by heat pumps or district heat may also lead to problem. Also newly built attics have problems. The quite novel technical solution with controlled mechanical ventilation of the attic is generally estimated to be risk free in Swedish climate. With controlled mechanical ventilation the attic is intentionally ventilated only when the inflowing air is drying out the attic, otherwise it is shut off. The drying potential of controlled ventilation is analyzed for different climate zone in order to map the relative efficiency compared with traditional natural ventilated attics.

Peer-review under responsibility of the organizing committee of CCHVAC 2015

Keywords: Attic;moistur;drying;natural ventialtion;controlled ventilation;climate

1. Introduction

Problems with high humidity levels in cold attics have been remarkably increasing in Sweden over the last decade. Beside clear evidence – the significant mould growth on the wooden parts of cold attics, which is recently confirmed in about 60-80 % single-family houses in Västra Götaland region (largely, the Gothenburg region; [1], mould odours

* Corresponding author. Tel.: +46317721989; fax: +46317721993.
E-mail address: carl-eric.hagentoft@chalmers.se

Peer-review under responsibility of the organizing committee of CCHVAC 2015
doi:10.1016/j.proeng.2016.06.345

in indoor air seem to be one of the most frequent side effects. Thus, cold attics are together with crawl spaces singled out as the two worst constructions in existing Swedish buildings with large existing and future mould 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 [2]. 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 [3,4,5]. 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.

Another important moisture source influencing the attic hygrothermal condition is the water vapour in the surrounding outdoor air. The advice given to the building sector in Sweden today is to have a not too high or not too low ventilation rate, by outdoor air, of the attic. A too high ventilation rate, in combination with under cooling, results in high relative humidity [6]. Too low ventilation is also risky in case of construction damp or leaky attic floor [4,5,7]. 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 [2,8,9]. The results from a recently finished SBUF-financed Swedish research project Risk assessment for Cold Attics is presented in [10].

2. Drying potential for cold attics and ventilated structures

Although one could expect a close correlation between the mould growth risk in cold attics and outdoor climate, specifically outdoor temperature and solar radiation intensity, previous investigations [11] show that such correlation is not straightforward. The results suggest that the risk is also correlated to the ventilation flow rate through the attic, which is determined by the wind and the orientation of the attic. This is further investigated in [10] by the means of a drying potential, DΠ, a new performance criterion which can be seen as an upgraded Π-factor [12,13]. For the period between the times t_a and t_b, DΠ is found as:

$$\mathrm{D}\Pi = \frac{1}{t_b - t_a}\int_{t_a}^{t_b} \tilde{R}(w,\theta)\cdot\left(v_{sat}(T_{eq}) - v_{out}\right)dt, \quad 1/\tilde{R}(w,\theta) = 1/R_a(w,\theta) + \frac{1}{A/Z(R_a)} \tag{1}$$

Where T_{eq} equivalent outdoor temperature, (°C)
v_{out}, v_{sat} water vapour content in outdoor air and at saturation, (g/m^3)
R_a air flow rate through the ventilation opening in the attic, (m^3/s)
w wind speed, (m/s)
θ angle between the wind direction and the azimuth of the ventilation opening, (deg)
A area of the roof slope (only shed roofs), (m^2)
Z resistance to convective moisture transfer between the air and the roof slope, (s/m)

While Π-factor is basically calculated from the weather parameters and radiation surface conditions, DΠ accounts in addition for the attic geometry and ventilation flow rate through the attic. This was shown to be a promising new indicator for the moisture safety of ventilated structures such as attics for evaluation and comparison of alternative designs, locations and orientation, including estimates for future climates. However, it should be developed further.

3. Drying potential differences between controlled and naturally ventilated cold attics

It is of interest to find out how efficient controlled mechanical ventilation is in comparison with natural ventilation. We can then get an idea of how beneficial it is to install such a system. For this purpose we use simple approximate formulas [14] for the ventilation rate of the attic. The wind pressure difference driving the natural ventilation is proportional to the actual quadratic wind speed:

$$\Delta p = C_1 \cdot \left(w_{10} \cdot 0.52 \cdot H^{0.2}\right)^2 \tag{2}$$

Here w_{10} (m/s) represents the wind speed at the height of 10 m and H (m) is the height of the building. The coefficients (0.52 and 0.2) correspond to terrain conditions representing country with scattered wind breaks. The coefficient C_1 (-) is a constant.

The air flow rate is in turn proportional the square root of the pressure difference, assuming flow through thin holes i.e. using Dick's formula.

$$R_a = C_2\sqrt{\Delta p} = C_2 \cdot \sqrt{C_1} \cdot w_{10} \cdot 0.52 \cdot H^{0.2} = C \cdot w_{10} \cdot H^{0.2} \tag{3}$$

The remaining coefficient C (-) is to be calibrated in order to get a correct given mean air exchange rate, n (1/h), of the attic, where:

$$n = \frac{R_a \cdot 3600}{V} \tag{4}$$

Here V (m^3) is the air volume of the attic space. For simplicity, we have neglected effects of volume expansion related to temperature changes.

For the case of controlled ventilation there is only two levels of air exchange rates; zero if the ventilation is not resulting in drying, i.e. $g<0$ (see Formula 7 below) or n_{Fan} when $g>0$.

For the actual drying of a non-moisture damaged attic we must assume that the relative humidity, φ *(-)*, of the materials inside the attic is below 1, i.e. below RH of 100%.

Further, we will assume that the temperature of the attic is in balance with the equivalent outdoor temperature, T_{eq} (Hagentoft, 2001). In this study only low sloped roof are considered so there is basically only one equivalent temperature for the attic roof. The drying rate, g (kg/s), of the attic then becomes:

$$g = R_a \cdot \left(\varphi \cdot v_{sat}(T_{eq}) - v_{out}\right) \tag{5}$$

The total drying during a period from time zero to time t becomes:

$$G(t) = \int_0^t g(t')dt' = \int_0^t R_a \cdot \left(\varphi \cdot v_{sat}(T_{eq}) - v_{out}\right)dt' \qquad \text{Natural ventilation} \tag{6}$$

$$G(t) = \frac{1}{3600}\int_0^t n_{Fan} \cdot V \cdot \left(\varphi \cdot v_{sat}(T_{eq}) - v_{out}\right) \cdot H_{step}\left(\varphi \cdot v_{sat}(T_{eq}) - v_{out}\right)dt' \qquad \text{Controlled ventilation} \tag{7}$$

Here, H_{step}, is Heaviside unit function (equal to zero when the argument is less than zero and equal to one when it is greater than zero).

The assumption of constant relative humidity inside the attic during the year can for instance represent a wooden interior *attic structure with a constant amount of absorbed moisture*, since the sorption isotherm is essentially only dependent on the relative humidity (i.e. mass of moisture is equal to the volume of the wood times the moisture content w(φ)). In the simulation modelling world *the drying, G, represents a moisture sink that is balanced by a corresponding moisture source in the attic construction; these two are perfectly balanced so that the mass of moisture in the attic remains constant.*

The total drying capacity of the ventilation systems represents a capability of handling for instance construction damp during the first year of a newly building or leakage of moist indoor air up to the attic.

4. Example

In these examples we will use different climate data for various locations in Sweden. We will also vary the assumptions of the average natural ventilation rate of the attic as well as the assumed relative humidity inside the attic. The height of the building, *H*, is 6 m, and the air volume of the attic, *V*, is 100 m^3. The roof slope is 20 degree, leaning towards east. The air exchange rate for the case of an active fan, n_{Fan}, is 5 1/h, given by the normal operational value from manufacturer. The start time for integrating the total drying out of the attic is July first in the examples, i.e.in the middle of the summer.

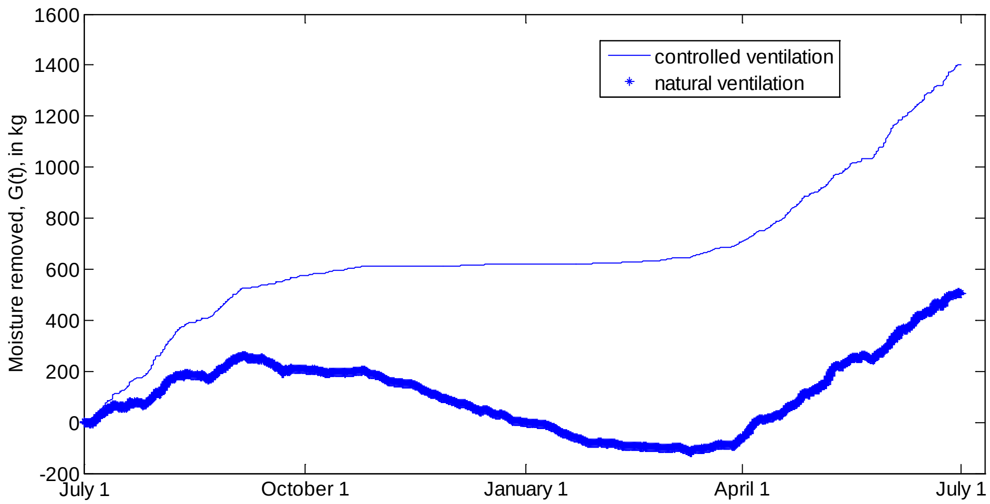

Figure 1. Moisture G (kg) dried out from the attic space for the case with controlled and natural ventilation. The location of the attic is Göteborg, climate year 2004, the average natural ventilation exchange rate, n, is 1.0 1/h and the relative humidity in the attic is 80% i.e. φ=0.8. The air exchange rate, n_{fan} , when the fan is switched on is equal to 5 1/h.

From the simulations we can see that during a period of the year, the natural ventilation adds moisture to the attic, while the controlled ventilation always dries the attic.

Table 1. Total amount of dried out moisture after 6 and 12 months for different natural ventilation levels and for controlled ventilation. The attic is located in Göteborg and the climate year is 2004.

		Natural ventilation		Controlled ventilation		Difference (kg) $G_{controlled}$-$G_{natural}$	
n (1/h)	φ (-)	G(6)	G(12)	G(6)	G(12)	t=6	t=12
1	0.7	-464	-399	421	995	885	1394
1	0.8	0	502	621	1403	621	901
1	0.9	463	1402	856	1875	393	473
2	0.7	-927	-798	842	1991	1770	2789
2	0.8	0	1003	1242	2806	1242	1803
2	0.9	926	2805	1713	3751	787	946

The total difference in dried out moisture between the different ventilation systems is in the range of 393 to 1770 kg for the 6 months case and 473 to 2789 kg for the annual case. Higher relative humidity levels in the attic will result in higher drying rates in general. However, it reduces the difference between the ventilation types, since the natural ventilation will be more beneficial for the drying when the outdoor air more often is drier than the attic air.

The natural ventilation is not able of keeping a low attic relative humidity such as 70%. For this level and drier, the outdoor air is instead adding moisture to the attic, i.e. no drying.

Table 2. Total difference in dried out moisture after 6 and 12 months for the different ventilation type, i.e. $G_{controlled}$-$G_{natural}$ at t=6 and 12 months, for a number of cities in Sweden. Climate data year 2004. The attic relative humidity, φ, is 0.8 (RH= 80 %) and the annual average natural ventilation rat, n, is 1 1/h. The air exchange rate, n_{fan} , when the fan is switched on is equal to 5 1/h.

Location/City in Sweden	t=6 months	t=12 months
Lund	552	701
Göteborg	621	901
Stockholm	552	802
Östersund	542	832

The results from the simulation for different locations show clearly that controlled ventilation is superior in drying. The difference between different locations in Sweden is quite small.

5. Conclusion

The drying capacity of an attic due to natural and controlled ventilation in Swedish climate is analyzed. It shows that natural ventilation will, on an annual and semi-annual bases, add moisture to the attic instead of drying it, if the RH of the attic is somewhere between 70-80%. The superior drying capacity of controlled ventilation is in the range of a few hundreds to a couple of thousands kg, which gives a more moisture safe and robust system, able of handling moisture sources. This difference in drying capacity is rather constant in the whole of Sweden.

In future investigations the spread in results between different climate years as well as future years should be analyzed.

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