MODELLING OF MOISTURE CONDITIONS IN A COLD ATTIC SPACE

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ABSTRACT

This study investigates numerically the occurrence and duration of higher relative humidities in a cold attic space, which are a consequence of excessive moisture supply from ventilating the attic and from air infiltration from inside the dwelling. Hygrothermal states of the attic air zone and the adjacent construction elements are calculated by a whole building heat, air and moisture simulation tool. Airflows to the attic are determined by taking into account the total distribution of pressure around and inside a building. The role of attic ventilation is analyzed by comparing naturally ventilated and unventilated attics in an open landscape or a city zone. For air infiltration from inside the dwelling only scenarios with the airflow directed mostly to the attic are analyzed. The simulations show that, if indoor air infiltrates through the attic floor, it is necessary to ventilate the attic. In that case, a building situated in a sheltered position is more susceptible to moisture problems in the cold attic than the same building in an unsheltered position. However, in the absence of air infiltration from inside the dwelling, the attic should not be ventilated. Simulations are performed for real climatic conditions.

KEYWORDS

Cold attics, moisture problems, mold in attics, air infiltration, attic ventilation, attic floor.

INTRODUCTION

The 1973 energy crises led to increased thermal insulation levels in buildings in Sweden. A common procedure was to add insulation to the attic floor in houses, which nowadays has the thickness of 384 mm on average (STEM, 2001). As a result, the climate of the attic turns colder during wintertime and becomes close to the one outdoors. Over the years, cold attics have shown to be susceptible to transfer of moist air from the environment, by ventilation, or, by infiltration from a living space. In that case, appearance of mold on internal wooden sides of the roof may be encountered. Although it is 30 years ago since moisture problems in attics became widespread, few investigations have been made which focus on attic ventilation only (Samuelson 1995, Arfvidsson and Harderup 2005). They show the more an attic is ventilated, the higher the relative humidity reached. The cited studies also include numerical investigations of ventilation airflow rate, moisture buffering capacity of the insulating material, the role of a heat source, etc. (Larsson 1996, Sasic 2004, Arfvidsson and Harderup 2005).

Attics are kept ventilated by tradition, a practice established in the past on uninsulated attics, aiming to reduce the melting of snow and the appearance of icicles on the roof. By introducing cold attics, the main purpose of ventilation is not appropriate any more. However, it may acquire another purpose, such as to remove humid air that can be transported from inside the dwelling by air infiltration through the attic floor. Three decisive causes for air infiltration – wind speed, wind pressure on the building envelope and location of leakage paths –can only be roughly estimated without performing extensive measurements. Although the majority of airflow experiments on attics focus on air infiltration or air change rates (Gustén, 1989, Forest and Walker, 1995), little can be gained with respect to the impact of wind on air infiltration through attic floors.

The present work reports results from numerical investigations of the impact of wind and air infiltration from a living space on the moisture conditions in a cold attic. The role of attic ventilation is analyzed by comparing ventilated and unventilated attics, with and without air infiltration from inside the dwelling. Air infiltration rates are modeled by taking into account the pressure distribution around and inside the building as a whole. The aim of the paper is to find out whether ventilation (governed by wind) may help in removing convectively transported moisture through the attic floor. The simulations are performed using a CFD-tool (Fluent) for attic ventilation rates and HAM-Tools (Sasic, 2004a) for air infiltration rates through the attic floor and the hygrothermal states in the attic.

THE MODELLED BUILDING AND ASSUMPTIONS REGARDING BOUNDARY CONDITIONS

The model building is a one storey single-family house with a cold attic under a 30^o pitched roof, Figure 1. The floor area is 8 by 12 m and the wall height is 2.5 m. The volume of the attic is 110 m^3. The roof is covered with concrete tiles on the outer side, followed by an underlay and lined with 19 mm thick wooden spruce boards on the internal side. Gable sides are constructed of wooden boards and painted on the outer side. The attic floor is insulated with a 500 mm thick loose-fill insulation with an air barrier below and gypsum board as internal lining. The roof sides face south and north respectively.

The airtightness of the house is specified to be 0.8 $l/(m^2 \cdot s)$ of the surface area that separates the indoor climate from the outdoor one, or from any unheated space. The indicated value meets the requirement of the Swedish building code (BBR, 2002) and is related to a pressure difference of 50 Pa across the building envelope, in which case the air change rate for the building is equivalent to 3.5 ACH.

To have naturally correlated weather parameters (air temperature and relative humidity, solar and long-wave radiation and wind), measured climate data are used in the simulations. The data are recorded in the southwest coastal area of Sweden, characterized by mild winters and summers, but with heavy and lengthy rainy periods throughout the year. The data cover one year. The climate in the house is designed in the following way: air temperature is constant and equals 22^oC, while the air relative humidity varies between 40 % in wintertime and 70 % in summer, according to recommendations in CEN TC 89. This gives approximately 4 g/m^3 higher moisture content in the indoor air than in the outdoor.

CALCULATIONS OF AIRFLOW

Ventilation airflow of the attic

In the simulations the attic is denoted as ventilated when there are ventilation openings below the eaves, as it is shown in Figure 1a. Otherwise, the attic is unventilated. However, in such cases also, it is assumed that air infiltrates the attic through this path, since attention is usually not paid to make this detail completely airtight.

For ventilated attics the airflow through the ventilation openings dominates the total air balance of the attic. This implies that, although the pressure difference across the roof can be substantial, air will mainly enter and exit the attic through these openings. The roof decking of the modeled building is assumed to be perfectly airtight (as being covered with a roofing felt underlay, a procedure rather common for Swedish single-family houses).

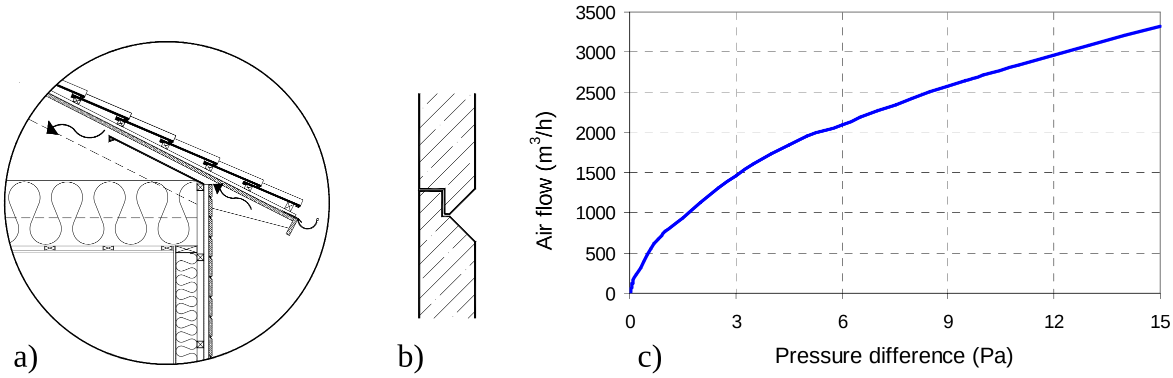

Figure 1: a) The common design of the ventilation opening below the eaves. b) The possible air leakage path through the joint between wooden boards at the gables. c) The airflow through the ventilation openings as a function of the pressure difference between the outdoor pressure and the pressure in the attic.

The airflow through the ventilation openings is modeled as a function of the pressure difference across the openings, according to Figure 1c. The air leakage rate for this detail (when there are no intentional openings) is assumed to be 1/20 of the airflow rate in the case when intentional ventilation openings are present. The air leakage paths through the gables consist of gaps between the wooden boards in the façade, as it is shown in Figure 1b, with the airflow assumed to be laminar (Mattsson, 2005).

The total ventilation airflow rate of the attic represents the resulting airflow through the openings (or leakages) on the roof eaves and through the leakages on the gables. The flow is calculated for real climate data and for two different exposures to the wind, Figure 2, taking into account the wind direction The prevailing wind is from the south-west with average speed of 4.2 m/s. Wind pressure coefficients are obtained from Orme et al. (1998).

Airflow through the attic floor

The stack effect governs the transport of air from a living space to the attic during wintertime. However, the type of house ventilation system may alter the air direction; in case of mechanical exhaust ventilation, the system makes such under pressure in the house, which, in turn, counteracts the stack effect and, as a result, the air from the attic is sucked into the house. Finally, the effect of wind on a building can support or decrease the airflow through the attic floor, depending on the position of air leakages or intentional openings on a house, as well as on the house exposure to the wind.

A number of different scenarios and interactions between these effects is analyzed in the work of Mattsson (2005). The present investigation is focusing on some of the cases from the work cited, i.e. those with the largest risk of indoor air infiltration. Thus, the model house is assumed to be equipped with the mechanical exhaust-supply ventilation system that extracts 120 m^3/h and supplies 90 % of this ventilation rate when the climate does not influence the ventilation system, i.e. when the outdoor and indoor temperatures are equal and there is no wind. Air leakages on the house are distributed in such a way that the stack effect has its maximal impact - when half of the leakages are concentrated at the floor level and half at the ceiling.

The airflow through all leakages is modeled using a power-law equation with a flow exponent of 0.67, (see for example ASHRAE, 2001). As in the case of attic ventilation, the air flow through the attic floor is calculated for the real climate data and for two different exposures to wind. Some results are shown in Figure 3.

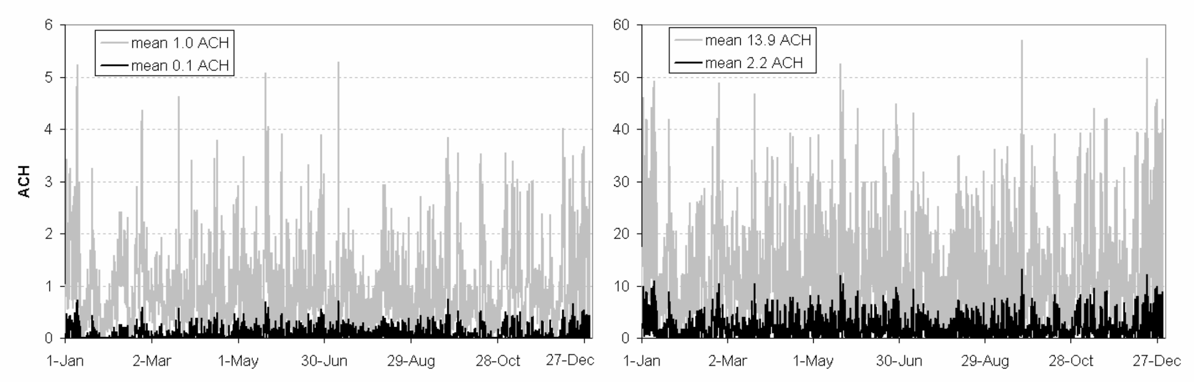

Figure 2: The diagram to the left shows the ventilation air change rates of the unventilated attic for the house in open position to the wind (the gray line) and in closed (city) position to the wind (the black line). The diagram on the right shows the same for the ventilated attic. The volume of the attic is 110 m^3.

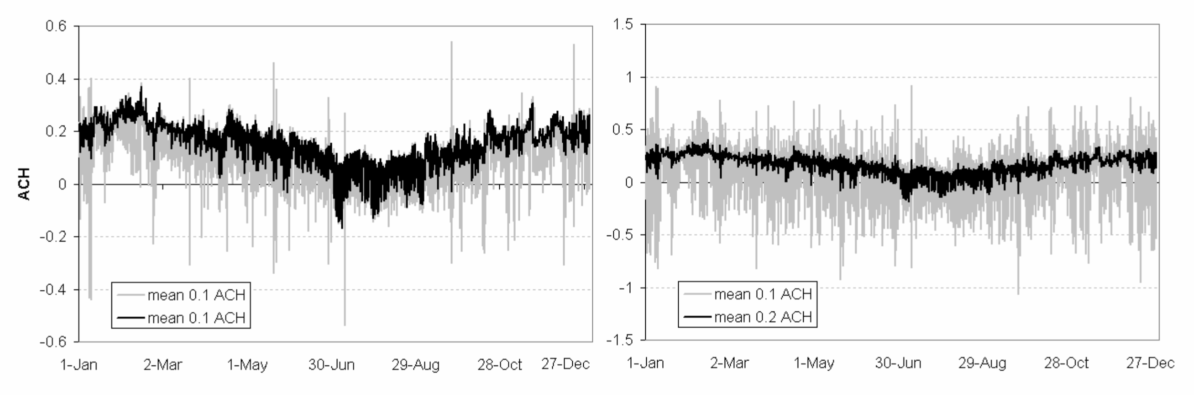

Figure 3: Airflow through the attic floor for the unventilated (to the left) and ventilated attic (to the right). Gray lines denote results for the house in open position to the wind, blacks for the house in closed position to the wind. Positive values represent flows directed upwards to the attic.

HYGROTHERMAL CALCULATIONS

The hygrothermal states in the attic are calculated by taking into account the outdoor climate load, the airflows by ventilation and infiltration, as well as the heat and moisture transfer through construction elements (roof sides, gable walls and attic floor). The attic is treated as a single air zone, while heat and moisture transfer through construction elements is calculated as an one-dimensional phenomenon.

The attic indoor climate varies with respect to the attic ventilation, air infiltration from the living space and the attic exposure. The overview of all cases concerned is given in Table 1, together with the reference case – the absolutely airtight attic (e.g. no ventilation or infiltration).

Repeating the climate and air infiltration load, year by year, each case is run until a periodical behavior is reached. For the majority of them, it is in the second simulated year. Final results for the reference case are used as initial conditions (i.e. initial temperature and relative humidity in construction elements and indoor air) for all other cases where the air load appears. Material properties, transfer coefficients and other parameters of interest are carefully modeled in order to represent reality in a credible way, (Sasic, 2004b).

TABLE 1
Overview of the cases concerned

Roof ventilation	**R**eference case	**V**entilated				**U**nventilated			
Wind exposure		**O**pen		**C**ity		**O**pen		**C**ity	
Air-tightness of the floor	Unventilated and absolutely air-tight attic	**T**ight	**L**eaky	**T**ight	**L**eaky	**T**ight	**L**eaky	**T**ight	**L**eaky
Notation	**R**	**VOT**	**VOL**	**VCT**	**VCL**	**UOT**	**UOL**	**UCT**	**UCL**

Results for air relative humidity in the attic are given as duration curves, Figure 4a, for all nine cases. This method, also presented in Samuelson (1995), illustrates the differences between the cases in a straightforward way. The time (per year) when a certain relative humidity is exceeded is given on the x-axis. In case of the reference attic the relative humidity never exceeds 80 %; for the ventilated attics in open position it is over 85 % half of the year. The highest values are found in the UCL attic, where the relative humidity is greater than 85 % the most of the time. Besides, results for the ventilated attics are quite grouped indicating the similar climate. On the other hand, the results for the unventilated attics are very spread and the presence of air infiltration from the outside and from the inside the dwelling are easily distinguished.

Mold growth risk on wooden surfaces can be assessed from the duration of favorable conditions for growth which are ranked in respect to the temperature and relative humidity in the attic (Hukka and Viitanen, 1999). To illustrate this, the duration of some characteristic ranges of relative humidity and temperature at the internal side of the southern roof slope are shown in Figure 4b. The data are given for two different ventilation airflow rates and they complement the results in Figure 4a.

CONCLUSIONS

There are considerable differences in relative humidity variations for the cases analyzed. In the absence of air infiltration from the dwelling, the climate in the attic becomes drier as the ventilation rate decreases. Having in mind that mold growth risk increases with increasing relative humidity, it seems that attics, in general, should not be ventilated. However, when air infiltration from inside the dwelling is present, attic ventilation helps in removing excessive moisture. In this case, the effect of ventilation is more pronounced as airflow rates become higher, but the final upgrade is nevertheless limited, since ventilation itself brings moisture to the attic. The simulations also reveal that a building situated in a sheltered position is more susceptible to moisture problems in the cold attic compared to the same building in an unsheltered position. Future work will focus on more detailed investigations on air leakage paths through the attic floor, as well as on the moisture analyses in other climate conditions.

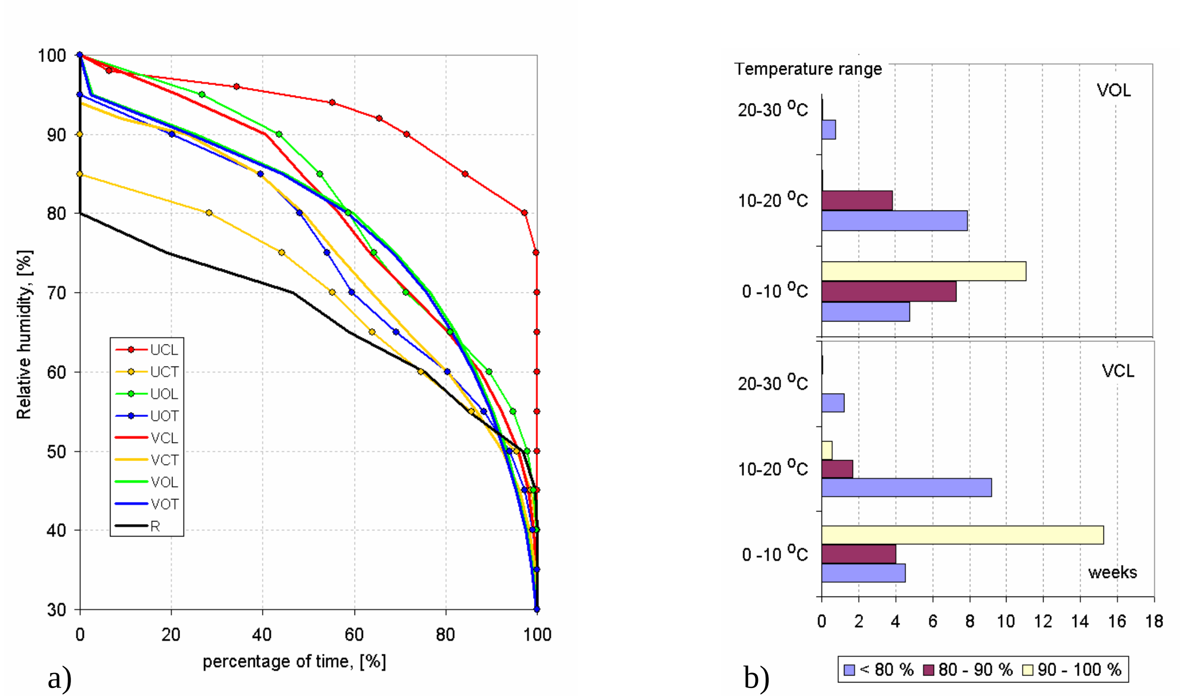

Figure 4 a) Results for the air relative humidity for all cases, sorted in descending order. b) Duration of some characteristic ranges of relative humidity and temperature at internal wooden side of a southern roof slope, for ventilated attics in two different positions and with leakages from a dwelling.

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