Air leakage variations due to changes in moisture content in wooden construction - magnitudes and consequences

Fredrik Domhagen*[1], Paula Wahlgren[1]

1 Division of Building Technology
Chalmers University of Technology
SE- 412 96 Gothenburg, Sweden
**Corresponding author:*
Fredrik.Domhagen@chalmers.se

ABSTRACT

The airtightness of buildings is important for several reasons, such as being a prerequisite for low-energy buildings and for a healthy indoor air quality (without i.e. mould or radon). The airtightness of buildings can vary over time and investigations are made on these variations due to moisture induced movements in wooden constructions, and subsequent consequences, using both measurements and numerical simulations.
Measurements were performed in a wooden guest house that was built in a laboratory hall with an approximate relative humidity of 30 %. The guest house was designed with a wind barrier but without a moisture barrier, and with a majority of the leakages situated in the wall/floor connection. The relative humidity in the guest house was varied so that the indoor relative humidity was kept at 90 % during 8 days and then decreased to 25 % during 7 days. This variation in moisture content in the wooden part can also illustrate the built in moisture in construction timber (starting at a moisture content of 16%). The air permeability was measured frequently during both periods and showed a change in air permeability from 0.74 l/sm^2 to 1.21 l/sm^2 at 50 Pa pressure difference. Consequently, for a wooden construction with a moisture dependent air permeability, it is easier to fulfill airtightness demands (checked by measurements), when the building is just erected, compared to a couple of months later.
Numerical simulations on the moisture induced leakage variations and the impact of the resulting variation in air permeability are performed in Simulink and MATLAB. Air leakage is calculated using a set of object oriented functions within the MATLAB environment. These functions follow the same mathematical principle as presented in the airflow simulation software CONTAM. The simulations are made for the climate of Gothenburg in south-west part of Sweden. Results show, among other things, that the orientation of the building is decisive for the magnitude of the total exfiltration rate and that air leakage from the indoor environment up to the cold attic is higher during winter months compared to summer months.

KEYWORDS

Air tightness, air permeability, air leakage

1 INTRODUCTION

The air permeability of a wooden frame building can vary over time. In a study by Wahlgren et al. (2015), the air permeability in two wooden buildings was measured during one year, resulting in variations up to 10 %, considering the total airflow through leakages at a pressure difference of 50 Pa. The variations correlated with fluctuations in relative humidity indoors, resulting in higher air permeability airtightness during winter and lower air permeability during summer. The fact that buildings often are less airtight during winter months has also previously been shown (Kim, 1986; Persily, 1982). Skogstad et al. (2011) show a substantial increase in air permeability with the drying of wood in cross laminated timber structures.
A varying airtightness raises a number of questions. For example, how the moisture safety is affected if air is allowed to move from the inside towards the outside of the thermal envelope

(exfiltration) and possibly condensate inside the construction, and if there is an increase in leakage in wintertime? Normally this exfiltration is inhibited by adjusting the ventilation in a way that ensures negative internal pressure and thus forcing the air to move from the outside towards the inside. However, if the airtightness decreases, the negative pressure caused by the ventilation system might also be reduced. Moisture condensation and mould growth in cold attics is a problem that relates to air that leaks from the interior of the building up to the attic (Hagentoft and Sasic Kalagasidis, 2014). It is likely that the infiltration of air to the attic changes with changes in airtightness, but to what extent? In the following, the variation in air permeability and subsequent effects is investigated.

2 LABORATORY MEASUREMENTS ON A SMALL GUEST HOUSE

In order to investigate the correlation between indoor relative humidity and airtightness of a wooden building, laboratory measurements are performed on a small guest house in a controlled environment. The guest house is built in a storage hall with an approximate relative humidity of 30 %. It is for example designed with a wind barrier but without a moisture/air barrier. There are some differences between the guest house and a conventional residential building.

It is likely that the way the airtightness of the guest house reacts to changes in humidity is somewhat different from that of an ordinary wooden building. For instance, since there is no moisture barrier, the timber parts will react faster to changes in indoor humidity compared to with the moisture barrier. Without the moisture/air barrier, the airtightness of the guest house will react faster to changes in indoor humidity compared to a building with moisture/air barrier. A leakage search of the guest house showed that the majority of the leakages were situated in the connection between the wall and the floor. This means that the majority of changes in airtightness is caused by swelling and shrinkage in that particular leakage. However in an ordinary building, air leakage typically occurs at many different locations.

2.1 Experimental Setup

In order to test how the airtightness changes with changes in relative humidity, air permeability measurements are performed on the guest house. The measurement periods are divided into two phases, moistening phase and drying phase. In the moistening phase, the relative humidity in the air inside the guest house is increased and kept steady at around 90 % with the use of a humidifier. Blower door measurements are then performed at intervals of one to two days. During the drying phase, the indoor relative humidity decreased by heating the indoor environment and ventilation of the guest house. Blower door measurements are performed at intervals of one to two days. Throughout the entire test period, temperatures and humidities are continuously measured both inside the guest house and inside the storage hall outside the guest house.

2.2 Results from Measurements

The results from the measurements of relative humidity and airtightness can be seen in

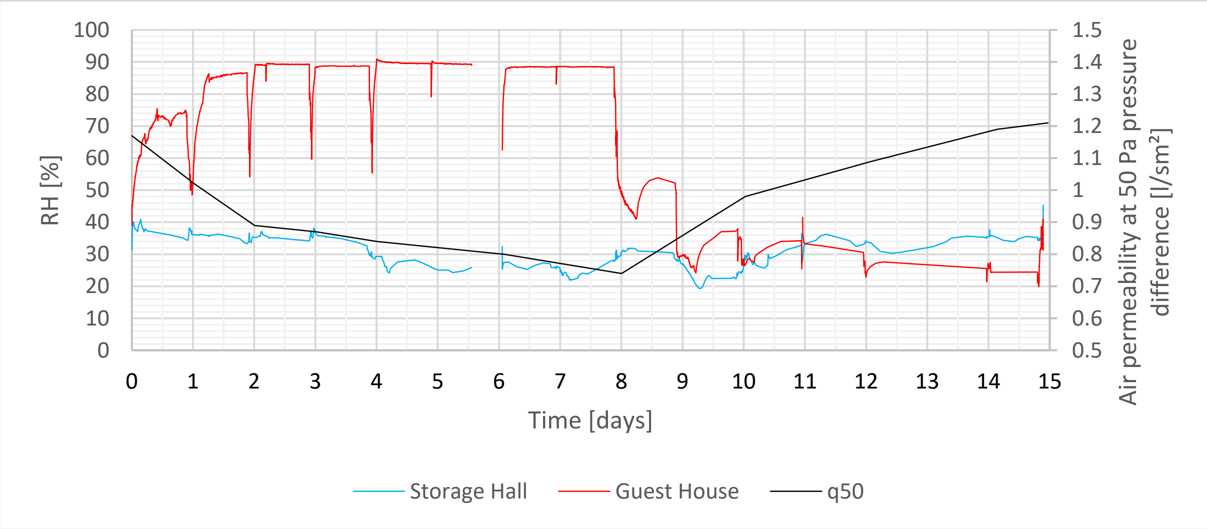

Figure 1. The airtightness changed from 0.74 l/sm^2 to 1.21 l/sm^2 at 50 Pa pressure difference during the measurement period. The measured relative humidity varied from about 90 % during the 8 days in the moistening phase to about 25 % during the 7 days in the drying phase. The moisture scenario can as a comparison be related to common levels of inbuilt moisture. For instance, a relative humidity of 80 % corresponds to moisture content of 16 % in wood, which is often found in construction timber (Olsson, 2014).

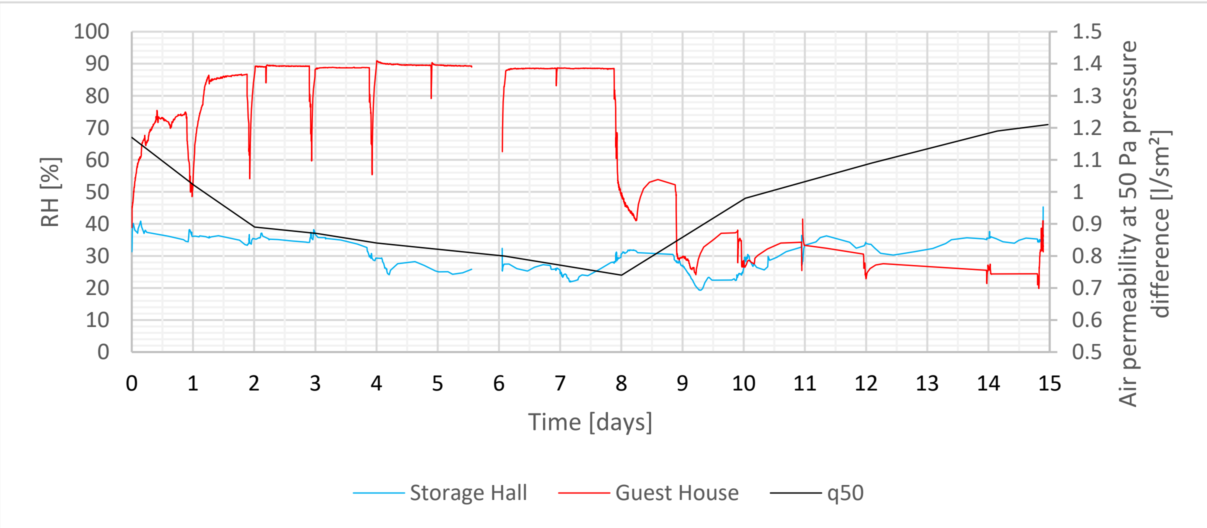

Figure 1. Shows the air permeability, relative humidity inside the guest house and relative humidity in the storage hall throughout the test period.

It is also of interest to couple these results to airtightness demands. As a result of the drying of the wooden parts, airtightness demands (checked by measurements) can be easier to fulfill when the building is erected with inbuilt moisture, compared to a couple of months later.

3 NUMERICAL SIMULATIONS

In order to study the impact of varying airtightness on the airflows in a building, numerical simulations are performed in Simulink and MATLAB. Air leakage is calculated using a set of object oriented functions within the MATLAB environment. These functions follow the same mathematical principle as presented in the airflow simulation software CONTAM (Walton, 2003). Simulink is used to couple the step-wise air leakage calculations in MATLAB to input weather data and to determine the indoor relative humidity.

Previous research (Wahlgren, 2014) has shown that the air permeability variation follows the indoor two- to three-day mean relative humidity in a residential building. In order to take this moisture inertia into account, the relative humidity of the building is simulated as a function of outdoor humidity, indoor moisture production, indoor moisture buffer capacity and the total air-exchange rate. Furthermore, the airtightness follows the relative humidity with a dampening factor which is adjusted to make the airtightness follow the two-day mean relative humidity. The program flow structure for one time step is illustrated in Figure 2.

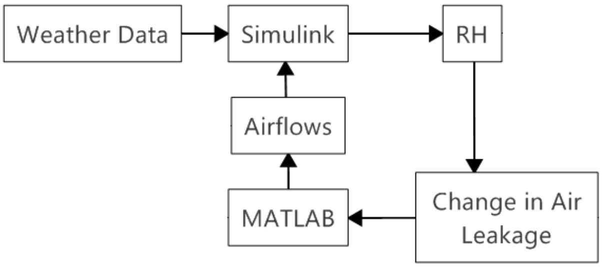

Figure 2. Flow chart over the calculations performed during one time step.

The airflow model takes into account the airflow at pointwise defined leakages where the driving force is the total pressure difference caused by stack-effect, wind and mechanical ventilation. Terrain characteristics are taken into account with by tabled pressure coefficients (Orme, 1998), pressure coefficients for intermediate wind angles are found by linear interpolation.

3.1 Climate Data

Airflows are simulated for a building situated in Gothenburg. Climate data is taken from the Swedish Meteorological and Hydrological Institute, SMHI, where all data is collected from year 2016. Figure 3 shows the outdoor temperature and wind speed throughout the year.

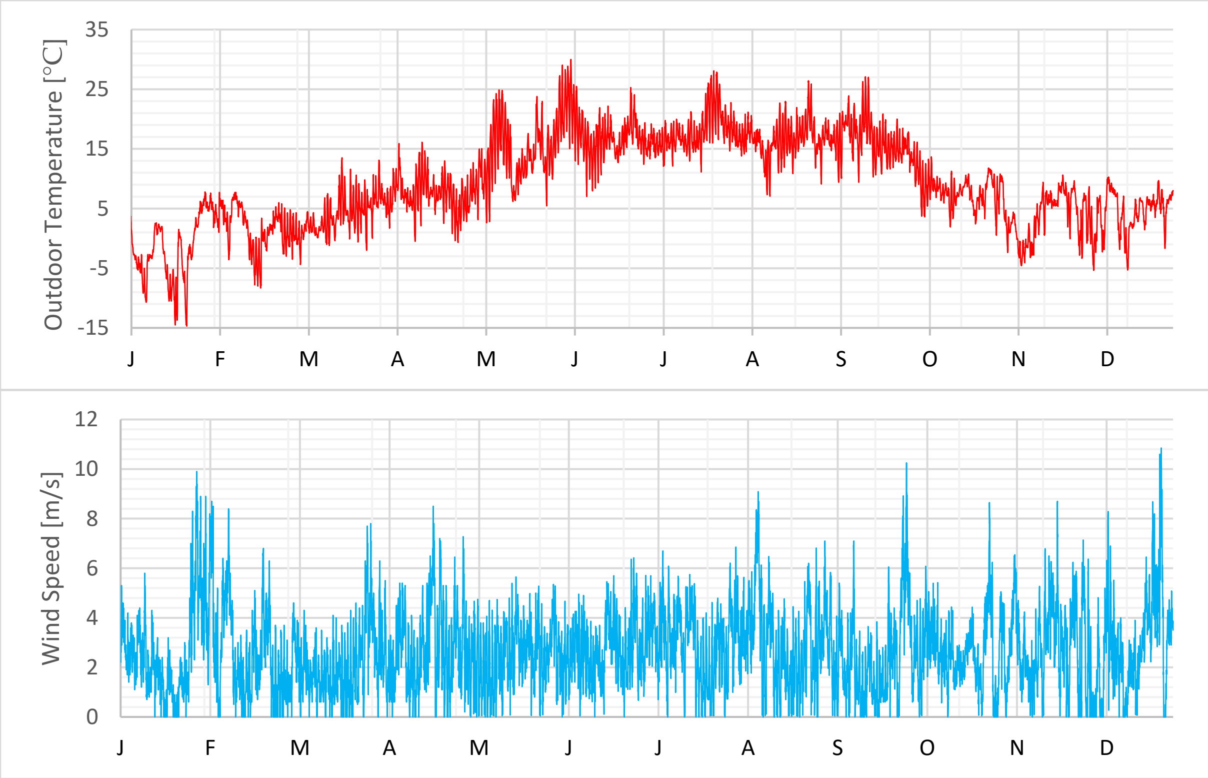

Figure 3. Climate data for Gothenburg, 2016 (SMHI Öppna data, 2017).

Figure 4 shows a wind rose with the distribution of wind speeds at different wind directions. It is clear from the wind rose that wind speeds higher than 4 m/s dominate the south-westward direction while wind speeds lower than 4 m/s are mainly from north-east.

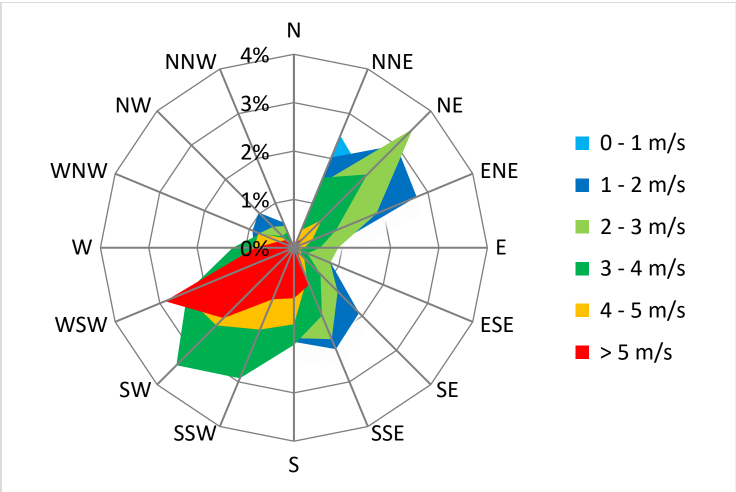

Figure 4. Wind rose showing wind speeds for different wind directions in Gothenburg, 2016 (SMHI Öppna data, 2017).

3.2 Model Description

The simulated building is a wooden detached building, with two floors and a concrete ground slab. The roof is a pitched gable roof with a cold attic and the attic is ventilated through two horizontal air gaps along the roof eaves. The total envelope area of the building is 300 m^2. For a more thorough description see (Domhagen, 2016).

The indoor moisture production is simulated according to (Pallin, 2013). Here, the moisture production increases during the morning until 12.00 AM and decreases slightly before it increases again and peaks at around 18.00 PM. The moisture production has its minimum during night time. Indoor air temperature is 20°C.

The ventilation rate of the building is constant throughout the entire simulation and is adjusted to agree with the requirements set up by the Swedish National Board of Housing, Building and Planning (Boverket). The building has both a supply and an exhaust fan which are balanced so that a negative indoor pressure of 3.5 Pa is achieved. The purpose of the imbalance between the fans is to reduce air-exfiltration from the building. The ventilation rates in the simulation are handled as constant mass flows and are therefore independent of pressure.

Figure 5 shows three orientation scenarios for which airflows are simulated. The dashed lines marks the side with attic ventilation gaps.

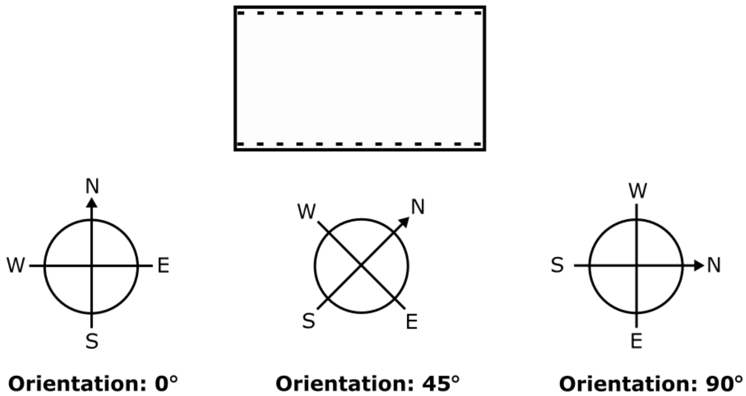

Figure 5. Orientation of building in relation to the cardinal direction of north. Dashed lines marks the sides with attic ventilation gaps.

Output from the simulations is pressure conditions, infiltration and exfiltration, over the whole building as well as for individual leakages. In the following, exfiltration is shown since it has a strong impact on moisture safety and also on energy efficiency.

3.3 Results of Numerical Simulations

Exfiltration from the simulations performed for three building orientations, 0 °, 45 ° and 90 ° with wind, stack effect and mechanical ventilation can be seen in Figure 6. Simulations are performed for a scenario where the airtightness follows the indoor relative humidity with a dampening factor, as described earlier in Chapter 3. Variations are between 0.58 [l/sm^2] and 0.52 [l/sm^2]. Where the building is more airtight during summer which is also the period when indoor relative humidity reaches its maximum.

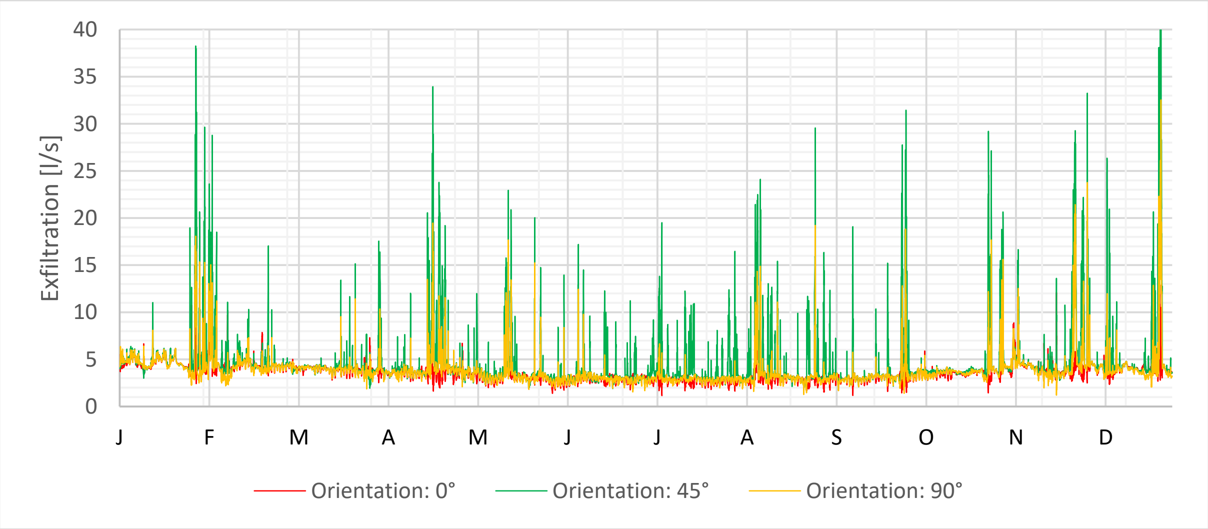

Figure 6. Exfiltration rates for three building orientations with airtightness variation between 0.58 [l/sm^2] and 0.52 [l/sm^2].

Results also show a higher exfiltration rate with the 45° orientation. The reason is that at this orientation wind blows alongside the attic ventilation gaps during windy periods of the year (see wind direction in Figure 4) which in turn causes a negative pressure in the attic which draws air out from the indoor environment.

As a comparison exfiltration is also simulated for a scenario where stack effect is deleted by setting the indoor temperature to the same as outdoors. It is clear from the results that wind is the major driving force for exfiltration. When stack effect is included, it results typically in exfiltration of about 2 l/s during colder winter days, whereas exfiltration caused by wind may account for 30 l/s, or more, for windy periods (see Figure 7).

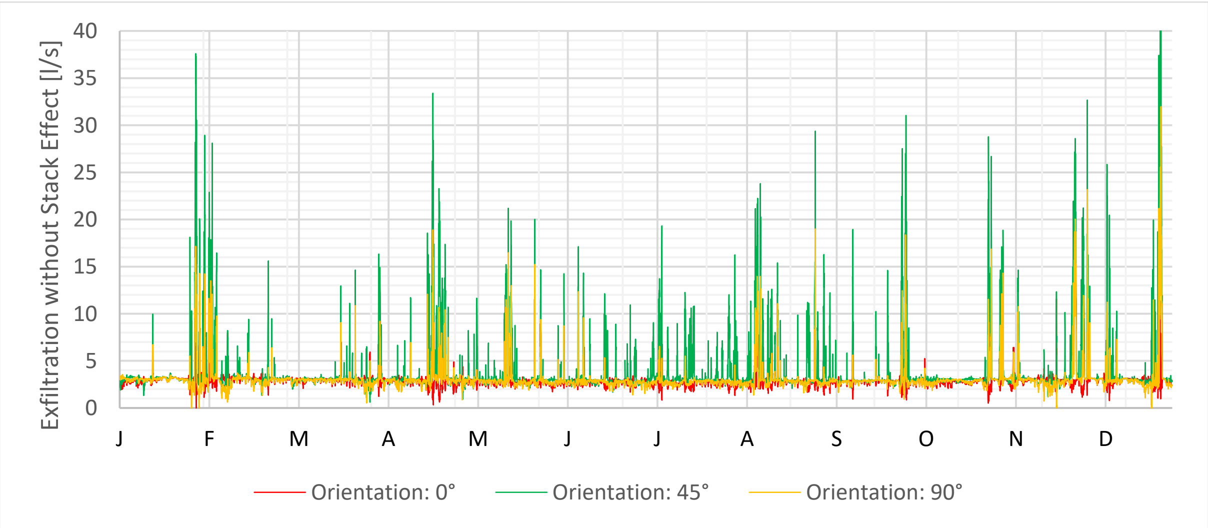

Figure 7. Exfiltration rates without stack effect for three building orientations with airtightness variation between 0.58 [l/sm^2] and 0.52 [l/sm^2].

In contrast to varying airtightness due to moisture variations, the exfiltration is also simulated for constant airtightness calculated as the average of the varying airtightness which is 0.56 l/sm^2 at a pressure difference of 50 Pa. The difference between the exfiltration for the case with varying airtightness and the case with constant airtightness is shown in Figure 8.

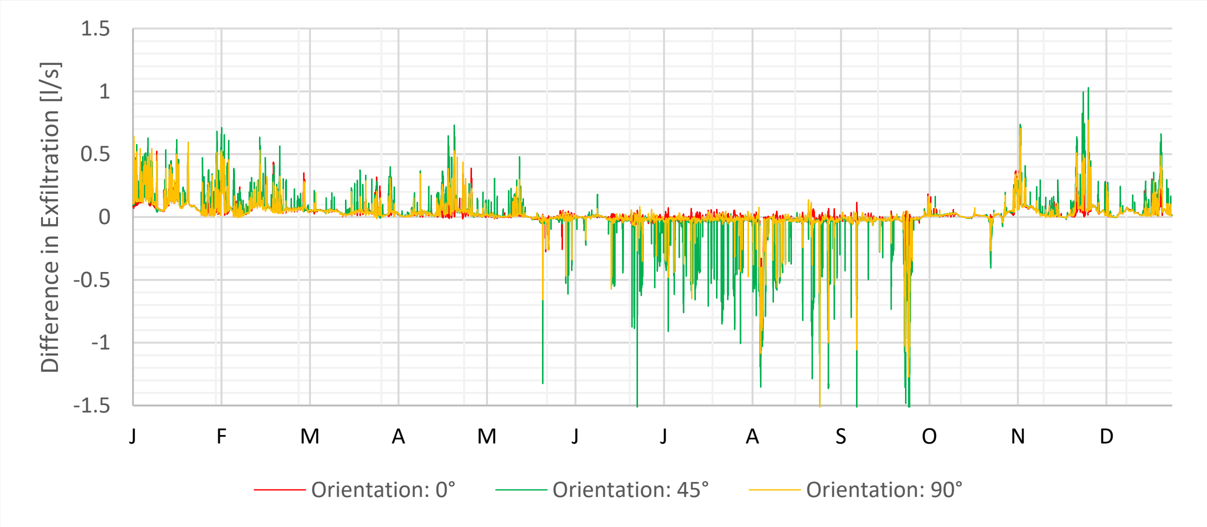

Figure 8. Difference between exfiltration for the case with varying airtightness (variation between 0.58 [l/sm^2] and 0.52 [l/sm^2]) and a case where the airtightness is constant at the average of the varying airtightness.

The graphs show that the exfiltration is slightly increased during colder months and slightly decreased during summer, due to variations in air permeability.

Figure 9 shows exfiltration for January (same simulation as in Figure 6 and Figure 8). There are some climatic differences during the month which are reflected in the exfiltration rates. The first half of the month is slightly colder than the second half which increases exfiltration caused by stack effect. The last couple of days of the month are windier than the rest of the month which is why there is more exfiltration in the end of the month. A comparison shows that during the first 10 days of January the exfiltration is in average 4 %, 5 % and 5 % (for orientations: 0 °, 45 ° and 90 ° respectively) higher with varying airtightness compared to constant airtightness. During the last 6 days of January exfiltration is in average 2 % higher for all orientations (orientations: 0 °, 45 ° and 90 °) with varying airtightness compared to constant airtightness.

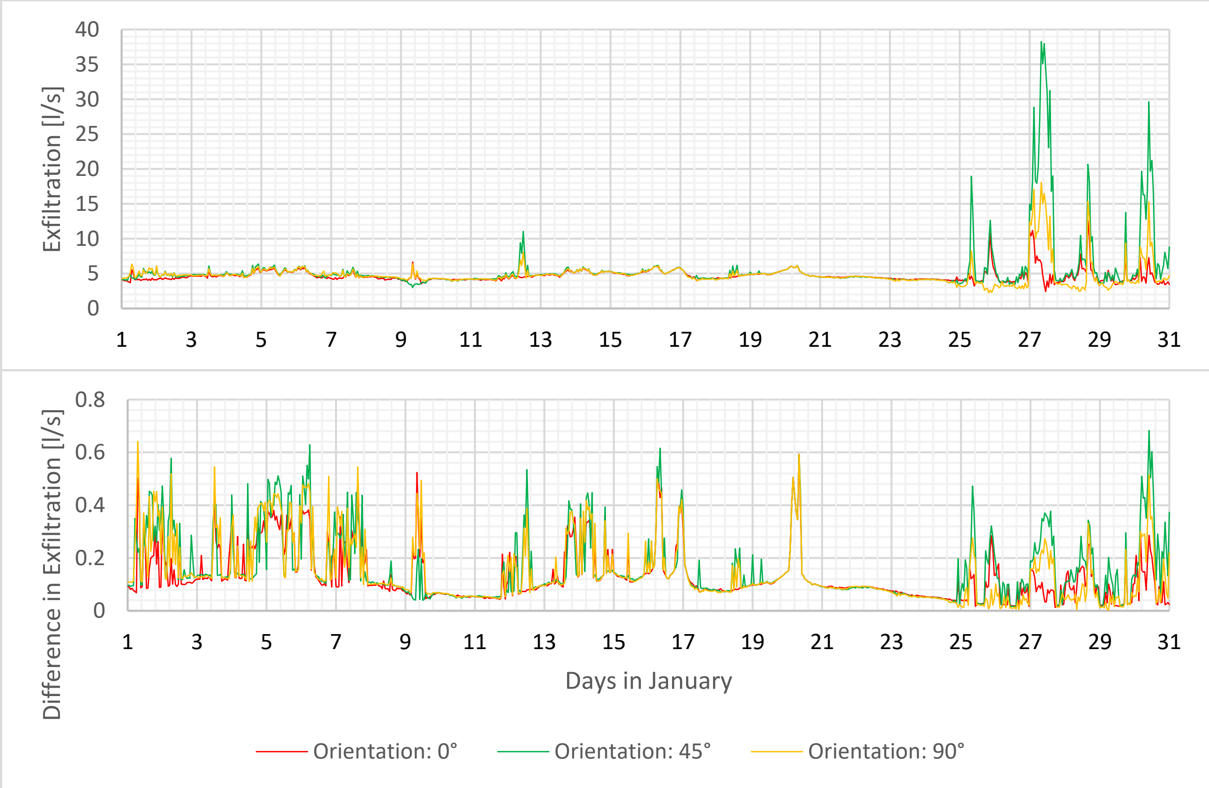

Figure 9. Shows exfiltration for January.

Airflow up to the cold attic is of interest since problems with mould growth in cold attics is common in Sweden (Hagentoft, 2014). A main cause of mould growth in attics is increased relative humidity due to air leakage from the indoor environment. The situation is worsened by night sky radiation during cloud free nights that lower the attic temperature. Simulations show that the airflow to the attic increases during winter months. Airflow to the attic also increases if the building is oriented with the long side of the building in south-western direction, same direction as the wind direction of the majority of the strong winds in Gothenburg, see Figure 4. Wind direction along the ventilation gaps of the attic will draw air out from the attic and cause a negative pressure difference between the attic and the indoor environment.

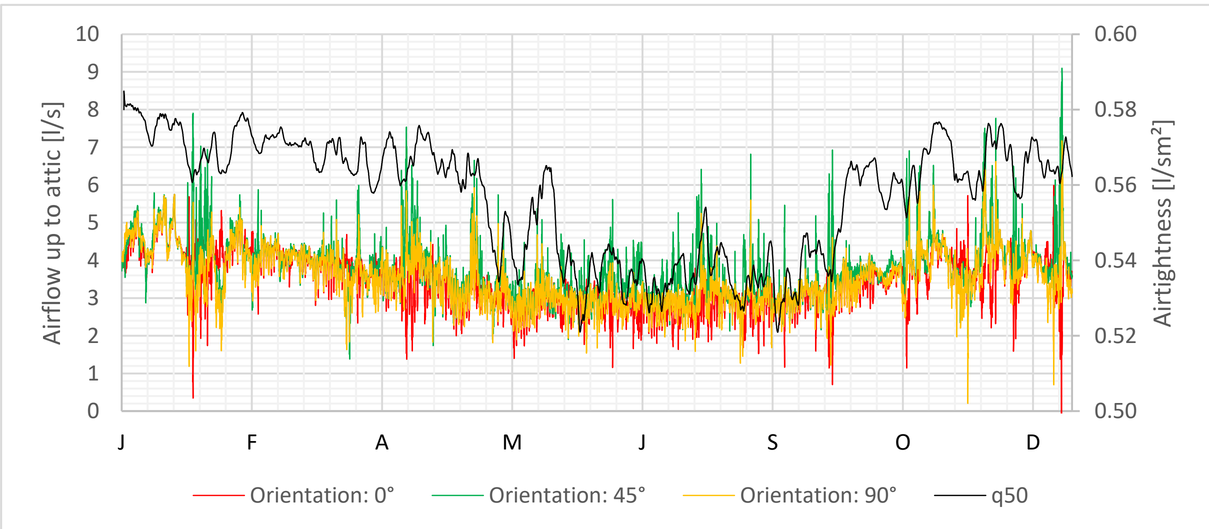

Figure 10. Airflow up to the attic cold space from the indoor environment together with moisture dependent airtightness. Airflows are shown for three different building orientations.

From the results, it becomes clear that a negative pressure caused by the imbalance between supply- and exhaust fans is not enough to eliminate the exfiltration. In fact, there is exfiltration through the thermal envelope during most times of the year.

Figure 11 shows an example of a building with greater variation in airtightness in comparison to the previously described building. The airtightness for this building varies between 0.95 [l/sm^2] and 0.80 [l/sm^2].

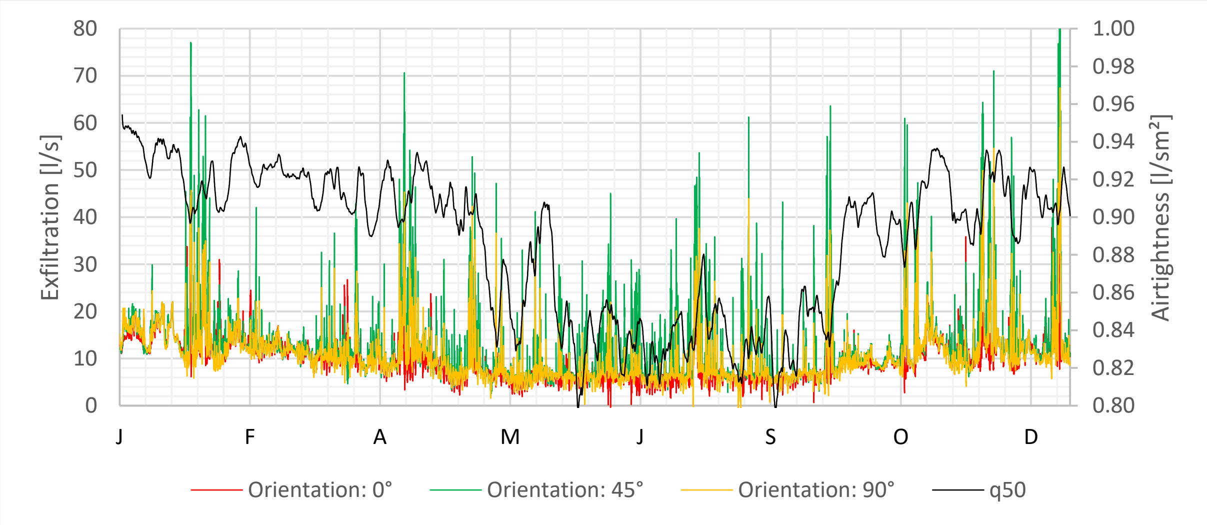

Figure 11. Exfiltration for building with an air permeability that varies between 0.95 [l/sm2] to 0.80 [l/sm2] at a pressure difference of 50 Pa.

For this building, the exfiltration is almost doubled during winter months in comparison with summer months. The increase in air permeability is nearly 19 % which is in agreement with previous findings. For example (Persily, 1982) found that the air permeability can vary with as much as 25 % in a year.

4 CONCLUSIONS AND DISCUSSIONS

Laboratory measurements further strengthens the claim that the airtightness of a timber building is affected by the indoor relative humidity. However, since the investigated guest house is different from a conventional residential timber building more measurements need to be done on conventional residential buildings in order to better understand the extent of these variations.

The levels of relative humidity may also be related to levels of inbuilt moisture in the construction. If a building is constructed when timber components has a moisture content of 16 % it is likely that the measured air permeability will be lower than at a later stage when the moisture content of the timber components is lower. It might therefore be important to let inbuilt moisture dry out before measuring the air permeability or that the air permeability of the building is created so that it is independent of swelling and shrinkage of timber components.

Numerical simulations show a number of effects from moisture induced airtightness. For instance, when looking at the coldest month, January, the exfiltration is 5 % higher during cold days with little wind when comparing varying airtightness with average airtightness.

The driving forces for exfiltration is somewhat different, depending on the orientation of the building. The building with 0° orientation, has slightly more exfiltration at low wind speeds than 45° orientation, while the building with 45° orientation has more (at times twice as much) exfiltration at higher wind speeds. This fact is also true for the airflows up to the cold attic from the indoor environment. Here, the 45° orientation has more airflow up to the cold attic in comparison with 0° and 90° orientations. This is of importance since it will increase the moisture transport up to the attic, which in turn leads to increased risk of moisture related hazards.

When comparing the exfiltration driven by wind with exfiltration driven by stack effect, results show that wind may account for more than ten times the airflow from stack effect.

An imbalance between supply- and exhaust ventilation is often applied with the purpose of reducing exfiltration. In this study, the imbalance was adjusted to achieve a negative pressure inside the building of 3.5 Pa. However, it is clear from the simulation results, that exfiltration occurred most of the time during the year. Since the level of imbalance in order to reduce exfiltration is dependent on the airtightness of the building, as well as exfiltration rates, more work is needed to determine an appropriate imbalance and how it is affected by variations in airtightness.

5 FUTURE WORK

In the near future, more measurements of air permeability in residential buildings over time will be made, in order to study the variations in airtightness, in particular the first time after construction.

The model will be further developed to include pressure-dependency in ventilation-systems and a more detailed description of cold attics in order to investigate risk of mould growth.

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