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Consequences of Varying Airtightness in Wooden Buildings

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Abstract

Previous research has shown that the airtightness in wooden buildings can vary over the year and that buildings can be less airtight during wintertime, likely caused by variations in humidity. In order to investigate possible causes and consequences, such as increased energy use and moisture damage, a number of numerical simulations and laboratory measurements have been performed. In a wooden guesthouse, without a moisture barrier, the indoor relative humidity is kept at 90 % during 8 days and then decreased to 25 % during 7 days. The airtightness is measured frequently during both periods and shows a change in airtightness from 0.74 l/sm^2 to 1.21 l/sm^2 at 50 Pa pressure difference. The moisture scenario can be related to common levels of inbuilt moisture as well as moisture loads from indoor activities. In order to investigate the consequences of varying airtightness, a numerical model is set-up to resemble a typical wooden detached house. Airflows and pressure profiles are then calculated for different values of airtightness. Simulations show that the total increase in exfiltration is dependent not only on airtightness value but also on leakage distribution. For example, exfiltration will increase with 1.9 % per percentage point of decrease in airtightness, if the distribution of leakages are concentrated to the lower parts of the building, compared to 1.6 % if leakages are more evenly distributed. Interestingly, results also show that if the cold attic is accessible through an attic hatch that is not airtight, air is likely to leak from the indoor environment to the attic during some periods of the year and downward to the indoor environment during other periods. Results show that variations in airtightness in wooden houses is affected by surrounding humidity and that the consequences of varying airtightness will affect both moisture and energy performance.

Keywords: airtightness; air leakage; infiltration

1. Introduction

Previous research has shown that the airtightness in wooden buildings can vary over the year and that buildings often are less airtight during winter months, [1, 2]. In a recent study *Blower door* measurements on detached wooden houses showed that the total air leakage at 50 Pa pressure difference can vary with as much as 10 % throughout the year [3]. Also less recent studies show similar results where variations in airtightness of as much as 25 % throughout the year has been found [4]. There are also indications that the variation in airtightness follows variations in relative humidity, indicating that swelling and shrinking of timber parts affects the airtightness of the buildings, something which has been shown by Skogstad [5] for a number of wooden buildings. It has also been shown by [6] that air leakage through clamped joints increases with decreased moisture content in included timber

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members. Since airtightness affects many aspects of a building's functionality, it is vital to broaden the understanding of what consequences such variations might have on the performance of a building and why they occur.

Nomenclature

q_{50}	air permeability per envelope area of the building at a pressure difference of 50 Pa [l/m^2s]

2. Project aim and outline

The aim of this project is to investigate the causes and possible consequences of varying airtightness as well as the correlation between relative humidity and varying airtightness. The study focus on wooden frame houses subjected to Swedish climate.

3. Methods

The investigations are made using laboratory measurements on a small wooden house (guesthouse) and numerical simulations representing a two storey residential wooden building.

3.1. Laboratory testing of a guesthouse

In order to test how the airtightness of a building reacts to changes in relative humidity, measurements using a *Blower door* according to standard *EN-15004* are performed on a guesthouse with a controlled indoor humidity. The guesthouse has a living area of about 13 m^2, it is a timber construction and the foundation consists of plinths. All walls have a wind barrier (building paper) but no moisture barrier, meaning that moisture is allowed to diffuse in and out from the construction, see Figure 1. The guesthouse is situated in a large storage hall where the relative humidity is between 20 % and 40 %.

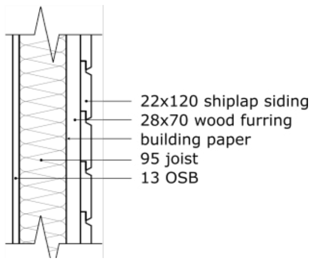

Fig. 1. Detail drawing of the wall used in the guest house.

During the first phase of the experiment, the moistening phase, the relative humidity in the living space of the guesthouse is increased to ~90 % during 8 days, the airtightness is measured daily during the first 4 days and every second day during the remaining 4 days. The increased relative humidity is achieved with a small office humidifier controlled with a programmable microcontroller and a humidity sensor.

During the second phase of the experiment, the drying phase, the relative humidity in the guesthouse is lowered by means of heating and ventilating. During nighttime the relative humidity is lowered by heating the cabin with radiators and during daytime the guesthouse is ventilated with the blower door set at cruise. The drying phase is 7 days long and the airtightness is measured every second day using the *Blower door* equipment. The relative humidity and temperatures are measured continuously inside the guesthouse as well as outside the guesthouse throughout both phases. The temperature inside the storage hall where the guest house is situated is between 19 °C and 21 °C throughout the test period. Inside the guest house, temperatures are slightly higher during the moistening phase (20–21 °C) while during the drying phase temperatures are between 30 °C and 32 °C.

In the end of the test period, a leakage search is performed with the use of an anemometer to map leakages in the construction. The *Blower door* equipment is mounted and run at cruise mode while airspeeds are noted along walls, floor and ceiling. A map of the results from the leakage search can be found in [6].

3.2. Calculations in simulations software CONTAM

To investigate what consequences a varying airtightness might have on the functionality of a building, a model is built in the simulation software CONTAM. CONTAM is a multi-zone airflow analysis software that calculates airflows between well mixed zones dependent on pressure differences. It takes into account stack effect, wind and mechanical ventilation. Airtightness is entered into the model as individual leakages where the airflow is described with a function that relates the airflow through the leakages with the pressure difference over the leakage [7].

The reference model created in CONTAM is designed to resemble an ordinary wooden detached building as much as possible. It has a concrete ground slab, two floors and a cold ventilated attic with an indoor attic hatch, see Figure 2. The ventilation system consists of both a supply fan and an exhaust fan with the possibility to add a heat recovery unit. In order to have a leakage distribution that is representative for a somewhat typical building, a well-studied building with known airtightness and with results from a leakage search is used. The details of the building (construction and leakages) are taken from a previous study [8].

All leakages in the building are listed and added to the model with corresponding leakage-values taken from [9, 10]. Leakages are then adjusted so that the airtightness of the model is the same as for the residential building, namely $q_{50} = 0.6$ l/m^{2}s. A more detailed description of the model can be found in [6]. The model is used to determine the position of the neutral pressure plane, the pressure difference between interior and exterior side of the building and airflows through leakages added to the model dependent on changes in airtightness. All simulations assumes stationary conditions.

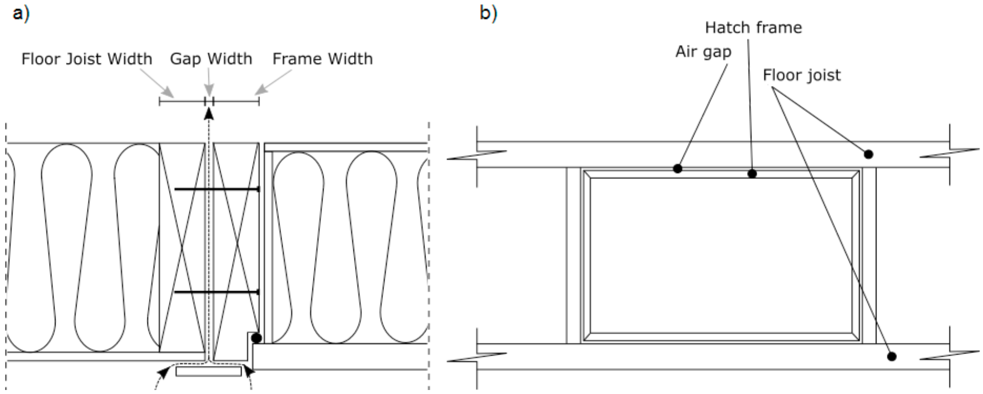

Fig. 2. Detail drawing of the attic hatch. (a) shows the connection between the attic hatch and the ceiling construction. The arrows indicates the leakage paths; (b) shows the attic hatch from above.

4. Results and discussion

Results are presented for the full-scale measurements in the guesthouse and the numerical simulations of air flows and consequences at different leakage distributions and weather conditions.

4.1. Airtightness measurements in guesthouse

The results from the blower door measurements and measured relative humidity during both moistening phase and drying phase are shown in Fig. 3. Graph showing relative humidities together with specific air leakage at 50 Pa pressure difference during the entire test period. RH in the storage hall fairly constant during the measurement period (approximately 30 %). The sudden drops in relative humidity seen inside the guesthouse corresponds to each time a blower door measurement is conducted. The smaller drops in relative humidity during the moistening phase corresponds to when the humidifier is refilled with water.

During the entire moistening phase, the air leakage drops from the initial value 1.17 l/sm^2 to 0.74 l/sm^2, a total decrease of almost 40 %. The initial relative humidity in the guesthouse is about 40 % and is increased to 90 % within the first two days. During these two first days air leakage drops to 0.89 l/sm^2 and then decreases more slowly with about 3 % per day during the remaining 6 days.

The drying phase is initiated after 8 days and blower door measurements are conducted every second day. During the first two days leakage increased from 0.74 l/sm^2 to 0.98 l/sm^2, a total increase of about 38 %. Since a radiator is used during the drying phase, the relative humidity in the guesthouse eventually becomes lower than the relative humidity outside the guesthouse.

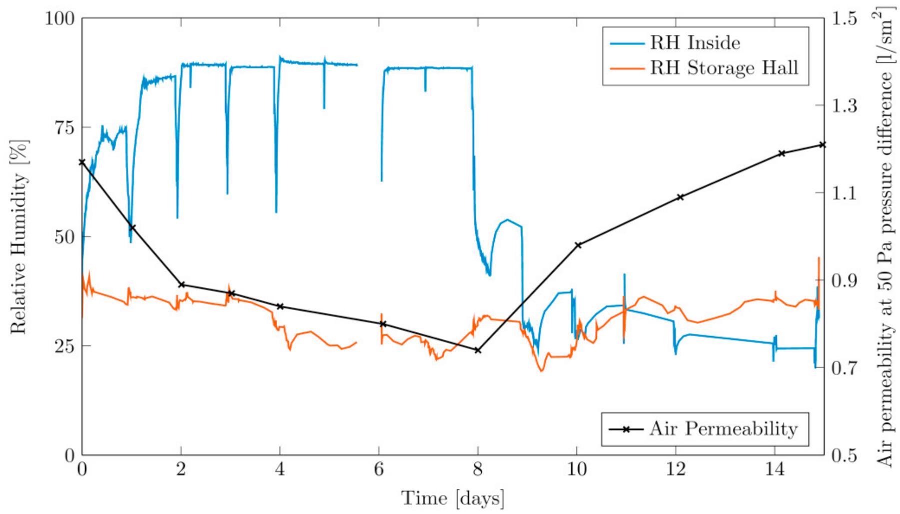

Fig. 3. Graph showing relative humidities together with specific air leakage at 50 Pa pressure difference during the entire test period.

Due to limited access to the guesthouse, the moistening phase had to be interrupted before the air leakage had stopped to increase, this was unfortunate since it would have been valuable to find the highest and lowest air leakage for each of the two phases.

The leakage search performed showed that the majority of the leakages are situated in the connection between walls and floor. This means that it is the leakage in the floor wall connection that is changing with changes in relative humidity. The floor construction itself did not have any leakages, the reason is probably that the floor was a type of tongue and grove construction which, if properly mounted, should prevent air leakage between the boards.

Results clearly shows that the indoor relative humidity is affecting the airtightness of the guesthouse, but since the construction itself is different from a conventional detached wooden house it is difficult to draw more general conclusions. However, it seems that the lack of moisture barrier might increase the variations. This would suggest that the airtightness of buildings without a moisture barrier (which usually also is the air barrier) is more sensitive to changes in humidity than buildings with a moisture/air barrier.

The moisture behavior of the guesthouse during drying can correspond to the drying out of inbuilt moisture in wooden constructions. Newly built timber constructions should according to recommendations not exceed a moisture content of 16 % [11] which corresponds to a relative humidity of 80 % at 20 °C. If such amounts of moisture is built into the construction and allowed to dry out, it is likely that new buildings are initially more airtight than at a later stage. This fact raises another question; when is the proper time to perform airtightnessmeasurements? If there are certain demands on the airtightness of the building how should they be formulated to take evenutal changes into account and how long after the completion of a building should measurements be performed.

4.2. Numerical simulations of air leakages

A number of different scenarios where simulated using CONTAM in an attempt to get an overview of how and when changes in airtightness might cause problems. Fig. 4 shows the resulting airflows (exfiltration, infiltration, difference in supply- and exhaust ventilation and leakage to and from cold attic) from five different climate scenarios and for different levels of airtightness. Simulations are based on the previously described reference model where an increase as well as decrease in airtightness is simulated with $q_{50} = 0.6$ l/m^{2}s as a starting point.

For the simulated scenarios the imbalance between exhaust- and supply airflow is adjusted so that the exhaust airflow is close to 44 l/s and the supply airflow is close to 22 l/s for the case with no wind, no stack effect and an airtightness of q_{50} = 0.6 l/sm^2. The reason for this is to keep the building depressurized to avoid exfiltration.

The imbalance between supply- and exhaust ventilation results in a pressure difference of about 2 Pa. The reason to the relatively low pressure difference despite the high difference between exhaust- and supply airflow is the relatively low airtightness of the building. (In Sweden many construction companies aim for 0. l/m²s.) The airtightness of a building is thus crucial for achieving high enough pressure difference to minimize exfiltration.

Climate parameters used for the numerical simulations are monthly mean values for Gothenburg. For calculated scenarios in February the temperature of -4 °C and wind speed of 5 m/s is used. For July a temperature of 15.5 °C and wind speed 5 m/s is used.

The cold attic in the calculations is ventilated with ventilation gaps only along the long side of the building which makes the wind direction decisive for the pressure difference and airflows in the attic. This can be seen in Figure 4.d where air is leaking from the living space up to the attic when the wind direction is perpendicular to the short side of the building. However, when the wind direction is perpendicular to the long side of the building air is instead leaking from the attic down to the living space. This means that the indoor air is affecting the air in the cold attic during some parts of the year and vice versa during other parts of the year. Results also show that the

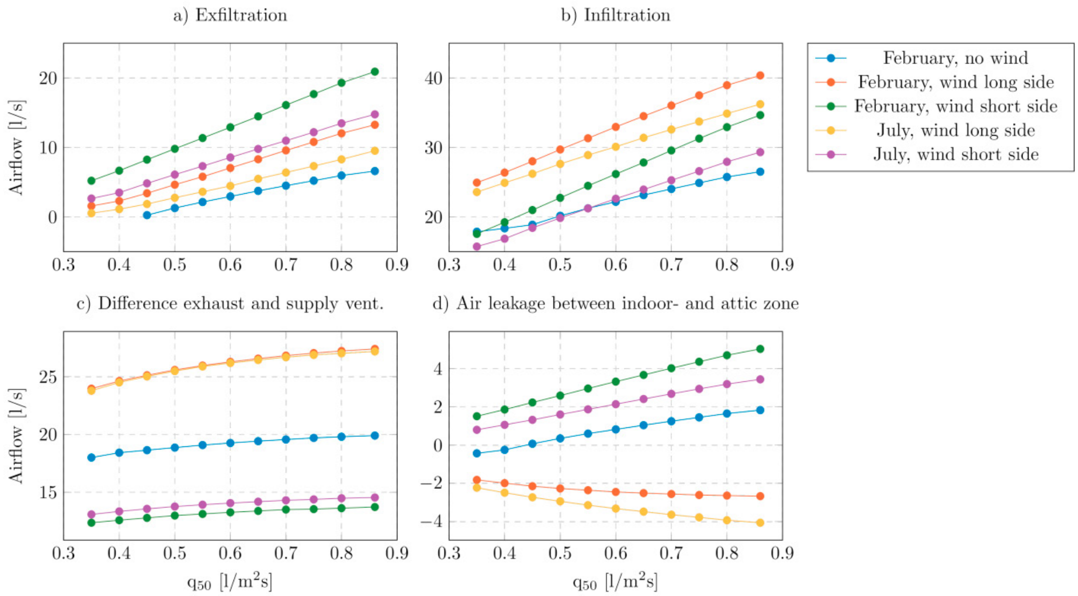

Fig. 4. Results from CONTAM simulations showing leakage and ventilation for different scenarios. (a) shows the total exfiltration; (b) shows the total infiltration; (c) shows the difference between exhaust- and supply ventilation airflow (values for "wind long side" are nearly identical and therefore hard to distinguish from each other); (d) shows the air leakage between the indoor zone and the attic zone where negative values denotes airflow from attic zone to the indoor zone.

leakages to and from the attic increases with decreased airtightness.

As a consequence of a change in airtightness, air leakages and pressure profiles will change dependent on the distribution of leakages. Results from simulations in CONTAM show that exfiltration increases with 1.9 % per percentage point of decrease in airtightness when close to the starting point of $q_{50} = 0.6$ l/m²s if distribution of leakages are concentrated to the lower parts of the building. While the increase in exfiltration is 1.6 % per percentage point of decrease in airtightness when close to the starting point of $q_{50} = 0.6$ l/m²s if leakages are more evenly distributed. This means that how much the exfiltration changes is not only dependent on the overall air leakage but also on where the changing leakages are situated in relation to the neutral pressure plane.

5. Conclusions and discussion

Measurements on the wooden guesthouse show that there is a substantial difference in airtightness when the indoor air is moist and dry. The building was much leakier (1.17 l/sm²) when the indoor air was dry (RH 25 %) than when the air was moist (0.74 l/sm², RH 90 %). The reason is changes in the dimensions of wooden based construction parts when subjected to drying and moistening. The condition of the moist phase can correspond to the initial conditions of a wooden building and the dry phase corresponds to the building in use. Furthermore, the leakages in the guest house were mostly concentrated to the floor/wall connection. For higher buildings, these conditions would result in high pressure difference over the attic floor and, in case of local leakages in the upper ceiling, might also result in local moisture damage in the attic construction.

When constructing wooden buildings it is often a common recommendation to protect the timber members during construction and to ensure that the construction timber is properly dried before the start of the construction work. The main reason is to avoid high levels of inbuilt moisture and an increased risk of moisture related problems. The fact that the construction gets more leaky when it dries is yet another incentive to try to reduce the moisture content of the construction timber before and during construction. However, the todays recommended moisture content for construction timber might be too high and in need of reconsideration if changes in airtightness is to be taken into account.

Another issue raised by the fact that the airtightness of a building might increase for some time after it has been ready-built is when to perform airtightness measurements. If regulations or clients have certain demands on the airtightness of the building, how can it be ensured that the demands are fulfilled. It becomes clear that only measuring the airtightness of the building directly after construction is not a trustworthy way of evaluating the true airtightness of the building. Also the fact that the airtightness varies over the year makes measurements more problematic since it practically means that the airtightness must be measured at several occasions in order to give a complete picture.

The variations in leakage rate in the numerical simulations were based on CONTAM simulations, described in Domhagen [6]. The simulations were performed on individual leakages to investigate how moisture induced swelling and shrinking in timber connections affect the air flow through the leakage path. These simulations show that relatively small changes in relative humidity can have a quite large effect on the air leakage rate. This means that even though the total airtightness of a building changes with 10 %, the change in individual leakages might be many times greater. Results also show that the design of the connection where the leakage occurs affects how much the leakage will change due to changes in relative humidity [6].

When investigating the air leakage using CONTAM, as shown in Figure 4, several conclusions were drawn. The distribution of leakages affect the pressure conditions and the air flows and when changing the airtightness, the affect will be different depending on the distributions of leakages. As an example, the exfiltration increases with 1.9 % per percentage point of decrease in airtightness (when close to the starting point of $q_{50} = 0.6$ l/m^{2}s) if distribution of leakages are concentrated to the lower parts of the building. Similarly, the increase in exfiltration is 1.6 % per percentage point of decrease in airtightness (when close to the starting point of $q_{50} = 0.6$ l/m^{2}s) if leakages are more evenly distributed. This means that how much the exfiltration changes is not only dependent on the overall air leakage but also on where the changing leakages are situated in relation to the neutral pressure plane. This will be more pronounced in higher buildings.

Cold attics with mold growth is a well-known problem in Sweden [12]. The simulations of the air leakage to and from the cold attic shows that air is likely to move both ways during the course of a year. With respect to mold growth, investigations show that there are times during the year when moist indoor air leaking up to the attic may lead to mold growth in the attic, and that this air can transport mold spores into the living space during other periods. In Domhagen [6], there are also illustrations of how changes in airtightness affect the efficiency of heat recovery in the ventilation air.

The project will continue to investigate the initial changes in airtightness in buildings, where the next step is to measure airtightness in newly constructed residential wooden frame houses.

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