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Airtightness Development in Large Timber Buildings: Case Study of a Zero-Emission Building in Norway

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Abstract. Large timber buildings are increasingly used in the Nordic countries because of low greenhouse gas emissions and good access to timber. There is however uncertainty about the airtightness of the envelope of such buildings over time because of the possible timber's shrinking and swelling, in particular when using cross laminated timber (CLT) in external walls. Therefore, two measures are often suggested to avoid moisture transport from inside to outside due to gaps in the joints of CLT external walls, i.e., a vapour barrier on the outside of the CLT elements and/or a local sealing of the joints. However, the airtightness development over time with only local sealings is uncertain. This paper presents the airtightness and thermographic assessment of a new zero-emission office building, built in 2020 in Norway. This building has a timber load-bearing system, including external timber frame walls and CLT-based walls. The timber frame walls have a vapour barrier on the warm side of the construction, while the CLT-based walls only present local sealing measures. Two thermal imaging and airtightness tests were performed: the first upon construction completion and the second after one year, to investigate possible changes in the airtightness of the building envelope over time. The air leakage results during the two tests performed with one year difference showed comparable building's air change rate values of 0.46-0.47 h^{-1} at a pressure difference of 50 Pa. However, the thermographic examination of the envelope from inside the building showed that local sealings had cracked in several places because of the elements' movement. This will be further investigated as it may affect the hygro-thermal and acoustic performance of the building.

INTRODUCTION

In Nordic countries, the zero-emission goal in the building sector has led to the increasing use of timber, due to the low greenhouse gas emissions and good access to this material, as well as a growing policy support. As a building material, timber can contribute to a high envelope performance, where the airtightness, often expressed as air leakage rate at 50 Pa pressure difference, is central to achieving low energy use and avoiding moisture problems, especially in the harsh Nordic climate [1].

The airtightness of buildings can undergo significant changes over time. Verbeke & Audeneart [2] investigated the evolution of the airtightness performance of 41 dwellings in a period of 0.5-12 years after first measurement (upon construction), demonstrating an increase in the air leakage rate of around 38%. However, they pointed out that the large relative changes in the airtightness were due to the low initial value (i.e. air leakage rate at 50 Pa < 0.6 h^{-1}) in most of the examined buildings. Furthermore, a tendency to increased air leakages was noticed as more time between measurements occurred.

The airtightness of timber buildings over time can be uncertain because of the possible timber shrinking and swelling, but it can be preserved as shown in a few studies. Moujalled et al. [3], for instance, studied the durability of

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building airtightness of low energy houses through mid-term and long-term measurement campaigns. They concluded that the airtightness of timber framed houses with a vapour barrier tends to stabilise or even improve over the years. Moujalled et al. also emphasized the need to better understand where and why leakages appear during the early years after construction, as this can cause the progressive deterioration of building airtightness. Ylmen et. al [4] investigated the airtightness over time for small timber houses in Sweden, showing that the airtightness can be preserved. They compared the airtightness measurements when the building was new and several years later (between 10 and 21 years later). They had a sample of 6 houses, where 3 of them had changes in original climate envelope. The 3 remaining samples with original building envelope showed a similar air leakage on both tests.

The airtightness of timber buildings where CLT is used in the external envelope can be weakened if no proper sealing methods are used. Three main measures are usually suggested to fulfil airtightness requirements: 1. use of sealing products between CLT elements; 2. an additional cover to the CLT joints with adhesive tape or airtight membrane strips; 3. an airtightness membrane over the whole CLT surface, [5,6]. The moisture content (MC) in CLT components at the construction stage can also influence the development of air leakages during building operation because of timber shrinking, as shown in several studies. Kukk et al. [5] did laboratory testing on 12 different walls with CLT elements, investigating, among others, the effect of initial high MC. Test walls were made by CLT elements with two different initial MC values, i.e. ca. 13 weight-% and ca. 26 weight-% to cover an expected span of built-in moisture. The results of Kukk et al. showed that elements with high initial MC significantly weakened the airtightness of the external wall. They concluded that 5-layers CLT elements can be used as the airtight layer in external walls if the initial MC content is low (about 13%) during both construction and service life. Their results also showed walls with large air leakages due to possible aligned cracks in the elements.

Skogstad et al. [7] performed laboratory investigations of the airtightness of CLT element joints. The study showed the need for airtight joints to avoid water vapour transport caused by convection. They recommended a local sealing of the joints between the CLT elements through sealing compound, rubber moulding or sheets of airtight material. Another suggested method consisted in the use of a separate water vapour barrier on the inside of the insulation and an external wind barrier.

The objective of this study is to investigate the airtightness of timber buildings over time and the influence of common sealing measures to the air leakage development in the envelope joints. Thus, the article presents the airtightness and thermographic assessment of a large timber building that was completed in October 2020 in Norway. As this building presents a combination of timber frame and CLT components with different sealing measures, our study aimed at investigating the changes in the envelope airtightness after one year of operation, as well as the preferable sealing solutions and the most critical joints regarding sealing.

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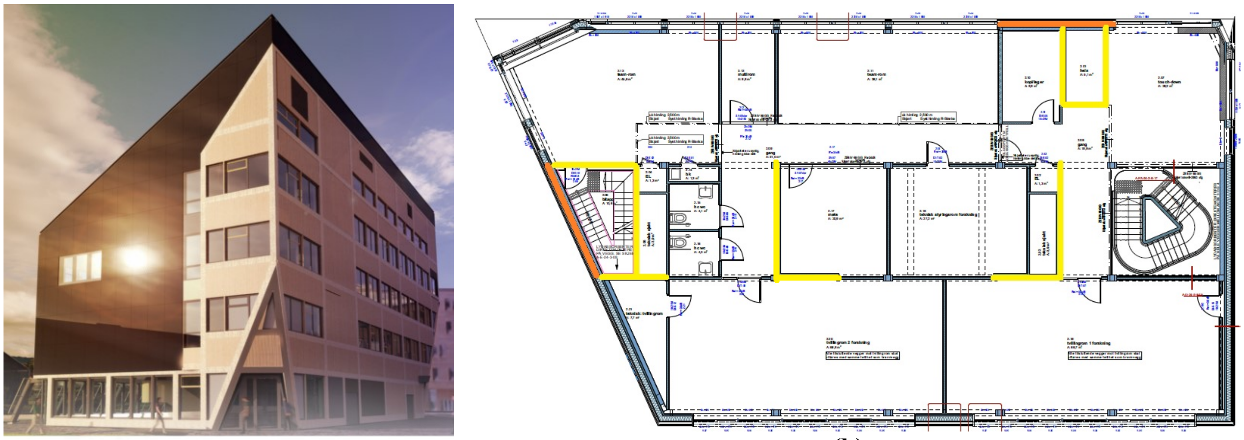
METHODS

Case Study Building and Sealing Measures

This study was carried out on a new zero-emission office building (the ZEB Laboratory), built between 2019-2020 in Trondheim, Norway. This building, shown in Fig. 1 (a), consists of 4 floors with a total gross area of ca. 2000 m^2. It has a timber load-bearing system with glued laminated (glulam) timber beams and columns, CLT floors, external insulated timber frame walls and a few stiffening CLT-based internal and external walls. The external CLT-walls have five cross laminated layers. The roof is a compact insulated timber-based construction with a vapour barrier on the warm side. In Fig. 1 (b) the second floor of the building is illustrated with the distribution of the CLT-based walls, which is quite similar for all floors. The timber load-bearing system was mounted in the summer of 2019, and the building was weatherproofed during October the same year.

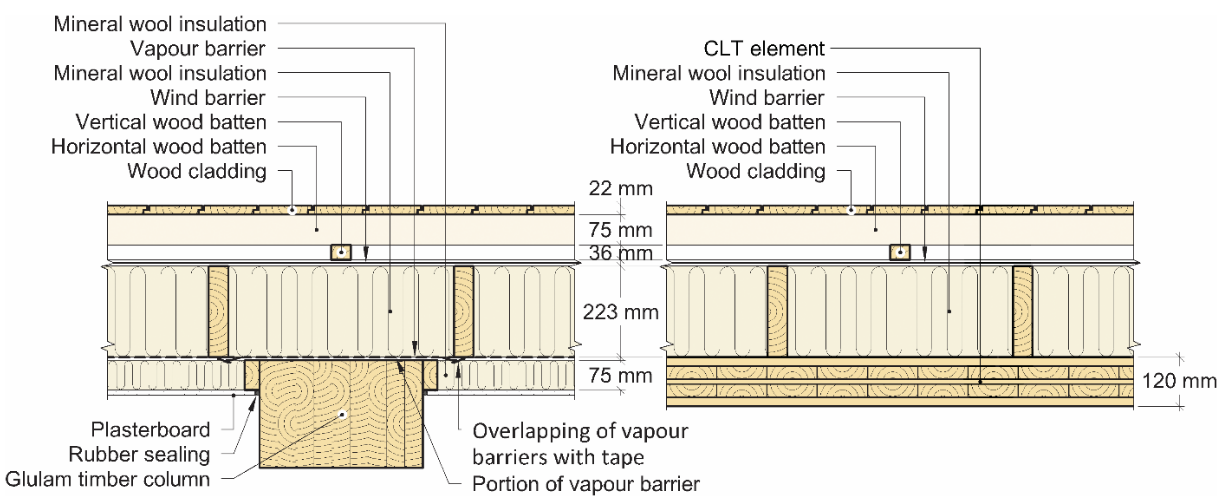


(a) (b)

FIGURE 1. (a) Illustration of the ZEB Laboratory and (b) plan drawing of second floor showing external CLT-based walls illustrated in orange and internal CLT-based walls in yellow. Source: [8]

The project goal during design and construction phase was to achieve an air leakage rate $\leq 0.3\ h^{-1}$, at a pressure difference of 50 Pa. Therefore, different sealing methods were used on the building envelope components. All external walls present a wind barrier on the outside of the insulation. The insulated timber frame walls have a PE-foil as a vapour barrier on the inside of the framework, as shown in Fig. 2 (a). Both the wind barrier and the vapour barrier have taped seams. The external CLT-based walls, illustrated in Fig. 2 (b) do not have any vapour barrier but only local sealing measures. Furthermore, the horizontal transitions between CLT-based walls and other constructions are sealed with tape products, while the vertical joints between elements have no sealings. Furthermore, on the inside of the CLT elements, a rubber sealant is used in the transition to other constructions, with no particular airtightness purpose for the building envelope. This sealant's main objective is aesthetic and acoustic, as it helps soundproofing between rooms and floors. The two main types of external walls are shown in Fig. 2, which also illustrates how the main load bearing system is placed on the inside of the vapour barrier, to prevent thermal bridges and achieve the high airtightness requirement of the project more easily.

Portions of PE-foil were attached on the outwards side of the glulam beams and columns before mounting the other wall layers, to make a continuous vapour barrier with the PE-foil of the timber frame external walls. The overlapping of the PE foils was sealed, as illustrated in Fig. 2 (a).



(a) (b)

FIGURE 2. Horizontal section illustration of the two main types of external walls and sealing methods. (a) Insulated timber frame wall and (b) CLT-based wall.

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The initial MC of the timber components in the studied building was measured during the construction phase, resulting in an average value below 15 weight-%.

Testing Methods

Two thermal imaging and airtightness tests were performed on the assessed building: the first upon construction completion (i.e the day after the building was taken over) and the second after one year of use. This allowed to investigate the development in the airtightness of the building envelope over time.

The airtightness measurements were carried out in accordance with the standard ISO 9972:2015, Method 3 [9]. A Blower door equipment was used for the measurements and the testing was done with both over- and underpressure at 50 Pa difference.

The thermographic assessment was done in accordance with EN 13187:1998 [10]. During the two tests, ca. 100 thermograms were taken at the same locations on the building envelope, to compare possible changes and developments.

Table 1 shows climate data for the two testing days. The tests were done approximate one year apart, in similar weather conditions, i.e. during fall with quiet wind and dry weather. The internal volume of the building was measured to be 7691 m^3.

TABLE 1. Weather condition during the tests

Test [No.]	Date [dd.mm.yyyy]	Wind [m/s]	Weather [-]	Ext. Temp [°C]	Ind. Temp [°C]
1	23.10.2020	~2	Dry	3	21
2	29.10.2021	~2	Dry	8	21

Before the tests was carried out, several measures were done, as suggested in ISO 9972:2015:
- Top of the elevator shaft sealed with a plastic foil.
- All drains in the floor and sinks refilled with water.
- All interior doors open, including doors for stairwells.
- All windows closed.

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RESULTS AND DISCUSSION

Air Leakage Measurements

Table 2 and Table 3 present the results from the airtightness measurements for test No. 1 and No. 2 with pressure difference of 50 Pa, given as underpressure, overpressure, and final average value. Table 2 shows the measured air volume and Table 3 presents the measured air leakage rate of the building.

TABLE 2. Measured air volume flow, q_{50}, with pressure difference of ± 50 Pa.

Test [No.]	Underpressure [m³/h]	Overpressure [m³/h]	Average [m³/h]
1	3282 (± 4.5%)	3959 (± 5.8%)	3620
2	3390 (± 0.5%)	3731 (± 4.7%)	3560

TABLE 3. Measured air leakage rate, n_{50}.

Test [No.]	Underpressure [h^{-1}]	Overpressure [h^{-1}]	Average [h^{-1}]
1	0.43	0.51	0.47
2	0.44	0.49	0.46

The results of the measurements show an average air volume flow of approximate 3600 m³/h for both tests. The difference in average air volume flow between test No. 1 and No. 2 was less than 2%, which is within the measurements' margin of error. The average measured air leakage rate in test No.2 was ca. 2% lower than in test No. 1, showing no considerable change in airtightness of the building after one year of building operation. Note that the relatively low initial MC of the analysed building may have contributed to the negligible change in the air leakage rate, as pointed out in similar studies [5].

The results of our measurements are in line with the findings of similar research works, which pointed out very low to null change in timber buildings' air leakage rate [3,4].

Thermographic Assessment

A selection of thermograms taken during the tests is presented in Table 4. All thermograms show construction joints of the building envelope and were selected because of air leakages seen in connection with the timber load-bearing system. Note that a different temperature scale is shown in the thermograms from year 2020 and 2021. This was necessary to get a clear view of the temperature difference in the construction due to different outdoor temperature on the testing days.

Table 4 (a) illustrates an external CLT-wall. The correspondent thermograms shows an air leakage in the vertical joint between two adjacent CLT elements, with no negative development of the air leakage between year 2020 and 2021. A further investigation of the joint in construction phase revealed that this vertical joint has no air sealing measures on the outside. This leads to additional heat loss and may cause moisture transport outwards due to convection. A similar issue was presented by Skogstad et. al., who recommended to have a separate airtight sealing between the elements in addition to the external wind barrier to avoid this leakage point. Also, Kukk et al.[5] revealed that the use of tape was not sufficient to ensure airtightness of external CLT-based walls due to the formation of large cracks in the CLT surface during the building use.

Table 4 (b) shows the joint between the gable wall (in brown) and the sloped roof. The air leakage is probably due to an untight sealing between the vapour barrier in the wall and the vapour barrier in the roof. The recurring warm areas shown in the thermograms are likely caused by the timber studs in the wall that tightens the joint further.

Table 4 (c) and (d) illustrate different connections where the geometry makes it challenging to construct an airtight joint. These connections are also difficult to discover during the drawing phase without 3D-modelling. The pre-mounted PE-foil on the column was probably not sealed properly with the vapour barrier in the external walls. In addition, the inside rubber sealing is cracked most likely due to timber movements.

Figure 3 (a) shows a knot hole in the external 5-layer CLT element. This can represent a weak area regarding airtightness. The thermogram assessment does not show reduced temperature, most likely due to the layered CLT element, i.e. the knot hole is only present in one of the five layers. Other research works demonstrated that knot holes are not necessarily leakage points when the CLT element is made of several layers. For instance, Gullbrekken and Bunkholt [11] found similar knot holes in laboratory tests and recommended a separate air barrier for 3 layer CLT-elements.

Figure 3 (b) illustrates a cracked sealing joint between a CLT element and an external wall. Without a separate air sealant layer, these cracks could lead to unnecessary heat loss and moisture transport into the walls, by also affecting the acoustic performance of the building. On-site investigation showed that the rubber sealing did not crack due to poor adhesion.

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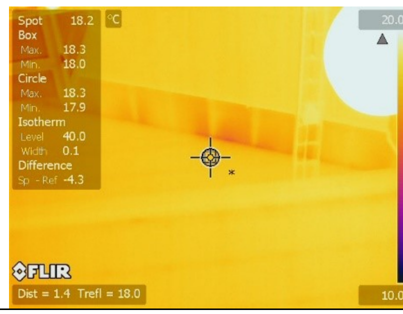
TABLE 4. Pictures of selected construction joints and thermograms taken during the two assessments in 2021 and 2021.

Description	Year 2020	Year 2021

(a) Element connection, 2nd floor

(b) Roof and ext. wall joint



(c) Column and CLT-joint, 1st floor

(d) Column and wall joint, 3rd floor

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FIGURE 3. Knot hole in external CLT-element (a) and cracked sealing joint between CLT-element and external wall (b)

CONCLUSIONS

This article presents the findings from two thermal imaging and airtightness tests performed on a case study timber building, i.e. a new zero-emission office building, completed in 2020 in Norway. The first test occurred upon construction completion, while the second after one year. This allowed to investigate the development in the airtightness of the building envelope over time.

The main conclusions can be summarized as follows:

- There was no significant change in the air leakage rate between 1st and 2nd measurement (0.46-0.47 h^{-1} at a pressure difference of 50 Pa, respectively). The drying of the timber, which represents the main material in the analysed building, did not considerably affect the building airtightness in this period.
- The thermography assessment showed similar heat losses for both measurements in the assessed joints. However, cracks between CLT-elements without a separate airtight sealing led to additional heat loss. Therefore, we believe that a separate local sealing between the CLT-elements, in addition to the external wind barrier, would be beneficial to reduce heat loss and possible moisture transport due to convection into the external walls. Further analysis is necessary regarding the long-term adhesiveness of tape sealing products and their ability to endure the movement and moisture transport from the timber.
- Local rubber sealings cracked in joints between the load-bearing timber system and other components, such as the external walls, most likely due to the timber movement. Therefore, this sealing method is, in our opinion, not sufficient as the only air sealing measure on the warm side of the construction.
- Knot holes in CLT elements were detected in the assessed building, showing no additional thermal losses. Such holes do not necessarily represent air leakage points and may be accepted without additional sealing measures if the CLT elements have multiple cross laminated layers.

Future research could focus on further mid-term and long-term airtightness and thermographic assessments on the case study building, thus allowing a systematic data collection over time. Furthermore, as internal sound transmission measurements in the analysed building revealed an increased airborne sound transport between rooms due to wall cracks, future research should focus on methodologies to measure and assess internal leakages in this kind of buildings. Finally, other similar buildings should be examined aiming to gradually build a portfolio of airtightness measurements for representative large timber buildings in the Nordic climate.

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REFERENCES

1. N. S. Bunkholt *et al.*, J. Phys. Conf. Ser. **2069**, 012040 (2021).
2. S. Verbeke and A. Audenaert, E3S Web Conf. **172**, 05005 (2020).
3. B. Moujalled *et al.*, Energy Build. **250**, 111257 (2021).
4. M. Hansen and P. Ylmén, "Changes in airtightness for six single family houses after 10-20 years," in *Proceedings of TightVent- AIVC International workshop: "Achieving relevant and durable airtightness levels: status, options and progress needed* (AIVC, Brussels, Belgium, 2012), pp. 67–75.
5. V. Kukk *et al.*, J. Build. Eng. **44**, 102610 (2021).
6. J.-L. Herms, E3S Web Conf. **172**, 10011 (2020).
7. H. B. Skogstad *et al.*, "Air leakages through cross laminated timber (CLT) constructions," in *Proceedings of 9th Nordic Symposium Building Physics NSB 2011*, edited by J. Piironen *et al.* (Tampere University of Technology, Tampere, 2011), pp. 89–96.
8. ZEB Laboratory. *A ZEB Office Living Laboratory*. Available at: https://zeblab.no/ (Accessed: 10.01.2022).
9. ISO 9972:2015, Thermal *Performance of Buildings - Determination of Air Permeability of Buildings - Fan Pressurization Method* (ISO, Geneva, Switzerland, 2015).
10. EN 13187,1998, *Thermal Performance of Buildings - Qualitative Detection of Thermal Irregularities in Building Envelopes - Infrared Method* (CEN, Brussels, Belgium, 1998).
11. L. Gullbrekken and N. Bunkholt Schjøth, Building with CLT Elements (SINTEF Community, Trondheim, Norway). (in Norwegian)

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