Hygrothermal conditions in Cross Laminated Timber (CLT) dwellings

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Abstract. The use of CLT has been increasing the last decade, and a subsequently focus on documentation of the accompanying indoor climate and exposed wooden surfaces on human well-being. This study presents the results of a measurement campaign conducted over one year of a CLT apartment building in Grimstad, Norway. The apartment building consists of three floors with 35 apartments and comply with the Norwegian passive house standard and energy grade A. Measurements of the relative humidity (RH), indoor air temperature and wood moisture content (MC) were performed in the exposed CLT spruce panels in three apartments in two different floors. The results from the three apartments show a relatively small variation in the MC values regardless the residents behavior measured as RH variation through a complete year. Selected periods from a cold period (winter) and a warm period (summer) show the variation in relative humidity (RH) and moisture content in the CLT element. However, results from control measurements showed higher MC values. The gap between the measurements and methods are discussed.

1 Introduction

A need for more sustainable materials in the building industry to meet the goals to reduce carbon emissions has led to a bigger market for the use of wood in especially building structures. Cross laminated timber elements (CLT) is a building system which can replace much of the bearing steel and concrete structures in the buildings. The use of CLT has therefore been increasing the last decade. In addition to reduce the carbon footprint of a building, focus on the indoor climate quality and comfort has been increasing. Wood as a hygroscopic material has the capacity to adsorb or desorb moisture and moderate the relative humidity (RH) in a building[1, 2]. When moisture migrates in hygroscopic structures energy is released through latent heat phenomena, and hold a potential for contributing in the buildings energy balance [1]. The moisture buffering capacity and latent heat of sorption of exposed CLT spruce have been investigated by [3] . However [4] argue that the potential of saving energy in buildings by the use of latent heat from sorption of exposed interior wood surfaces, is not significant enough to conclude it in the energy budget. While there have been several studies on CLT elements in lab and test facilities, few of them included verification with real time measurements from buildings with occupants[3, 5]. The purpose of this paper is to 1) contribute to more knowledge of hygrothermal conditions in CLT buildings and 2) discuss measurement methods and field measurements of the hygrothermal conditions in a CLT wall element.

2 Materials and method

2.1 The case project

The measurements were conducted in three apartments in a CLT apartment building in Grimstad, Norway. The apartments have occupants from the age of 25 to 70, with different behavior patterns measured as RH variation. The three apartments are a part of Skonnertveien hageby that were completed in 2017 and consist of 35 low- energy apartments. The main building structure is cross laminated timber elements (CLT) with exposed CLT in interior surfaces. All surfaces are treated with water- based stain. The building comply with the Norwegian passive house standard NS3700[6] and energy grade A. Figure 1 shows an illustration of Skonnertveien hageby.

Fig. 1. Illustration of Skonnertveien hageby[7]. The highlighted area shows where the three CLT apartments are situated.

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The building structure consists of CLT wall, floor and roof elements. A typical CLT wall element from Skonnertveien is shown in Figure 2. Passive energy design such as balcony, outdoor gallery and façade projection for sun protection is used to prevent high temperatures in the apartments.

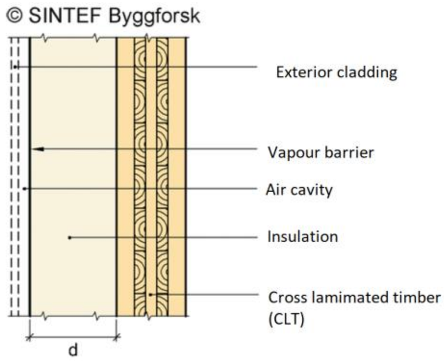

Fig. 2. Illustration of CLT wall element with insulation from Byggforskserien 471.421[8] All interior surfaces inn Skonnertveien hageby are treated with water- based stain.

Each apartment is accessed via a joint gallery on the northeast and southeast side. The combined kitchen and living rooms (LR+KI) are situated towards either west or south whereas the bedrooms are primarily oriented towards either north or east.

The heating system in the apartments consists of hydronic underfloor heating in LR+KI, bedroom, bathroom and hallway. Each apartment has a balanced ventilation unit placed in the storage room, which means that occupant can set the temperature and ventilation speed manually.

2.2 Long- term measurements (wireless)

Long- term measurements of the selected indoor climate parameters such as temperature and relative humidity were conducted in three apartments. In addition, wood moisture content (MC), dry basis, were measured to evaluate the actual moisture content of the first millimeters from the interior side of the CLT wall element. An overview of the monitored apartments and measured parameters is presented in Table 1.

The indoor climate parameters in kitchen/ living rooms in AP. 1, AP. 2 and BR2 in AP.3, the room air temperature (T), the relative humidity (RH) and the wood moisture content (MC) were measured using wireless sensors (Protimeter HygroTrac S-16)[9]. The sensors were calibrated for Douglas fir, and the MC has not been adjusted for European Spruce which have been used in the CLT element in Skonnertveien hageby. Estimated difference between Douglas Fir and European Spruce is approximately 0.2%MC in the actual measurement range. The sensors were mounted on the walls in three different heights (0,10 m from the floor, 1-2 m from the floor and 0,10 m from the ceiling). The sensors were attached with two stainless steel screws into the CLT exposed wall panels (indoor), acting as electrodes to measure the MC. The screws penetrate the wooden surface to a dept of 10 mm and measure the electric resistance. The RH and T sensors is inside the plastic casing at a distance of 30 mm from the wooden surface, see Fig. 3. The values were recorded with 5 minute intervals.

Table 1. Overview of monitored one floor apartments and measured parameters.

Apartment	Features	Monitored rooms	Measured parameters	Measuring period
Ap. 1	• Floor area: 91 m² • Orientation main façade: South • Number of bedrooms: 2	• LR+KI: Combined living room and kitchen • BR1: Bedroom for 2 adults facing north • BR2: Guest bedroom/ TV room	T, RH, CO_2 and MC in Livingroom/ kitchen T, RH and CO_2 in bedrooms	September 2018- October 2019
Ap. 2	• Floor area: 106 m² • Orientation main façade: East • Number of bedrooms: 2	• LR+KI: Combined living room and kitchen • BR1: Bedroom for 2 adults facing northeast • BR2: Guest bedroom	T, RH, CO_2 and MC in Livingroom/ kitchen T, RH and CO_2 in bedrooms	September 2018- October 2019
Ap. 3	• Floor area: 75 m² • Orientation main façade: East • Number of bedrooms: 2	• LR+KI: Combined living room and kitchen • BR1: Bedroom for 2 adults facing north • BR2: Guest bedroom	T, RH and MC in Livingroom/ kitchen T and RH in BR1 T, RH and CO_2 in BR2	September 2018- October 2019

Fig. 3. Position of measurement point in AP.1

In addition log- term measurements of the indoor climate parameters such as the room air temperature (T), the relative humidity (RH) and the CO_2 concentration were measured in kitchens, living rooms and bedrooms in AP.1,2 and 3 using wireless Wisensys DLC. The sensors have a measurement interval of twenty seconds. The sensors were mounted on the walls in a height between 1-2 m and located at a placement to ensure free air movement. This sensor uses the outside conditions (approximately 400 ppm) for a self- calibration technique. An overview of the used measurement equipment and their accuracy is given in Table 2.

Table 2. Overview of measurement equipment and accuracy [9].

Measurement System	Parameter	Equipment	Accuracy
Websensys	CO_2, T, RH	Wisensys WS-DLC	CO_2: ±40 ppm + 3% of reading @ 22 ºC Humidity: ±1.8%RH from 10% to 90%RH; ±4%RH otherwise Temperature: ±0.3 ºC @ 25 ºC; ±0.5 ºC from 0 ºC to +50 ◦C; ±1.2 ◦C from −20 ◦C to +80 ◦C
Websenys	T, RH	Wisensys WS-DLTc	Humidity: ±1.8%RH from 10% to 90%RH; ±4%RH otherwise Temperature: ±0.3 ºC @ 25 ◦C; ±0.5 ºC from 0 ºC to +50 ◦C; ±1.2 ◦C from −20 ◦C to +80 ◦C
Omnisense	T, RH, MC	HygroTrac s- 16	Humidity: ±2%RH from 10 to 90%RH Temperature: ±0.5 ºC @ 25 ºC Moisture content: ±1% MC in wood, 10 to 25% subject to adjustments for species and temperature Calibration Temperature: 68°F (20°C)

2.3 Control measurements

Control measurements were performed of the temperature of the exposed CLT surface and wood moisture content in apartment 1. The measurement were performed using Testo 6160 non-destructive moisture meter and Testo Surface thermocouple, see Fig. 4. An overview of the used measurement equipment and their features and accuracy is given in Table 3. The electromagnetic field penetrates the material via the contact plates and creates a measuring field with a depth of approx. 50 mm. Both the surface temperature and the moisture content were measured every 50 cm, from 50-250 cm, on the left and right side of the vertical line with the wireless sensors. This were performed four times (test1- test4). In addition, horizontally measurements of an interior CLT wall element were conducted to see if there were any variations between an exterior and an interior wall element with an expected more even MC (test5-test8), see Fig. 4.

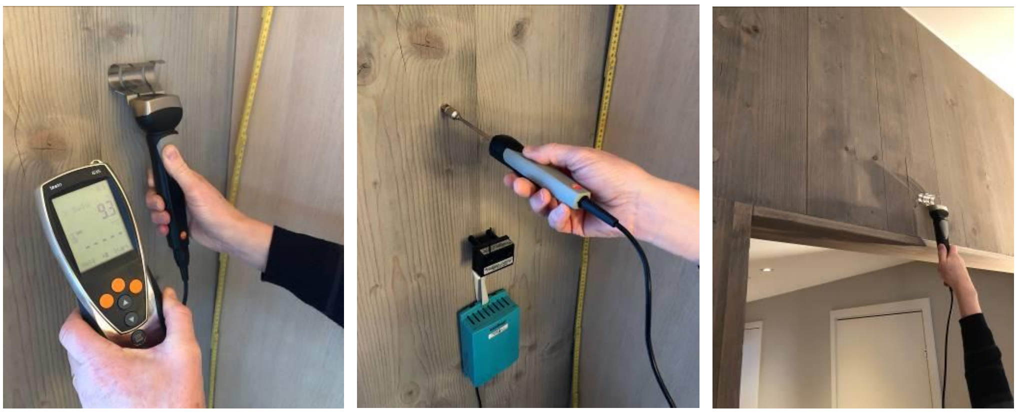

Fig. 4. Left: The non- destructive moisture meter on the inner surface of the exterior CLT wall element. Middle: The surface thermocouple on the inner surface of the exterior CLT wall element. Right: The non- destructive moisture meter on the surface of the interior CLT wall element.

Table 3. Overview of measurement equipment and features and accuracy.

Equipment	Parameter	Features and accuracy
Testo 6160 electromagnetic field	MC	Moisture content: Softwood lumber ± 3% MC, Operating temperature: +5 to + 40 °C (+41 to + 104 °F) / 10 to 80 % RH Calibration Temperature: 68°F (20°C) and 65 %RH
Testo Surface thermocouple	T	Measurement range: - 60 to + 300 °C Accuracy : Class 2 According to standard EN 60584-2, the accuracy of Class 2 refers to -40 to +1200 °C.

3 Results

3.1 Measured long- term indoor climate conditions (wireless)

The reported results include measurements of the room air temperature, the relative humidity, and the wood moisture content during a cold period in winter with low RH (January 21st to February 3rd) and a warm period in summer with high RH (July 22nd to August 4th) in apartment 1. The CO_2 levels are measured but not included in this paper. Figure 5 shows the indoor relative humidity, the indoor air temperature and moisture content of the CLT wall element facing northwest in a cold period in winter. Outdoor climate is reported as observation approximately 4 km away from the apartment building (Landvik weather station). In the cold period in winter, outdoor temperature has a range from -17 to 3 °C. In the warm period in summer outdoor temperature have a range from 12 to 28 °C. The outdoor relative humidity had a rather stabile range of 65 to 95 %RH in the cold period in winter.

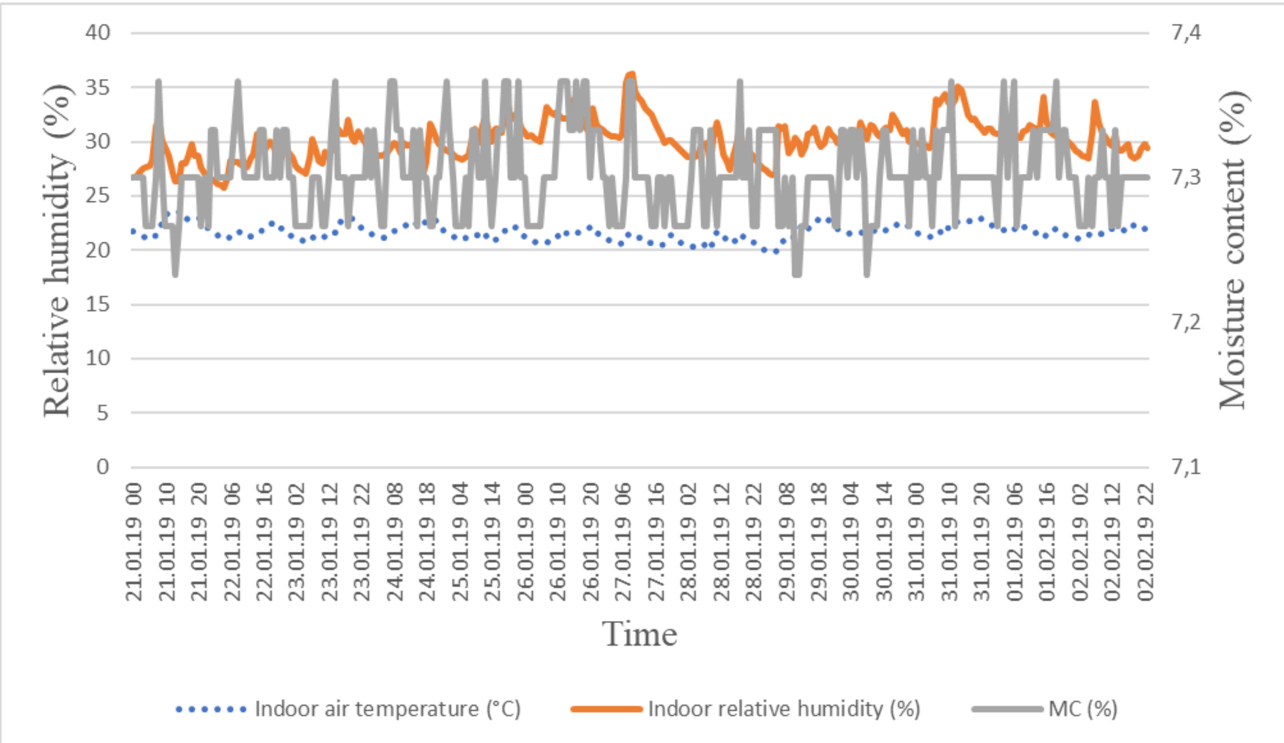

Fig. 5. Hourly mean indoor relative humidity, indoor air temperature and wood moisture content in Ap.1 from January 21st to February 3rd.

Figure 6 shows the indoor and ambient relative humidity, the indoor air temperature and moisture content of the same CLT wall element facing northwest in a warm period in summer.

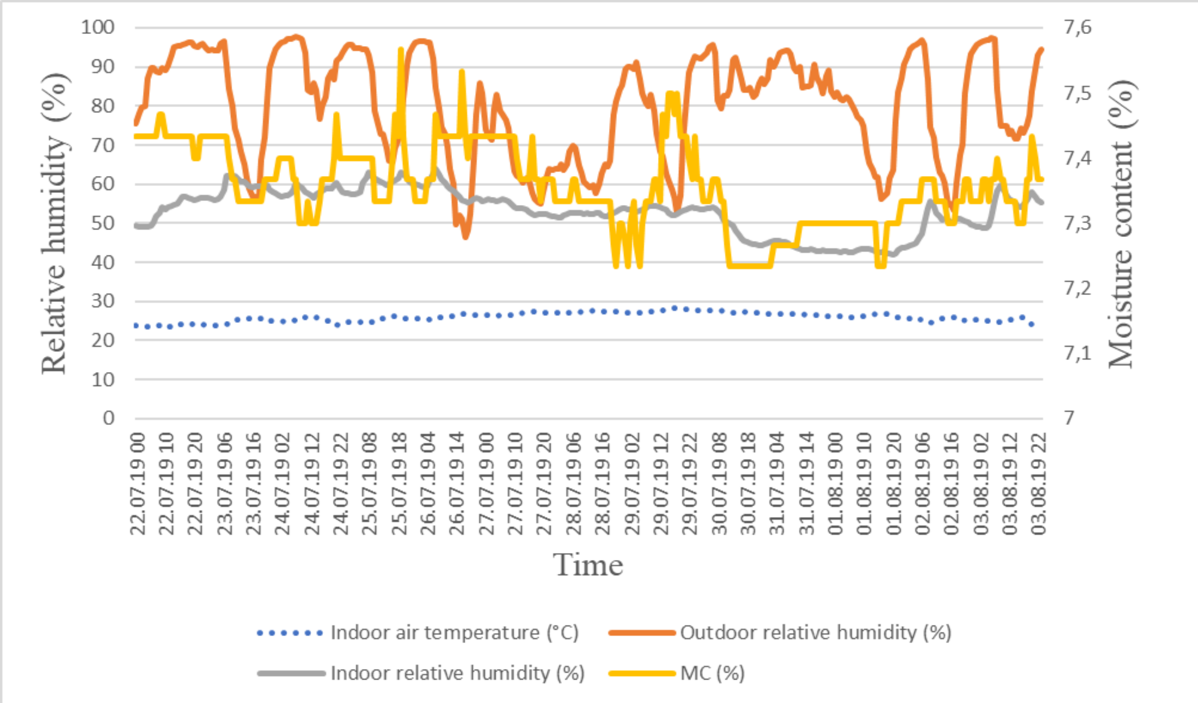

Fig. 6. Hourly mean outdoor and indoor relative humidity, indoor air temperature and moisture content in Ap.1 from July 22nd to August 4th Same CLT element and sensors as in Figure 5.

The measured MC values presented in Figure 5 and 6 are relatively low. Especially in the warm period in summer the MC values are significantly low compared to a normal spruce sorption curve shown in [10]. Further investigation was therefore conducted with control measurements of the MC% and surface temperature in the CLT wall element as described in 2.3.

3.2 Control measurements

The results include measurements of the surface temperature and the moisture content in the exposed CLT wall element in apartment 1. The measurements were conducted on January 8th, 2020. The indoor air temperature was measured twice during the experiment and showed 21,5 °C the first two tests and 22,8 °C the second two tests. The RH value in apartment 1 were around 30 % during the experiment. Figure 7 shows the moisture contents of the four repeated tests at the right and left side of the wireless sensors and the sensors value at the time where the measurements were conducted. Figure 8 shows the surface temperatures of the four tests.

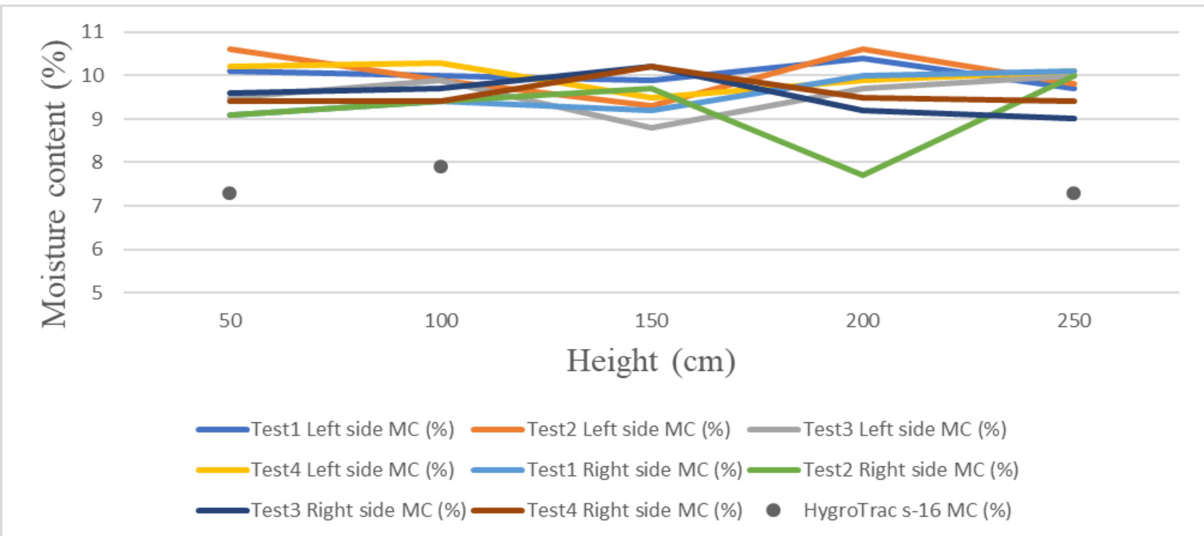

Fig. 7. Moisture content of test1-test4 at the right and left side of the wireless sensor (HygroTrac s-16) in Ap.1 January 8th, 2020.

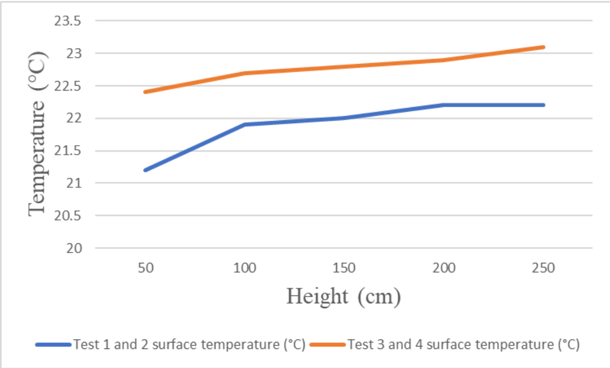

Fig. 8. Surface temperatures of test1-test4 at the right side of the wireless sensor (HygroTrac s-16) in Ap.1 January 8th, 2020

Figure 9 shows the moisture content of the interior CLT wall element that were measured above the entrance to the KL+LI, see Fig. 4.

Fig. 9. Moisture content of the interior CLT wall element in Ap.1 January 8th, 2020.

4 Discussion

The measured results presented in Figure 5 and 6 are results from the sensors mounted on the inner surface of the exterior CLT wall element in the combined kitchen and living room in Ap.1. The measuring periods were chosen to represent a cold period in winter with a range in the outdoor temperatures from – 17 to 3 °C with a relative low RH around 25- 35 %, and a warm period in summer with outdoor temperatures from 12 to 28 °C with a relative high RH of around 60-70 %. However, the summer period also shows relatively low levels of indoor RH of 40 %. The results in Figure 5 and 6 show a small variation in the moisture content, regardless the season and the residents' behavior, measured as RH. The sensors were mounted on two different wooden planks in the CLT wall element, see Fig. 3 and 4. The HygroTrac s-16 sensor use electrodes to measure the resistance between the two stainless steel screws. Since the resistance over two different wooden plank is different than if the sensor was mounted on one wooden plank only, this may be some of the explanation to why the measured MC values in Figure 5 and 6 are low compared to the control measurements presented in Figure 7 and 9 and Hygrotrac emc curve for generic wood [11].When the control measurements were conducted the RH in apartment 1 were around 30 % and the MC values showed results around 10%, compared to the field measurements in Figure 5 and 6 that showed MC values around 7 % when the RH were 30%. Thhe spruce sorption curve [10] shows that with a RH level of 60% the MC value should be around 11%, compared to the results in Figure 5 and 6 that shows MC values just above 7% when the RH is 60%. The HygtroTrac s- 16 sensor should be mounted on one wooden plank to avoid misleading values caused by glue and larger cracks in the CLT element that will affect the resistance. The measured surface temperatures in Figure 8 and moisture content in Figure 7 and 9 are results from the control measurements on the inner surface of the exterior CLT wall element in the combined kitchen and living room in Ap.1. The results presented in the control measurements show a significant higher moisture content of 8.0- 10.5 MC% compared to the long-term measurements presented in Figure 5 and 6 of 7.2- 7.6 MC% for summer and winter. The HygroTrac s-16 sensor have an accuracy of ±1% MC in wood, and it is difficult to argue an exact MC value because of this uncertainty factor. The measurement equipment that were used in the control measurement (Testo 6160) have an accuracy of ± 3% in wood, and have a higher uncertainty factor than the long-term measurements. The high uncertainty factor in the measurement equipment makes it difficult to argue why the MC values represented in the control measurements are higher than the MC values presented in the long- term measurements. However, we can argue that the position of the HygroTrac s-16 sensors affect the resistance, and therefore the MC are most likely uncertain.

The premilitary results from Ap.2 and Ap.3 shows MC values from 8-9 %MC. The HygroTrac s-16 sensors in Ap.2 and Ap.3 are mounted on one wooden plank in the CLT wall element and will therefore measure the right resistance between the stainless steel screws. The presented results in this paper have a high uncertainty level and therefore further measurements in lab are to be carried out. The lab measurements will contribute to further knowledge of the hygrothermal conditions in the CLT element.

The measured RF results presented in Figure 5 and 6 shows that the relative humidity have a moderate development, similar to other studies [1, 3].

5 Conclusion

The presented measurements of Ap.1 in Skonnertveien hageby show that the variation in the moisture content (MC) is too small given the variation in the relative humidity (RH) over a year. The results show that the RH is relatively stable and in the measured period.

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References

1. D. Kraniotis, K.Nore, *Latent Heat Phenomena in Buildings and Potential Integration into Energy Balance.* Procedia Environmental Sciences, 2017. **38**: p. 364- 371.
2. C. Rode, K. Grau, *Moisture buffering and its consequence in whole building hygrothermal modeling.* Journal of Building Physics, 2008. **31**: p. 333-360.
3. I. Katavic, K. Nore, T. Aurlien, *Measured moisture buffering and latent heat capacities in CLT test houses* in *The 35th AIVC, "Ventilation and airtightness in transforming the building stock to high performance"*. 2014: Poznan.
4. S. K. Asphaug, B. Time., J. V. Thue, S. Geving, A. Gustavsen, H. M. Mathisen, S. Uvsløkk, *ZEB Project reports Kunnskapsstatus – Fuktbufring i materialer og påvirkning på energibehov*. 2015, ZEB: Trondheim.
5. R. McClung, H.Ge, J. Straube, J. Wang, *Hygrothermal performance of cross-laminated timber wall assemblies with built-in moisture: field measurements and simulations.* Building and Environment, 2014. **71**: p. 95-110.
6. Standard Norge, *Kriterier for passivhus og lavenergibygninger - Boligbygninger*. 2013, Standard Norge.
7. BGM Arkitekter, *Skonnertveien Hageby boligbrosjyre*. 2017.
8. P. G Schild, *Byggdetaljer 471.421 U-verdier, Vegger over terreng – massivtre*, B. Roald, Editor. 2013, SINTEF Byggforsk.
9. Protimeter Industrial, *Protimeter HygroTrac-wireless Environmental monitoring*. Downloaded 04.12.2019.
10. S. Geving, J. V. Thue., *Fukt i bygninger*, ed. SINTEF Byggforsk. 2002.
11. Protimeter, *Generic material emc curves*, P.G.m.e. curves, Editor. 2001, Protimeter plc.