Air leakages through cross laminated timber (CLT) constructions

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Summary
The harsh Norwegian climate requires that buildings need to be designed to high standards. Global warming is making the built environment even more vulnerable. Climate change will mean more extreme weather conditions and buildings will have to withstand greater stresses concerned to water penetration and air leakages. Air leakages from the indoor climate through out the construction are undesirable to avoid moisture problems. An airtight building envelope is critical in order to achieve an energy efficient building.

For some years cross laminated timber (CLT) constructions have been used. Some of these buildings are designed without separate wind barrier and water vapour barrier. The resistance to penetration of air through CLT constructions is tested in accordance with EN 12114. The test sections consist of CLT elements and include variations of joints between wall elements and between wall and floor elements, equal to the CLT construction systems used in Norway. Two different types of CLT are tested, with or without gluing the board edges. The air leakages are measured at three different moisture contents in the timber; delivery moisture content of approximately 0.14 kg/kg and after drying at < 0.10 kg/kg. The test results highlight best performance detailing of CLT joints. The results are also used to evaluate the need of separate wind barrier and water vapour barrier in CLT constructions.

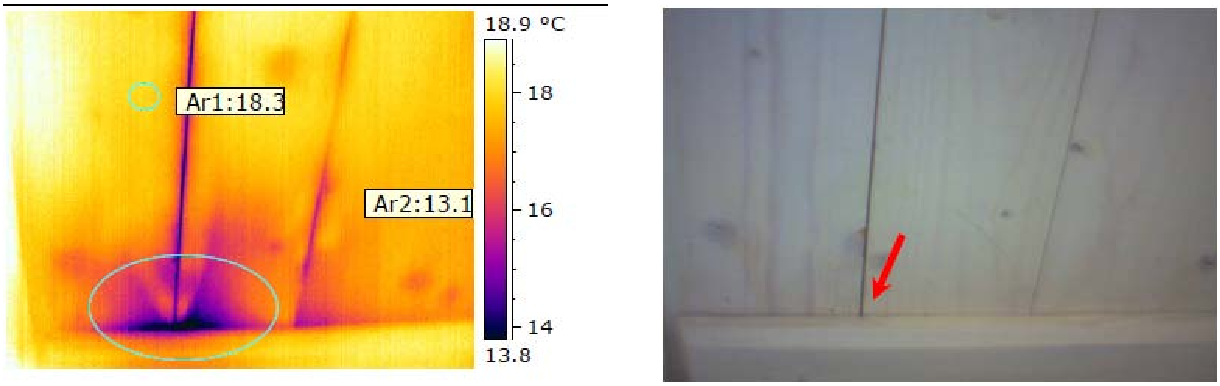
1. Introduction

Buildings in the Nordic climate have to be designed to high standards to withstand greater stresses concerned to water penetration and air leakages. The national building regulations include more stringent requirements to air leakages through the building envelope to reduce the energy consumptions due to heating. Air leakages from the inside through the construction are undesirable to avoid moisture problems. Joints between flats and between sections within a building have to be designed air tight to avoid fire proliferation, reduce sound transfer and avoid transfer of gases.

Cross laminated timber (CLT) is a development from the long known glue laminated wood. CLT is construction elements which upholds wood stability and reduce the shrink and swell challenges, by crossing the boards in each layer of the panel, see FIG 3c. In Norway CLT constructions are increasingly used for the last decade. CLT constructions however have a very low market share which may be due to lack of knowledge and design details. CLT constructions are more widespread in the central Europe.

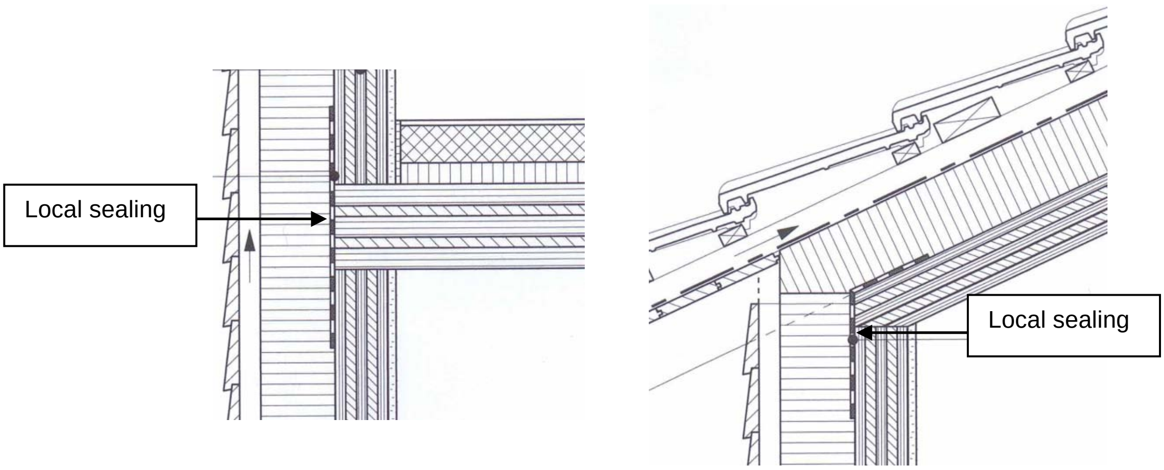
CLT used in wall, floor and roof constructions have a load bearing function, and an aesthetical function if choosen to keep the CLT visible. Due to cost efficiency most CLT projects in Norway have visible CLT surfaces.

Some of the buildings in Norway with CLT in the external climate screen have been constructed without a vapour barrier. Only a few projects with measurements of the buildings air tightness have been published. One of the most recent projects measured is Geilo Kulturkyrkje, a mountain church at Geilo, which was sanctified November 29th 2010. The climate screen is performed in glass, CLT and concrete, and the CLT construction is similar to the CLT elements described in this paper. Omega Termografering AS has performed measurements of the church's air tightness. The thermograph and the photo in FIG 1 are collected from the test report and show air leakages in the joint between the wall elements.



a *b*

FIG 1. Thermograph (a) and photo (b) from a joint between the wall elements in Geilo Kulturkyrkje. (Photo Omega Termografering AS)



a *b*

FIG 2. Section of cross laminated timber element to show the structure (Kolb 2008)

Kolb (2008) presents design solutions with locally sealed joints with plastic sheeting, see FIG 2.

In order to reduce sound transmission between neighbour rooms CLT elements may be decoupled in the joints. In multi-storey buildings CLT wall elements can be installed on elastic sylomer or similar material, or on 100 x 100 mm^2 plywood blocks as shown in FIG 4c and FIG 4d. Sylomer mat and plywood blocks used in the joint between the floor section and the wall section, are both included in the air leakage measurements described in this paper.

The purpose of the laboratory measurements described in this paper is to investigate the air tightness of a CLT construction without a separate water vapour barrier and wind barrier. The results are used to evaluate the need of a separate water vapour and wind barrier in CLT constructions.

2. Test method

The resistance to penetration of air through the CLT wall-floor-wall construction is measured according to NS-EN 12114 *Thermal performance of buildings. Air permeability of building components and building elements. Laboratory test methods.* The air leakages are measured at 50 Pa pressure difference over the test section. The measurements are performed in the air permeability chamber located at SINTEF Building and Infrastructure in Trondheim.

3. Test sections

The CLT construction is shown in FIG 3 and consists of spruce boards with dimension approximately 30 mm x 110 mm. The wall elements consist of three layers of boards and have a total thickness of 98 mm. The floor elements consist of five layers of boards and have a total thickness of 160 mm. Each layer of boards is mounted perpendicular on each other and glued together.

The test sections are shown in FIG 3 and FIG 4 and are assembled of wall and floor elements. Each wall and floor section consists of three elements with two joints, two elements have a width of 1200 mm and the third element has a width of 264 mm. The floor section is laid onto the wall section, and the upper wall section rest against the floor section.

a *b* *c*

FIG 3 The two test sections. Section without glued board edges (a), section with glued board edges (b) and detail from the CLT construction (c)

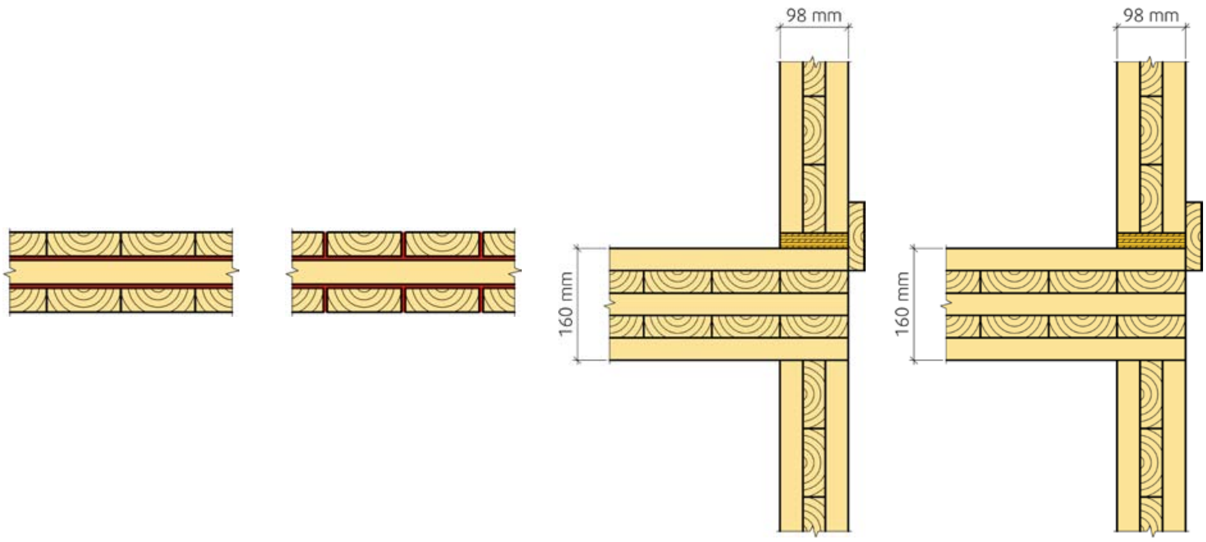
There are two different test sections. Both the wall and the floor sections are glued between the layers of boards. The wall sections shown in FIG 3a and FIG 4a are not glued between the board edges, while the wall sections shown in FIG 3b and FIG 4b are glued also between the board edges.

The test section without glued board edges is performed with a 21 mm x 94 mm board of spruce covering the joint between the wall elements and a 27 mm x 150 mm board of plywood covering joint between the floor elements. The upper wall section which rest on the floor section is laid on 100 mm x100 mm plywood blocks, two blocks for every element.

The test section with glued board edges is performed with a 21 mm x 94 mm board of spruce covering the joint between the wall elements and a 21 mm x 94 mm board of spruce covering the joint between the floor elements. The upper wall section which rest on a continuous sylomer mat with a thickness of 11 mm.

The test sections were fixed by mounting a 48 x 98 mm around the edge. The joint between the test section and the 48x98mm frame was sealed with sealing compound of acrylic paste.

A picture from mounting of the test sections is shown in FIG 5.



a b c d

FIG 4 Details from the test sections. CLT without glue between the board edges (a), CLT with glue between the board edges (b), sylomer mat between the floor section and the wall section covered with a spruce board 21 mm x 98 mm (c), plywood blocks between the floor section and the wall section covered with a spruce board 21 mm x 98 mm (d).

a b

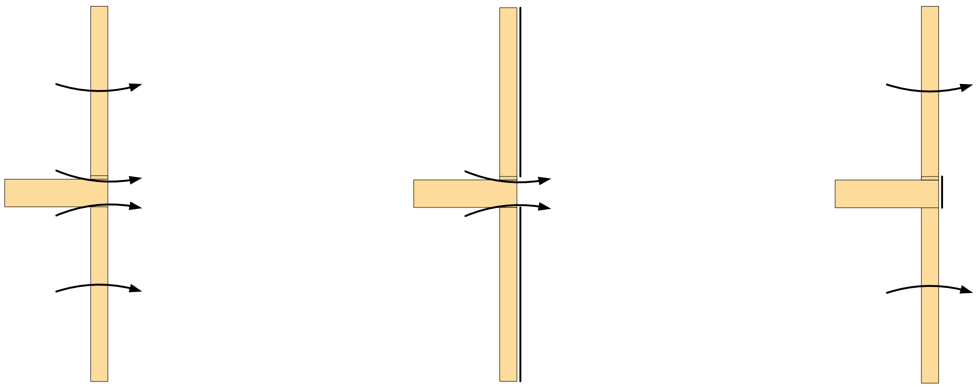
FIG 5. Mounting of the cross laminated timber test section. The joint between the wall elements are covered with a spruce board fastened with screws (a). Typical gap between the wall and floor element caused by rough and uneven surfaces (b).

4. Test performance

The test is performed to determine the air leakages through the wall section and the floor section separately. The air leakages are measured through the whole test section (FIG 6a), through the floor section (FIG 6b) and trough the wall sections (FIG 6c). To obtain the measurements of the different test sections as shown in FIG 6, the different test sections are sealed with polyethylene foil and gypsum boards. The sealing of the wall section is performed such that the air leakage through the joints between the floor section and the wall section is included in the floor leakage. The test chamber reference air leakage is measured with test section sealed with polyethylene foil and gypsum boards.

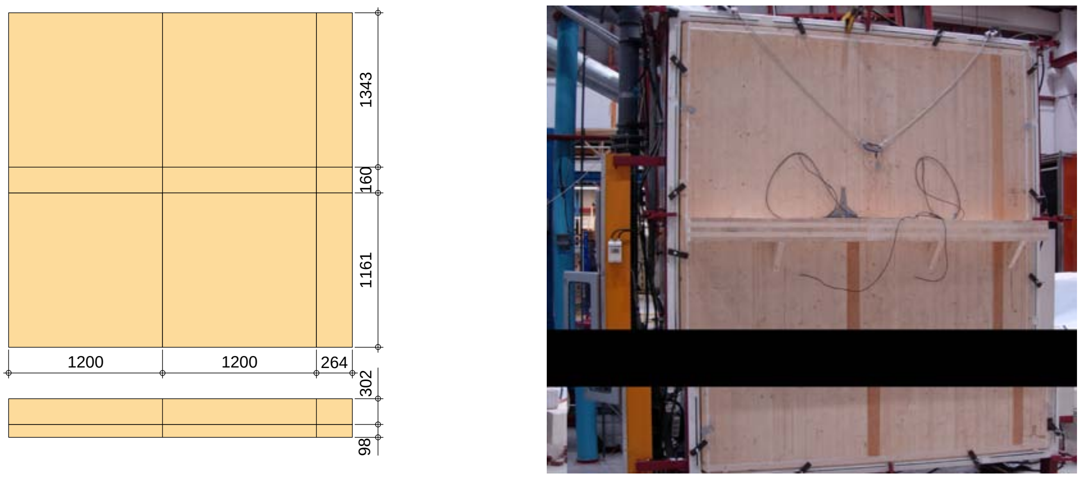
All the measured air leakages are corrected for the reference air leakage in the test chamber. The test section mounted in the test chamber is shown in FIG 7b.

The air leakages are measured at two different moisture contents, first at delivery moisture content of approximately 0.14 kg/kg and after drying at moisture content less than approximately 0.10 kg/kg. The first measurements were performed just after arrival at the laboratory at SINTEF. The second measurements were performed after 2 months drying in the laboratory areas.



a *b* *c*

FIG 6. The test section consists of CLT wall and floor sections. The air leakages are measured through the whole test section (a), through the floor section (b) and trough the wall sections (c)



a *b*

FIG 7. Dimensions of the test section (a), and the test section mounted in the test chamber with the indoor surface turned out (b)

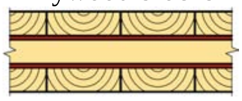
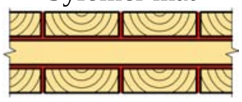
5. Test results

The measured air leakages through the different areas of the two test sections are given in TABLE 1 and FIG 8. The measurements performed on the test sections at delivery moisture content of approximately 0.14 kg/kg show that the air leakage through the wall section without glued edges is approximately equal to the wall sections with glued edges. The air leakage through the floor section with a sylomer mat in the joint against the wall sections is approximately 70 percent less than for the for the floor section with plywood blocks in the joint between the floor section and the wall section.

After drying to a moisture content of approximately 0.10 kg/kg, the air leakage through the wall section is approximately 10 times higher for the wall section without glued edges and approximately two times higher for the wall section with glued edges.

Common for the two test sections are that the air leakages through the floor sections and the joints between the floor section and the wall sections represent the main part of the total air leakages.

TABLE 1. Air leakages measured at 50 Pa pressure difference over the test section

Test section	Moisture content kg/kg	Test section m^3/h	Wall section m^3/h	Floor section m^3/h	Wall section m^3/hm^2	Floor section m^3/hm
Board edges not glued Plywood blocks	~ 0.14	75	8	67	1.2	25
	< 0.10	146	78	69	12	26
	< 0.10		73 [1])			
Board edges glued Sylomer mat	~ 0.14	44	8	36	1.2	14
	< 0.10	64	16	49	2.4	18
	< 0.10		7 [1])			

[1]) The values are calculated based on comparative measurements done on the wall sections with and without sealant acrylic paste in the joints between the wall elements

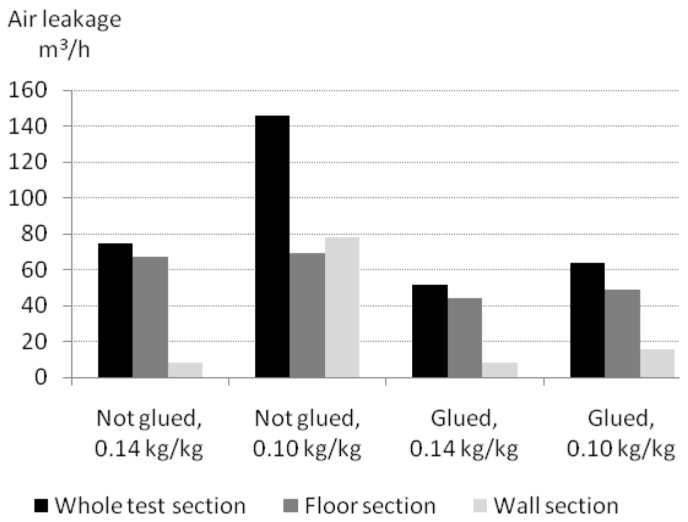


FIG 8. Air leakages through the test sections and the floor and the wall sections separately, measured at 50 Pa pressure difference with delivery moisture content of approximately 0.14 kg/kg and after drying to approximately 0.10 kg/kg

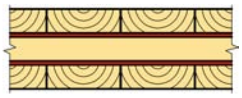
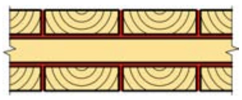
6. Discussion and conclusion

CLT elements are often produced in quite a rough design. The boards in the CLT element and the element itself will shrink and swell depending on the relative humidity in the surroundings. CLT constructions and the joints between the different CLT elements can be produced in different design. The measurements performed in this laboratory test must be considered as an example on how the air leakage through a CLT construction can vary depending on the moisture content. However the results can be used to evaluate the influence on the buildings air change rate and the need of a separate water vapour barrier and air barrier.

FIG 5b shows a typical gap between the floor and the wall elements. Such gaps are caused by unevenness in the elements surface. Similar gaps can be seen in most joints between CLT elements.

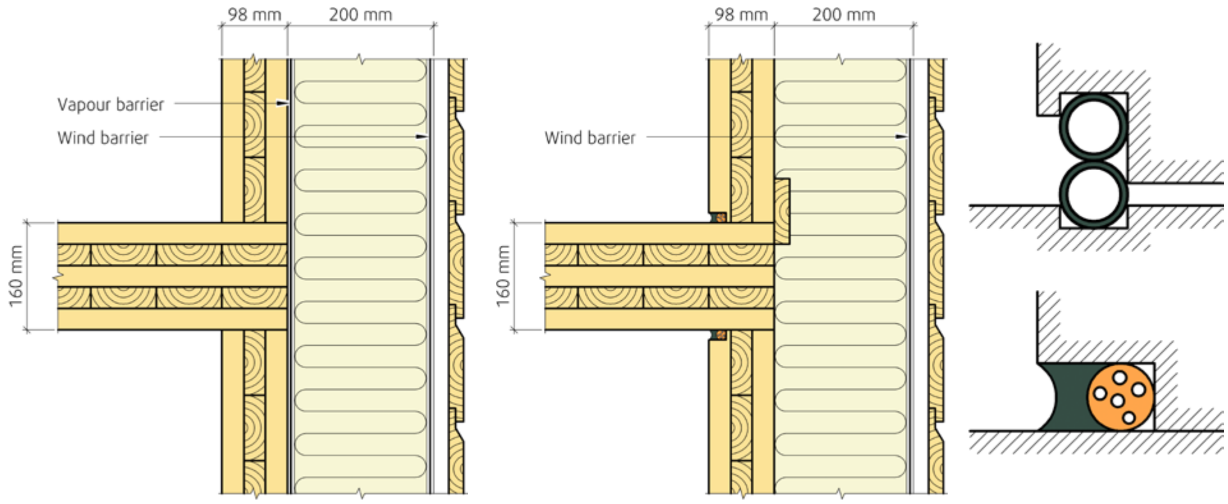
In order to evaluate how the measured air leakages can influence on a buildings air flow rate a typical wooden family house is considered. The building has a base area of 80 m^2. The length of the external walls is set to 10 m and 8 m. The building has two floors and the floor height is set to 2.4 m which gives a total building volume of 384 m^3. The measured air leakage through the floor and wall sections is used to calculate the air leakage in the example building. The air leakage through the wall and floor sections and the influence on the buildings air change rate is shown in TABLE 2.

TABLE 2. The influence on a buildings air change rate at 50 Pa pressure difference calculated on the measured air leakages through wall and floor sections.

Test section	Moisture content kg/kg	Air leakage wall m^3/h	Air leakage floor m^3/h	Influence on the buildings air change rate h^{-1}
Board edges not glued	~ 0.14	210	904	2.9
	< 0.10	2023	934	7.7
Board edges glued	~ 0.14	202	489	1.8
	< 0.10	411	658	2.8

Buildings performed in CLT elements normally needs extra thermal insulation to fulfil the requirements in the building regulations. Buildings are normally designed with an air barrier and the thermal insulation in wooden houses is normally covered by a water vapour barrier on the inside and a wind barrier on the outside. The same recommendations will regard to a building performed in CLT elements. Water vapour transport caused by diffusion through the wood will normally not cause any moisture problems. Water vapour transport caused by convection however may cause moisture problems.

The measurements performed in this study support the recommendation that CLT constructions need to be designed with airtight joints. The joints can be sealed local as shown in FIG 2 and FIG 10 with sealing compound, rubber moulding or with sheets of airtight material. Because of shrinking cracks near the boundary of the CLT elements and movements in the elements caused by shrinking and swelling, local sealing have some uncertainties regarded to how airtight the sealing will stay over time. In the cold Nordic climate a recommended performance with separately water vapour barrier and wind barrier as shown in FIG 10a is a more safe way to ensure minor air leakages through the building envelope and avoid moisture problems than a local sealing as shown in FIG 2, FIG 10b and FIG 10c.



a *b* *c*

FIG 10. Cross section of CLT construction with separate water vapor barrier and wind barrier (a), and local sealing of joints between floor and wall elements with separate wind barrier under a ventilated wooden cladding (b). Examples of local sealing with rubber molding or sealing compound.

7. Acknowledgements

Thanks to John S. S. Nygård and Øystein Holmberget for practical assistance in the laboratory

8. References

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