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Vertical relative displacements in a medium-rise CLT-building

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ABSTRACT: Four buildings with clt-panels in their load bearing structure were built at the block Limnologen in Växjö, Southern Sweden. Their architecture is an example of the new architecture possible with this building system. Properties of these new structures are sought, one of these being their relative vertical displacement over time. These displacements are measured continuously for six storeys, up to now for just over two years. So far, the total measured displacements have reached a maximum of 21.1 mm over the 17.95 meter measuring length. Annular variations of the displacements corresponding to the varying climate may be observed in the data.

1 INTRODUCTION

Several buildings have been built using clt-panels (cross-laminated timber) in Sweden and Europe during the last few years. There are various advantages of using clt in the load-bearing system instead of using the conventional stud and rail technique. One of the major advantages is that the technique enables larger freedom for the architect since the capacity of the panels for vertical as well as for horizontal loads is much higher as compared to conventional timber building technique using studs and rails. This implies that the design of the structure is not to the same extent as before limited due to the chosen material of load bearing system but enables the usage of wood in more complex structures that were not likely to be built with wood before.

Figure 1. Detailed plan of the building block (a) and photo of the construction site in April 2008 (b).

One of the modern projects in which clt-panels have been used in the majority of the vertically and horizontally oriented load bearing elements is the Limnologen block in Växjö, southern Sweden. In this block four similar eight-storey residential houses have been built. The detailed plan of the site and the houses, one of them during construction, can be seen in Figure 1. The total number of apartments in the block is 134, 33 or 34 in each house. The builder of this block is Midroc property development, the architect is Arkitektbolaget AB and the structural engineering work has been done by the system deliverers Martinsons AB and in part by Tyréns AB. The Limnologen block is one of the projects in the area Wälle Broar located between city center and University campus in Växjö. Within this area the municipality has set a goal of building around 100,000 m^2 residential and commercial buildings only using timber in the load-bearing system within 10 to 15 years.

One of the difficulties associated with building high wooden houses is that they will displace vertically over time. This topic has been addressed previously. Persson (1998) studied the relative vertical displacement of a five-storey house at the block Wälludden, also located in Växjö. Wälludden is a block built with a more conventional technique using studs and rails in a timber frame. The displacements were measured once every month during the first year of the lifetime of the structure. After this time period the average of the total relative displacement was calculated to 22 mm over the 11.6 meter measurement distance. When the measurements started the house was fully erected, although there being some more work to be done on the facades and some more internal walls to be built. Grantham and Enjily (2000) estimated by calculations and measured the differential movements in the TF2000 experimental building. They started the measurement of the relative displacements before the house was completed and reported them for about one year. A displacement-time curve is given for the first storey. In the curve the time for important events such as when plaster boarding starts and finishes and when heating of the house starts is indicated. At the end of the year the total displacement for the walls and the flooring in the first storey is 8 mm. The calculated total displacement for the six-storey house was 20 mm due to the compressive and shrinkage movement.

The studies of the displacements in the house at Wälludden as well as the study of the displacements in the TF2000 building are interesting in order to find out how large the vertical relative displacements are during the first year of the life time of a timber stud and rail house. The measurements of the displacements in Limnologen will provide similar results with two important differences. The first of these is that the building is built using clt-panels. Since much more timber material is used in the load bearing structure there are reasons to believe that displacements will be smaller compared to the stud and rail system since much more material is used. The second is the time period over which the measurements are done. The measurements at Limnologen have already been ongoing for two years. Currently there are no plans to stop measuring as long as there still are interesting results to gain.

The aims of the current paper are two. The first is to describe in detail how the displacements are monitored and how installations of the devices have been carried out. The second is to show results from displacement measurements for the first two years of data collection.

2 STRUCTURAL COMPONENTS ALONG THE MEASURING PATH

All the exterior walls in the Limnologen block are similar in there design, the only difference being the exterior cladding used, timber boards or plaster respectively. As shown in Figure 2 the load bearing part in the walls is a three layer clt-panel with the two outer layers oriented vertically and the mid-layer oriented horizontally. The thickness of the clt-panel is 85 mm, the mid-layer being thicker than each of the outer layer. Compared to a conventional stud and rail system the area of the wood loaded parallel to the grain is much greater in the clt-panel. The flooring used in the building is also shown in Figure 2. The load-bearing parts are built up by a clt-panel interacting fully with a glulam beam. This beam functions as a web, and another glulam beam interacts fully with the web, functioning as the bottom flange. Under the load bearing part of the flooring is a self-bearing non-structural ceiling to which the gypsum is fastened. It should be noted that only the three layer clt-panel has its support on the walls. This implies that the flooring material loaded perpendicular to the grains is only 73 mm.

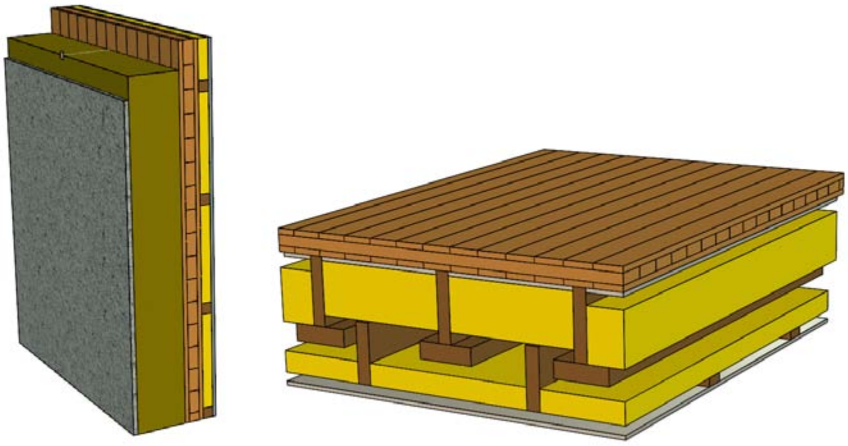

Figure 2. Typical design of the wall and floor elements used in Limnologen.

3 TESTING EQUIPMENT

The measuring devices were installed after the house was erected, but before the isolation was completed and before the plaster was attached. They were installed on the northern façade of the second house from north along the path indicated in Figure 3. Note that the curved shape of the building is due to the fish eye perspective.

The equipment for measuring the displacements consists of 6 steel bars, 20 mm in diameter and with rounded ends, cantilevers for supporting the bars and concentric bearings supplying lateral support for the bars. The cantilevers and the lateral supports were screwed to the clt-panels. At one end of the bar a displacement measurement potentiometer (Regal – WPL 50EFZ) was installed, see Figure 4 and Figure 5. The steel bar is supported at its lower end by the cantilever, and is only supported in the horizontal directions by the aligning devices. Each of the potentiometers is separately connected to a data acquisition device – the logger (Datataker DT85). The temperature and relative humidity (capacitive) is measured at two locations, the bottom of the second storey and at the top of the seventh storey, using a device of brand Vaisala model HMP50.

Figure 3. The northern façade of the house where the measuring devices were installed. The devices were installed along the path indicated in the figure. Note that the curved shape of the building is due to the fish eye perspective.

The data logger contains a built-in battery which supplies back-up power for retaining already acquired data. In case of power failure, additional data acquisition is, however, not possible since the measurement equipment operates with external low voltage power supply.

The accuracy of the deformation measurements is estimated to be approximately +/-0.12 mm. Of these 0.12 mm +/-0.05 mm relate to the accuracy of the potentiometer itself. The remaining uncertainty relates to the thermal expansion of the bars at a temperature change of 10 ˚C. The bars are made of the alloy invar with a low coefficient of expansion, $\alpha = 1.5 \cdot 10^{-6}$/K. The corresponding value for ordinary steel alloys is $\alpha = 12 \cdot 10^{-6}$/K. The accuracy of the relative humidity measurements is estimated to be +/-3 %, and the accuracy of the temperature measurements is estimated at +/-0.6 ˚C. The equipment is contained in a plastic channel, 60 mm deep and 100 mm wide, see Figure 4. Thus the insulation thickness is diminished from 180 to 120 mm along the line of measurement. However, since this only affects a small width, and since the channel is filled with insulation before closing the channel with its plastic cover, see Figure 5, no major influence on the local temperature and moisture distribution is expected at the level were the measurements take place (outer face of the clt-panel).

The data logger samples each 60 minute, obtaining results from displacements for each of the six storeys, and for temperature and relative humidity at the two locations were these are measured. The logging has been going on from 6:th September 2007 and are shown in this current study to 29:th October 2009. Due to a power failure in late autumn 2007 data lacks for around one month.

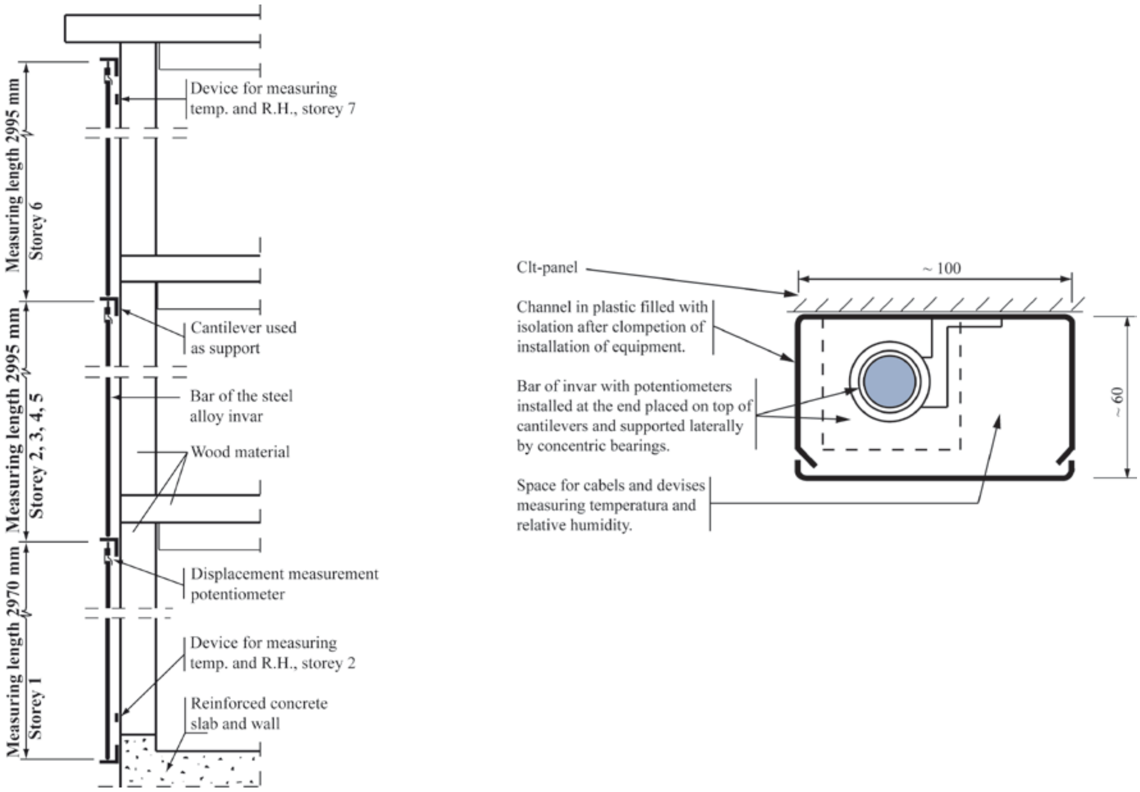

Figure 4. Drawings of how the measuring device was installed on the northern façade at one of the four houses in the block.

Figure 5. Figures showing the installation of the measuring devices on site. The devices for measuring relative humidity as well as temperature are shown as well as the LVDT:s used for measuring the displacement. The data logger can also be seen.

4 RESULTS

In Figure 6 the relative displacement is shown as a function of time for each of the six storeys that was measured for separately. There are two important properties of the curves in the figure that needs to be addressed. The first of these is that for each of the curves two local maximums might be identified. The first occur during June 2008 and the second occur during June 2009. This phenomenon is due to the moisture content in the timber and it will be discussed further in the coming. The second topic is the order of which the curves occur in. As displayed in the figure storey three has the highest displacement followed by storey number four. These are followed by storeys five, six and seven in turn which are similar in the displacement. Finally the second storey has the smallest displacement. The fact that storey 2 has the least displacement can be understood by the design. Since it is built on casted concrete there is on timber flooring loaded perpendicular to the grains included in the measurements of the second storey, see Figure 4. In storey three, and the rest of the storeys, displacements are measured over a wall height but also including the flooring under the wall. Comparing storey 2 and 3 it can be seen that the displacements obtained, at a maximum 5 mm, are substantially higher if the flooring is included. The displacements are approximately the double in the third storey compared to the second though the vertical load is less. For storeys 5, 6 and 7 the displacements are similar to each other. Load levels here are low, and the displacements can be understood mainly by variation in moisture content in the wood material.

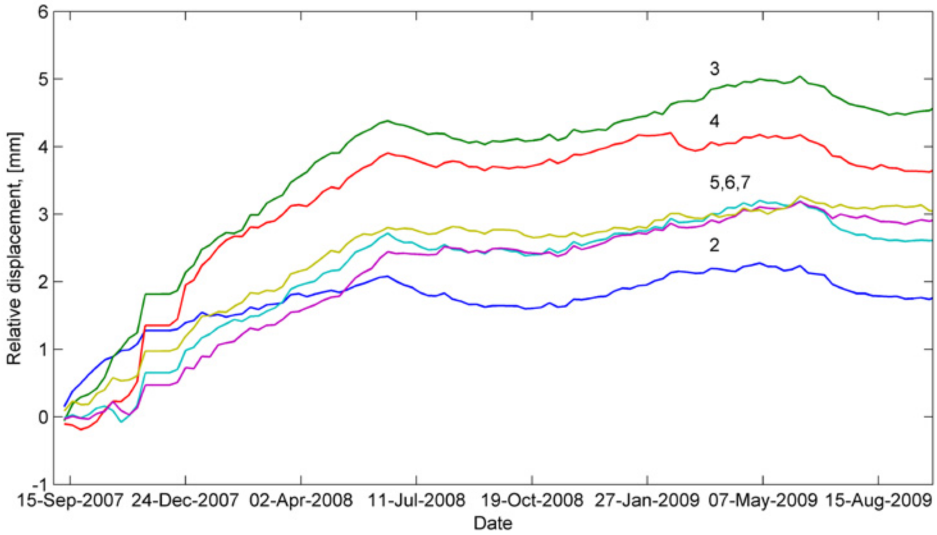

Figure 6. Relative displacement as a function of time for each storey separately. The number of the storey respectively is indicated in the figure.

If the displacements in each storey are added together the total displacements are obtained. These are shown together with the displacements for each storey individually in Figure 7. The curve shows that during the first nine months there is a continuous increase in the displacements. After that time period the displacements are 18.3 mm. Thereafter only small variations, cyclic in there nature, occurs. The two local maxima may easily be identified in this curve showing the total displacements as well as in Figure 6 showing more clearly displacements for each storey. The maximum value is obtained on 8:th of June 2009 about one year after the first local maxima and is 21.1 mm.

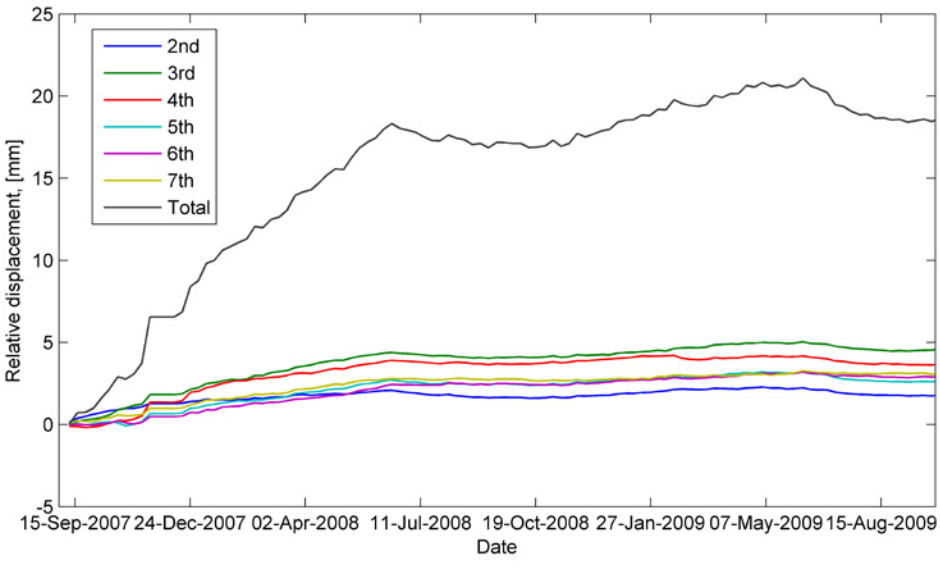

Figure 7. Relative displacement as a function of time for each of the six storeys measured at and for the summation of these, governing the total relative displacements.

The measured temperature and relative humidity over the specified time period is shown in Figure 8. As it is interesting to compare these data to the total displacement, the latter is also shown, but in order to be able to see it in detail in the current scale displacements are magnified four times. The seasonal changes in relative humidity and temperature are obvious. Temperatures at the measuring points are around 20 ˚C in summertime and around 10 ˚C in wintertime. The corresponding values for the relative humidity are around 35 % in summertime and around

50 % in wintertime. It should be noted though that the relative humidity is higher at the beginning of the measurements. Values here reach up to about 80 % as an average of the two measured points. This indicates that the corresponding moisture content in the wood material is higher in the start of the measurements as compared to later in the measured period. It can be explained by the fact that they have been exposed to outdoor climate before being installed.

Simpson (1973) used the Hailwood-Horrobin model to calculate the equivalent moisture content [%] (EMC) for Sitka Spruce based on temperature and relative humidity. In the current study the timber used is Norway Spruce (Picea abies), but if the differences that might occur due to the different species are ignored the moisture content corresponding to the temperature and the relative humidity at the current time may be calculated according to this model. The equation used is

$$EMC = \left(\frac{KK_1h + 2K^2K_1K_2h^2}{1 + K^2K_1K_2h^2 + K_1Kh} + \frac{Kh}{1 - Kh} \right) \cdot \frac{1800}{W} \quad (1)$$

where

$$W = 349 + 1.29T + 0.0135T^2$$
$$K = 0.805 + 0.000736T - 0.00000273T^2$$
$$K_1 = 6.27 - 0.00938T - 0.000303T^2$$
$$K_2 = 1.91 + 0.0407T - 0.000293T^2$$

T is the temperature in ˚C and h is the relative humidity. It should be observed that the EMC does not correspond to the average EMC through the thickness of the clt-panel, but rather to an estimation of the value that might be obtained in the outer parts of the outer layer in the clt.

The calculated equivalent moisture content is shown as a function of time in Figure 9. The maximal EMC, around 16 %, is obtained in the beginning of the time period. Thereafter it decreases to a local minimum in June -08, roughly the same time as the local maximum value of the total displacement is achieved. From this date the annular sinusoidal variation of the EMC can be noted. The lowest values, 6.4 %, are found in May and June, while the highest values, 10.5 %, are found in September and October.

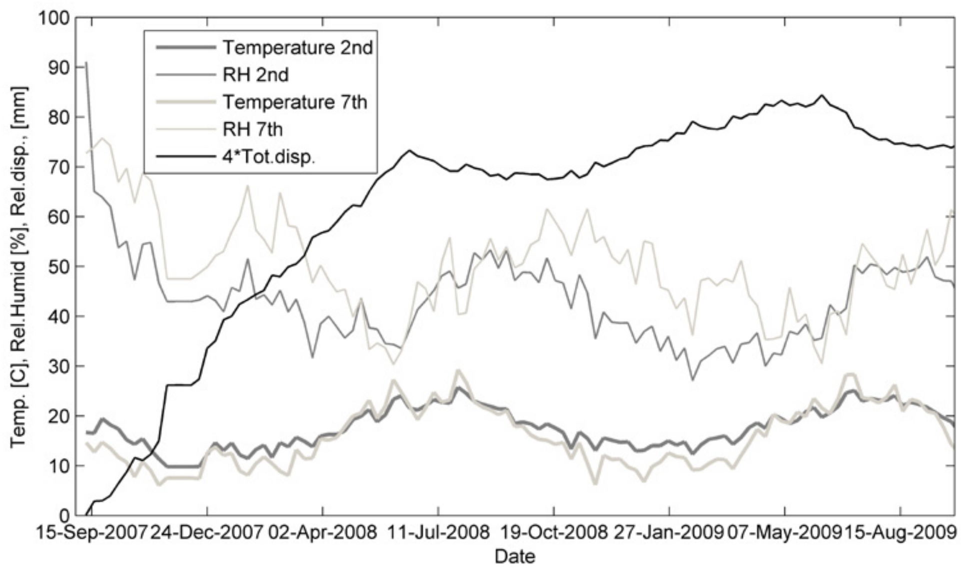

Figure 8. Temperature, relative humidity and the total displacements magnified four times as a function of the time period measured.

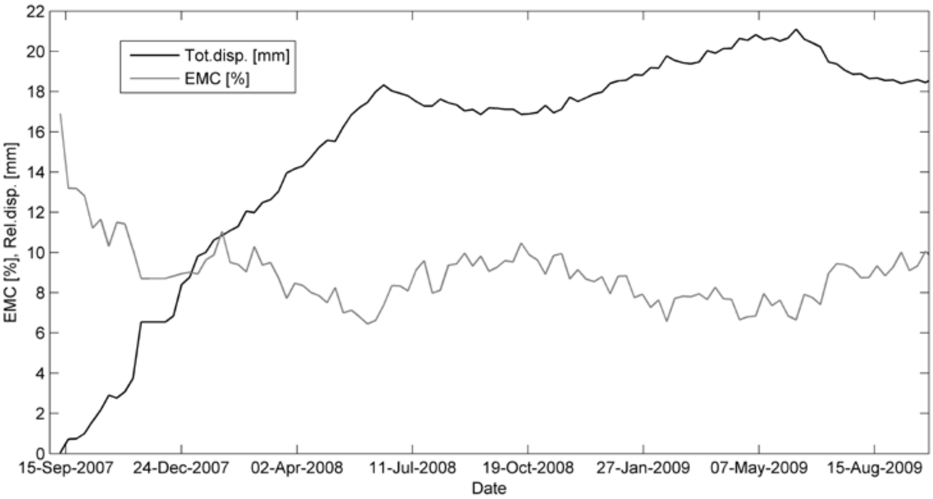

Figure 9. Calculated equivalent moisture content and total displacement as a function of the time period analyzed.

5 CONCLUSIONS

Vertical relative displacements have been measured along one path for six of the eight storeys, storey 2-7, at one of the four clt-buildings at the Limnologen block. These relative displacements have been logged continuously, together with temperature and relative humidity at two locations along the same path, for a two year period. The time period spans from September -07, when the house was erected but not completed with interior walls, to October -09. A rod made from the steel alloy invar, with low thermal expansion coefficient, was used for installing the measurement devices inside the isolation and outside the load-bearing clt-panel. Three conclusions can be drawn from the measurements:

- Over the 17.95 m measuring length the maximum relative vertical displacement was 21.1 mm corresponding to 0.12 % of the total length.
- Most of the displacements occurred during the first nine months that data was collected. During the same time period the calculated equivalent moisture content decreased by roughly 10 %.
- A sinusoidal shaped pattern may be identified in the total relative displacements after the first nine months. These may be correlated to the calculated equivalent moisture content.

6 REFERENCES

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