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SOUND INSULATION PROPERTIES OF SINGLE AND DOUBLE CLT WALLS

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ABSTRACT

Cross laminated timber (CLT) elements have rapidly gained in popularity in Norway and other European countries. Experimental data and improved engineering tools are essential for the development of sustainable solutions. During the last decade, an increasing number of measurement results and experiences from completed buildings became available. Several studies have been performed both regarding wall and floor constructions, and several handbooks and papers offer data and prediction methods. For the development of a Norwegian design guide on CLT inner walls, we have collected and analysed both laboratory and field measurement data on CLT single and double walls. In this paper, we present results of the analysis over the building acoustics frequency range focusing on two aspects; the comparison of the collected measurement data with predictions based on the transfer matrix method and secondly the comparison between laboratory measurements and relevant field measurement results. Results show that the estimate of the stiffness properties and thereby the determination of the coincidence frequency is crucial to obtain reliable prediction results. A positive observation is the relatively small deviation between laboratory and field measurement result when the workmanship on site is according to recommended practice and flanking transmission plays a minor role.

Keywords: *Massive wood, wall construction, airborne sound insulation, measurement, prediction.*

1. INTRODUCTION

Cross Laminated Timber (CLT) is a building material that has become common in the Nordic and European countries in the last 5 to 10 years. In Norway the concept was introduced early 2000, in the beginning introduced without sufficient documentation of sound insulation properties either from measurements or predictions. During the last two decades there have been a number of research projects and laboratory measurement actions, especially in Europe and Canada. Field measurement results are also available from several completed buildings. Data are available in both databases, for example [1] and [2] and publications [3] and [4]. Although solutions exist, the topic of flanking transmission involving visible CLT elements and high sound insulation requirements is still object of intensive discussion and research.

A large part of the data available in the databases is given as single number values. In this paper, we focus on the airborne sound insulation of wall elements and present the analysis over the building acoustics frequency range.

2. LABORATORY MEASUREMENT DATA

2.1 Single wall

For single walls, our collection consists of laboratory measurement results from [5], [6] and [7], i.e. laboratories in Canada, Austria and Norway. The element thickness varies between 78 mm (3 layers) up to 245 mm (7 layers). Figure 1 shows laboratory measurement results of 78 mm to 100 mm thick CLT elements. In the diagram we also show the theoretical 30 log frequency slope for single wall elements above the critical or dilatation frequency. For bare CLT elements, the critical frequency is normally between 250 and 500 Hz for relatively thin elements which correlates with the measurement curves in figure 1.

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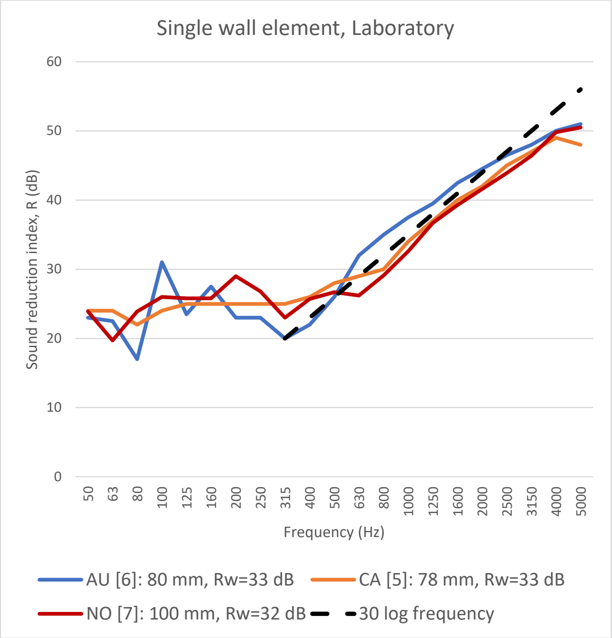

Figure 1. Laboratory measurement results of single wall CLT elements.

With respect to the single number quantity, there are minor differences between the three laboratory measurements, but within some 1/3-octave band, significant differences at medium and low frequencies. Both influence of thickness and scattering in the spectrum below 500 Hz in object [6] and [7] is probably related to stiffness properties of the different layers. Above the critical frequency, the slope of the measured curves matches well the expected theoretical slope.

2.2 Double wall

For double wall elements, our collection consists of laboratory measurement results also from [5], [6] and [7]. In this collection, the thickness of each wall element varies between 78 mm up to 100 mm, combined in different configurations for a total thickness up to 300 mm. The cavity between the elements varies from 25 mm to 150 mm. The cavity was dampened with glass wool for all items. We could not find exactly the same configuration for the comparison. Figure 2 shows laboratory measurement data from a selection of results featuring reasonably comparable properties. The thickness of the elements and the depth of the cavity for each configuration is given in the legend in millimeter as first element – cavity – second element.

The figure also shows the theoretical 40 log frequency slope for double wall constructions above the double wall resonance frequency [9].

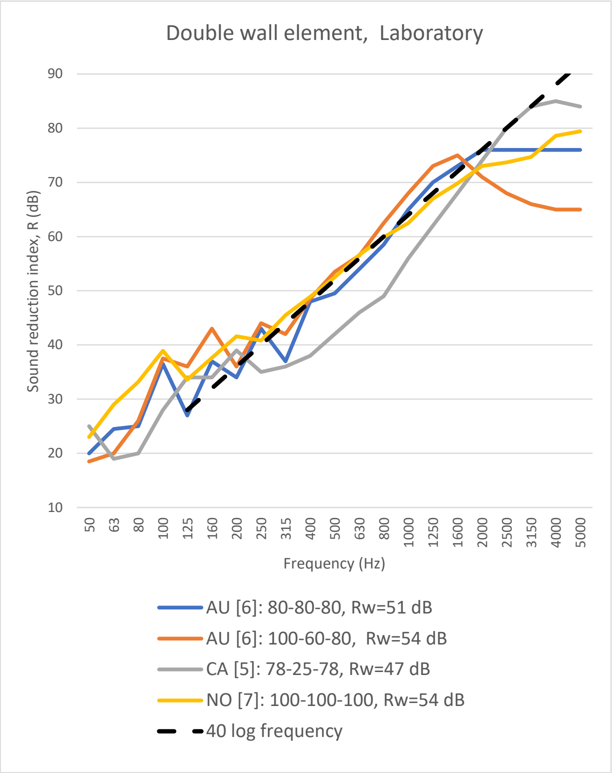

Figure 2. Laboratory measurement results of double wall CLT elements, glass wool absorber in cavity.

The sound reduction index varies as expected as a function of the element thickness and the cavity depth. For the selected objects, R_w-values vary between 47 and 54 dB. The small cavity of the CA [5] object moves the sound reduction curve towards higher frequencies. The results show to a certain degree the effect of unsymmetric of the two elements [6] and the positive effect of larger cavity, see results at low frequencies from the NO [7] example. Between 250 Hz and 2000 Hz, the sound reduction index follows reasonably the theoretical slope.

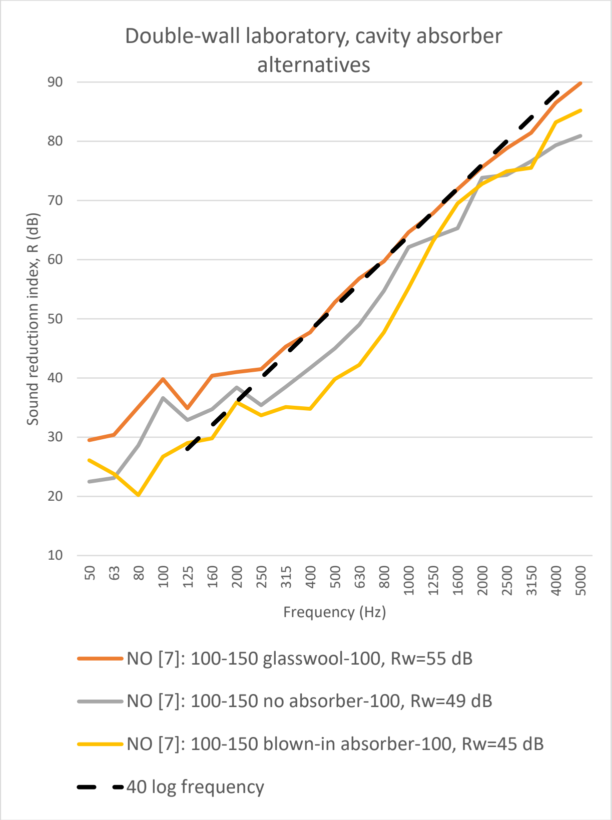

Figure 3. Laboratory measurement results of double wall CLT elements. Cavity absorber alternatives

Figure 3 shows a collection of results depending on the type of cavity filling, including: empty cavity, glass wool and blown-in cavity filling. The total difference with respect to single number quantity is 10 dB, with the glass wool configuration ranging best and the blow-in insulation ranging worst, even worse than the empty cavity. The frequency spectrum shows the negative effect at almost all frequency bands. Results with blown-in absorber also show significant difference compared to the theoretical 40 log frequency slope.

3. FIELD MEASUREMENT DATA

3.1 Ordinary porous absorber in the cavity

In our collection, field measurement results were only available for double wall elements and limited to Norwegian data from [7]. The collection comprises only symmetric configuration with element thickness varying between 98 mm and 120 mm on each side. The cavity depth varies between 100 mm and 150 mm for field case 4. Dip at the 500 Hz frequency band for field case 4 is probably caused by a small signal cable pipe. All examples with ordinary glass wool in the cavity, except case 4 with soft blown-in cavity absorber. No further details exist regarding attached constructions. Figure 4 shows field measurement results from three different apartment buildings and the theoretical 40 log frequency slope.

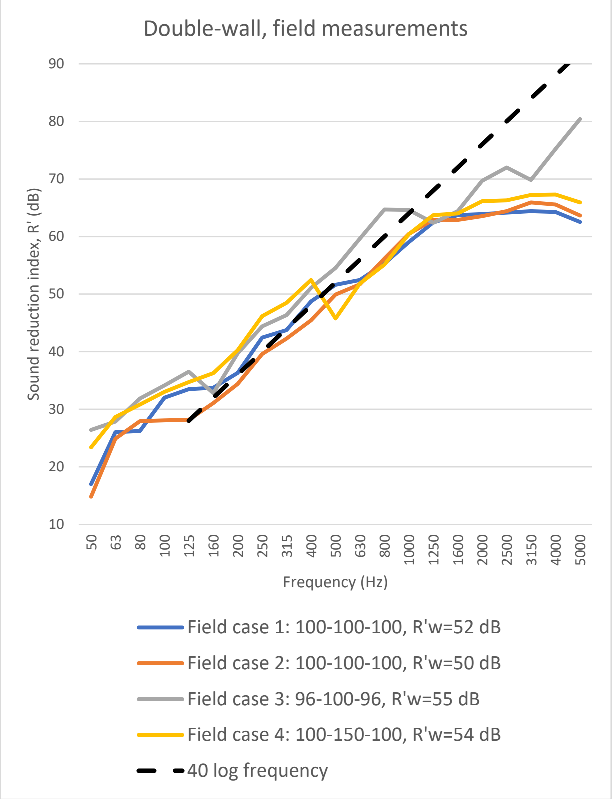

Figure 4. Field measurement results of double wall solutions from three different apartment buildings.

As shown in figure 4, the single number quantity, R'_w varies between 50 and 55 dB even when the element thickness is approximately the same (100 mm). The deviations between the different objects are significant at almost all 1/3 octave bands. At higher frequencies, the sound reduction index seems to drop off, probably due to flanking transmission.

3.2 Blown-in cavity absorber

In this section, measurement examples with blown-in porous absorber in the cavity will be presented. The element thickness of these objects is both 100 mm with a cavity depth of 150 mm. The level of absorber filling varies between "soft" and "compressed" based on information from the craftsmen, but it is of course not possible to quantify the filling in kg/m^3 or some pressure parameter without removing one of the CLT elements. Figure 5 shows results from three measurements at the same apartment building. The figure also shows the 20 log frequency slope according to the mass law (total CLT weight) and 30 log frequency relevant for single wall theory above the critical frequency.

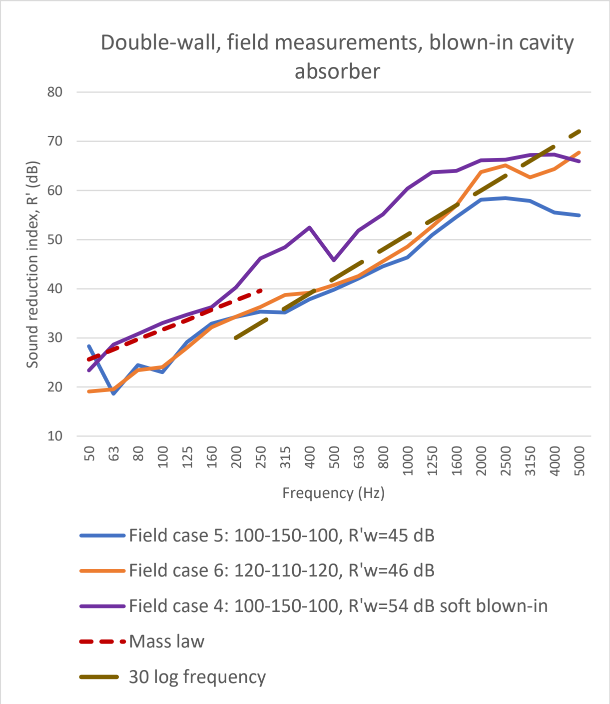

Figure 5. Field measurement results of double wall solutions. Blown-in cavity filling measured at the same apartment building.

Results in figure 5 show a total difference of 9 dB with respect to the single number quantity, R'$_w$ between an "ordinary" blown-in absorber and an example with "soft" application of the porous absorber. The reason for the negative effect is the structural connection between the CLT elements due to the compressed absorber similar to a more or less stiff connector in ordinary double wall constructions. A guideline for future applications is therefore to avoid blown-in absorber unless the installation process can be controlled so to avoid excessive filling. At low frequencies, the frequency slope seems to follow the mass law even if the double-wall resonance is below the frequency range.

4. PREDICTION OF SINGLE WALL ELEMENT

4.1 Applied theory

The classical modelling of a single wall construction is often (and for simplification) based on a homogeneous and isotropic structure, see for instance [9]. Due to the characteristic of wood, the material is per definition orthotropic. However, for non-procsessed wood beam or panel, the simplified mass law theory seems to be sufficient accurate. When an additional wooden layer is fixed 90 degrees to the first one like a CLT element, a significant change of the stiffness properties occurs depending on the direction. This is the reason for suggesting a physical behavior like a sandwich panel. One possible method of prediction is the use of the *Transfer Matrix Method (TMM)*. Using this technique, the different layers and structural connections is easy to implement. For transmission calculations we need at least the particle velocity and stress in two directions. Describing the relation between input and output, a 4 x 4 matrix will be necessary, sometimes simplified to a 2 x 2 matrix. The software tool NorFlag [10] implements the *TMM* procedure for different applications, for instance a sandwich panel as a special case. The sandwich model consists of a core with two face sheets. The calculation routine is based on paper by Moore & Lyon [11] who describe the wave motion of a panel with thin face sheets and a thicker and lighter core. The program presupposes that the core as well as the face sheets are isotropic and the face sheets to be identical. In a similar way as an elastic layer we have symmetric as well as antisymmetric propagating modes which means that there may be thickness deformation of the core (dilatational modes) as well as deformation of the panel without changes in thickness. Both types of modes give rise to coincidence phenomena and limited sound transmission properties.

Calculation of the critical frequency depends of course on stiffness and thickness of the layers. The correct way of calculating a CLT element is therefore not obvious for numbers of layers with different properties. Regardless, for prediction accuracy, the input parameters are crucial. Depending on the stiffness properties and thickness, we obtain a more or less flat range of the transmission curve before reaching coincidence. See [8] with respect to an alternative model based on Sharp's theory [12].

4.2 Prediction examples

The input parameters for the modeled panels are presented in table 1. Youngs modulus used for the predictions correspond to numbers in [8] and generally used for structural wood components. Normally, core layers have lower density and stiffness compared to the face layers for such CLT panels. Even if such CLT element deviate from the strict assumption of thin face sheets [11], a sandwich model seems more relevant compared to solid, thin plate theory. Results calculated using NorFlag as described above are given in figure 6.

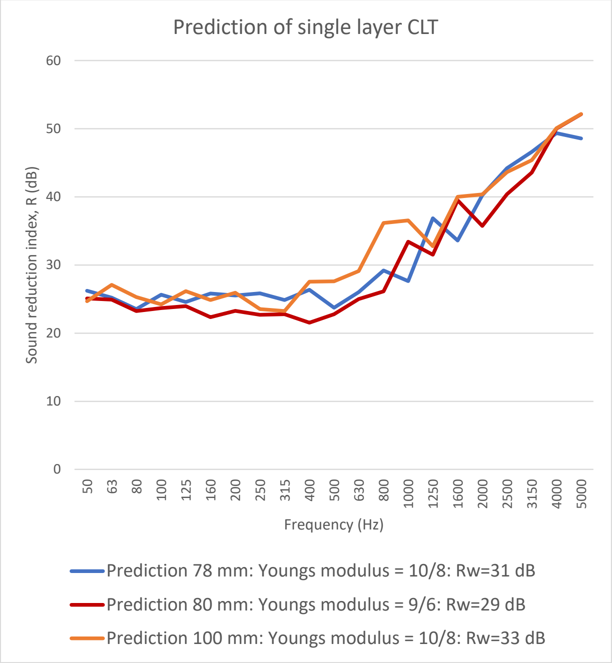

Figure 6. Calculated sound reduction index for objects listed in table 1.

Calculation results presented in figure 6 follow the expected behavior: a "flat" range of the transmission curve under the coincidence frequency and 30 log frequency slope above. At lower frequencies, the level is controlled by the E-modulus of the face layer. The coincidence frequency and dilatation effect are controlled by the stiffness and mass (thickness) of each layer. Note that a verification of the model presupposes specific information from the producers on the Youngs modulus and wood density.

Table 1. Input parameters for 3 layer CLT modelled as a sandwich panel.

	CLT thickness (mm)		
Parameter	78	80	100
Youngs modulus (GPa)			
face	10	9	10
core	8	6	8
Poisson's ratio	0,25	0,25	0,25
Loss factor	0,02	0,02	0,02
Material-density (kg/m^3)			
face	480	480	480
core	450	450	450

5. DISCUSSION

5.1 Comparison of lab and field measurements

Figure 7 shows a comparison of laboratory and field measurements from results presented in figure 2 and 4.

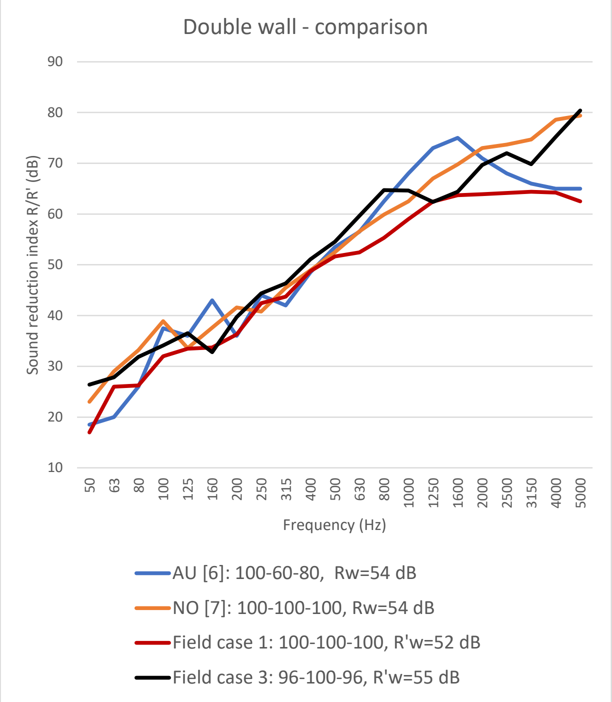

Figure 7. Comparison of field and laboratory measurement results of double-wall CLT solutions.

Selected results are the most relevant objects to compare with respect to element thickness and cavity depth. When we choose the laboratory measurements as a reference, the single number quantity from field measurements deviates from -2 to + 1 dB. It means it is realistic to obtain approximately laboratory measured results in buildings when the workmanship and flanking transmission is satisfactory, which is the case in these objects. Especially at medium frequencies, the deviation between laboratory and field measurement results is low. At higher frequencies there are significant differences between some measurement results, but not systematic between lab and field measurement. The reason for this is not examined. Presented results shows that it is difficult to achieve $R'_w \geq 55$ dB for such double wall solutions without additional measures, contrary to conclusion in [8].

5.2 Comparison of measurements and predictions

Figure 8 and 9 shows a comparison of predicted and laboratory measured results of respectively 78 mm and 100 mm CLT wall element.

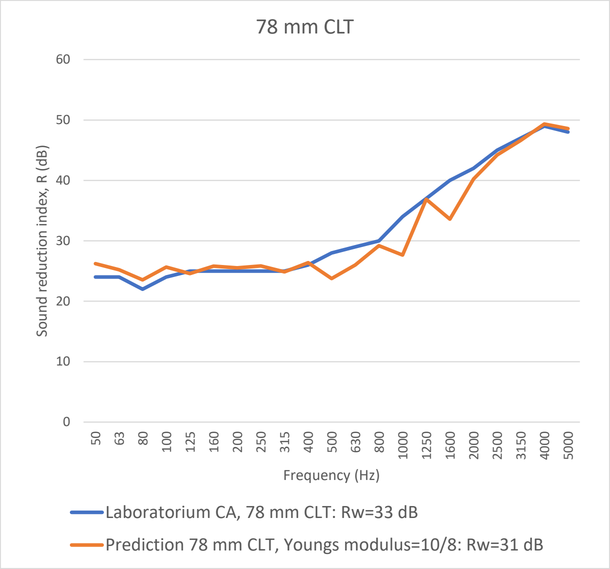

Figure 8. Comparison of predicted and laboratory measured results of 78 mm CLT element.

Comparison between predicted and measured values in figure 8 and 9 shows good agreement. As mentioned in chapter 4, the predicted values are sensitive for the input value of the elastic modulus of the wooden layers, showing high correlation either at lower frequencies or in the medium frequency range. With respect to single number quantity, these predictions are conservative compared to the laboratory measurement results. The comparison seems to correlate well with predictions from Ljunggren [8] at least with respect to single number quantities.

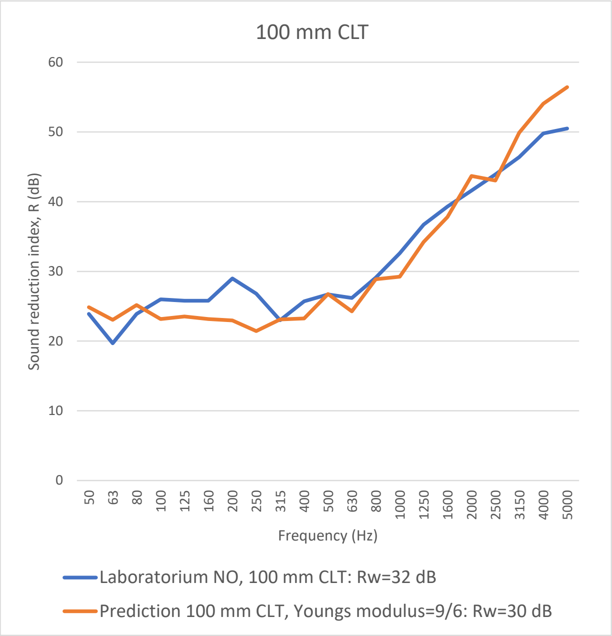

Figure 9. Comparison of predicted and laboratory measured results of 100 mm CLT element.

6. SUMMARY

From the collected laboratory and field measurement results and predictions, we can summarize following findings:

- For single wall elements, results from laboratories show minor differences when we take the element thickness, layer thickness and probably stiffness differences into account.
- Comparison of double wall solutions from laboratory and field measurements shows minor differences. It is therefore realistic to obtain approximately laboratory measurement results in real buildings when the focus is on proper workmanship and limited flanking transmission.

- Blown-in absorber in the cavity is confirmed to have a major negative effect on the airborne sound insulation of a double wall solution unless it is possible to ensure a very soft installation process.
- Measurement results show that, in general, it is not possible to achieve $R'_w \geq 55$ dB (common requirement between apartments) for such double wall solutions without additional measures.
- Proposed prediction model shows that it is relevant to apply a sandwich model for such CLT elements. Calculation results are sensitive to E-modulus of the wood and of course thickness and density of all layers.
- Comparison of predicted and measured sound reduction index of a single wall element shows good correlation, but somewhat conservatively.

7. ACKNOWLEDGMENTS

This work is a collection of measurement results processed as a part of developing Building Detail Sheet on CLT wall constructions. This Building Detail Sheet (in Norwegian) is expected to be published by SINTEF during 2023.

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