

## **Simplified model for sound insulation of cross laminated timber walls with external thermal insulation composite systems**

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### **ABSTRACT**

**Solid wood structures made of Cross Laminated Timber are more frequently applied for multi storey residential buildings. Therefore a reliable, simplified methodology for prediction of exterior walls made of CLT and ETICS is needed. Since CLT has significantly lower mass compared to concrete, a 2-mass-spring system with a basic wall with orthotropic behaviour has to be modelled. The „mass law for CLT“ was derived from several sound measurement results provided by Stora Enso Wood Products, Austria. Based on these results, the resonance frequency of the system was identified and a simple prediction model for the construction element CLT with ETICS was developed. Finally, results are compared to different frequency dependent calculation models, capable to deal with boards with orthotropic behaviour.**

**Keywords:** Sound reduction index, CLT, ETICS

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### **1. INTRODUCTION**

Thermal insulation is an essential component of the characteristic exterior building element used in Austria since local climate is defined by cold winters and, due to climate change, hot, humid summers. One method for increasing energy performance and reducing environmental impact of buildings are external thermal insulation composite systems (ETICS). But ETICS also have an impact on acoustic behaviour of the component, which have been closely investigated during the last decades (i.a. 1-7). Interest in these studies was focused on combination with mineral structures. A relatively new base wall structure, and not that good investigated in combination with ETICS, is cross laminated timber (CLT). Since CLT has lower mass, ordinary prediction models based on huge mass differences cannot be applied on this specific combination.

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## **2. ACOUSTIC BEHAVIOUR OF CLT**

CLT plates can neither be assigned as heavy nor as lightweight, multilayered elements. Whilst acoustic requirements are fulfilled by mass of heavy elements or low bending stiffness of the planking of post and beam structures, solid wood elements cannot be classified in one of these categories. Generally sound insulation is decreasing around the critical frequency. Heavy elements show this decline at very low, lightweight elements at very high frequencies.

In both cases it can be found outside the building acoustics frequency range. At CLT structures the critical frequency is situated between 100 and 500 Hz, which is exactly in the relevant frequency range. This is a fact which has to be considered whilst configuration of the building element in order to assure a satisfying level of sound insulation and noise protection (8).

According to (9), a CLT plate can exhibit large differences in modulus of elasticity between its major and minor axis what leads to different critical frequencies. This property of CLT leads to the fact that there is no single dip in the sound insulation spectrum in a narrow frequency band, but a range with increased sound transmission between these two critical frequencies. Depending on the ratio between the deflection stiffness in the longitudinal direction and that in the transverse direction, this “coincidence region” can extend from a few third-octave bands up to a few octave bands, leading to increased sound transmission in this range (10).

## **3. ACOUSTIC BEHAVIOUR OF ETICS AND THE INSULATION LAYER**

Application of ETICS affects significantly the acoustic behavior of the external wall component. Due to the mass-spring-mass system, formed by the basic wall, the thermal insulation and the light exterior plaster, the system inherent resonance effect leads to reduced sound insulation around the resonance frequency and increased sound insulation in the higher frequency range. According to (11), changes in single number rating due to the combined impact of ETICS at high frequencies and the resonance frequency vary from -8 to +19 dB. Main drivers of the acoustic performance seem to be the sound insulation spectrum of the carrier wall, the dynamic stiffness of the thermal insulation layer and the mass of the external plaster layer.

The main property of a thermal insulation material used for ETICS in terms of acoustic, is the dynamic stiffness  $s'$  (MN/m<sup>3</sup>). It is defined as the ratio between dynamic force to the dynamic displacement and has a major impact on airborne sound insulation properties of the exterior wall where this insulation material is mounted to. The sound reduction index spectrum of an exterior wall with ETICS, compared to a sole CLT plate, shows a dip at the mass-spring-mass resonant frequency due to the masses of CLT and the exterior plaster and the insulation layer acting as the spring.

Methodology of how to determine  $s'$  is specified in EN 29052-1. Nevertheless a round robin test in 2016 showed differences up to 55 % (12) in results when standardized methods are applied and even up to 300 % when plaster layer and sealant material is not processed with the same precision. Considering this, even measurement results of  $s'$  do not seem to be entirely reliable, what unfortunately must lead to an impact on accuracy of prediction results as well.

## **4. METHODOLOGY**

The aim was to find a relation between thickness of the CLT-plate (which means the mass of the plate) and the sound insulation properties of the element in order to create an equivalent to Berger’s Mass Law which is successfully applied to heavy mineral structures according to EN ISO 12354-1. This new “mass law for CLT” formula allows

the determination of the weighted sound reduction index  $R_w$  for the CLT basic wall, as a prerequisite for the calculation with ETICS. The next step is the creation of a comprehensive database for the weighted sound reduction index  $R_w$  of exterior walls made of CLT with ETICS. Based on these databases and considering the fact that a couple of parameters can be varied in this system, the particular resonance frequency  $f_R$ , (equation 1), provides a basis for the calculation with the dynamic stiffness of the insulation material  $s'$ , the mass of the CLT wall  $m'_{CLT}$  and the mass of the plaster  $m'_{plaster}$ .

$$f_R = \frac{1}{2\pi} * \sqrt{s' * \left(\frac{1}{m'_{CLT}} + \frac{1}{m'_{plaster}}\right)} \text{ in Hz} \quad (1)$$

Different existing prediction models were applied and compared to measurement results. Since dynamic stiffness is the most critical parameter concerning indication and accuracy of determination, measurement results without reliable specification of  $s'$  were excluded from the model. Finally standard deviation of the new single number value prediction model for CLT with ETICS was verified and limits of application defined.

## 4. EXISTING PREDICTION MODELS

### 4.1 Models for Sound Insulation of CLT

Prediction models for airborne sound insulation spectra of CLT have been developed i.a. by Stora Enso, published in (9). The model is based on a modular system adding e.g. various floor packages and ceiling packages to the CLT structural system by Stora Enso. The model build up is made in order to perform fast and efficient updates as soon as new products are implemented or material characteristics are changed. A detailed description of the model is not published.

A single number value model for prediction of weighted sound reduction index of lightweight wooden plates is provided in EN 13986. The particular acoustic behavior of different installation angles and, thus, different applications of CLT plates cannot be addressed with this simplified equation.

Further methods which seem to be appropriate, have been recently published.. Di Bella shows in (13) a simple equation which leads to similar results as the method from the authors, but do not cover higher CLT thicknesses with the same precision Finally a comprehensive method to predict the single number value of solid wood plates was developed by Rabold et al. and published in (14). Calculation can also be applied for covered CLT walls, but limited to thicknesses of 160 mm.

### 4.2 Models for Sound Insulation of External Walls with ETICS

The most famous method has been developed years ago, refined and recently published in (7), and is used in a simplified version in EN ISO 12354-1 as well. Calculation is limited to heavy and semi-heavy (vertically perforated bricks) mineral structures. Nevertheless, special cases are addressed as well like double layer ETICS (refurbishments) and very thick insulation layers (e.g. as necessary for passive houses). Since mass differences between the resonant masses (basic wall and plaster) are high, resonant frequency is calculated by considering only the mass of the plaster.

The aim of the method is to obtain  $\Delta R_w$  (the improvement of the weighted sound reduction index  $R_w$ ), which is the difference between  $R_{w,0}$  of the sole CLT element and  $R_w$  of the element with ETICS. Basic calculation is carried out without anchor plugs, with glue application covering 40 % of the surface and a  $R_{w,0}$  of the raw wall without ETICS

of 53 dB. All deviations from these default values are taken into account with correction terms. However, this method seems to be widely used, but it is not suitable for semi-lightweight structures like CLT.

### 4.3 Single Number Prediction Model for ETICS on Solid Wood Structures

Apart from the prediction of airborne sound insulation of CLT, methodology of (2) offers prediction results for different mounting conditions of ETICS and additional internal installation walls as well. Once the  $R_{w,0}$  of the CLT basic wall is determined, an equation for the improvement of the sound insulation with ETICS is applied. Only Mineral wool and wood fibre insulation boards are covered with this method. Calculation is based on the resonance frequency (equation 1) of the system, and additional correction terms for applications on solid wood elements and mounting conditions of the ETICS with amount of glue and anchors.

## 5. SIMPLIFIED PREDICTION MODEL

This new model is exclusively developed for the application on CLT basic walls with thermal and acoustical improvement with ETICS. Therefore complexity, compared to existing models, could be reduced, since only one single type of basic wall had to be covered.

### 5.1 Prediction Model for Sound Insulation of CLT

In order to start with a comprehensive database, several measurement results of airborne sound insulation of CLT plates have been provided by Stora Enso and other databases. Figure 1 shows mean values of  $R_w$  for different thicknesses (corresponds to the different masses) of CLT plates and variance if more measurements were carried out for one single type.

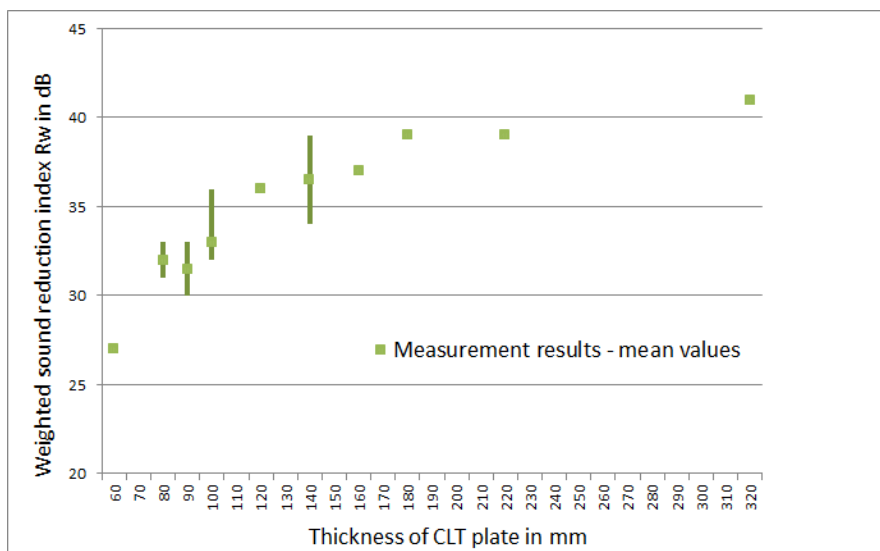


Fig.1: Measurement results (mean values and variance) for sound insulation of CLT

Mass of the plate is calculated from thickness and an average density of  $\rho = 440$  kg/m<sup>3</sup>. This is the basis for the equations of weighted sound reduction index  $R_w$  of the CLT plate. Furthermore it is considered, that the installation angle has an impact on  $R_w$ , so two equations have been developed (one for walls and one for floors), taking the usual thicknesses of the particular application into account. “Mass laws for CLT” is derived from mean values of available measurement results, excluding peculiar outliers. Results

are given in equation 2 for walls (for CLT from 60 to 150 mm) and equation 3 for CLT floors (for CLT from 120 to 320 mm).

$$R_{w,CLT,wall} = 25 \lg m'_{CLT} - 8 \text{ in dB} \quad (2)$$

$$R_{w,CLT,floor} = 12 \lg m'_{CLT} + 15 \text{ in dB} \quad (3)$$

Figure 2 shows the results of the two equations graphically in relation to the measurement results. Previously mentioned models according to (13) and (14) have been calculated and are pictured as well. Both models seem to fit for walls quite well, but obviously are not developed for the usual thicknesses of CLT floors.

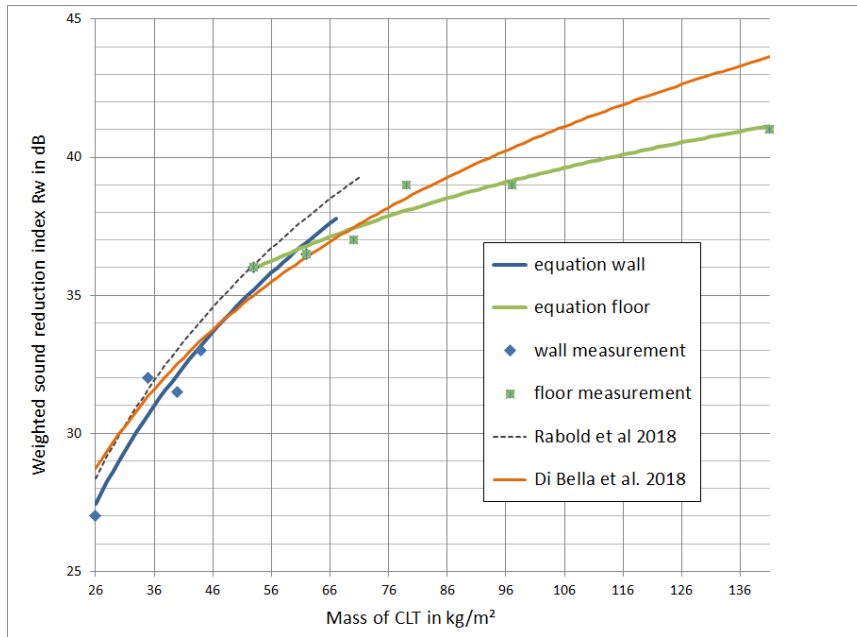


Fig.2: Measurement results of  $R_w$  of CLT and results from different prediction models

## 5.2 Single Number Prediction Model for Sound Insulation of CLT with ETICS

For this CLT+ETICS model, only measurement data were used which could provide reliably measured values of the dynamic stiffness of the applied insulation material. So special emphasis was given on material properties of the layers of the investigated building components. Measurement results were provided by Stora Enso. Once  $R_w$  of CLT is calculated, the resonant frequency  $f_R$  is obtained by applying equation 1, taking the two masses of CLT and the plaster as well as the spring (defined by  $s'$ ) of the insulation material into account. Based on  $f_R$ , calculation of the insulated element is carried out according to the simplified equation 4 and results are pictured in figure 3.

$$R_w = -30 \lg f_R + 110 \text{ in dB} \quad (4)$$

## 5.3 Calculation with Stora Enso Acoustic Prediction Tool Calculatis

Comparing the simple solution with more complex calculation tools like the software Calculatis, which has been developed by Stora Enso, leads to similar results. This prediction tool can already be used by planners and architects and shows the acoustic

frequency dependent behaviour of CLT structures, considering airborne and impact sound insulation. It also calculates single number values according to EN ISO 717-1. Calculation was carried out with exactly the same input parameters as used in the simplified model. Figure 3 shows the excellent accordance with the measurements.

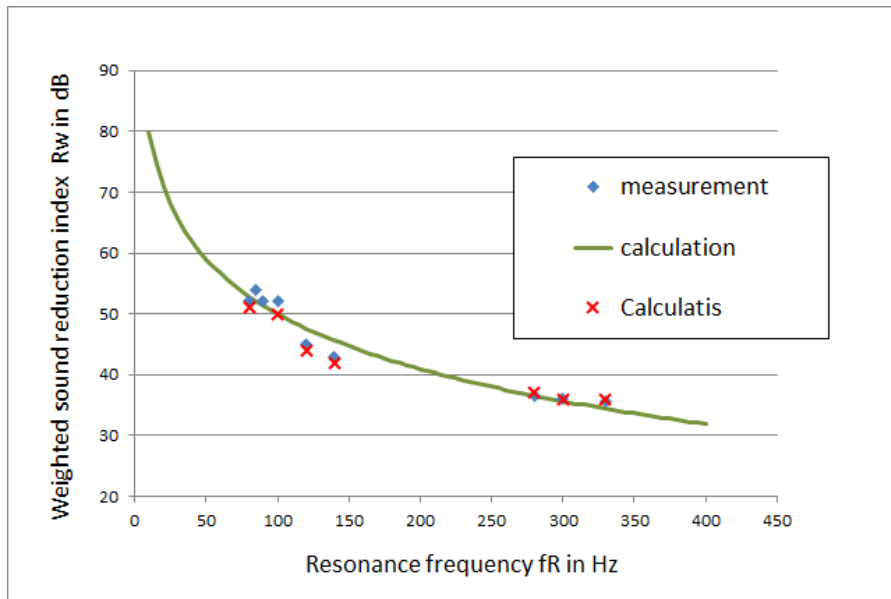


Fig.3: Measurement (blue rhomb), simplified calculation (green line) and result from Calculatis acoustic prediction tool (red cross) of  $R_w$  for CLT with ETICS

#### 5.4 Accuracy of the Simplified Model

Described prediction model for  $R_w$  is based on a semiempirical approach with a limited amount of reliable measurements. Thus, it should be improved and extended by adding additional measurements and refining equation 4. Nevertheless, accuracy of the model, considering a standard deviation of  $\sigma = 1,6$  dB (figure 4), seem to be within common precision of building acoustical applications according to EN ISO 12999-1.

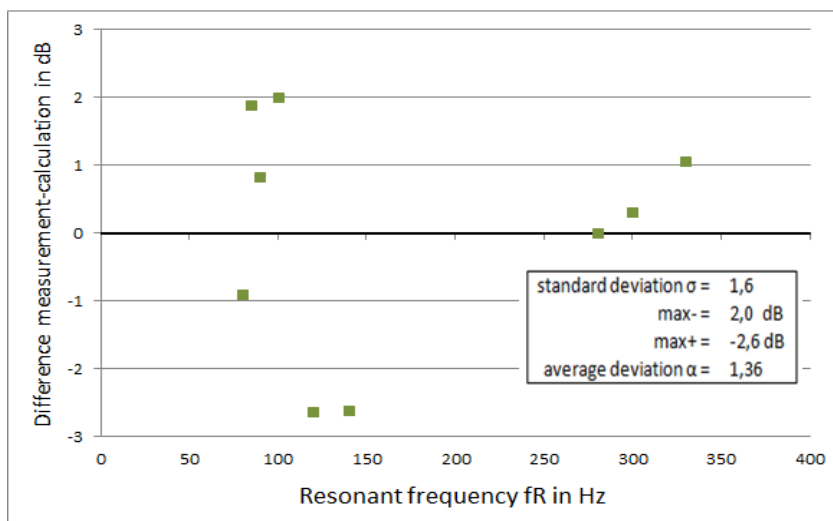


Fig.4: Difference between measurement and calculation according to the simplified prediction model

## 5. ADDITIONAL ASPECTS

As already mentioned above, sound insulation varies with mounting conditions of the ETICS. For this model, 100 % glue (applied with a toothed spatula) and anchors, covered with insulation material, is assumed, since this (according to the opinion of producers and practitioners) seems to be the typical fixing technique. Non covered anchors lead to a reduction of  $R_w$  of 1 dB. Application of the ETICS without anchors does not affect the result in a significant way (compared to the covered situation).

It was also investigated, if including mass of the insulation material into the model has an impact on the accuracy. But no significant evidence for this assumption could be found.

Since traffic noise is the main impact source of an exterior wall, it is necessary to take a closer look at the spectrum adaptation terms for traffic –  $C_{tr}$  and  $C_{tr,50-5000}$  – according to ISO 717-1 as well. For the CLT plate, inclusion of  $C_{tr}$  or  $C_{tr,50-5000}$  only reduces results between 2 and 4 dB. Application of ETICS on one hand always leads to a significant improvement of  $R_w$ , but on the other hand sound reduction index spectrum usually is worsen in the lower frequency range. This leads to lower results for  $R_w+C_{tr}$  (lowest value for  $C_{tr} = -9$  dB) and particularly for  $R_w+C_{tr,50-5000}$  (lowest value for  $C_{tr,50-5000} = -23$  dB). As shown in figure 5, reduction is related to the improvement of the specific insulation material - the higher the improvement (e.g. with hemp), the higher the reduction in the lower frequency range as well.

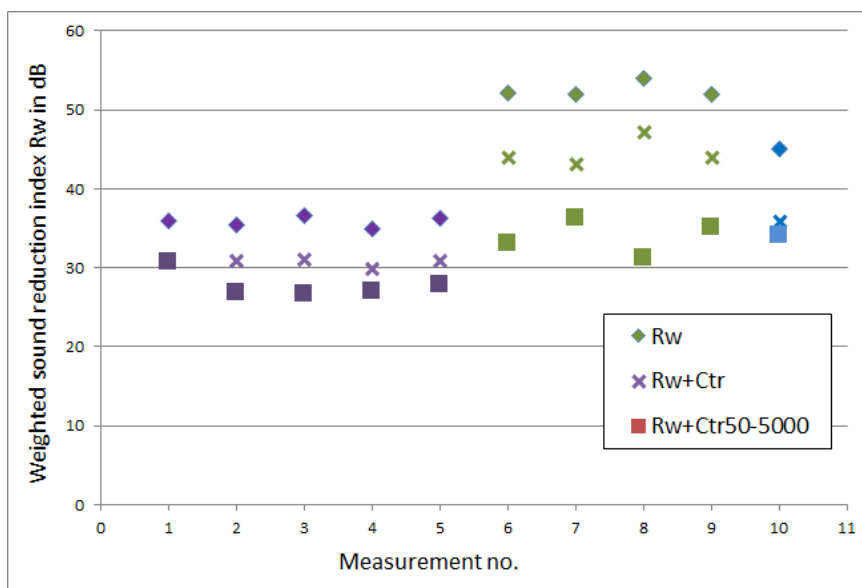


Fig.5. Measurement results of CLT with ETICS  $R_w$  (rhomb),  $R_w+C_{tr}$  (x) and  $R_w+C_{tr,50-5000}$  (square); polystyrene (purple), hemp (green), mineral wool (blue)

On the inner side of the external wall, CLT is often covered with gypsum boards, which allow for painting and wallpaper. The impact of one or two interior gypsum layers has been investigated as well in this survey. It could be shown, that one additional layer of 12,5 mm gypsum board (standard type) leads to the improvement of + 1 dB, a second layer to another + 1 dB (2 dB in total). These values can be used as default values for the prediction model. In case,  $R_w$  of the exterior wall is very low, like polystyrene insulation with a thin plaster layer, a 15 mm gypsum board can lead to an improvement of  $R_w$  of + 2 dB.

## 7. CONCLUSIONS

A semiempirical prediction model for weighted sound reduction index  $R_w$  of CLT and CLT with ETICS has been developed. Basis was a comprehensive database of airborne sound measurements, provided by Stora Enso. Starting with the calculation of the basic CLT element (by developing a “mass law for CLT”), the resonant frequency of the system, including the masses of CLT and plaster and the dynamic behaviour of the insulation material, is determined. Finally the equation for  $R_w$ , derived from measurement results, is applied. A satisfying accuracy has been demonstrated. Compared to a more sophisticated frequency dependent acoustic prediction model like Calculatis of Stora Enso, single number values, of course, are far from this quality.

Generally, weighted airborne sound insulation of CLT always seems to be improved by adding additional layers like ETICS. Significant parameters are dynamic behaviour of the insulation material and mass of the plaster applied. Nevertheless, although improvement can be very high for  $R_w$ , considering  $C_{tr,50-5000}$  reduces results significantly for all insulation materials. Particularly for polystyrene, resulting  $R_w+C_{tr,50-5000}$  can be lower than the same parameter for the single CLT plate itself. This should be considered during design stage.

A special topic for air borne sound measurements of CLT plates in laboratories seems to be the fact, that they produce weighted results with differences up to 4 dB. Reasons for these diverging performances lead to the conclusion of the need for guidance of mounting conditions of CLT plates in transmission suites in order to harmonise results of laboratories and to picture the situation on the building site adequately.

An important aspect is the data of the dynamic behaviour of insulation material and its determination by measurement in laboratories. It has to be concluded that producers should provide appropriate data and laboratories are requested to minimize differences of measurement results in order to have the opportunity to improve existing prediction models.

Finally it has to be captured, that the model at hand is developed as an open system which easily can be developed further by taking additional, well documented airborne sound measurements into account. Moreover, additional internal layers have not been considered yet (apart from gypsum board). This should be addressed in further research. Nevertheless, the model seems to be easy to be applied for the practitioner and could be a useful instrument in standards for prediction of acoustic performance of CLT building elements.

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