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Sound insulation prediction of single and double CLT panels

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ABSTRACT

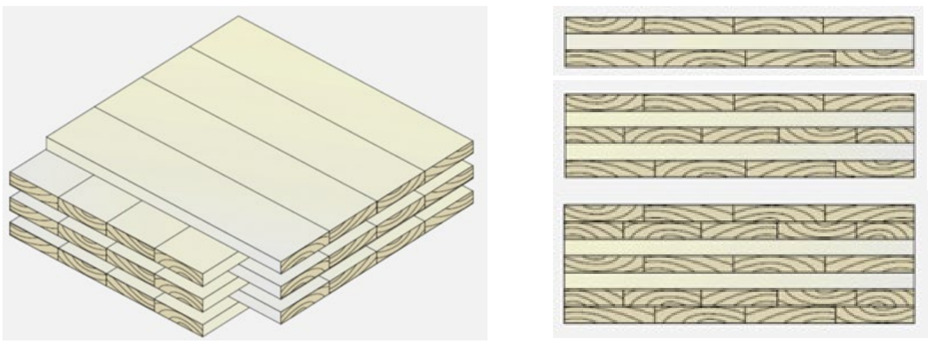
Cross laminated timber (CLT) as building material has rapidly gained in popularity in recent years, and thereby also the demand of engineering tools to predict the sound insulation through CLT walls. The sound reduction through walls of single and double panels is predicted and the results are compared with those found in the literature as well as with a series of measurements conducted in a test mock-up of two rooms. Various configurations are considered where the plate thickness, addition of plaster boards and cavity distance (in case of a double panel) are altered. The prediction of single panel walls is based upon an established model (by Sharp) for homogenous materials, based upon theory and empirical data. For optimized application to CLT constructions specifically, the model is modified to some extent. The double panel walls are analytically modelled under the presumptions of no mechanical connection between the two panels and a cavity filled with mineral wool. The model make use of the results from the developed model for individual panels. The accuracy of the predicted sound insulation is estimated to be within a couple of dB's concerning the weighted sound reduction indexes from 100 and 50 Hz.

Keywords: Sound insulation, Cross Laminated Timber, Modelling

1. INTRODUCTION

The interest to use of CLT – Cross Laminated Timber – in building frames has rapidly increased over just a few years. CLT panels are in many ways easy to handle, are light (compared to concrete), have high bearing capacity and can handle large spans. Another important aspect is that CLT is a sustainable and renewable material.

A CLT panel consists of planks, often 20-30 mm thick, glued together in typical 3-7 layers of orthogonal orientation, see Figure 1.



3-layer

5-layer

7-layer

Figure 1 – Example of CLT panels.

In this paper, the sound insulation of single and double wall panels is in focus. The purpose is to find out how accurate established analytical models, slightly modified if needed, can predict the airborne sound insulation.

2. SINGLE PANEL WALLS

2.1 Model

The calculations originate from Sharps's model from 1978 (1), a model that is based upon theory but also to some extent has been adjusted to empirical data. The model is divided into three frequency regions related to the panel's coincidence frequency f_c; 1) f below half the coincidence frequency, 2) f around f_c and 3) f above the coincidence frequency. The sound reduction is calculated accordingly:

$f \leq f_c/2$	$R=20\log(Mf)-48$	6 dB/octave band
$f = f_c$	$R_c=20\log(Mf_c)+10\log(\eta)-40$	
$f > f$	$R=Rc+30\log(f/f_c)$	9dB/octave band

where M is the surface weight (kg/m^2) and η is the loss factor of the panel.

Sharp's model has in the next phase undergone a couple of modifications in order to work especially well for CLT panels including better matching against available measurement data. The idea to several of the modifications are found in (2).

a) For $f \leq f_c/2$ the constant take the value 48 dB for thicknesses up to 130 mm, for thicknesses from 180 mm 47 dB is used and between 130-180 mm a successive adjustment of 0,2 dB per 10 mm take place. Within the literature, both 47 (2-3) and 48 dB (1) is reported.
b) In the region $f_c/2 < f \leq f_c$, the sound reduction takes the same value as for $f_c/2$, the so called coincidence dip thereby gets less pronounced.
c) The sound reduction of twice the coincidence frequency is calculated taking the loss factor into account
d) For $f > 2f_c$, the slope of curve is 6 dB/octave band

The described adjustments leads to the following set of equation to model the sound reduction:

I.	$f \leq f_c/2$	$R=20\log(Mf)-k^*$	6 dB/octave band
II.	$f_c/2<f \leq f_c$	$R=R_{c/2}$	0 dB/octave band
III.	$f = 2f_c$	$R_{2c}= R_{c/2}+10\log(\eta)+23$	
IV.	$f > 2f_c$	$R=R_{2c}+20\log(f/2f_c)$	6 dB/octave band
	*) k=48 for t ≤ 130 mm, k=47 for t ≥ 180 mm		

The sound reduction is thus divided into four frequency regions, shown in Figure 2.

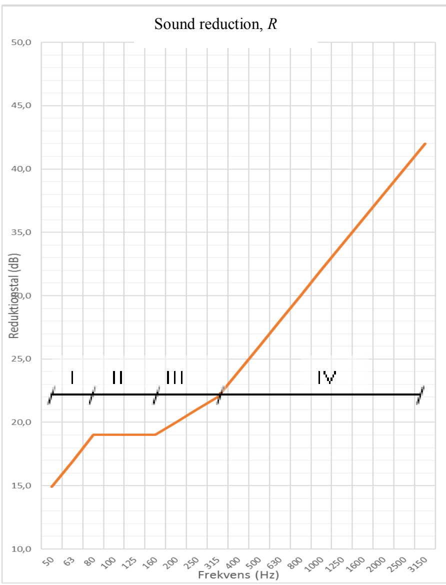


Figure 2 – The sound reduction model is divided into four frequency regions.

The material parameters for a number of modeled panels are presented in Table 1 together with the calculated coincidence frequency according to equation 1. The CLT density is auumed to be 400 kg/m^3 and the Young's modulus (4), Poisson's ratio (5) and loss factor (6) have been obtained from the given references.

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{12M(1-\nu^2)}{Et^3}} \tag{1}$$

Table 1 – Parameters of CLT panels

Thickness (mm)	**70**	**90**	**120**	**140**	**160**	**180**	**210**	**300**
Youngs' m. (GPa)	10,2	10,6	7,86	7,11	9,82	7,86	7,89	8,16
Poisson's ratio	0,3	0,3	0,3	0,3	0,3	0,3	0,3	0,3
Loss factor	0,01	0,01	0,01	0,01	0,01	0,01	0,01	0,01
Weight (kg/m^2)	28	36	48	56	64	72	84	120
Coinc.f. (Hz)	175	134	116	105	78	78	66	46

2.2 Results

Examples of sound reduction curves for CLT panels of three different thicknesses; 70,120 and 210 mm are shown in Figure 3. The single number ratings R_w and $R_{w,50}$ (abbreviation for $R_w + C_{50\text{-}3150}$) for all modelled configurations are presented in Table 2 and Figure 4. The effect of adding one or two layer of gypsum board (9 kg/m^2) is included in Table 2. In the presence of gypsum board, only the additional mass is considered by the model, possibly influence from other material parameters are overseen.

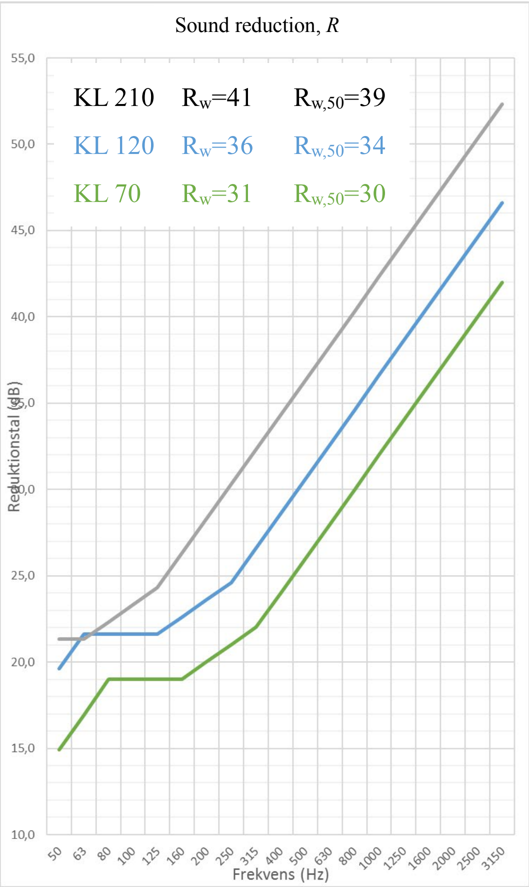


Figure 3 – Sound reduction for CLT panels of three thicknesses; 70, 120 and 210 mm.

Table 2 – Singe number ratings of single panel walls.

Plate thickness	CLT		CLT + 1 gypsum board		CLT + 2 gypsum board	
	R_w	$R_{w,50}$	R_w	$R_{w,50}$	R_w	$R_{w,50}$
65	31	30	-	-	-	-
70	31	30	34	32	36	34
90	33	32	35	34	37	35
100	34	33	36	34	37	36
120	36	34	37	36	38	37
140	37	35	38	37	39	38
160	38	37	40	38	41	39
180	40	38	41	39	42	40
210	41	39	42	40	43	41
240	42	40	43	41	44	42
300	44	42	45	43	45	43
320	45	43	-	-	-	-

2.3 Comparisons

The calculated single number ratings are compared with those found from the literature (7-16). The references are a mix of results reported from measurements as from other theoretical models. Overall, the matching seems satisfactory with most of the references within ±1 dB from the predicted value, but also note the lack of validation for greater thickness than 180 mm.

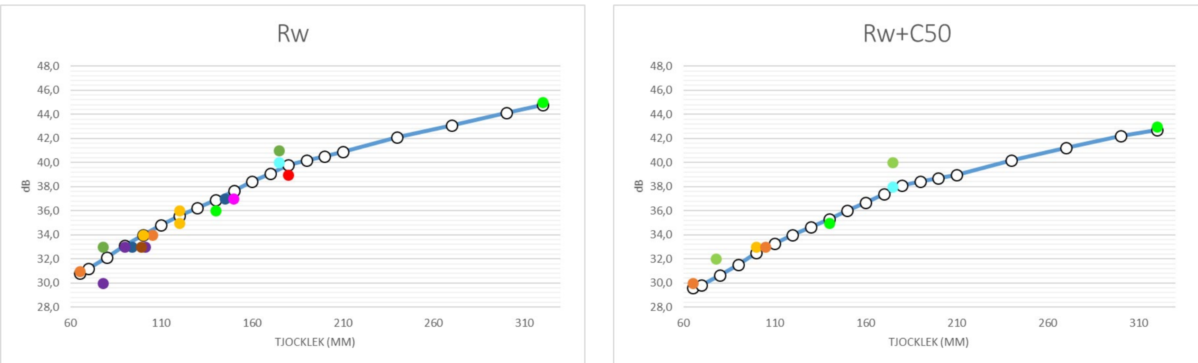


Figure 4 – Single number ratings of CLT panels. Open circles are predicted values and filled colored circles represent verifying data from various references.

3. DOUBLE PANEL WALLS

3.1 Model

The model for the double panel walls start with modelling the individual panels according to previous section. The special characteristic of a double wall is then applied in accordance to Sharp (1) where the double wall resonance f_0 and the limiting frequency f_l, equation 2 and 3 respectively, take a central role.

$$f_0 = \frac{c}{2\pi}\sqrt{\frac{1{,}8(M_1 - M_2)}{dM_1M_2}} \tag{2}$$

$$f_l = \frac{c}{2\pi d} \quad (3)$$

where M_1 and M_2 are the weight of the individual panels and d is the free distance in between. The model assumes a cavity filled with mineral wool and without any sound bridges between the plates, e.g. studs.

The sound reduction is calculated within three frequency regions:

I.	$f \leq f_0$	$R=20\log((M_1+M_2)\cdot f)-k^*$	6 dB/octave band
II.	$f_0 < f < f_l$	$R=R_1 + R_2 + 20\log(fd)-29$	
III.	$f \geq f_l$	$R= R_1 + R_2 + 6$	
	*) k=48 for t ≤ 130 mm, k=47 for t ≥ 180 mm		

where R_1 and R_2 are the sound reduction from the individual panels.

3.2 Results

The outcome for a number of various wall configurations is summarized in Table 3. All the walls are symmetric, the single panel thickness range from 70 to 160 mm and the cavity from 45 to 145 mm. The configurations are modelled with and without complementary gypsum boards.

Table 3 – Data of calculated sound insulation of double CLT walls. Configuration is given as CLT-cavity-CLT and *G* indicates gypsum board.

Config.	f_0 (Hz)	f_l (Hz)	R_w	$R_{w,50}$
70-45-70	102	1200	46	43
70-70-70	81	780	50	46
70-95-70	70	580	52	49
70-120-70	62	460	54	50
70-145-70	57	380	56	51
120-45-120	78	1200	53	49
120-70-120	62	780	57	52
120-95-120	53	580	59	55
120-120-120	47	460	61	57
120-145-120	43	380	63	58
160-45-160	67	1200	56	51
160-70-160	54	780	60	54
160-95-160	46	580	63	56
160-120-160	41	460	65	58
160-145-160	37	380	66	60

Config.	R_w	$R_{w,50}$
G70-45-70G	51	48
G70-70-70G	54	51
G70-195-70G	57	53
G70-120-70G	59	55
G70-145-70G	61	56
G120-45-120G	56	52
G120-70-120G	60	55
G120-95-120G	62	58
G120-120-120G	64	60
G120-145-120G	66	61
G160-45-160G	58	53
G160-70-160G	62	56
G160-95-160G	65	58
G160-120-160G	67	60
G160-145-160G	69	62

3.3 Comparisons

Reported values for this specific type of walls are limited in the literature. A few references (9, 12-13) referring to measurements in laboratory are valid for comparisons, see Table 4.

Table 4 – Comparisons of single number ratings of double panel walls.

Configuration	*LAB.MEASUREM.*		*MODELLING*		*DIFFERENCE*	
	R_w	$R_{w,50}$	R_w	$R_{w,50}$	R_w	$R_{w,50}$
65-100-65	55	52	54	50	-1	-2
100-60-100	52	-	52	49	0	-
100-110-100	≥ 55	≥ 53	56	52	≈1	≈-1
G100-110-100G	≥ 56	≥ 55	60	55	≈4	≈0

Another comparison is done from horizontal measurements conducted inside a two room test mockup (17), Table 5. As the measurements includes flanking transmission of the mockup, the sound reduction should take a lower value compared to the calculations, and a difference of 1-4 dB is noticed for most of the configurations. However, focusing on the difference between the configurations, the difference in sound insulation is rather similar for measurement and calculation for many of the configurations.

Table 5 – Comparisons of single number ratings of double panel walls.

Configuration	*MOCK-UP MEASURE.*		*MODELLING*		*DIFFERENCE*	
	R_w	$R_{w,50}$	R_w	$R_{w,50}$	R_w	$R_{w,50}$
70-70-70	50	45	50	46	0	1
G70-70-70G	56	50	54	51	-2	1
G70-145-70G	59	55	61	56	2	1
120-70-120	53	50	57	52	4	2
G120-70-120G	58	53	60	55	2	2
120-145-120	59	56	63	58	4	2
G120-145-120G	61	58	66	61	5	3
160-45-160	53	49	56	51	3	2
G160-45-160G	56	52	58	53	2	1
G70-70-160G	58	54	59	54	1	0

4. DISCUSSION AND CONCLUSIONS

The modelled sound insulation for single CLT panels showed in terms of single number ratings (R_w and $R_{w,50}$) good agreement with corresponding values found from literature references. The proposed model, a modified version of Sharp's approach, may therefore serve as an engineering tool in predicting the sound insulation performance. The deviation between measured and predicted ratings was within ±2 dB in all cases but typically ±1 dB.

When it comes to walls of double CLT panels, the results indicate a fairly agreement with available data for validation. But due to the limited amount of reference data, it is hazardous to quantify the uncertainty until further validating measurement results are found. The results indicates that a double CLT panel wall, with appropriate combination of plate thickness and cavity depth, will serve as a good alternative in terms of sound insulation when it comes to partitions between apartments.

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