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MULTI-FAMILY HOUSES WITH CAVITY BRICK WALLS: SOUND INSULATION AND VIBRATION TRANSMISSION INDICES

H. Martin*, M. Van Gaal*, E. Gerretsen, J. Niggebrugge*****

* Eindhoven University of Technology, Faculty of Architecture, P.O.box 513, NL-5600 MB, Eindhoven, Netherlands

** TNO-Institute of Applied Physics, P.O.box 155, NL-2600 AD, Delft, Netherlands

*** Kupers&Niggebrugge, P.O.box 40217, NL-3504 AA, Utrecht, Netherlands

Tel.: ++31 40 247 29 97 / Fax: ++31 40 246 36 14 / Email: h.j.martin@bwk.tue.nl

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ABSTRACT
Airborne and impact sound insulation measurements have been carried out between dwellings in multi-family houses erected with cavity brick walls in combination with massive concrete floors. Also vibration reduction indices K_{ij} across different types of junctions have been determined. Calculations of airborne and impact sound insulation between dwellings have been done, both with calculated and measured values of K_{ij}. All dwellings fulfil Dutch building regulations. In vertical direction measurement and calculation results show good agreement whereas in horizontal direction calculation results show a 10 dB higher sound insulation, unless the measured values of K_{ij} are used as input data for the calculations. Then again good agreement was found. The TNO calculation model seems to overestimate the values of K_{ij} across the cavity by at least 10 dB.

1 - INTRODUCTION
In single-family houses in a row often cavity brick walls are applied to achieve a high sound insulation in horizontal direction between dwellings. Often they are constructed with leafs of 120 mm (surface mass 210 kg/m^2) or 150 mm (surface mass 260 kg/m^2) calcium silicate blocks, separated by an air gap of 50 mm width.
When applying this type of cavity brick walls in multi-family houses Dutch rules of practice demand a surface mass of at least 350 kg/m^2 for each leaf to reduce flanking sound transmission in vertical direction.
Two types of cavity brick walls have been applied in a multy-family apartment building of 6 storeys height. Fur structural reasons cavity walls of 214-52-214 mm (calcium silicate-air gap- calcium silicate) have been applied at ground floor level and at first and second floor level. Each leaf weighs about 375 kg/m^2. At 3rd, 4th and 5th floor level the leafs of the cavity walls consist of 150 mm calcium silicate blocks separated by an air gap of 50 mm, resulting in a leaf surface mass of 260 kg/m^2.
To obtain a better understanding of the acoustical behavior of this type of buildings two series of measurements and two series of calculations have been carried out.
Concerning the measurements:
Firstly, both the airborne and impact sound transmission have been determined between rooms in different dwellings in horizontal as well as in vertical direction.
Secondly, the vibration reduction index K_{ij} across different junctions has been determined in situ to gain data and to evaluate the differences.
Concerning the calculations:
The airborne and impact sound insulation has been calculated using the TNO computer program Basluco, which is in accordance with prEN 12354-1 and prEN 12354-2. This was done in vertical as well as in horizontal direction in two ways.

At first the sound insulation between different rooms was calculated using the values of K_{ij} calculated by the computer model. Secondly, the sound insulation between different rooms was calculated using the measured values of K_{ij} as input data for the computer model. The calculations have been made on the those geometrical situations in which measurements have been carried out.

2 - BUILDING STRUCTURE

A short description of the rest of the building structure is given to get an impression of the other sound transmission paths.
The floors:

- at ground floor level a prefabricated element floor consisting of concrete elements with thermal insulation underneath it and a 40 mm cement finish on top was applied on the foundation; total thickness 360 mm, surface mass 250.. 300 kg/m^2
- at all other levels 250 mm massive concrete floors with a 46 mm cement finish were used, resulting in a surface mass of 660 kg/m^2.

The roof:

- 200 mm hollow-core concrete slabs with 80 mm thermal insulation and bituminous material on top.

Facades (apart from the windows):

- end walls of the apartment building:
  - at ground floor level and at first and second floor level: cavity walls consisting (from the outside to the inside) of 100 mm brick – 30 mm air gap – 100 mm thermal insulation – 214 mm calcium silicate blocks; leafs connected by iron cramps
  - at 3rd, 4th and 5th floor level: cavity walls consisting of (from the outside to the inside) 100 mm brick – 30 mm air gap – 100 mm thermal insulation – 150 mm calcium silicate blocks; leafs connected by iron cramps
- lateral facades: cavity walls consisting of (from the outside to the inside) 100 mm brick – 30 mm air gap – 100 mm thermal insulation – 100 mm brick; leafs connected by iron cramps.

Separation walls inside the dwellings:

- 70 mm massive gypsum blocks with surface masses varying from 56 to 88 kg/m^2.

3 - MEASUREMENTS

3.1 - Coding of measurements

For airborne and impact sound insulation measurements:
Dwellings can be situated at the end of the building or in the middle of the building. These situations are encoded as K and M respectively. They may be also on different floor levels: ground floor (code 0) and 1st to 5th floor (codes 1 to 5 respectively). Furthermore measurements can be done between living rooms (code W) and/or bed rooms (code S) and in horizontal or vertical direction.
So, as examples: code K_W1W0 means a measurement between two living rooms (W) in a dwelling at the end of the building (K) from first floor (1) to ground floor (0) level in vertical direction, whereas M_W1//S1 means a measurement between a living room (W) and a bed room (S) both at first floor level (1) in the middle of the building (M), so in horizontal direction across the cavity (//).
For K_{ij}-measurements:
In a vertical section, across the cavity wall and the floors or across the facade and a floor, each junction consists of one (T-junction) or two (+-junction) floors, encoded 1 and 3, and always a cavity wall, encoded 2 above floor level and 4 beneath floor level. K_{ij} can be determined either across the cavity or not. So, K_{12} means K_{ij} from a floor to the directly connected leaf of the cavity wall and $K_{1//2}$ means K_{ij} from a floor across the cavity to a leaf in the adjacent dwelling.
In a horizontal section, across the lateral facade and a cavity wall code 1 means the cavity wall and codes 2 and 4 mean the lateral facades on each side of the cavity wall.

3.2 - Measurements

Airborne and impact sound insulation, D_{nT} and L_{nT} respectively, between rooms are determined:

$$D_{nT} = L_1 - L_2 + 10\lg\frac{T}{T_0} \qquad L_{nT} = L_2 - 10\lg\frac{T}{T_0}$$

L_1, L_2 are the averaged sound pressure levels (dB) in source and receiving room respectively; T is the receiving room reverberation time (s); T_0 = 0,5 s
Airborne and impact sound insulation have been determined in third-octave band. The results are presented here by means of the single number quantities and their spectrum adaptation terms D_{nTw} *(C; C_{tr})* and L_{nTw} *(C_l)* respectively, calculated according to ISO 717.
Vibration reduction index K_{ij} (dB):

$$K_{ij} = \bar{D}_{vij} + 10\lg\frac{l_{ij}}{\sqrt{\alpha_i\alpha_j}} \qquad \alpha_i = \frac{2,2\pi^2 S_i}{cT_{s,i}}\sqrt{\frac{f_0}{f}}$$

$$D_{v,ij} = L_{vi} - L_{vj} \qquad \bar{D}_{v,ij} = \frac{D_{v,ij} + D_{v,ji}}{2}$$

L_{vi}, L_{vj} are the velocity levels (dB) of source and receiving element respectively; $D_{v,ij}$ is the junction velocity level difference between excited element i and receiving element j; l_{ij} is the coupling length (m) of the common junction between elements i and j; α_i, α_j are the equivalent absorption lengths (m) of elements i and j resp., calculated in the same way from their structural reverberation times and areas; S_i is the area of element i (m^2); c the speed of sound in air (m/s); f is the center band frequency (Hz); T_s is the element structural reverberation time (s); f_0 = 1000 Hz
K_{ij} has been determined in third-octave bands by exciting the source element by means of the standard tapping machine and measuring the velocity levels of source and receiving element and the structural reverberation time. Results are presented here by means of some form of single number quantity, the linear average of K_{ij} over the frequency range of the octave bands 250, 500 and 1000 Hz.

4 - RESULTS

Table 1 shows the results of the measurements and the calculations of airborne and impact sound insulation between different rooms.
Minimal requirements are D_{nTw} *(C; C_{tr})* $\geq$ 52 (-2; -6) dB and L_{nTw} *(C_l)* $\leq$ 71 (-11) dB.
As can be seen from this table the agreement between the results of measurements and calculations is quite good for the first four cases, all of them concerning dwellings above each other where sound transmission via the cavity is of less relevancy. The differences are 1 or 2 dB, for airborne as well as for impact sound insulation.
In those situations in which sound transmission takes place across the cavity, there is a discrepancy between measurement and calculation results.
For airborne sound insulation, there are two cases:

- in the first one the calculated value of D_{nTw} is 15 dB higher than the calculated one; if the measured values of K_{ij} are used as input data for the calculation model there is only 1 dB difference
- in the second one it is the other way round: a good agreement between measurement and calculation result and 8 dB difference when using the measured K_{ij}-values for the calculations.

For impact sound transmission the picture seems to be more clear: in both cases the measured impact sound levels are 15 dB higher than the calculated ones; this difference decreases to 3 to 5 dB when using the measured K_{ij}-values in the calculations.

	D_{nTw} *(C; C_{tr})* (dB)			L_{nTw} *(C_l)* (dB)		
meas.code	meas.	calc.	calc.2	meas.	calc.	calc.2
K_W1W0	57 (-2; -5)	56 (-2; -5)	55 (-2; -5)	65 (-12)	64 (-10)	64 (-10)
M_W1W0	54 (-1; -4)	56 (-2; -6)	56 (-2; -6)	64 (-11)	64 (-11)	64 (-11)
K_W4W3	57 (-1; -6)	55 (-1; -5)	55 (-1; -5)	65 (-11)	64 (-10)	64 (-10)
M_W4W3	55 (-1; -4)	56 (-2; -6)	56 (-2; -6)	63 (-11)	64 (-11)	64 (-10)
M_W1//S1	61 (-1; -3)	76 (-3; -10)	62 (-1; -6)	37 (-4)	22 (-2)	40 (-4)
M_W4//S4	70 (-1; -4)	71 (-2; -7)	62 (-1; -5)	38 (-8)	23 (-4)	43 (-6)

Table 1: Survey of the results of measured and calculated airborne and impact sound insulation.

In table 2 the measured and calculated values of K_{ij} are given for the junctions which are relevant for the sound transmission in vertical direction. It concerns +- and T-junctions between homogeneous building elements or outer cavity walls of which the leafs are connected by iron cramps.
The agreement between measurement and calculation results is rather good in those cases where the junction consists of two simple homogeneous elements: floor and one leaf of the cavity wall, not connected to the other leaf.
For those T- junctions including the facades the agreement is less good: differences of 4 to 6 dB occur for the vertical T-junction till up to 10 dB for the horizontal T-junction. Especially the calculated values of K_{ij} for the facade-facade path (K_{24}) in horizontal direction are 10 dB higher than the measured ones.

situation	junction	K_{12} (dB)		K_{24} (dB)	
		meas.	calc.	meas.	calc.
150 mm leaf	+	6,7	7	10,4	12
				11,0	
	T, vertical, end facade	8,4	7	11,5	15
	T, horizontal, lateral facade	-	-	25,2	35
214 mm leaf	+	5,3	6	9,4	10
		5,9			
		3,7			
	T, vertical, end facade	2,9	7	8,7	15
	T, horizontal, lateral facade	-	-	29,0	39
	T, vertical, lateral facade, with balcony	6,9	7	14,7	15
				14,9	

Table 2: Survey of results of K_{ij}-measurements between coupled building elements (not across the cavity), relevant for the sound insulation in vertical direction, compared with some calculated values.

In table 3 the measured and calculated values of K_{ij} are given for the junctions which are relevant for the sound transmission in horizontal direction. It concerns only +- junctions between homogeneous floors and cavity walls of which the leafs are not connected to each other.
Only $K_{1//2}$ and $K_{1//3}$ are relevant for the sound insulation in horizontal direction. The value of $K_{2//2}$ is not calculated by the computer model. No calculation has been done in a diagonal direction, but $K_{2//4}$ can be compared to $K_{2//2}$.
For $K_{1//2}$ the calculations yield a 13 to 15 dB higher value than the measurements; for $K_{1//3}$ this is even more than 20 dB.
The computer model seems to overestimate the vibration transmission indices highly when it concerns transmission across cavity walls.

Situation	junction	$K_{1//2}$ (dB)		$K_{1//3}$ (dB)		$K_{2//2}$ (dB)		$K_{2//4}$ (dB)	
		meas.	calc.	meas.	calc.	meas.	calc.	meas.	calc.
150 mm leaf	+	23,7	39	22,6	47	17,7	-	30,5	-
						27,5			
214 mm leaf	+	25,2	38	23,7	46	18,2	-	23,3	-
		24,0		25,0		17,4			
		23,7							

Table 3: Survey of results of K_{ij}-measurements across the cavity, relevant for the sound insulation in horizontal direction, compared with some calculated values.

Table 4 shows the increase of K_{ij} measured in only one direction when one leaf of the cavity wall is excited on the fifth floor (source element) and all the other leafs directly underneath it on the 4th, 3rd, 2nd 1st and ground floor act as receiving elements.
Every time a floor is met K_{ij} increases by 3 to 4 dB but a sudden increase in K_{ij} can be found when at the junction between second and third floor level the leaf increases in width from 150 mm to 214 mm. In most calculation models data are only available for junctions where the elements at either side of the junction in the same plane have the same mass

receiving element on	leaf thickness (mm)	K^*_{ij} (dB)
fourth floor	150	10,7
third floor	150	15,1
second floor	214	23,5
first floor	214	26,4
ground floor	214	28,9

Table 4: Increase of K_{ij} by transmission of vibrations over several storeys.

5 - CONCLUSIONS

In multy-family houses with two types of cavity brick walls between dwellings the airborne and impact sound insulation between dwellings have been measured and calculated. Calculations were done twice: once using the calculated vibration reduction indices and once using the measured vibration reduction indices as input data in the calculation model. Vibration reduction indices have been determined between building elements forming different types of junctions.
For junctions that consist of homogeneous building elements a good agreement was found between the measured and the calculated vibration reduction indices and, as a consequence, also between the measured and calculated airborne and impact sound insulation in vertical direction. With respect to the latter, negligible differences seemed to occur between junctions with 150 mm leafs and those with 214 mm leafs of calcium silicate blocks.
For junctions that (partly) consist of cavity walls the calculated vibration reduction indices were found to exceed the measured ones by 10 to 20 dB. Consequently, the calculated airborne and impact sound insulation in horizontal direction sketched a rather positive picture compared with the measured sound insulation when based on the calculated vibration reduction indices. Using the measured values of the vibration reduction indices as input data for the calculation reduced these large differences to acceptable ones.
A closer examination of the calculation of vibration reduction indices across cavity walls seems necessary.

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