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DESIGN OF DANISH BUILDINGS WITH HIGH SOUND INSULATION

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ABSTRACT
Danish building constructions with high sound insulation are described. The constructions are used in academies of music or dwellings with airborne sound insulation around 60 dB or higher. R'_w-values of 85-90 dB are obtained with a combination of heavy building elements, floating floors and linings. At 50 Hz R' can be 50-55 dB. Values for the measured sound insulation in-situ are compared with predicted values using the new European standard EN 12354-1, and the agreement is satisfactory. Differences between heavy and lightweight constructions are demonstrated from a considerable number of in-situ measurements. For both airborne and impact sound insulation it is important to take low frequencies into account when the acoustic quality of lightweight constructions is evaluated.

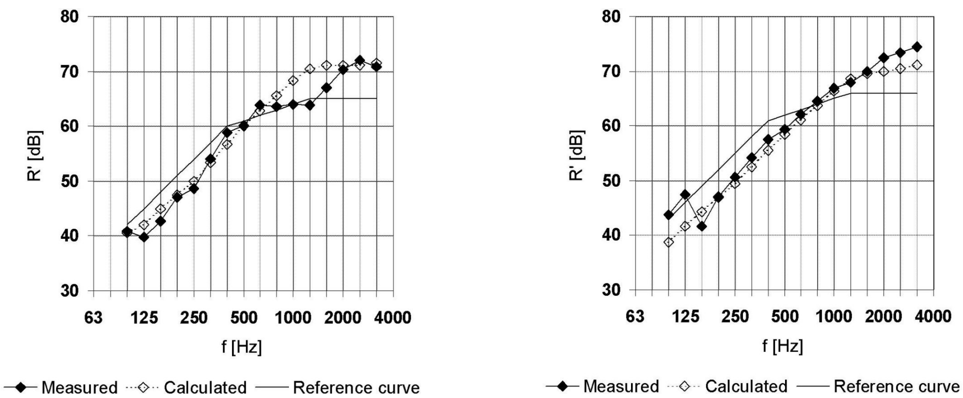
1 - INTRODUCTION
The acoustic requirements to building constructions are increasing in several countries. This paper presents measurement results from Danish dwellings with R'_w-values around 60 dB and from academies of music where the required sound insulation is even higher. Examples of building constructions are described, and it is demonstrated that the sound insulation can be predicted with the European standard EN 12354-1 [1] with satisfactory accuracy, provided that all necessary input data for floating floors, linings etc. are available.
Because of the mass-spring-mass resonance the sound insulation is often poor in the low frequency range for lightweight double constructions. The same tendency is expected when for example linings are used. Therefore, the frequency range below 100 Hz is considered in this paper especially for combinations of heavy constructions with additional layers and for lightweight double constructions.

2 - DWELLINGS WITH CONCRETE FLOORS AND LIGHTWEIGHT WALLS
In case of lightweight internal walls and large floor slabs between load-bearing walls or columns, the sound transmission is determined by the vibrations of the total floor area [2]. Since the vibration energy of the separating floor between two rooms is spread to a larger floor area, the sound insulation vertically is higher than for the same slab with heavy internal walls. The sound insulation is also increased because of a small amount of flanking transmission via internal lightweight double walls. In Danish buildings R'_w-values within the range 59-64 dB have been obtained for 160-220 mm massive concrete floors with wooden floors on joists on soft boards. The cavity depths under the wooden floors are 80-100 mm. In order to obtain the mentioned R'_w-values, the cavities normally have to be provided with a 50 mm thick layer of mineral wool. Figure 1 shows measured and calculated sound insulation for a system of 160 mm concrete floors with wooden floors, supported by 160 mm concrete inner leaves at the facades and concrete columns inside the building. Internal walls are double plaster board walls. The measured R'_w-values are 61 dB and 62 dB respectively, and reference curves corresponding to these values are shown in the figure. The calculated values for the sound insulation are predicted with the European standard EN 12354-1. Input data from the informative annexes of this standard are used with the following modifications [3]:

- The radiation factor is limited by a maximum value of 1;

- The value of the sound reduction index around the critical frequency is taken to be at least the same as the highest value calculated for lower frequencies; this means that the curve showing the sound reduction index as a function of the frequency is flat around the critical frequency;
- The calculated sound reduction index is corrected by 5 lg(m'/200), where m' is the mass per unit area of the element [kg/m^2].

For wooden floors on joists the sound reduction improvement measured in a laboratory is used. Comparisons between predicted and measured values in figure 1 show good agreement.



(a) (b)

Figure 1: Two examples of sound insulation for a 160 mm thick concrete floor with wooden floor on joists.

3 - ACADEMIES OF MUSIC

Measurements of airborne sound insulation have been performed in academies of music for an extended frequency range down to 50 Hz. The measurements were carried out as described in EN ISO 140-4 for the frequency range 100-3150 Hz but with stricter requirements regarding measurement periods, number of source positions etc.

The left hand graph of figure 2 shows the measurement result for a 230 mm thick brick wall with linings of 2 × 12.5 mm plaster board without connections to the wall on each side. The cavities are 100 mm deep and provided with mineral wool. The flanking constructions are:

- 350 mm thick brickwork façade with the same lining as described above;
- Lightweight double internal wall;
- Approximately 200 mm concrete floor with 2 × 19 mm plaster board on 50 mm mineral wool;
- 180 mm hollow concrete slab with a suspended ceiling of 2 × 12.5 mm plaster board.

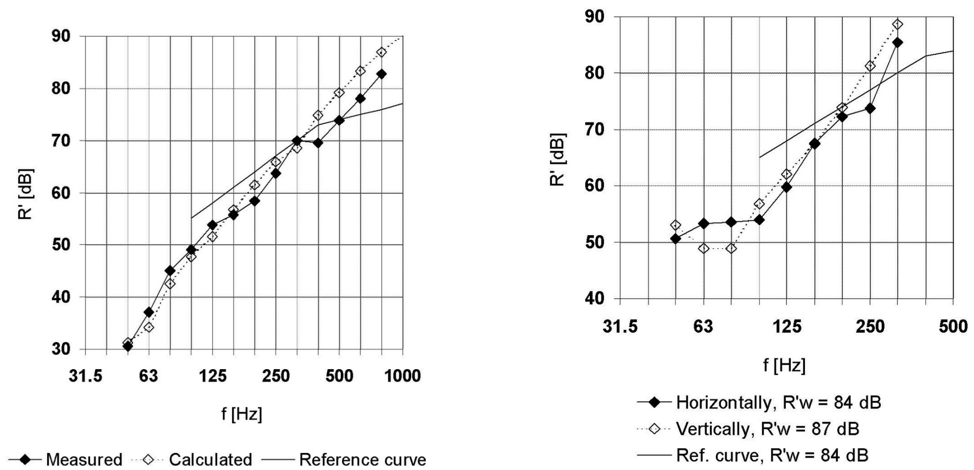
Predicted values using the same procedure as described in section 2 are also given in figure 2. Because of lack of measurement data for the floating floor, the sound reduction improvement was taken from laboratory measurements for a 50 mm thick floating concrete floor on 30 mm mineral wool. For the linings the sound reduction improvement was calculated as described in [4]. The measured and calculated R'_w-values are 74 dB and 75 dB respectively. The sound transmission has been analysed for different transmission paths with the prediction model, and subjective investigations took place by listening to the vibrations of the surfaces in the building. It turned out that the relatively low sound insulation at 50-63 Hz was related to the mass-spring resonance of the linings, and that flanking transmission through the floor was very important at higher frequencies.

In figure 2 measurement results are also given for constructions with more efficient linings and floating floors (right hand graph). Predictions have not been possible because no data were available for the sound reduction improvement of the applied floating concrete floors. The constructions in the building are:

- Separating walls of 230 mm brickwork with linings on each side;
- Façade inner leaves of 170 mm brickwork with linings;

- Lightweight double inner walls;
- 220 mm concrete floors with 80 mm floating concrete on 100 mm mineral wool and on the top a wooden floor on joists with mineral wool in the cavity; suspended ceilings.

All linings and suspended ceilings are 3 × 12.5 mm plaster board mounted with rubber vibration isolators and a cavity depth of 150 mm, including 100 mm mineral wool. The linings are placed on the floating floors. The total thickness of the separating wall construction is 610 mm, and the mass per unit area is approximately 450 kg/m^2. In other buildings with 200 mm thick concrete walls and linings R'$_w$-values up to 90 dB have been measured.



(a) (b)

Figure 2: The left hand graph shows the sound insulation for 230 mm brickwork with 125 mm linings on both sides; the right hand graph shows the measured sound insulation for 230 mm brickwork with 190 mm linings on both sides and for a 220 mm concrete floor with suspended ceiling, floating concrete floor and wooden floor (total thickness approx. 700 mm).

4 - LIGHTWEIGHT CONSTRUCTIONS

In a considerable number of dwellings airborne and impact sound insulation have been measured in a wide frequency range including very low frequencies. In figures 3, 4, 5 the sound insulation for conventional heavy constructions with floorings or floating floors is compared with results from new buildings with lightweight double constructions. Each curve shows the average for 9-10 measurements for heavy constructions and 4-5 measurements for lightweight constructions. Measurement results are shown both with and without corrections for the absorption of the receiving room, because the reverberation time was not measured below 50 Hz. Results are missing at some frequencies because of background noise. The lightweight constructions are typically 300-400 mm thick, and the walls are provided with 2-3 layers of plaster board on each side. Lightweight floors are heavier and more complicated than walls, partly because heavier materials have been used in the constructions, and partly because the load bearing system of steel or wood of course is more elaborated for floors than for walls.
Figures 3, 4, 5 show that above 100 Hz the sound insulation is higher for the lightweight double constructions than for the conventional heavy constructions. In average R'$_w$ is 61 dB for all lightweight constructions investigated. However, it is clearly demonstrated that at very low frequencies the heavy constructions have a higher sound insulation than lightweight double constructions. The difference between lightweight and heavy constructions is 7-20 dB at 25-50 Hz. Thus, high R'$_w$- and low L'$_{n,w}$-values for lightweight constructions are not sufficient for obtaining a high acoustic quality. Extending the frequency range down to 50 Hz and introducing the relevant adaptation terms in informative annexes of EN ISO 717 will to some extent take this into account.

5 - CONCLUSION

Measurement results from new Danish dwellings with R'$_w$−values around 60 dB have been presented in this paper. Both heavy constructions with wooden floors on joists and lightweight constructions are included. The presented values of R'$_w$ are 5-8 dB higher than in typical existing Danish dwellings where the sound insulation fulfils the requirements of the Danish building code. However, for new lightweight

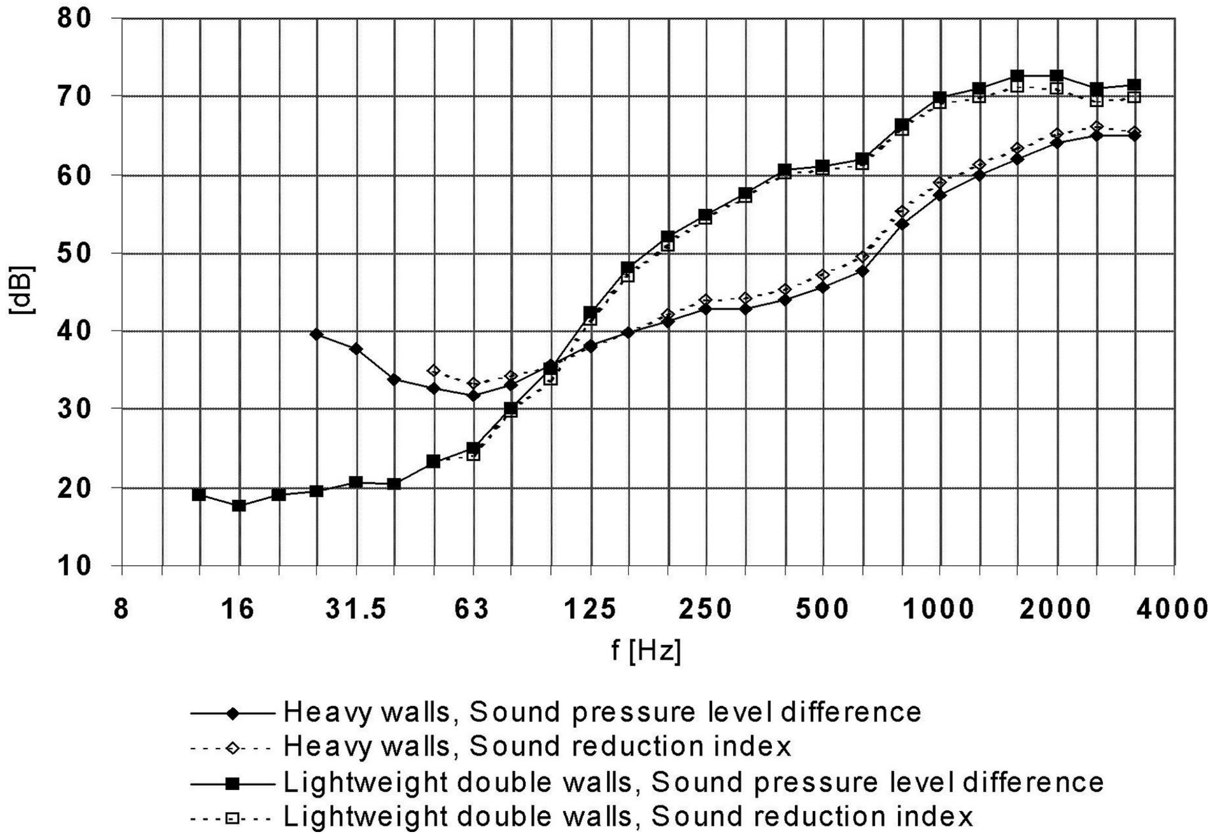


Figure 3: Airborne sound insulation horizontally, average for different buildings.

double constructions with R'_w−values around 60 dB, the sound insulation at low frequencies is lower than for conventional Danish building constructions used in existing dwellings. This is the case for airborne as well as impact sound insulation. Extension of the frequency range down to 50 Hz and application of spectral adaptation terms according to informative annexes of EN ISO 717 part 1 and 2 can improve the evaluation of sound insulation.

The standard for prediction of sound insulation, EN 12354-1 has proved to be useful when new constructions are introduced, provided that acoustic data are available for all constructions of the building. This has been demonstrated for constructions used in dwellings and in academies of music where the acoustic requirements are considerably higher. For Danish buildings lack of reliable acoustic data for floating floors is probably the most serious limitation for application of the standard in buildings with high sound insulation.

ACKNOWLEDGEMENTS

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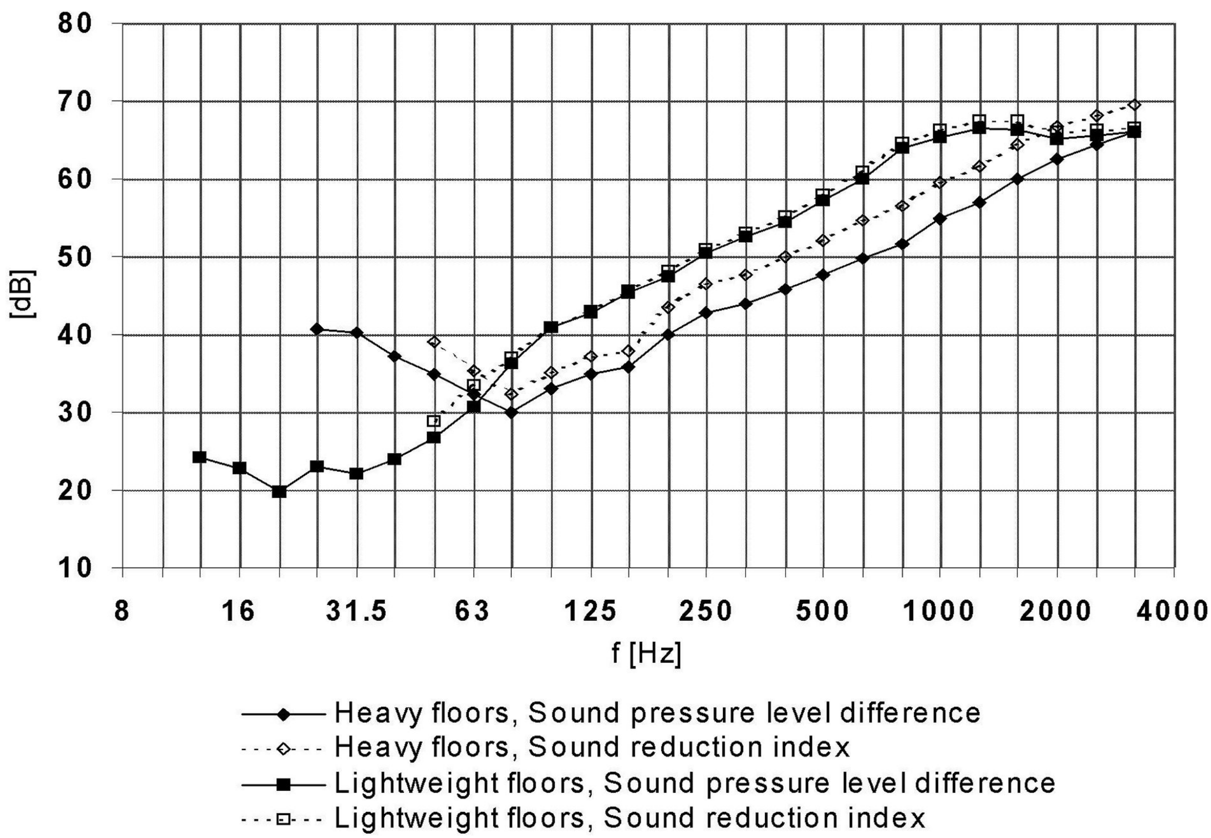

Figure 4: Airborne sound insulation vertically, average for different buildings.

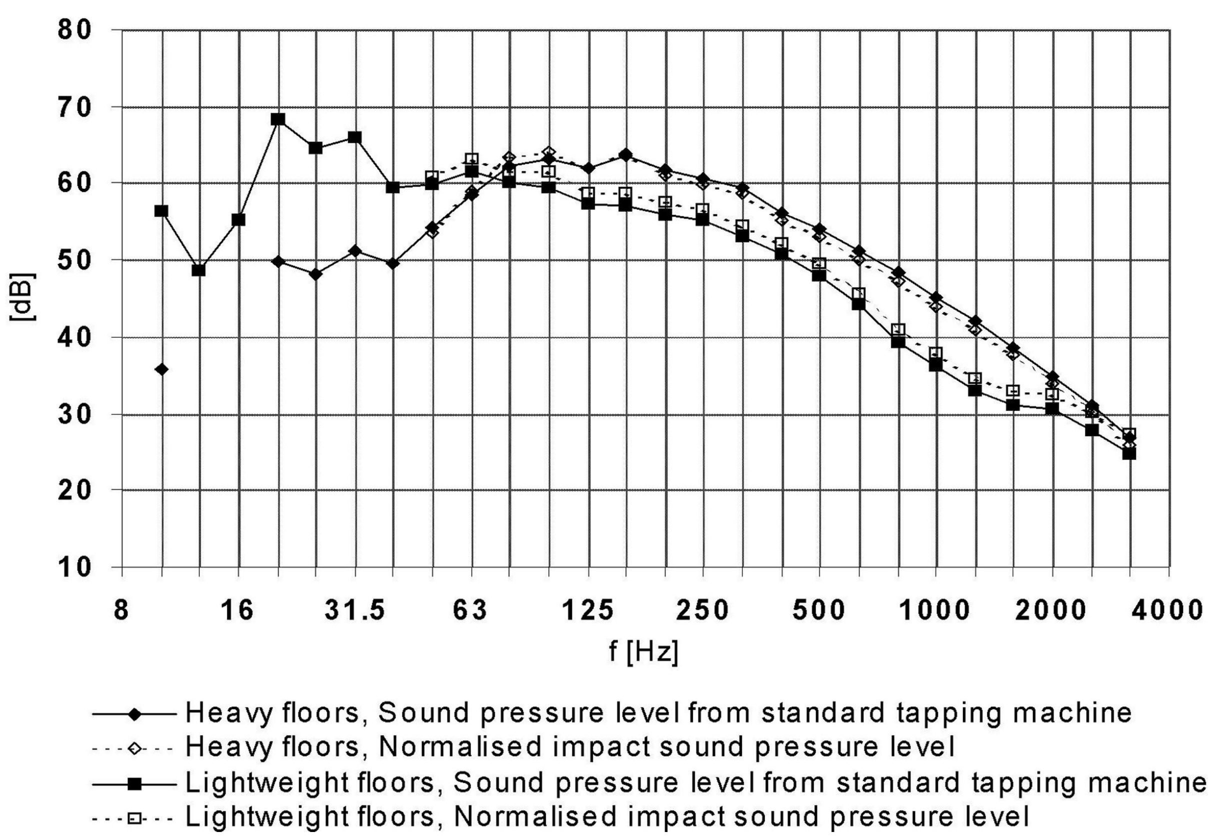

Figure 5: Impact sound insulation vertically, average for different buildings.