PREDICTED EFFICIENCY OF VIBRATION ISOLATORS FOR EQUIPMENT INSTALLED IN HEAVYWEIGHT AND LIGHT-WEIGHT CONSTRUCTIONS

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This work aims at evaluating the reduction in structure-borne sound power of building service equipment installed in heavy or lightweight constructions due to the use of vibration isolators. The example of an individual dual-flow ventilation unit is considered. The ventilation unit is characterized in the laboratory using the reception plate method following EN 15657. All source characteristics, i.e. equivalent blocked force level, equivalent free velocity level and equivalent mobility, are determined with and without vibration isolators at the connections to the receiving structure. These quantities are then used as input data in the prediction model of EN 12354-5 in order to estimate the amount of noise radiated by a heavyweight or lightweight supporting wall. Prediction results are presented and show the influence of the supporting wall on the efficiency of the vibration isolators.
Keywords: structure-borne sound, vibration, service equipment, lightweight buildings

1. Introduction

Noise produced in buildings by service equipment can cause annoyance for the occupants and is often subject to performance requirements in building codes or certification schemes. While air-borne noise can be easily addressed using common mitigation measures and design tools, structure-borne noise implies more complex physical phenomena, where the amount of injected power depends on both the source (equipment) and the receiver (supporting wall or floor). Common practice uses vibration isolators placed at the contacts between the source and the receiver, but no standard design methods are available to ensure that the required performance will be fulfilled in the completed building. This work aims at demonstrating the possibility to account for the presence of vibration isolators in predictions of noise generated in situ using existing standards, as well as the need to account for the dynamic characteristics of the supporting structure when designing mitigation measures.

To that end, a case study is conducted on a dual-flow ventilation unit. The equipment structure-borne sound characteristics of are measured in the laboratory, with and without vibration isolators, following the new version of EN 15657 [1]. These characteristics are the equivalent blocked force level $L_{Fb,eq}$ (in dB ref. 10^{-6} N), the equivalent free velocity level $L_{vf,eq}$ (in dB ref. 10^{-9} m/s) and the equivalent mobility $Y_{S,eq}$ (in m/(N.s)). Knowing the mobility of the receiving structure $Y_{R,eq}$, it is then possible to predict the installed power level according to the following relationship :

$$L_{Ws,inst} \approx 10 \lg \left[\frac{Re(Y_{R,eq})}{|Y_{S,eq}|^2 + |Y_{R,eq}|^2} \right] + L_{vf,eq} + 60 \quad (1)$$

In case the receiver mobility is much lower than the source mobility, Eq. (1) can be simplified as:

$$L_{Ws,inst} \approx L_{Fb,eq} - 10\lg\left(Re\left(Y_{R,eq}\right)\right) \tag{2}$$

This installed power level can then be used as input data in the calculation model of EN 12354-5 [2] (currently under revision to include lightweight construction) to predict the sound pressure level radiated in a neighboring room. Predictions are made by considering two different receiving structures: one made of concrete and representing heavy constructions, and the other one representing light timber frame constructions.

The piece of equipment under study is described in section 2 of this paper. In section 3, the laboratory characterization method is described and the resulting characteristics of the ventilation unit are presented. In section 3, the prediction method and hypotheses are presented, as well as the predicted sound pressure level in situ. Results obtained with and without vibration isolators are then compared and discussed.

2. System under study

In this work, a dual-flow mechanical ventilation unit for individual dwellings is considered as case study. It comprises a system of 2 fans to extract air from the dwelling and provide fresh air from outside simultaneously. 4 circular connectors allow connecting the unit to the ductwork. The airflow rate in both branches (exhaust air and fresh air) can be set to a constant value. Two operating points are considered here: 150 m^3/h is a representative value for individual dwellings and 370 m^3/h is the highest airflow achievable by this particular ventilation unit.

The equipment can be installed vertically on a wall or horizontally on the ceiling. In this study, only the vertical installation is considered. The ventilation unit is fixed to the wall using a set of 4 brackets equipped with removable vibration isolators (see Fig. 1). Note: this ventilation unit is usually installed using a mounting cradle (without vibration isolator) instead of the brackets.

Figure 1: Rigid mounting (left) and mounting with vibration isolator (right).

3. Influence of the vibration isolators on the equipment characteristics

The ventilation unit is characterized in the laboratory in terms of equivalent blocked force level, free velocity level and mobility. The characterization is performed with and without vibration isolators on the mounting brackets in order.

3.1 Characterization method

The indirect method of EN 15657 is applied using reception plates. The low mobility reception plate is made of 10 cm thick concrete and the high mobility reception plate is made of 1 mm steel with 48 % perforation rate and 6 mm perforation diameter. Vibration velocity measurements are performed on the reception plates when the ventilation unit is operating. The corresponded injected structure-borne sound power levels $L_{Ws,low}$ and $L_{Ws,high}$ are determined using the power substitution method. Knowing the equivalent mobilities of the reception plates (input mobility averaged over the contact points), respectively $Y_{R,low,eq}$ and $Y_{R,high,eq}$, it is then possible to estimate the equivalent blocked force level and free velocity level according to the following relationships:

$$L_{Fb,eq} \approx L_{Ws,low} - 10\,\lg\left(Re\left(Y_{R,low,eq}\right)\right) \tag{3}$$

$$L_{vf,eq} \approx L_{Ws,high} + 10\,\lg\left[\frac{\left|Y_{R,high,eq}\right|^2}{Re\left(Y_{R,high,eq}\right)}\right] + 60 \tag{4}$$

In order to avoid unwanted excitation of the reception plates, pieces of ductwork are placed at the connectors to deviate the airflows going in and out of the ventilation unit (see Fig.2). The pressure loss due to these elements probably differs from that of real ventilation ductwork in situ. As a consequence, this may affect the operating point of the ventilation unit.

Note: the new version of EN 15657 does not give any recommendation about the use of associated elements when these elements may affect the operating condition, e.g. and diffusers for ventilation units, ductwork and heaters for boilers, etc.

Finally, the source equivalent mobility is deduced from the equivalent blocked force and free velocity level following:

$$\left|Y_{S,eq}\right|^2 \approx 10^{\left(L_{vf,eq} - L_{Fb,eq}\right)/10}.\,10^{-6} \tag{5}$$

Note: in case the equivalent blocked force and free velocity levels are determined for different operating points, this may lead to different estimations of the equivalent mobility, although this quantity is supposedly independent from the equipment activity.

Figure 2: Ventilation unit mounted on the high mobility reception plate.

3.2 Characterization results

3.2.1 Equivalent blocked force

The measured equivalent blocked force level of the ventilation unit is represented in Fig. 3. For the two considered values of airflow rate, the equivalent blocked force level is reduced by 2 to 6 dB in third octave bands 50 Hz to 400 Hz when vibration isolators are used. According to Eq. (2), the same reduction of the radiated sound pressure level can be expected in this frequency range when the ventilation unit is installed on a low mobility supporting structure. Little variation on the equivalent blocked force level is observed in third octave bands 500 Hz and higher. The absence of data at 5000 Hz is due to poor signal-to-noise ratio when measuring the reception plate equivalent mobility.

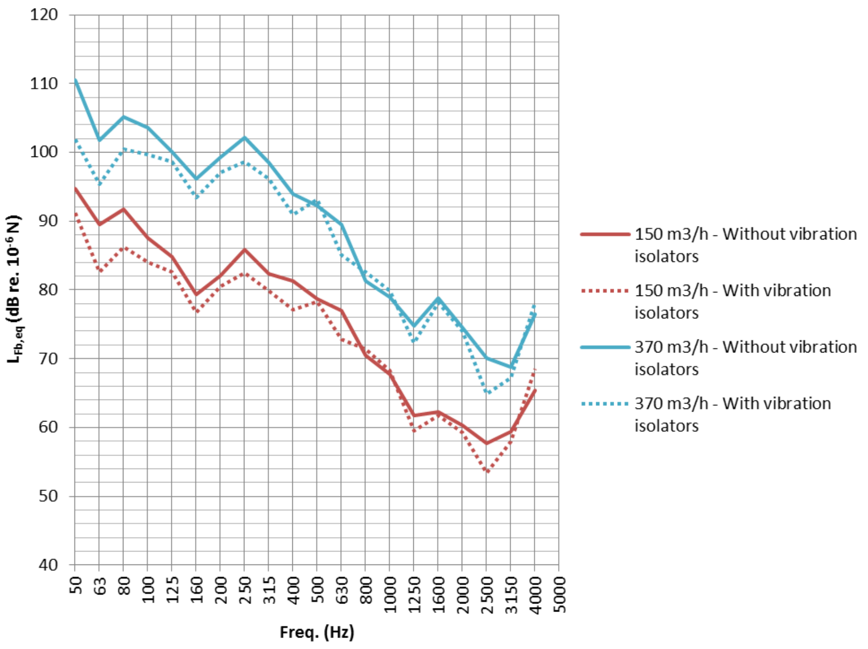

Figure 3: Equivalent blocked force level of the ventilation unit.

3.2.2 *Equivalent free velocity*

The measured equivalent free velocity level of the ventilation unit is represented in Fig. 4. The influence of the vibration isolators is significantly different here. Indeed, the equivalent free velocity level is almost the same at low frequencies with and without vibration isolators. Around 200 and 250 Hz, the equivalent free velocity level is even higher by 2 to 4 dB in presence of isolators. The free velocity level is significantly reduced in presence of vibration isolators between 500 and 1250 Hz; however the equipment activity in this frequency range is rather low. Some values are missing in high frequencies due to poor signal signal-to-noise ratio in the measurement of $L_{Ws,high}$.

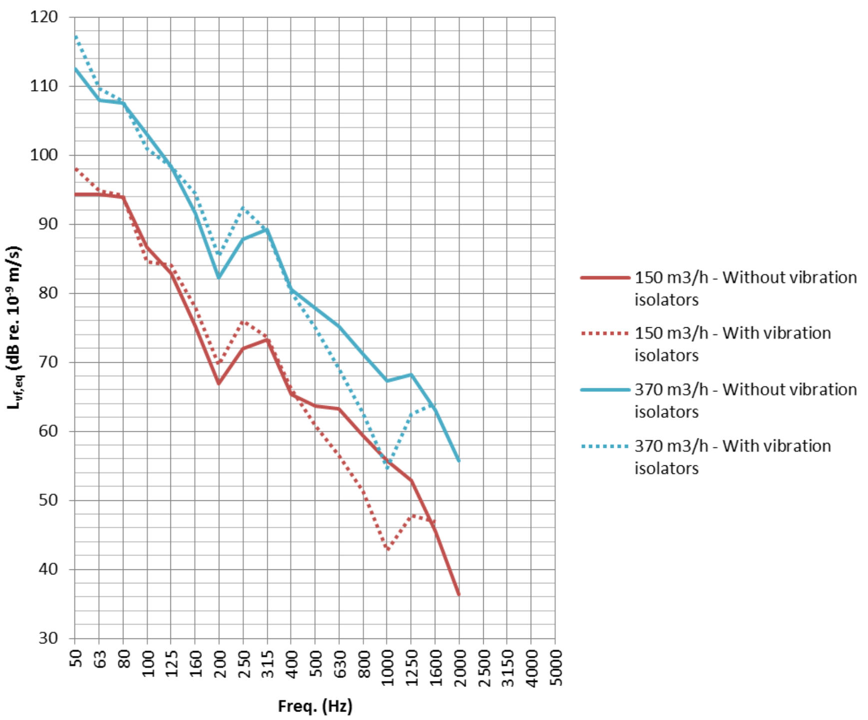

Figure 4: Equivalent free velocity level of the ventilation unit.

3.2.3 Equivalent mobility

The equivalent mobilities of the source and reception plates are represented in Fig. 5. It can be seen that the vibration isolators have a slight influence on the source equivalent mobility. However, the source mobility is practically independent from the equipment operating point.

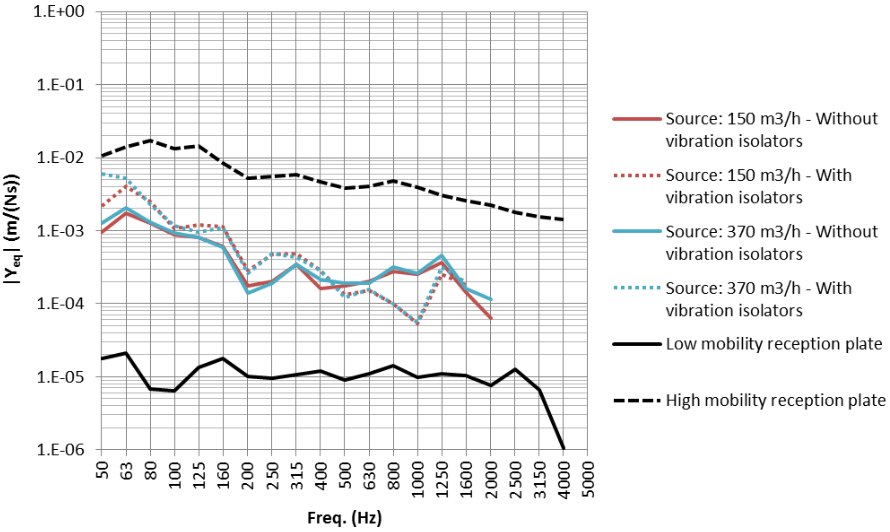

Figure 5: Equivalent mobility of the ventilation unit.

4. Influence of the vibration isolators on the equipment performance in situ

In this section, the equipment characteristics presented above are used as input data to predict structure-borne noise generated in situ for two typical heavy and lightweight constructions that are defined in Annex E of EN 15657.

4.1 Prediction method

In this study, the ventilation unit is virtually installed on two different supporting walls. The standardized sound pressure level L_{nT} in the adjacent room is calculated, considering direct transmission only. For heavy homogeneous constructions, EN 12354-5 gives the following relationship:

$$L_{nT} = L_{Ws,inst} - D_{sa} - D_n - 10\lg\left(\frac{S_i}{4}\right) - 10\lg(0.032V) \quad (6)$$

where D_{sa} is an adaptation term to the sound power level of an equivalent airborne sound (in dB), D_n is the normalized level difference between the emitting and receiving rooms (in dB), S_i is the surface area of the separating wall (in m²) and V is the volume of the receiving room (in m^3). Here S_i = 10 m² and V = 25 m^3. The terms D_{sa} and D_n are calculated using the on-site loss factor η_{situ} and radiation efficiency σ of the separating wall.

Note: so far EN 12354-5 is only valid for heavy homogeneous constructions. It is currently under revision in order to include lightweight constructions (work conducted within standardization group CEN/TC126/WG2). The current version is applied in this study for both types of construction and using available data.

4.2 Characteristics of the considered constructions

4.2.1 Receiver mobility

The following values are considered for the receiver equivalent mobility, 1.25 10^{-6} m/(Ns) for the heavy receiver and 10^{-3} m/(Ns) for the lightweight receiver. These mobility values are considered as invariant over frequency; the same value is used for the real part and magnitude of the lightweight equivalent mobility. Consequently, the installed structural sound power level is obtained using Eq. (1) for the heavy receiver and Eq. (2) for the lightweight receiver.

4.2.2 Loss factor

Previous studies showed that lightweight building elements without absorbing material had a similar loss factor as heavy masonry elements in situ [3, 4]. Consequently, the same loss factor is used for both receivers. It is obtained using Eq. (C.7) of EN ISO 12354-1 [5] Annex C.

4.2.3 Radiation efficiency

The radiation efficiency of the heavy receiver is taken from the database of building acoustic software AcouBAT [6]. For the lightweight receiver, an idealized spectrum obtained from laboratory measurements is used. Both spectra are represented in Fig. 6.

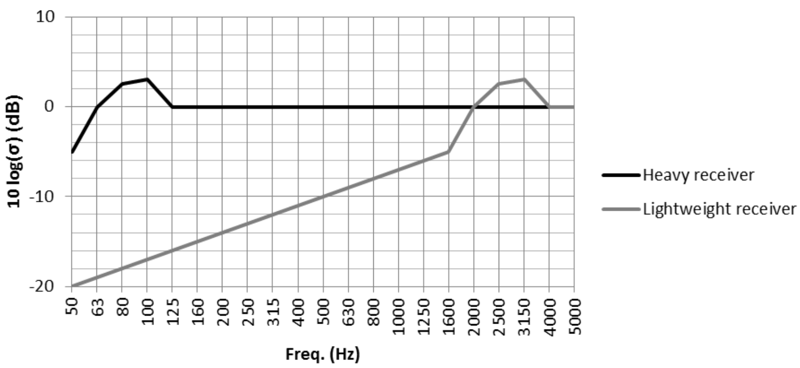

Figure 6: Radiation efficiency of the heavy and lightweight supporting walls.

4.3 Prediction results

The normalized sound pressure level in the adjacent room for the heavy receiver is represented in Fig. 7. Single number values are given in the legend as the A-weighted sound pressure level. As expected from the equipment equivalent blocked force level, a slight reduction of 2-6 dB is observed in frequency bands 50-400 Hz when vibration isolators are considered. At higher frequencies, this reduction is less significant. As a result, a 3 dB decrease of the A-weighted sound pressure level is due to the presence of the vibration isolators.

The normalized sound pressure level in the adjacent room for the lightweight receiver is represented in Fig. 8. Adding vibration isolators at the contacts results in a slight decrease of the sound pressure level at low frequencies, while a slight increase is observed around 200-250 Hz. Over 400 Hz, the structure-borne sound pressure level is significantly reduced. However, the A-weighted sound pressure level decreases by only 1 dB since most of the energy is contained in the low frequency range.

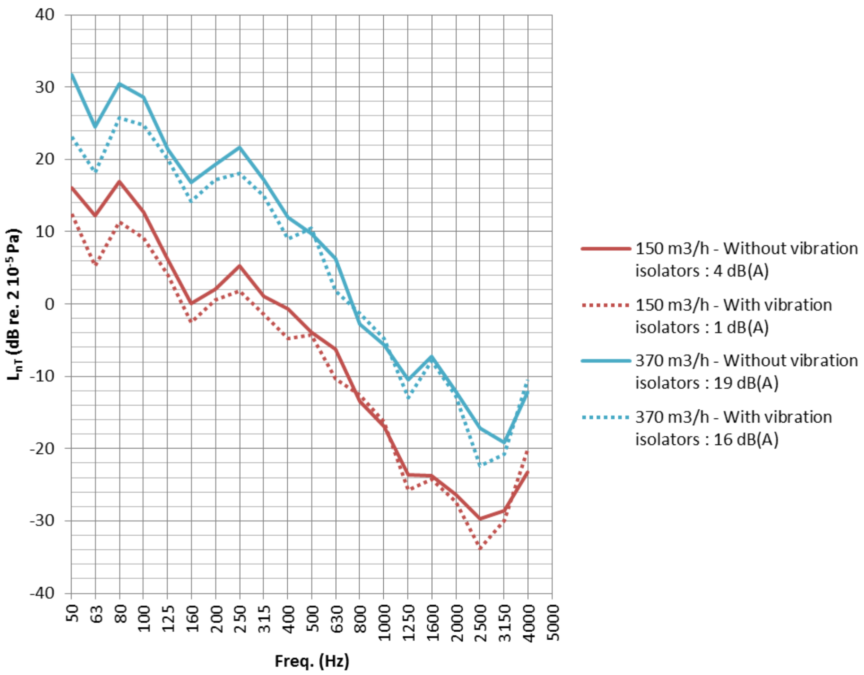

Figure 7: Predicted normalized sound pressure level generated by the ventilation unit installed in the heavy construction.

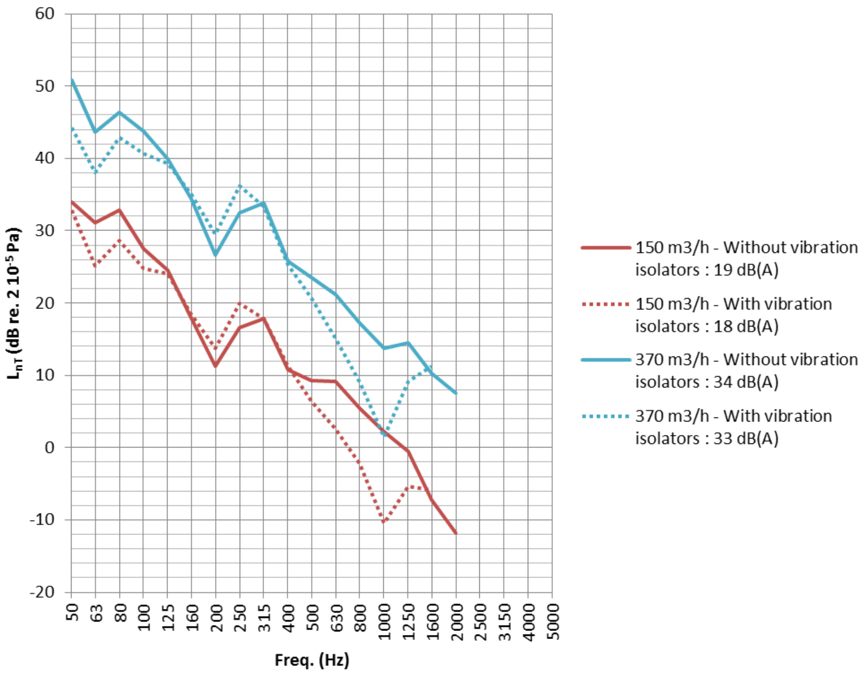

Figure 8: Predicted normalized sound pressure level generated by the ventilation unit installed in the light-weight construction.

5. Conclusions

In this work, a dual-flow ventilation unit was characterized in the laboratory following EN 15657. Its structural characteristics were determined with and without vibrations isolators at the connections. This characterization stage showed little influence of the vibration isolators on the equipment characteristics in the frequency range where its activity is important. Only a slight reduction in the blocked force level is observed in low frequency. From this observation, it is foreseen that the use of the vibration isolators can help reducing noise radiated by the supporting structure mostly in the case of a force source behavior, i.e. when the ventilation unit is installed in a heavy construction.

The equipment structural characteristics were then used to predict noise radiated by a heavy or a lightweight supporting wall using EN 12354-5. Results tend to confirm the expectation that the efficiency of the vibration isolators under study – probably designed for heavy constructions in the first place – are less adapted for installation in a lightweight building.

The predicted structure-borne sound pressure level due to direct transmission path is approximately 15 dB higher in the case of the lightweight building. Although no experimental verifications were conducted on site, this shows that special care should be given to the selection, mounting and setting of equipment installed in such constructions in order to fulfil acoustic performance requirements. In particular, it is recommended to consider the dynamic behavior of the equipment but also of the supporting structure when designing vibration isolators. The new version of EN 15657 together with the revision of EN 12354-5 should provide practical tools to ensure efficient mitigation of structure-borne noise from service equipment in different types of buildings.

6. Acknowledgements

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