Measurement of the Dynamic Stiffness of Porous Materials Taking into Account their Airflow Resistivity

Charlotte Crispin[1], Christian Mertens[2] and Juraj Medved[3]

[1,2]Belgian Building Research Institute (BBRI) - Acoustics Division

Lombardstraat 42 B-100 Brussel, Belgium

charlotte.crispin@bbri.be, christian.mertens@bbri.be

[3]STU Bratislava, Faculty of Civil Engineering, Department of Building Structures, Radlinského 11, 813 68 Bratislava 1, Slovakia

juraj.medved@stuba.sk

The dynamic stiffness of a resilient material used under a floating floor is often used to predict the improvement of the impact sound pressure level, L. It is also used to compare products. The measurement accuracy of this parameter is therefore essential. Unfortunately, the comparison between the predicted and the measured L results shows quite high deviations which could be attributed, in part, to an incorrect estimation of the dynamic stiffness. It is now accepted by all European laboratories that the measurement procedure described in the standard ISO 9052-1 should be reviewed. This paper proposes a first step in the improvement of the measurement setup by taking into account the actual contribution of the dynamic stiffness of the air enclosed in the materials on the total dynamic stiffness. A new setup is proposed and some results are presented for products with different airflow resistivities.

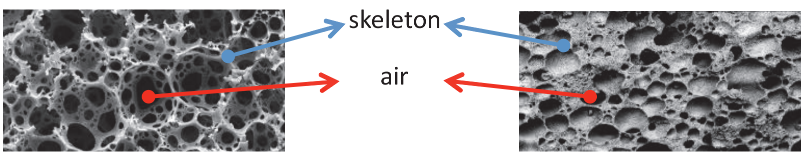
INTRODUCTION

The dynamic stiffness, s', of a material used under a floating floor is a property which can be used to predict the reduction of impact sound pressure level, ΔL on heavy base floors [1].

The standard ISO 9052-1 [2] specifies the method to determine the dynamic stiffness, s', per unit area of the resilient material. Unfortunately, the comparison between the predicted and the measured ΔL results shows quite high deviations which could be attributed, in part, to an incorrect estimation of the dynamic stiffness, s'. Some papers deal with the determination of the dynamic stiffness and raise different problems [3, 4, 5].

The dynamic stiffness, s', of a resilient material depends on the skeleton material stiffness, s'_S and on the stiffness of the air contained in pores, s'_a.

The dynamic stiffness of air contained in the material, s'_a, plays a more or less important role depending on its compression in the material during the dynamic stress. During the local dynamic excitation, in open cell materials, a certain amount of air will be expelled out of its cells and the degree of the air compression decreases. This degree depends, among other things, on the amplitude of the excitation, on the airflow resistivity in the transverse direction of the sample and on the



Open cell resilient material   Closed cell resilient material

Figure 1. Microscopic view of typical resilient materials

dimensions of it. The determination of the s'_s and s'_a contributions on the global dynamic stiffness can be relatively complex.

In laboratory, the measurement of the dynamic stiffness of resilient materials according to the ISO 9052-1 is carried out on relatively small samples (200 mm x 200 mm). In this way, the air trapped in the open cell material can be more easily pumped in and pumped out during the local dynamic excitation than in larger samples and leads to an underestimation of the air stiffness contribution. Hence, to predict its behaviour when applied under floating floors, the measurement results have to be corrected to take into account the air contribution. An approximate correction procedure, depending on the airflow resistivity of the sample, is proposed in ISO 9052-1.

The measurement procedure described in this paper proposes a simple and effective measuring method for the determination of the dynamic stiffness, s', taking into account the right contribution of the dynamic stiffness of the air for all types of products without any need to resort to the airflow resistivity and porosity measurements.

DETERMINATION OF THE DYNAMIC STIFFNESS ACCORDING TO THE STANDARD ISO 9052-1

The common method used for the determination of the dynamic stiffness is the measurement of the resonance frequency, f_0, of the mass-spring system where the mass is a steel plate of 200 kg/m^2 and the spring is the resilient material under test. The standard gives two measurement setups for open and closed cell resilient materials as shown in Figure 2.

The standardised result obtained is named the "apparent dynamic stiffness, s'_t " and is given by:

$$s'_t = (2\pi f_0)^2 . m' \qquad [\mathrm{N/m^3}] \qquad (1)$$

where f_0 is the resonance frequency of the system [Hz]; m' is the surface mass of the steel plate [kg/m^2]

The measurement of the dynamic stiffness of a material according to ISO 9052-1 is carried out on small samples (200 mm x 200 mm). For medium airflow resistivity materials, this method underestimates the air stiffness contribution because the air can be expelled from the sample unlike what happens under a floating floor. To take into account the air stiffness, the standard adds it to the measurement for resilient materials having an airflow resistivity between 10 kPa.s/m^2 and 100 kPa.s/m^2 as follows:

$$s' = s'_t + s'_a \qquad [\mathrm{MN/m^3}] \qquad (2)$$

where

s'_t is the apparent dynamic stiffness of the sample (200 x 200 mm^2) in MN/m^3;

s'_a is the dynamic stiffness of air contained in the material in MN/m^3;

Open cell resilient material Closed cell resilient material

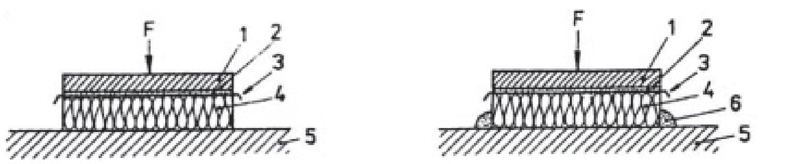


Figure 2. Dynamic stiffness measurement setups according the standard ISO 9052-1. (1.Load plate, 2. Quick setting plaster, 3. Foil, 4. Sample, 5. Base, 6. Petroleum jelly)

With,

$$s'_a = \frac{p_0}{\varepsilon . d} \text{ [MN/m}^3\text{]} \qquad (3)$$

p_0 is the atmospheric pressure, ε is the porosity of the material and d is the thickness of the sample. A simplified relation can be used considering a porosity around 0.9 and an atmospheric pressure of 0.1 MPa:

$$s'_a = \frac{111}{d} \text{ [MN/m}^3\text{]} \qquad (4)$$

where d is expressed in millimetres.

The measurement results for products with a high airflow resistivity ($r \geq 100$ kPa.s/m^2) or for closed cell resilient materials don't need a correction because in both small and large samples, the air is trapped and:

$$s' \cong s'_t \cong s'_s + s'_a \qquad (5)$$

For materials with low airflow resistivity ($r < 10$ kPa.s/m^2) only the skeleton material stiffness plays a role for any size of samples and:

$$s' \cong s'_t \cong s'_s \quad \textbf{(6)}$$

MEASUREMENT OF THE DYNAMIC STIFFNESS, S , WITH LARGE SAMPLES

With a large sample, during the local dynamic excitation, the enclosed air under the steel plate feels the real resistance (figure 3) and the right degree of compression of air is taken into account in the measurement.

In all cases, we have:

$$s' = s'_t \text{ ß}$$

The determination of the airflow resistivity is no longer needed overcoming its complex measurement. Indeed, the measurement of the airflow resistivity has to be carried out in the transverse direction of the sample and with the right static load [6, 7] asking some accommodations of the standard ISO 9053 [8]. The second source of possible error concerning the experimental determination of the porosity of the material is also eliminated.

A dimension of 1000 mm x 1000 mm for the sample is proposed for the measurement of the dynamic stiffness of the product (figure 4). A static-load of 200 kg/m^2 has to be applied on the top of it in order to ensure the right airflow resistivity. For the experimental test, a particle board loaded with sand bags is used. At its centre, a cut of 200 mm x 200 mm is done in order to introduce the steel plate needed for the measurement of s'_t.

Several tests have been carried out to compare the measurement results of s'_t for different common products. Apart from the particular measurement setup (see figure 5), the sample preparation and measurement method described in ISO 9052-1 is followed as closely as possible. The dynamic force is applied by a hammer hit and the acceleration is

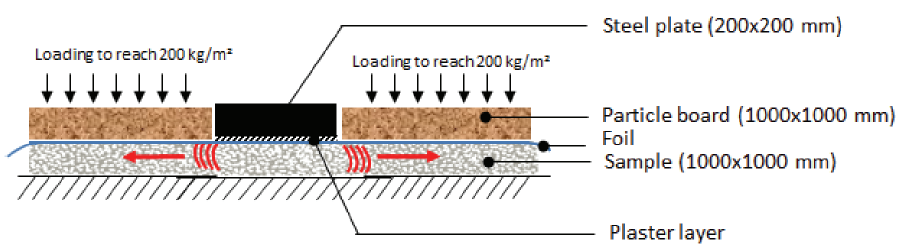


Figure 3. Diagram of the general principle

Figure 4. New test bench for the dynamic stiffness measurement

measured on top of the steel plate. A plastic foil is placed on the sample to avoid the expulsion of air through the gap around the steel plate between it and the particle board. A thin plaster layer is applied between the steel plate and the sample in order to ensure a good bonding between both. The samples are laid on a heavy concrete foundation.

- Test 1: This setup illustrates the new configuration (figure 5-1). A 1000x1000 mm^2 sample is used and covered by a loaded particle board (ca. 200 kg/m^2);
- Test 2: For this setup (figure 5-2), the sample is cut off to a 600x600 mm^2 sample and covered by a loaded particle board (ca. 200 kg/m^2);
- Test 3: This setup is performed always with the same sample but with the adjustment to the standardised size i.e 200x200 mm^2 without any lateral cover of petroleum jelly (figure 5-3). This setup corresponds to the standard setup for open-cell materials in ISO 9052-1 (see Figure 2). In this case, the enclosed air can easily be expelled. The contribution s'_a is the lowest for open cell materials.
- Test 4: The size of the sample is still 200x200 mm^2 but in this case, the lateral edges of the sample are covered with petroleum jelly *on the entire thickness* (figure 5-4). The enclosed air cannot escape and the contribution of s'_a is the highest. For open cell materials, the results of this setup should approach the results of Test 3 corrected with s'_a

$$s'_{t,test\ 4} \cong s'_{t,test\ 3} + s'_a \tag{8}$$

The measuring equipment is an impact hammer (PCB piezotronics – PCB 086D05, sensitivity 0.25 mV/N), an accelerometer (B&K Deltatron type 4396, sensitivity 10mV/ms^{-2}) and a dual channel PCMCIA data acquisition interface (01 dB Symphonie).

The airflow resistivity of each sample was measured by the CSTB acoustics laboratory.

TEST RESULTS

Six different open cell resilient materials have been tested in the four

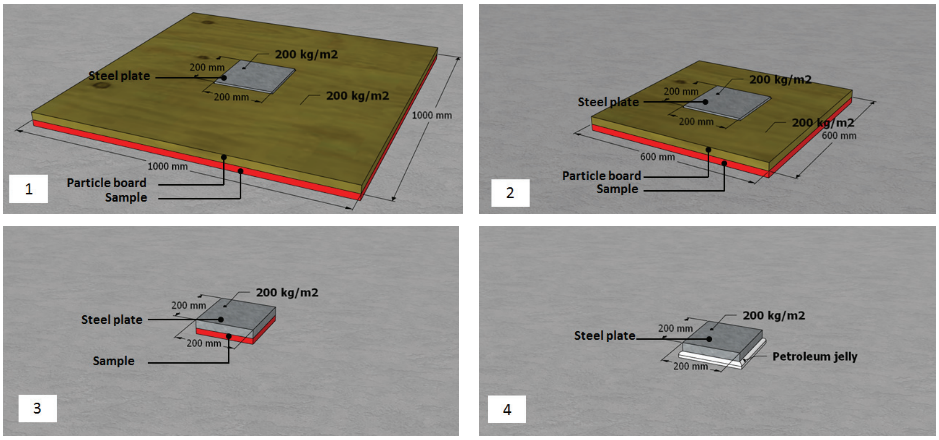


Figure 5. Sketch of four test configurations tested at BBRI laboratory

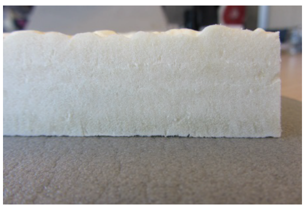
test configurations described above. Three samples for each product's type were tested (except for products 1 and 6) and five measurements were carried out for each sample. The graphs below present the average value of these five measurements for each sample and the standard deviation.

PRODUCT 1

The difficulty to prepare such a sample in a repeatable way explains the fact that we tested only one. If we analyse the results of this product, we can see an increase of 7% when the sample expands from 200x200 mm^2 to 600x600 mm^2 and 25% if it is expanded to 1000x1000 mm^2. The measurement of the airflow resistivity failed due to the high airflow resistance of the product. We consider thus an airflow resistivity bigger than 100 kPa.s/m^2 for this case. According the standard ISO 9052-1, the results from all the tests should be similar since the air is considered as trapped in all cases but Test 4 gives surprisingly an increase of 138%. This can be attributed to the fact that the airflow resistivity, in the transverse direction, is probably lower than the measurement result carried out in the vertical direction.

PRODUCT 2

The measurement results show a quite good repeatability for the four tests and the results dispersion is low between the three samples. This is the product which shows the biggest difference between test 3 and test 1: the difference reaches on average 41%. The similar results between Test 1 and Test 2 show that the dimensions of 1000 x 1000 mm^2



Material: Open cell polyurethane sprayed foam
Thickness: 25 mm
Density: 55-65 kg/m³
Airflow resistivity: ≥ 100 kPa.s/m²

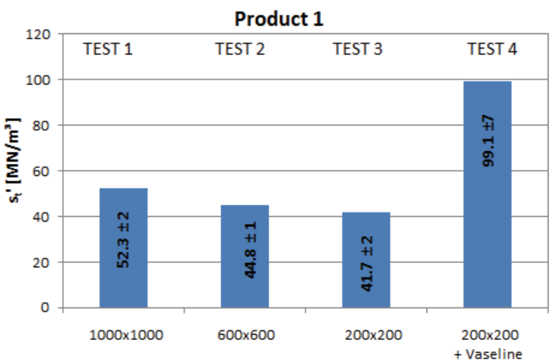
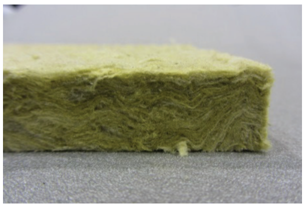


Figure 6. The average apparent dynamic stiffness for the open cell polyurethane sprayed foam for one sample and according to the four test procedures. The average and the standard variation are calculated on five measurements.



Material : Mineral wool
Thickness:20 mm
Density: 90 kg/m³
Airflow resistivity:119.4 ±19 kPa.s/m²

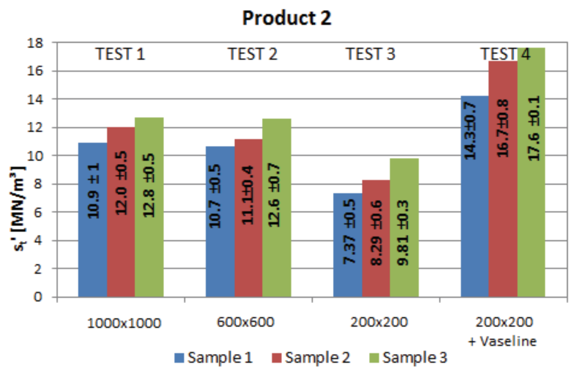


Figure 7. The average apparent dynamic stiffness for the mineral wool for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.

are sufficient to simulate the airflow resistance as in situ.

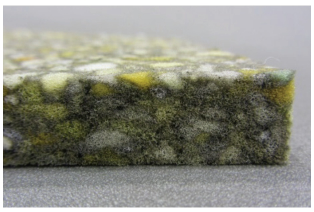
As with product 1, the airflow resistivity is bigger than 100 kPa.s/m^2 and all results should be similar since the air is considered as trapped but Test 4 shows an increase of 92%. As product 1, the airflow resistivity, in the transverse direction could be lower than the measurement result carried out in the vertical direction.

PRODUCT 3

On average, we can see an increase of ± 20 % of the apparent dynamic stiffness, s'_t, when the standardised sample is extended to 600x600 mm^2 or 1000x1000 mm^2. The results of test 1 and test 2 being equal, the dimensions of 1000x1000 mm^2 seem sufficient to simulate the airflow resistance as in situ. The result for test 4, with the total entrapment of the air in the sample, shows as expected the highest value (The increase is 56 % between test 3 and test 4). The result of this test is expected to be equal to the results of test 3 corrected with s'_a (Eq. 8). If we use Eq. 4 to estimate the dynamic stiffness of the air, we obtain:

$$s'_{t,test\ 3} + s'_a \approx 5.75+11 \approx 17 \text{ MN/m}^3$$

This estimation shows a high overestimation of $s'_{t,test\ 4}$.



Material : PU foam
Thickness:10 mm
Density: 100kg/m³
Airflow resistivity: 46.5 ±7 kPa.s/m²

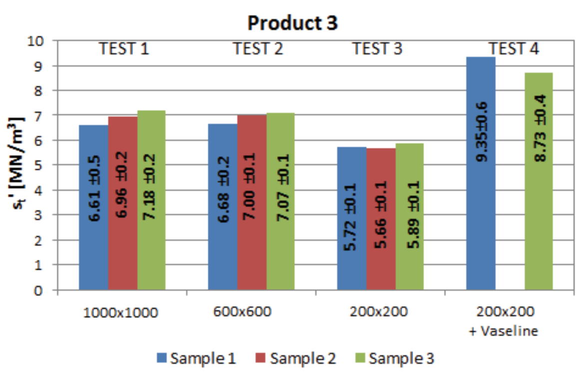
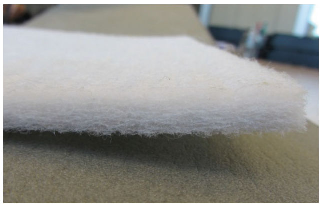


Figure 8. The average apparent dynamic stiffness for the PU foam for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.



Material : Low density felt
Thickness:10 mm
Density: ± 40kg/m³
Airflow resistivity: 40.2 ±6 kPa.s/m²

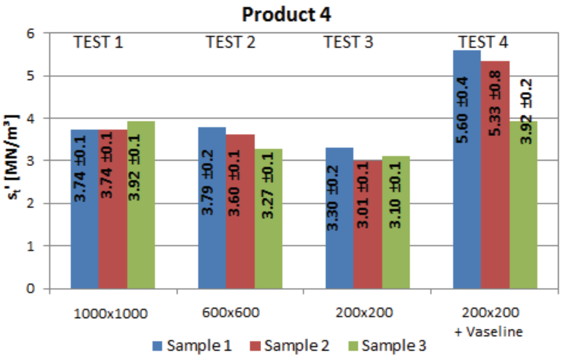


Figure 9. The average apparent dynamic stiffness for the low density felt for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.

PRODUCT 4

For this case, we can observe a continuous increase of s'_t with the enlargement of the sample dimensions: s'_t of the small sample increases of 13% when its size reaches 600x600 mm^2 and 21% when its size is 1000x1000 mm^2. Test 4 where the air is fully trapped shows an increase of 58% compared to the standardised result (Test 3).

After the loading, this sample has lost 3 mm of its thickness. d is then equal to 7 mm and we have:

$$s'_{t,test\ 3} + s'_a \approx 3.14+16 \approx 19\ \text{MN/m}^3$$

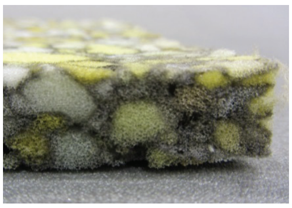
This result also shows a high overestimation of $s'_{t,test\ 4}$: 19 MN/m^3 instead of 4.95 MN/m^3.

PRODUCT 5

Products 3 and 5 are composed of the same material but with different densities. Product 5 has a lower airflow resistivity than product 3. The same trend is observed for this product: The results of test 1 and test 2 are almost the same and we can see an increase of s'_t of nearly 16% between test 3 and test 1. This increase reaches 38% if the air of the sample of 200x200 mm^2 is fully trapped.

For this case, we have:

$$s'_{t,test\ 3} + s'_a \approx 4.7+11 \approx 16\ \text{MN/m}^3$$



Material : PU foam
Thickness:10 mm
Density: 80 kg/m³
Airflow resistivity:38.6±6 kPa.s/m²

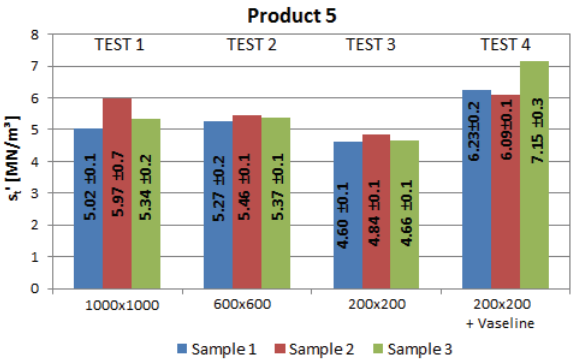
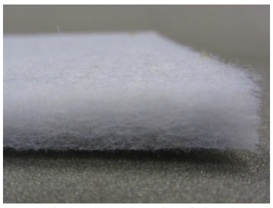


Figure 10. The average apparent dynamic stiffness for the PU foam for three samples (blue, red and green) and according to the four test procedures. The average and the standard variation are calculated on five measurements.



Material: Low density felt
Thickness: 9 mm
Density: ±20 kg/m³
Airflow resistivity: r < 10 kPa.s/m²

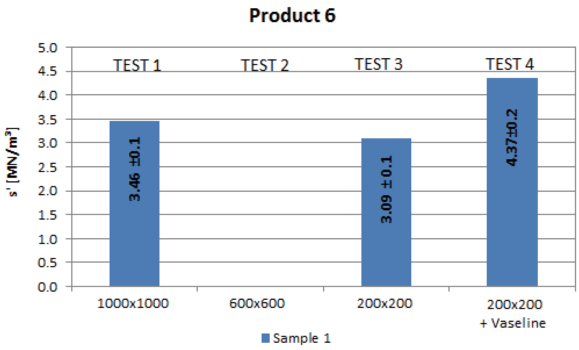


Figure 11. The average apparent dynamic stiffness for the Low density felt for one sample and according to three test procedures. The average and the standard variation are calculated on five measurements.

This result also shows a high overestimation of $s'_{t,test\ 4}{}^{o}$: 16 MN/m³ instead of 6.5 MN/m³.

PRODUCT 6

The measurements on this product were carried out during a previous measurement campaign where test 2 was not scheduled.

It is a very low density felt. It is always applied with another resilient layer. The airflow resistivity is very low (assumed lower than 10 kPa.s/m²) and the dynamic stiffness of the air doesn't play a role both for the small sample and for the larger samples. We are in the case where:

$$s' \cong s'_t \cong s'_s$$

However a slight increase is still observed between Test 3 and Test 1 (+12%). As expected, the increase of s'_t is higher for Test 4 (an increase of 41%). This is due to the air trapped in the sample.

SUMMARY AND CONCLUSION

For materials with a medium airflow resistivity (between 10 kPa.s/m² and 100 kPa.s/m²) the standard ISO 9052-1 proposes to add the dynamic stiffness of air contained in the material to the apparent dynamic stiffness measured on a sample of 200 x200 mm² to take into account the trapped air which occurs in large sample. The results presented in this article showed that this proposition leads to large overestimations.

The tests carried out with the standardized size but with the lateral borders completely sealed with Petroleum jelly (200x200 mm² + Petroleum jelly, test 4) also show an overestimation of the real dynamic stiffness of the products but to a lesser extent. This is due to the fact that, in this case, the compression of the air in the sample during the local excitation is higher than in the reality where the air can be expelled.

The tests done with the new test bench (i.e. with samples of 1000x1000 mm²) give more consistent results. With this new setup, the effect of the air enclosed in the sample is properly taken into account and reflects the on-site conditions. During the local dynamic excitation, the stressed air under the steel plate feels the real resistance and the right air compression is taken into account in the measurement. The determination of the airflow resistivity is no longer needed overcoming its complex measurement.

Different products have been tested and the results are summarized in table 1. This table gives the average absolute difference and the average relative difference of s'_t compared to the standardised results.

Table 1: The average absolute difference $\Delta s'_t$ and, in brackets, the average relative difference of s'_t in percentage compared to the standardised results of the standard ISO 9052-1 for each test procedure.

	$\Delta s'_t$ [MN/m³] 1000x1000 mm²	$\Delta s'_t$ [MN/m³] 600x600 mm²	$\Delta s'_t$ [MN/m³] 200x200 mm²	$\Delta s'_t$ [MN/m³] 200x200 mm² +Vaseline
Polyurethane sprayed foam, 25 mm, (55-65 kg/m³), r≥ 100 kPa.s/m²	10.6 (+25%)	3.13 (+7%)	0	57.4 (+138%)
Mineral wool, 20 mm (90 kg/m³), r=119.4 kPa.s/m²	3.40 (+41%)	2.99 (+36%)	0	7.71 (+92%)
PU foam, 10 mm (100 kg/m³), r=46.5 kPa.s/m²	1.17 (+20%)	1.16 (+20%)	0	3.24 (+56%)
Low density felt, 10 mm (40 kg/m³), r=40.2 kPa.s/m²	0.66 (+21%)	0.42 (+13%)	0	1.81 (+58%)
PU foam, 10 mm (80 kg/m³), r=38.6 kPa.s/m²	0.74 (+16%)	0.67 (+14%)	0	1.79 (+38%)
Low density felt, 9 mm (20 kg/m³), r < 10 kPa.s/m²	0.37 (+12%)	-	0	1.28 (+41%)

Figure 12 presents the relative differences of tests 1, 2 and 4 versus test 3 in function of the airflow resistivity.

The blue and red curves show the trend expected i.e. a low relative difference of s'_t for samples with a high airflow resistivity ($r \geq$ 100 kPa.s/m^2) and with a low airflow resistivity ($r <$ 10 kPa.s/m^2). The results for the mineral wool, with an airflow resistivity equals to 119.4 kPa.s/m^2, show however a high relative difference which leads us to believe that the limits between medium and high airflow resistivity products (100 kPa.s/m^2) proposed in the standard ISO 9052 should be increased.

For the products with medium airflow resistivities, the blue and red curves give similar results which confirm that a sample of 1000x1000 mm^2 is enough to take into account the right airflow resistance in the products.

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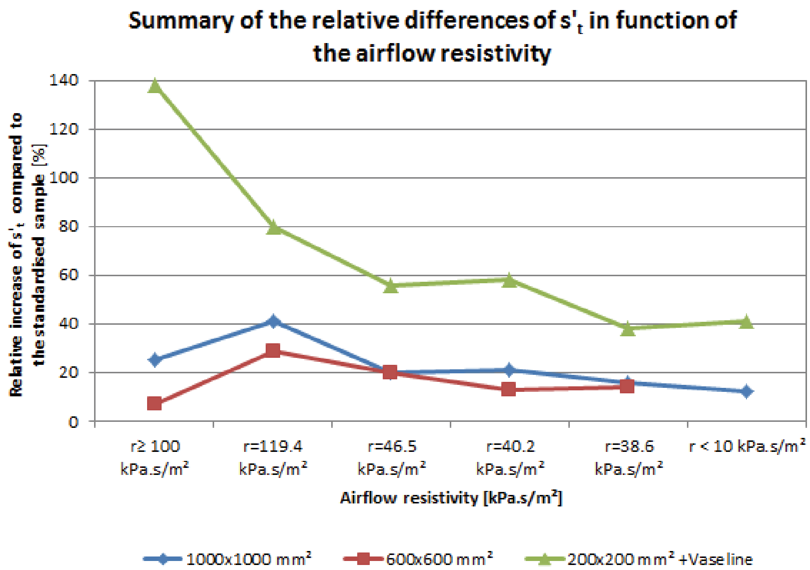

Figure 12. The average relative difference of s'_t in percentage compared to the standardised results of the standard ISO 9052-1 in function of the airflow resistivity.(In blue, the results for the 1000x1000 mm2 samples, in red, the results for the 600x600 mm2 samples and in green the results for the 200x200 mm2 samples with Petroleum jelly)

authors would also like to thank the CSTB Acoustics laboratory for the airflow resistivity measurements.

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AIRCRAFT NOISE MAKES YOU FAT?

Living beside an airport can make your stomach bigger, a Swedish study says, due to an increase in stress hormones which can often expand the stomach. The report, conducted by the Karolinska Institute in Stockholm, tracked 5,156 people over a 10-year period who were living in the Swedish capital. “If you are highly exposed to noise then it means an increase of six centimetres (in stomach size) compared to no exposure to noise at all,” said researcher Charlotta Eriksson, the study’s lead author.

SUNSHINE PAYS FOR NOISE BARRIERS

Solar barriers laid alongside a stretch of the A419 will be applied for by Swindon Council. The project will cost £2.6m for a 1.7km stretch of barriers. The expected revenue from the solar scheme is around £140,000 per annum, meaning the cost would be recouped by earning £3.5m over the next 25 years.