DELIVERABLE 5.5.1

CONTRACT N°	**SPC8-GA-2009-233655**
PROJECT N°	**FP7-233655**
ACRONYM	**CITYHUSH**
TITLE	**Acoustically Green Road Vehicles and City Areas**
Work Package 5	**Validation**
5.5	**Reduction of low frequency airborne noise**
	Validation report on solution for low frequency airborne noise reduction
Written by	**Inge Van Doorslaer APT**
Due submission date	**31-12-2012 (M36)**
Actual submission date	**31-12-2012**

Project Co-Ordinator
Partners

Acoustic Control	ACL	SE
Accon	ACC	DE
Alfa Products & Technologies	APT	BE
Goodyear	GOOD	LU
Head Acoustics	HAC	DE
Royal Institute of Technology	KTH	SE
NCC Roads	NCC	SE
Stockholm Environmental & Health Administration	SEP	SE
Netherlands Organisation for Applied Scientific Research	TNO	NL
Trafikkontoret Göteborg	TRAF	SE
TT&E Consultants	TTE	GR
University of Cambridge	UCAM	UK
Promotion of Operational Links with Integrated Services	POLIS	BE
Dynamcis, Structure and Systems International	D2S	BE
Akron NV	AKRON	BE

Project start date **January 1, 2010**
Duration of the project **36 months**

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Dissemination Level

PU	Public	✓
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for the members of the consortium (including the Commission Services)	

Nature of Deliverable

R	Report	✓
P	Prototype	
D	Demonstrator	
O	Other	

SEVENTH FRAMEWORK PROGRAMME

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0 EXECUTIVE SUMMARY

0.1 OBJECTIVE OF THE DELIVERABLE

Performing on site measurements on double façades.

0.2 DESCRIPTION OF THE WORK PERFORMED SINCE THE BEGINNING OF THE PROJECT

- Determination of the source spectra of buses and trucks through a measurement campaign near a bus stop in a city centre;
- Definition of criteria for low frequency indoor noise;
- Calculation of the indoor noise levels that occur when a bus is idling at a bus stop or when a bus is departing from a bus stop by means of a noise model;
- Determination of three prediction methods to calculate the sound insulation values of double ventilated façades (DVF);
- Determination of the dimensions of an optimized DVF with high low frequency insulation values;
- Construction of the prototypes of double façades in the laboratory;
- Performance of measurements on the prototypes of double façades in the laboratory;
- Construction of double façades on site;
- Performance of measurements on double façades on site.

0.3 MAIN RESULTS ACHIEVED SO FAR

The determination of the dimensions of an optimized DVF with high low frequency insulation values and the validation of the predicted insulation values through measurements in the laboratory.

0.4 EXPECTED FINAL RESULTS

The insulation values of the designed double façade on site.

0.5 POTENTIAL IMPACT AND USE

The potential impact of the use of the double façade is to reduce the low frequency airborne noise inside the buildings.

0.6 PARTNERS INVOLVED AND THEIR CONTRIBUTION

APT is involved in designing and testing the solutions to reduce low frequency noise by measures at the façade windows.

0.7 CONCLUSIONS

In the months M25 to M36, on site measurements were performed on double façades. The results of these measurements are presented in the present deliverable 5.5.1.

Six different setups have been installed and measured:

Setup	Inner side (existing window)			Cavity [mm]	Outer side
	Glass pane 1 [mm]	Cavity [mm]	Glass pane 2 [mm]		Glass pane 3 [mm]
1	4	20	6	-	-
2	4	20	6	300	12
3	4	20	6	650	12
4	4	20	6	650MW[1]	12
5	4	20	6	1000	12
6	4	20	6	1300	12

Table 0.1 Measurement setups

Figures 0.1.1 to 0.1.4 show the results from the measurements on site for the six different setups. The results are expressed as the difference between the outdoor and the indoor noise level:

- The outdoor noise level is the average of the noise levels measured in the two outdoor microphone positions (E1/E2).
- For the indoor noise level, no average is made: the results are given for the indoor microphone positions I1 and I2 separately.

The results are given:

- In 1/3 octave bands between 40 and 3150 Hz;
- In a narrowbands analysis between 40 and 100 Hz with a resolution of 1 Hz.

Tables 0.2.1 and 0.2.2 give the value of the increase in insulation value (in dB) averaged for the two microphone positions for a number of frequencies compared to setup 1 (no glass pane):

[1] Setup 4 is identical to setup 3, but the cavity is lined with mineral wool with a thickness of 60 mm.

	1/3 octave band frequency [Hz]				
increase in insulation value [dB]	40	50	63	500	1000
setup 1 vs. setup 2 (4/20/6 vs. 4/20/6-300-12)	-	2	4	16	6
setup 1 vs. setup 3 (4/20/6 vs. 4/20/6-650-12)	6	5	2	12	7
setup 1 vs. setup 4 (4/20/6 vs. 4/20/6-1000-12)	5	6	3	10	8
setup 1 vs. setup 6 (4/20/6 vs. 4/20/6-1300-12)	5	5	4	13	6
setup 3 vs. setup 4 (4/20/6-650-12 vs. 4/20/6-650MW-12)	-	-	-	4	-

Table 0.2.1 Increase in insulation value in dB – 1/3 octave bands

	narrowband frequency [Hz]		
increase in insulation value [dB]	40	50	60
setup 1 vs. setup 2 (4/20/6 vs. 4/20/6-300-12)	2	6	6
setup 1 vs. setup 3 (4/20/6 vs. 4/20/6-650-12)	8	8	7
setup 1 vs. setup 4 (4/20/6 vs. 4/20/6-1000-12)	8	9	5
setup 1 vs. setup 6 (4/20/6 vs. 4/20/6-1300-12)	7	9	6
setup 3 vs. setup 4 (4/20/6-650-12 vs. 4/20/6-650MW-12)	-	-	-

Table 0.2.2 Increase in insulation value in dB – narrowbands (1 Hz)

Following conclusions can be drawn from the measurement results:

- Adding the glass pane at the first distance (300 mm) gives an increase in the insulation value in the 1/3 octave bands of 50 Hz, 63 Hz and > 250 Hz. At 50 and 63 Hz, the value of the increase is 2 to 4 dB. In narrowbands, the increase in insulation value can be detected for frequencies up to 65 Hz;
- Increasing the cavity depth give increasing insulation values for the low frequencies (1/3 octave bands of 40 and 50 Hz) up to 5 or 6 dB;
- The insulation values in the 1/3 octave band of 63 Hz does not improve by increasing the cavity depth;
- Increasing the cavity depth also does not influence the insulation values for the higher frequencies (> 250 Hz);
- Figures 0.1.3 and 0.1.4 (narrowbands) show resonance problems for frequencies between 70 and 85 Hz. This is due to a combination of the dimensions of the receiving room and the frequencies of the sound;
- Adding absorption in the cavity hardly improves the insulation values for frequencies < 100 Hz and > 800 Hz;
- For frequencies between 100 and 800 Hz, there is an improvement of up to 4 dB by adding absorption in the cavity.

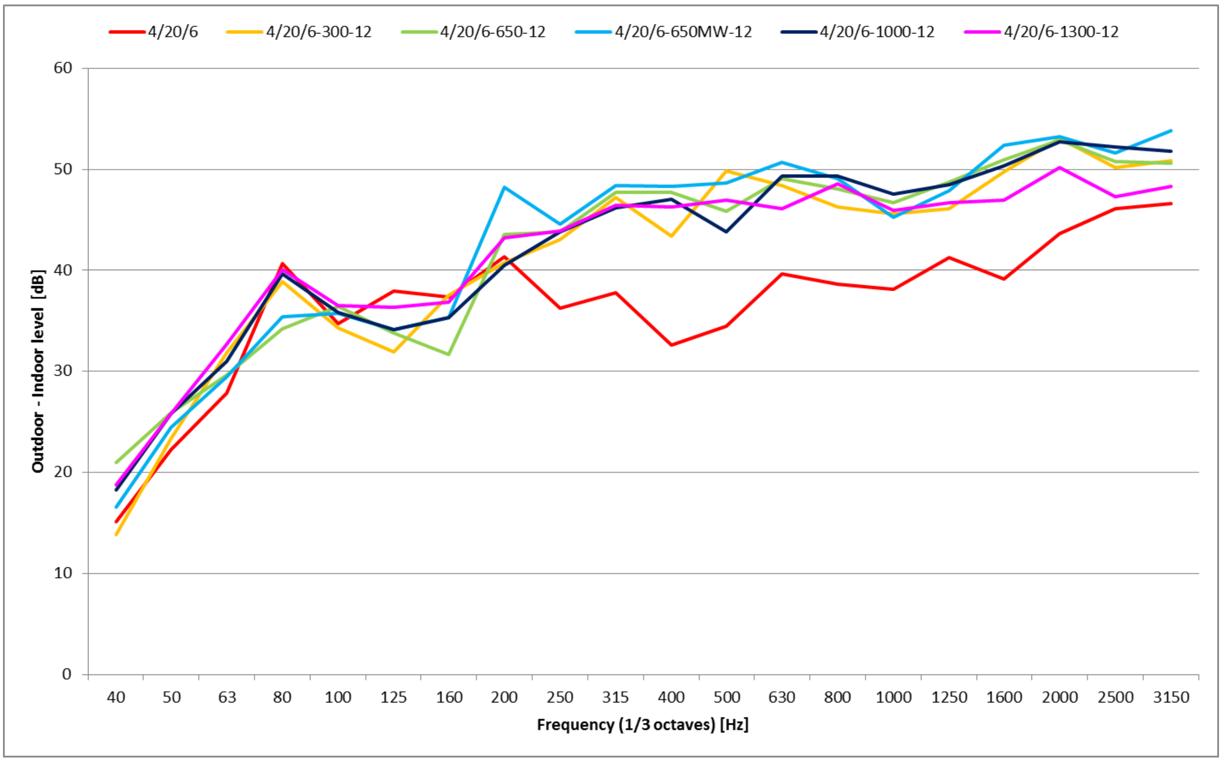

Figure 0.1.1

Measurement results: mic. position I1 – 1/3 octave bands

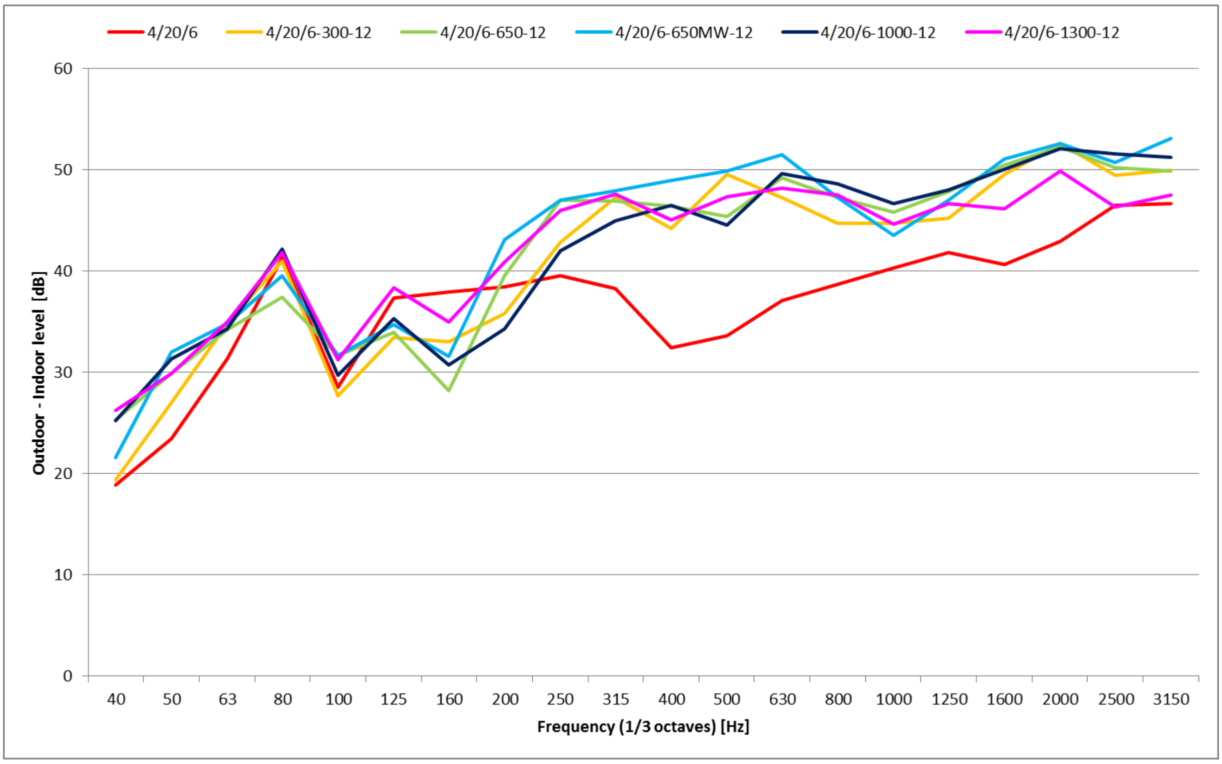

Figure 0.1.2

Measurement results: mic. position I2 – 1/3 octave bands

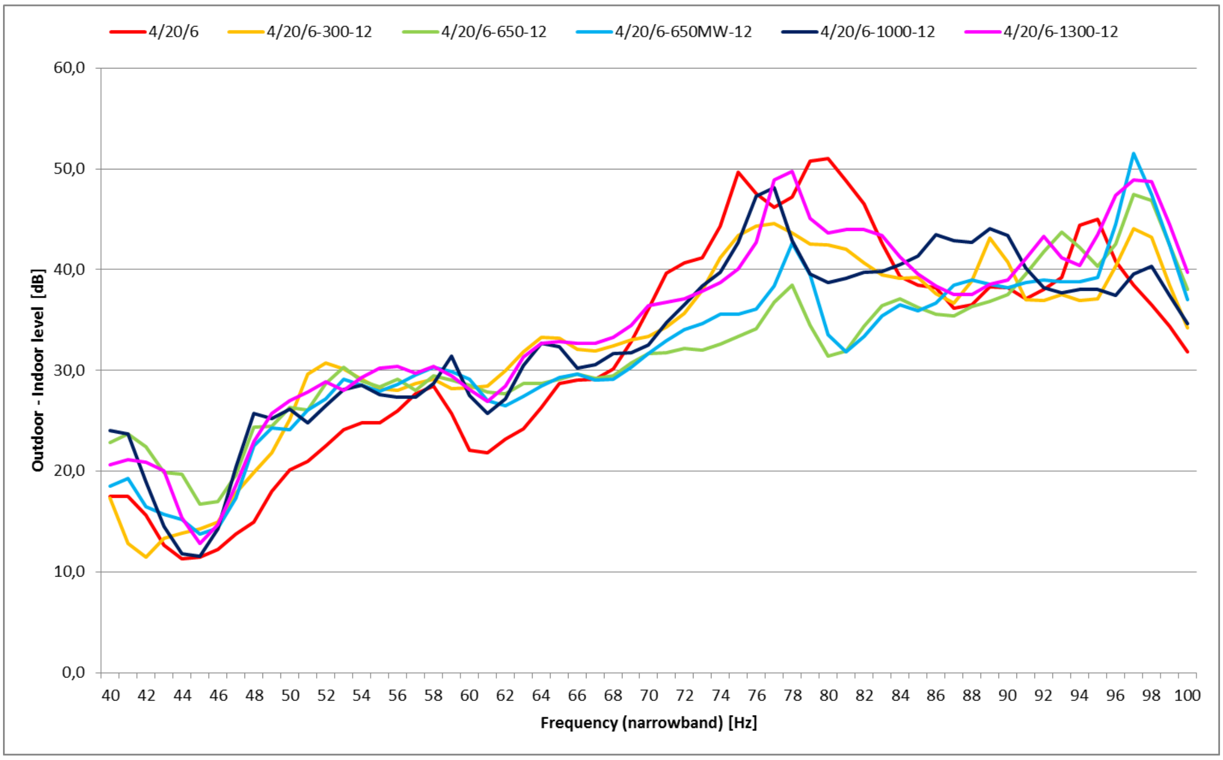

Figure 0.1.3

Measurement results: mic. position I1 – narrowbands (1 Hz)

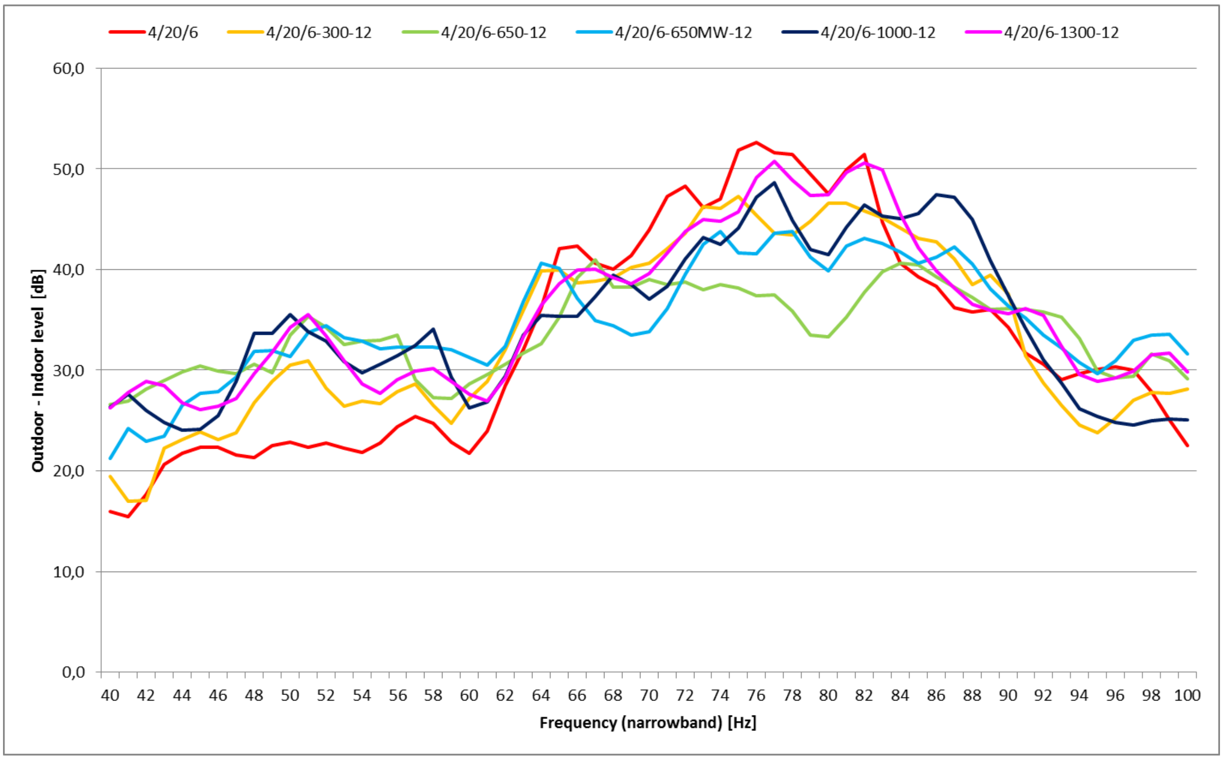

Figure 0.1.4

Measurement results: mic. position I2 – narrowbands (1 Hz)

1 PREFACE

In deliverable 4.3.3 (D040303_APT_M12) a double façade was developed to reduce low frequency noise (noise between 31,5 and 63 Hz) inside buildings. The results in deliverable 4.3.3 showed that the optimized double façade has following dimensions:

- Inner façade: 6-12-8 mm;
- Cavity depth: 1300 mm;
- Outer façade: 12 mm;
- A_{cavity} = S.

With this façade, insulation values are obtained that are theoretically around 20 dB higher in the frequencies between 31,5 and 63 Hz than those obtained with a 6 mm single pane glazing.

These results were obtained by using three methods to predict the insulation values of double façades:

- Prediction method 1: INSUL (*Marshall Day Acoustics)*;
- Prediction method 2: Three chamber model combined with Mass-Spring-Mass law;
- Prediction method 3: Three chamber model.

Between months M13 and M24, laboratory measurements were performed on prototype double façades and the results were presented in the deliverable 4.3.4 (D040304_APT_M24).

In the months M25 to M36, on site measurements were performed on double façades. The results of these measurements are presented in the present deliverable 5.5.1.

2 TEST SITE

The test site was located near Brussels, Belgium and consisted of a house adjacent to a railway line, see figure 2.1.

Figure 2.1 Test site

The house has standard double glazed windows with following dimensions:

- Glass pane1 : thickness = 4 mm;
- Cavity: thickness = 20 mm;
- Glass pane 2: thickness = 6 mm.

On one of the existing windows (see indication on figure 2.1), an extension was constructed in which a third glass pane could be mounted at various distances from the existing window.

The extension is shown in figures 2.2 and 2.3.

The extension consists of two Betonplex plates with a thickness of 18 mm separated by 40 mm of Accorub. The connection of the extension to the existing façade is completely airtight by means of mastic and rubbers.

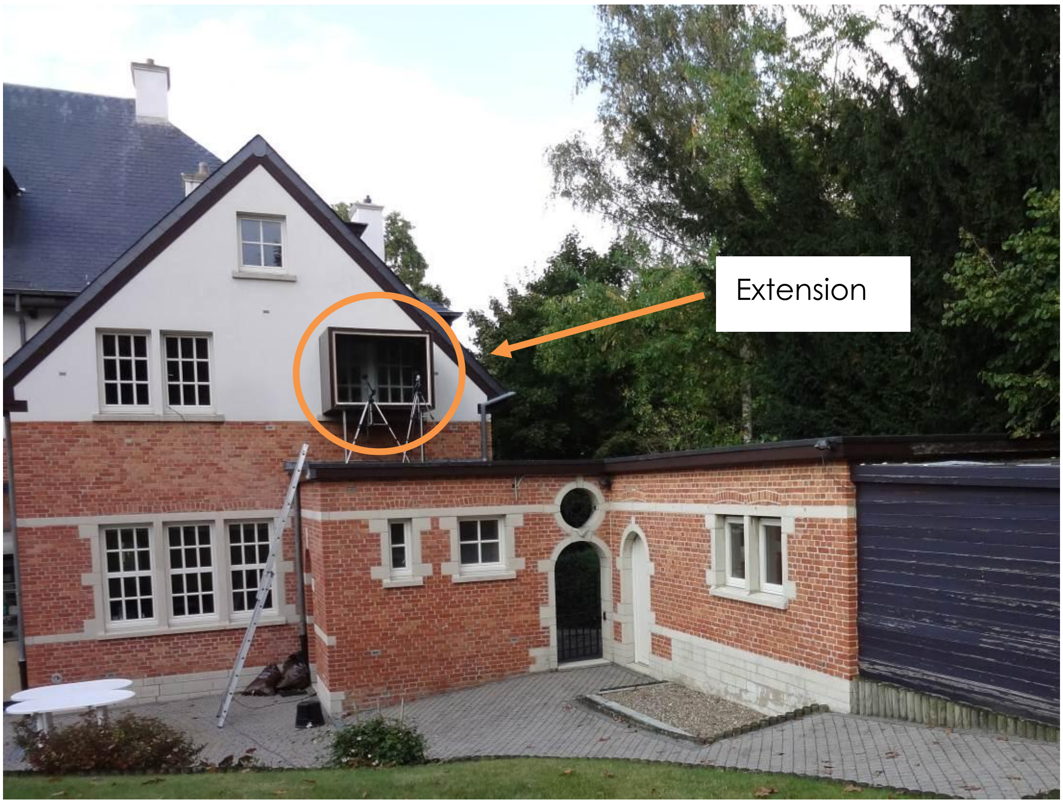

Figure 2.2
Test site with extension

Figure 2.3
Extension

3 MEASUREMENT SETUPS

In order to perform on site tests on double façades, it was possible to install a third glass pane (dimensions: 1100 mm x 1400 mm – thickness: 12 mm) in the extension at following 4 distances from the existing façade: 300 mm – 650 mm – 1000 mm – 1300 mm. The third glass pane is mounted with glazing laths and mastic.

In total, six different setups have been installed and measured:

Setup	Inner side (existing window) Glass pane 1 [mm]	Inner side (existing window) Cavity [mm]	Inner side (existing window) Glass pane 2 [mm]	Cavity [mm]	Outer side Glass pane 3 [mm]	Figures
1	4	20	6	-	-	3.1
2	4	20	6	300	12	3.2
3	4	20	6	650	12	3.3
4	4	20	6	650MW[1]	12	3.4
5	4	20	6	1000	12	3.5
6	4	20	6	1300	12	3.6

Table 3.1 Measurement setups

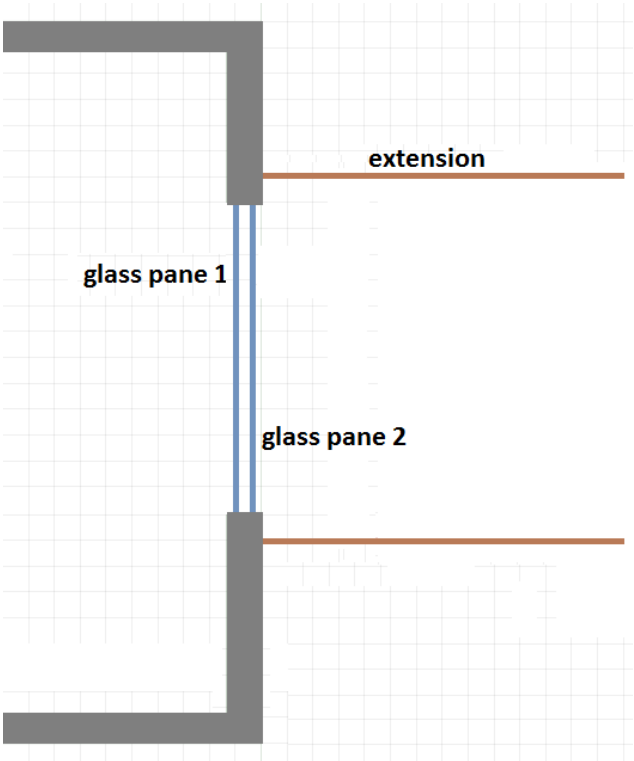

Figure 3.1

Setup 1: 4/20/6

[1] Setup 4 is identical to setup 3, but the cavity is lined with mineral wool with a thickness of 60 mm.

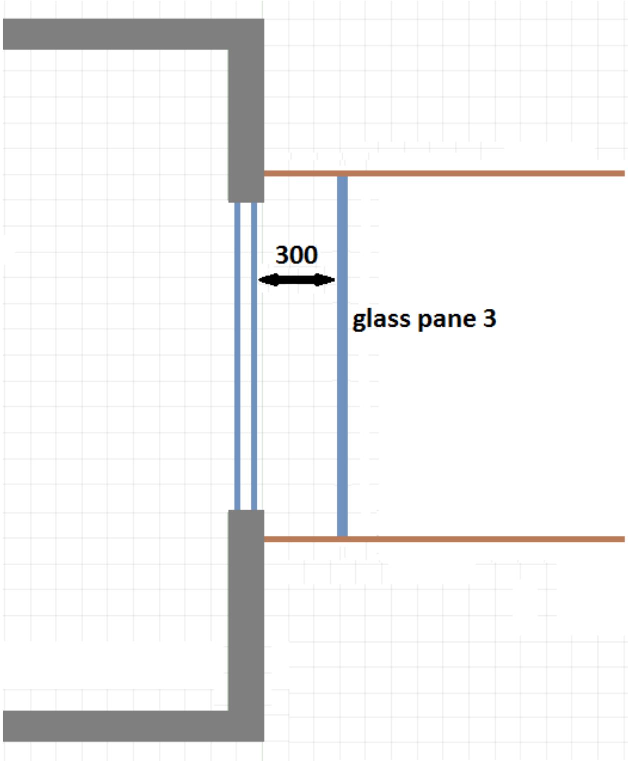

Figure 3.2

Setup 2: 4/20/6-300-12

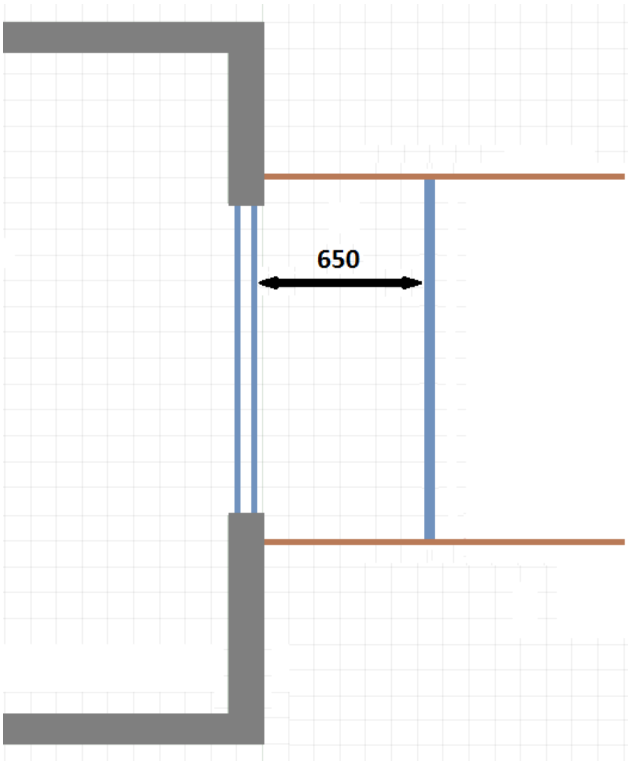

Figure 3.3

Setup 3: 4/20/6-650-12

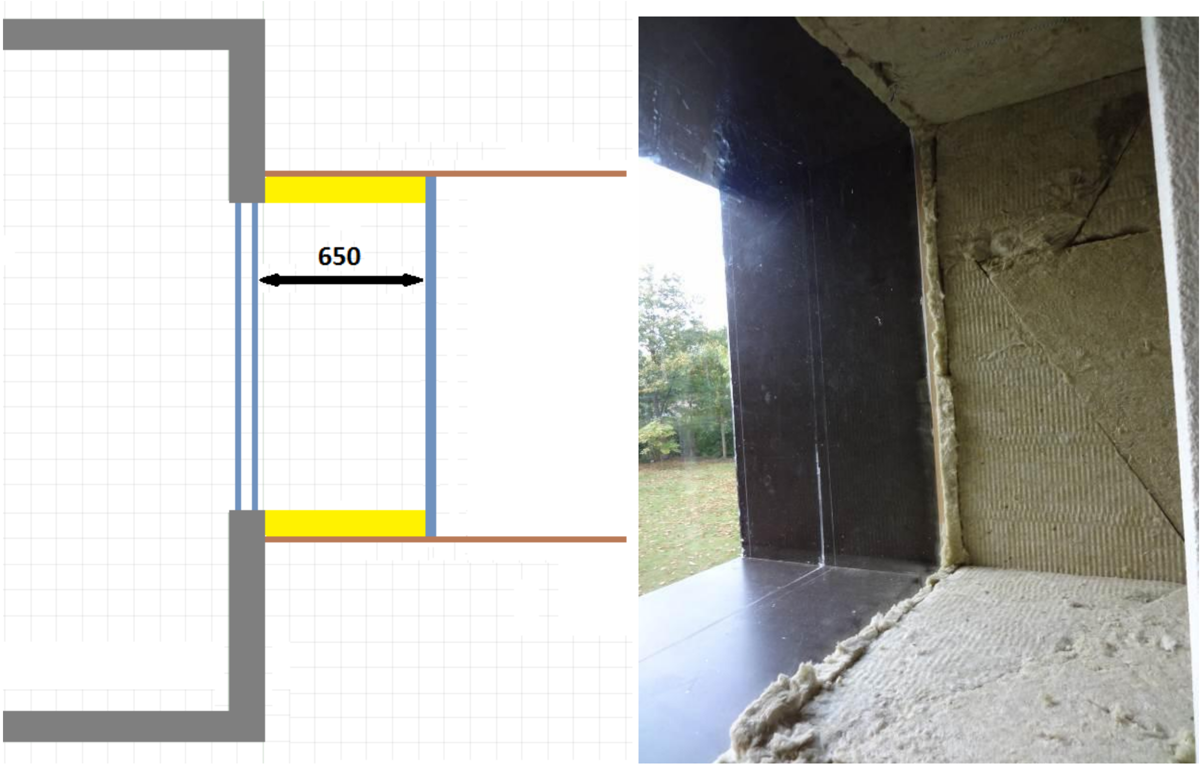

Figure 3.4

Setup 4: 4/20/6-650MW-12

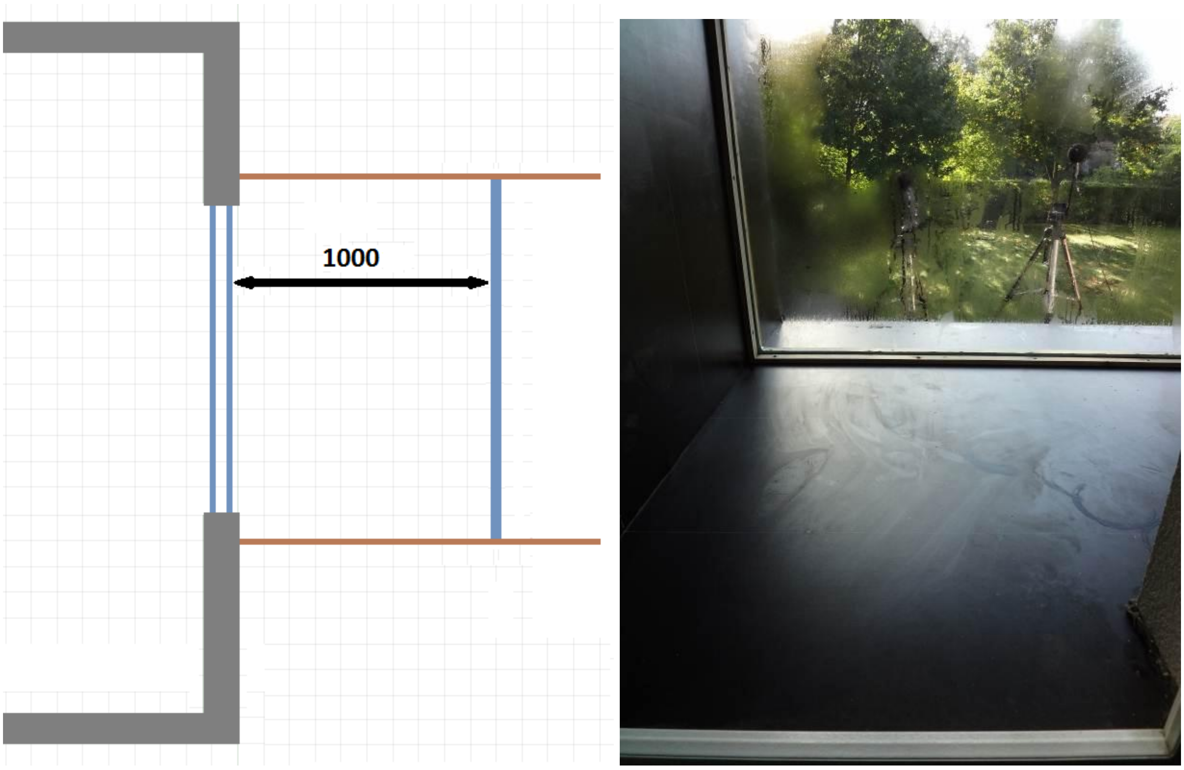

Figure 3.5

Setup 5: 4/20/6-1000-12

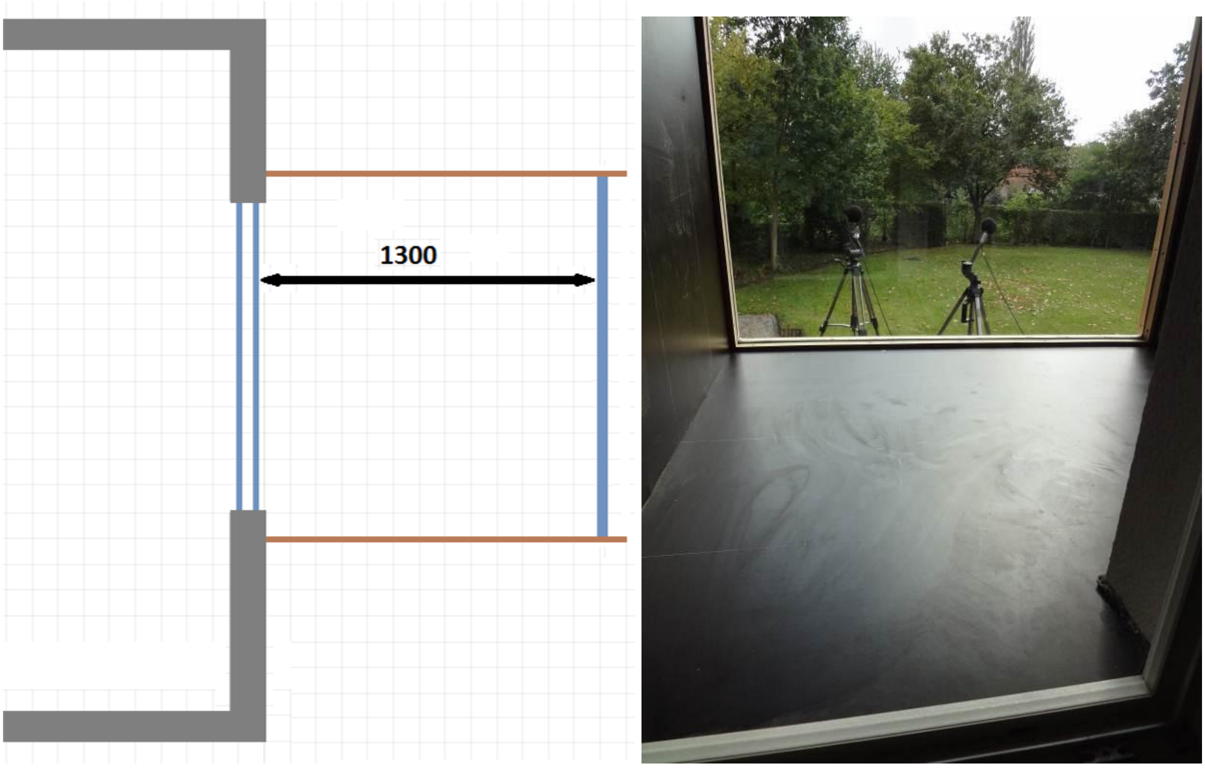

Figure 3.6

Setup 6: 4/20/6-1300-12

4 MEASUREMENT METHODS

The airborne sound insulation of the different measurement setups have been measured on site following NBN EN ISO 140-5. Two measurement methods were used:

- Measurement with railway traffic noise;
- Measurement with loudspeaker noise.

For both measurement methods, four microphone positions were used. Two microphones were positioned in front of the façade to record the outdoor noise levels. Simultaneously, the indoor noise levels were recorded by two microphones placed inside the receiving room. See figures 4.1 and 4.2.

Figure 4.1 Outdoor microphones

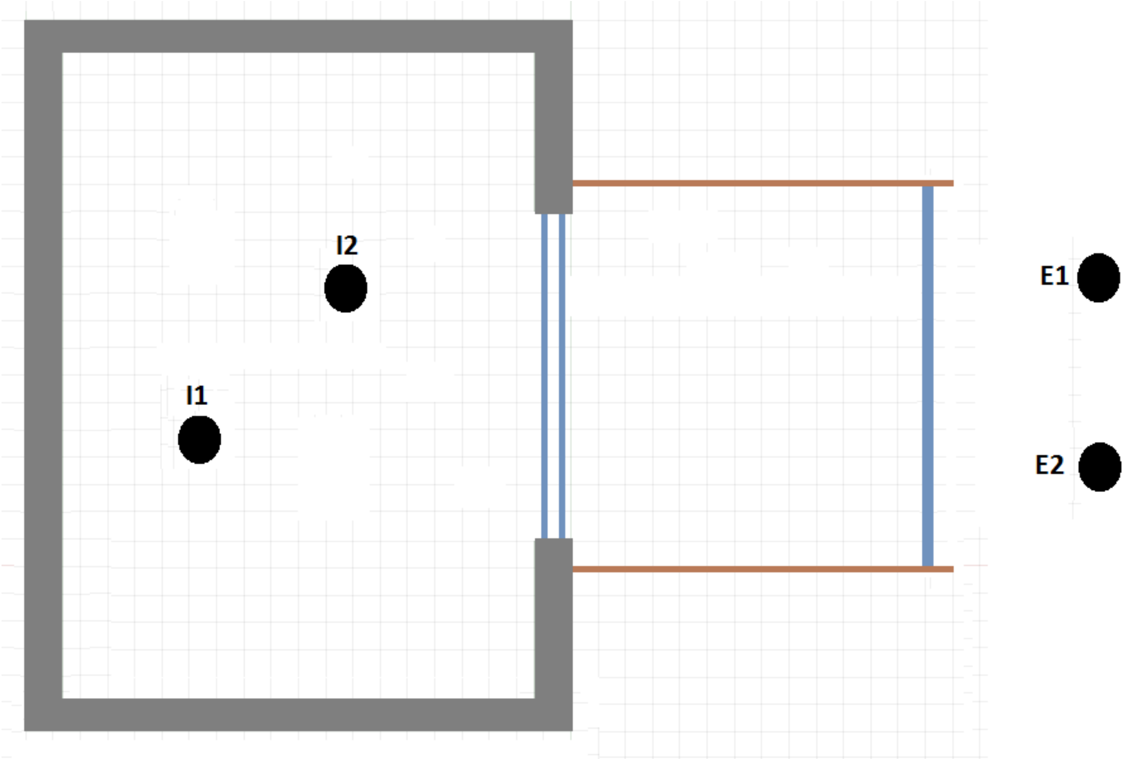

Figure 4.2

Schematic overview microphone position s

4.1 MEASUREMENT WITH RAILWAY TRAFFIC NOISE

Railway noise is used as the sound source. The railway line adjacent to the test site, is used by both passenger and cargo trains.

4.2 MEASUREMENT WITH LOUDSPEAKER NOISE

The sound field is generated by a loudspeaker with a sufficient sound power level in the frequency range between 40 and 3150 Hz, see figure 4.3.

Figure 4.3

Measurement with loudspeaker noise

5 MEASUREMENT RESULTS

In this chapter, the results from the measurements on site for the six different setups will be given. The results are expressed as the difference between the outdoor and the indoor noise level:

- The outdoor noise level is the average of the noise levels measured in the two outdoor microphone positions (E1/E2).
- For the indoor noise level, no average is made: the results are given for the indoor microphone positions I1 and I2 separately.

The results are given:

- In 1/3 octave bands between 40 and 3150 Hz;
- In a narrowbands analysis between 40 and 100 Hz with a resolution of 1 Hz.

It is chosen only to give the measurement results obtained by the measurement method with loudspeaker noise. The results from this measurement method have the highest reproducibility. The loudspeaker gives the most stable frequency spectrum in the 1/3 octave bands between 40 and 3150 Hz, as compared to the frequency spectrum of passenger and/or cargo trains.

5.1 1/3 OCTAVE BANDS

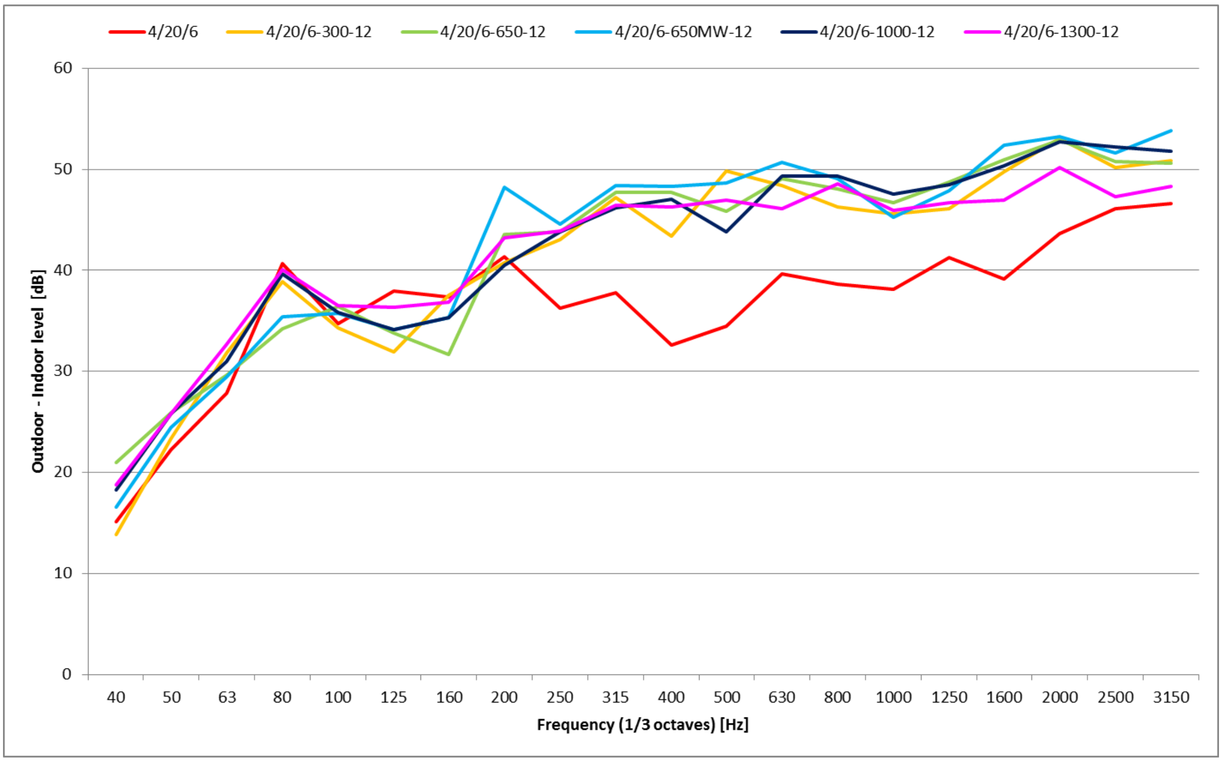

Figure 5.1.1

Measurement results: mic. position I1 – 1/3 octave bands

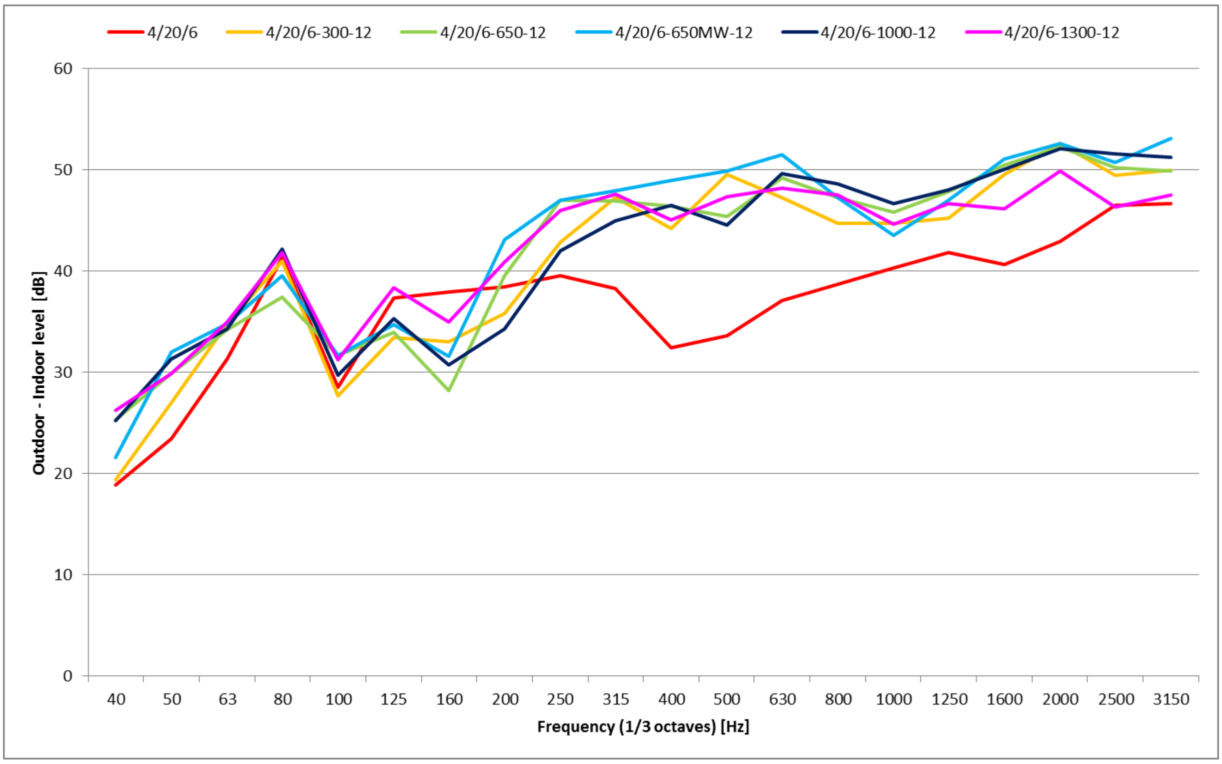

Figure 5.1.2

Measurement results: mic. position I2 – 1/3 octave bands

5.2 NARROWBANDS (1 HZ)

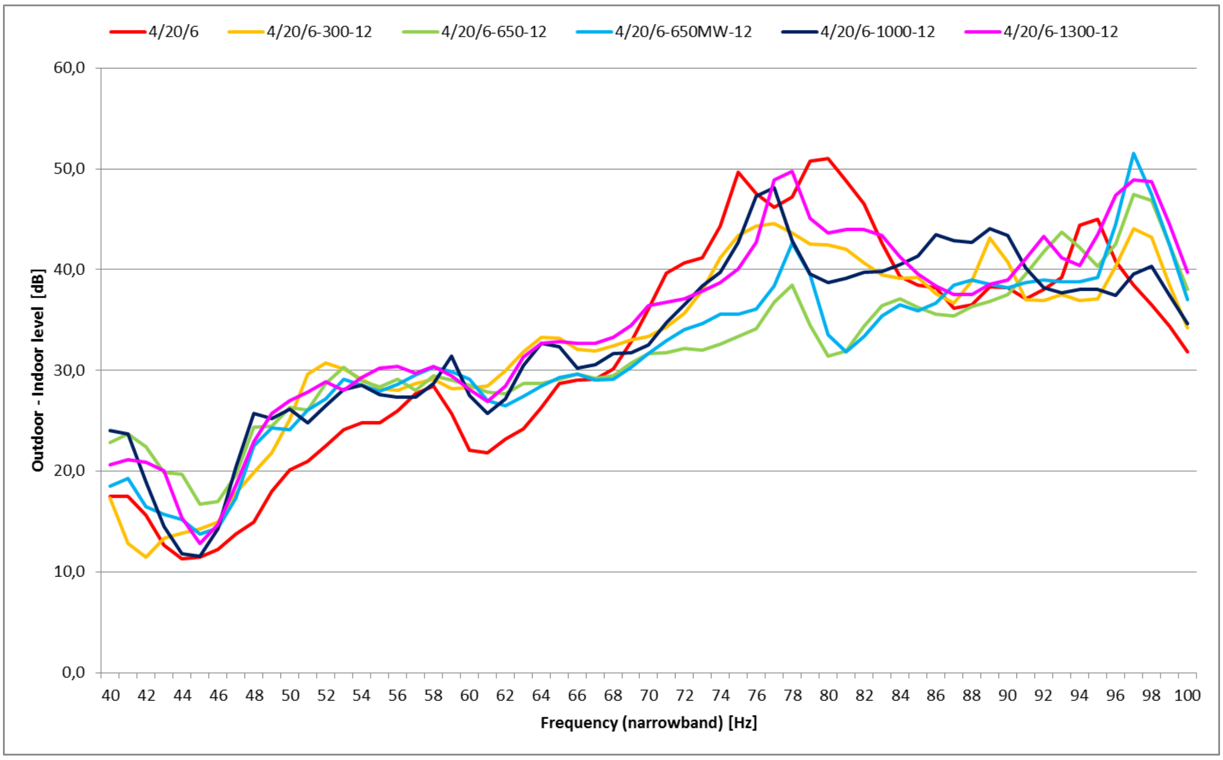

Figure 5.2.1

Measurement results: mic. position I1 – narrowbands (1 Hz)

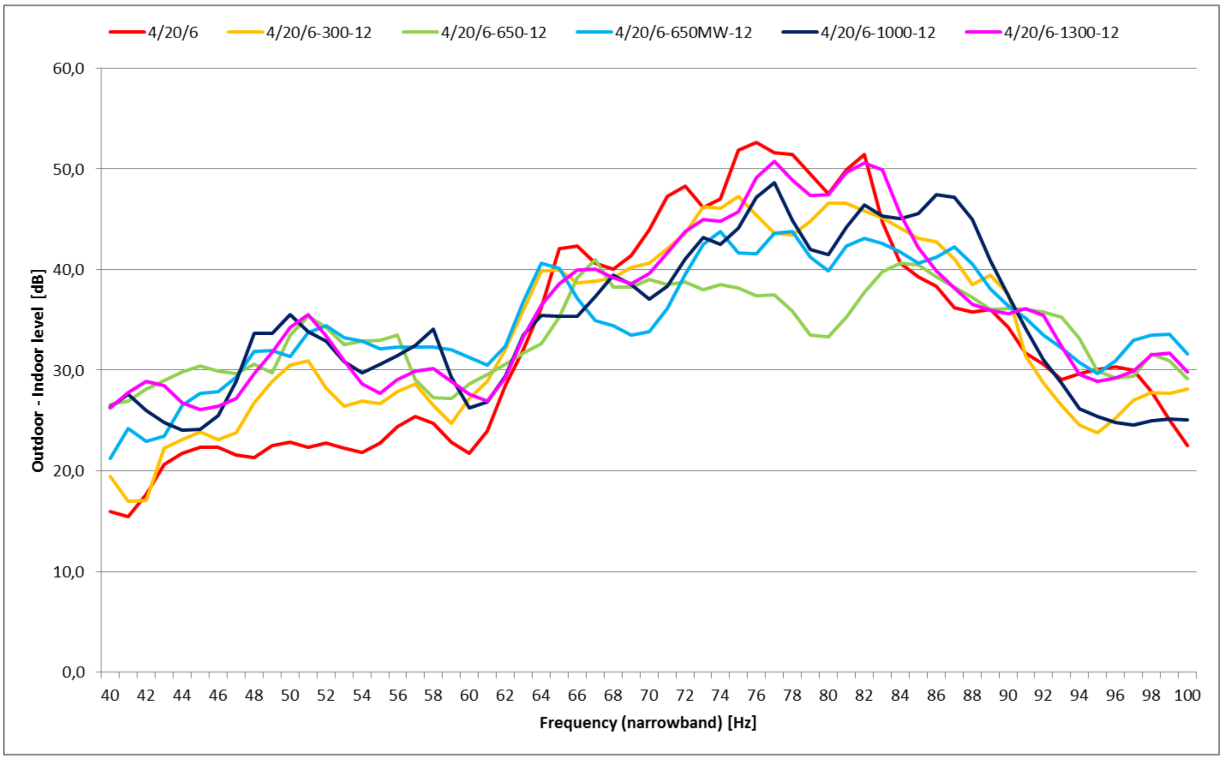

Figure 5.2.2

Measurement results: mic. position I2 – narrowbands (1 Hz)

6 DISCUSSION OF MEASUREMENT RESULTS

In this chapter, the measurement results are discussed.

6.1 EFFECT OF ADDING GLASS PANE AND INCREASING CAVITY DEPTH (SETUP 1 / SETUP 2 / SETUP 3 / SETUP 4 / SETUP 6)

Figures 6.1.1 to 6.1.4 show the effect of adding a glass pane and increasing the cavity depth between the existing window and the new glass pane.

Tables 6.1.1 and 6.1.2 give the value of the increase in insulation value (in dB) averaged for the two microphone positions for a number of frequencies compared to setup 1 (no glass pane):

	1/3 octave band frequency [Hz]				
increase in insulation value [dB]	40	50	63	500	1000
setup 1 vs. setup 2 (4/20/6 vs. 4/20/6-300-12)	-	2	4	16	6
setup 1 vs. setup 3 (4/20/6 vs. 4/20/6-650-12)	6	5	2	12	7
setup 1 vs. setup 4 (4/20/6 vs. 4/20/6-1000-12)	5	6	3	10	8
setup 1 vs. setup 6 (4/20/6 vs. 4/20/6-1300-12)	5	5	4	13	6

Table 6.1.1 Increase in insulation value in dB – 1/3 octave bands

	narrowband frequency [Hz]		
increase in insulation value [dB]	40	50	60
setup 1 vs. setup 2 (4/20/6 vs. 4/20/6-300-12)	2	6	6
setup 1 vs. setup 3 (4/20/6 vs. 4/20/6-650-12)	8	8	7
setup 1 vs. setup 4 (4/20/6 vs. 4/20/6-1000-12)	8	9	5
setup 1 vs. setup 6 (4/20/6 vs. 4/20/6-1300-12)	7	9	6

Table 6.1.2 Increase in insulation value in dB – narrowbands (1 Hz)

Following conclusions can be drawn from the tables and the figures:

- Adding the glass pane at the first distance (300 mm) gives an increase in the insulation value in the 1/3 octave bands of 50 Hz, 63 Hz and > 250 Hz. At 50 and 63 Hz, the value of the increase is 2 to 4 dB. In narrowbands, the increase in insulation value can be detected for frequencies up to 65 Hz;
- Increasing the cavity depth give increasing insulation values for the low frequencies (1/3 octave bands of 40 and 50 Hz) up to 5 or 6 dB;
- The insulation values in the 1/3 octave band of 63 Hz does not improve by increasing the cavity depth;
- Increasing the cavity depth also does not influence the insulation values for the higher frequencies (> 250 Hz);
- Figures 6.1.3 and 6.1.4 (narrowbands) show resonance problems for frequencies between 70 and 85 Hz. This is due to a combination of the dimensions of the receiving room and the frequencies of the sound.

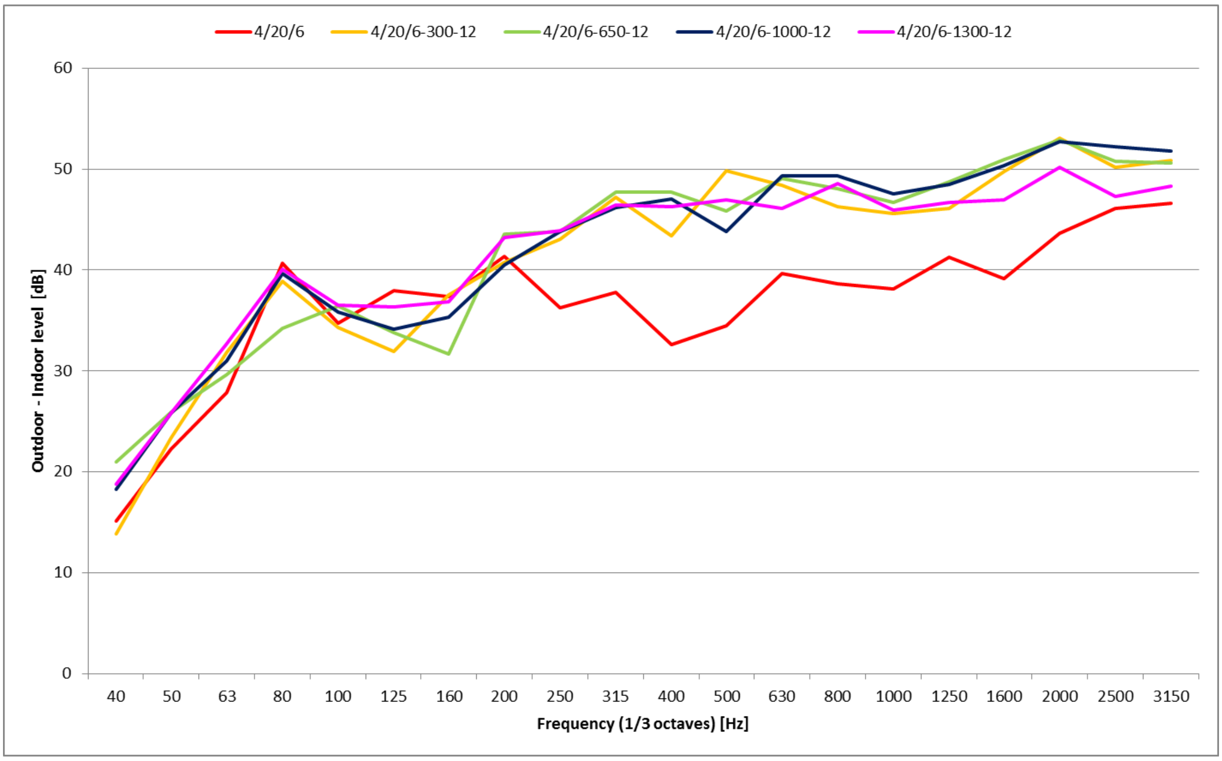

Figure 6.1.1

Measurement results: mic. position I1 – 1/3 octave bands

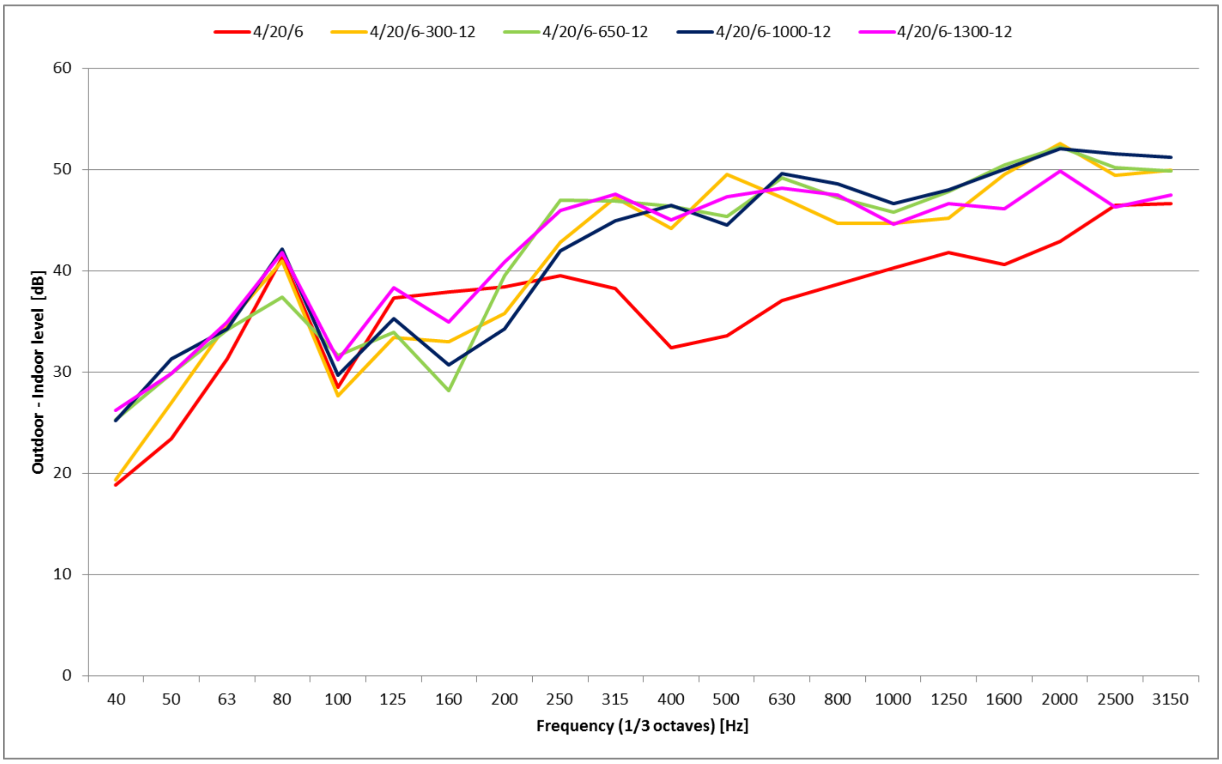

Figure 6.1.2

Measurement results: mic. position I2 – 1/3 octave bands

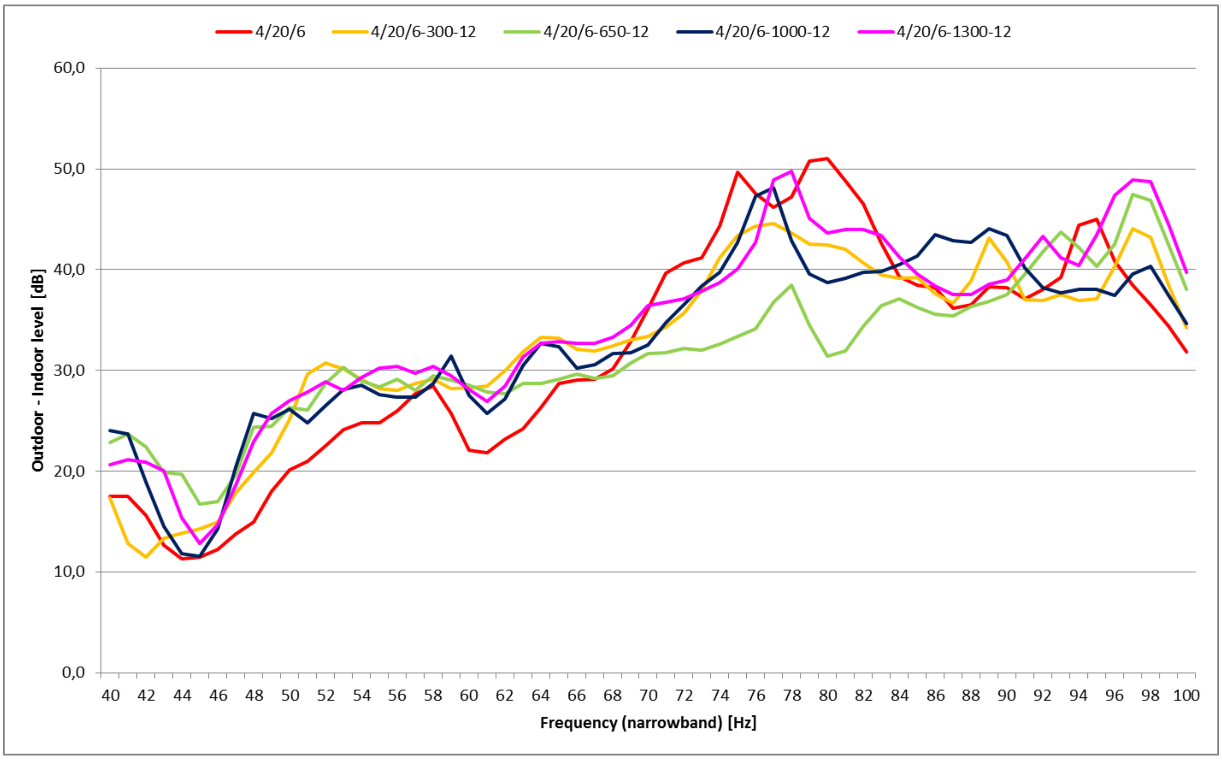

Figure 6.1.3 Measurement results: mic. position I1 – narrowbands (1 Hz)

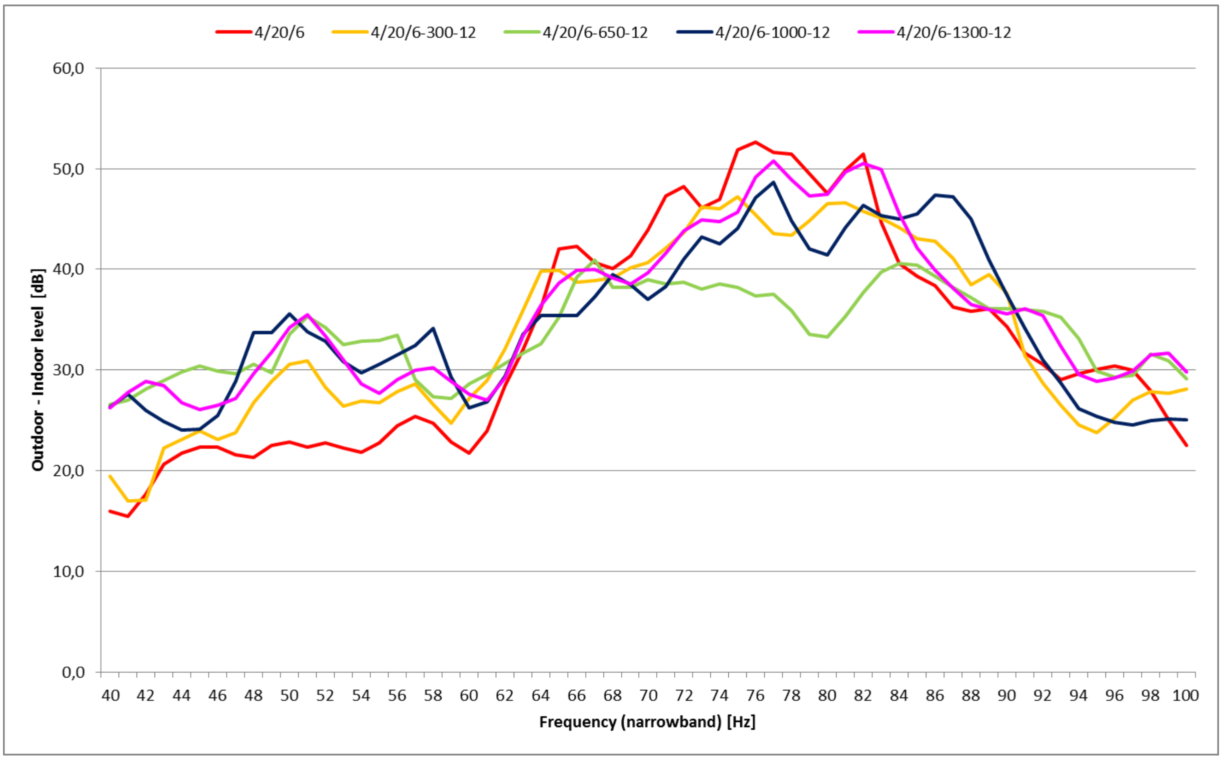

Figure 6.1.4 Measurement results: mic. position I2 – narrowbands (1 Hz)

6.2 EFFECT OF ADDING ABSORPTION IN CAVITY (SETUP 4 / SETUP 5)

Figures 6.2.1 to 6.2.4 show the effect of adding absorption in the cavity.

Tables 6.2.1 and 6.2.2 give the value of the increase in insulation value (in dB) averaged for the two microphone positions for a number of frequencies:

	1/3 octave band frequency [Hz]				
increase in insulation value [dB]	40	50	63	500	1000
setup 3 vs. setup 4 (4/20/6-650-12 vs. 4/20/6-650MW-12)	-	-	-	4	-

Table 6.2.1 Increase in insulation value in dB – 1/3 octave bands

	narrowband frequency [Hz]		
increase in insulation value [dB]	40	50	60
setup 3 vs. setup 4 (4/20/6-650-12 vs. 4/20/6-650MW-12)	-	-	-

Table 6.2.2 Increase in insulation value in dB – narrowbands (1 Hz)

From the tables and the figures, following can be conlcuded:

- Adding absorption in the cavity hardly improves the insulation values for frequencies < 100 Hz and > 800 Hz;
- For frequencies between 100 and 800 Hz, there is an improvement of up to 4 dB by adding absorption in the cavity.

Figure 6.2.1

Measurement results: mic. position I1 – 1/3 octave bands

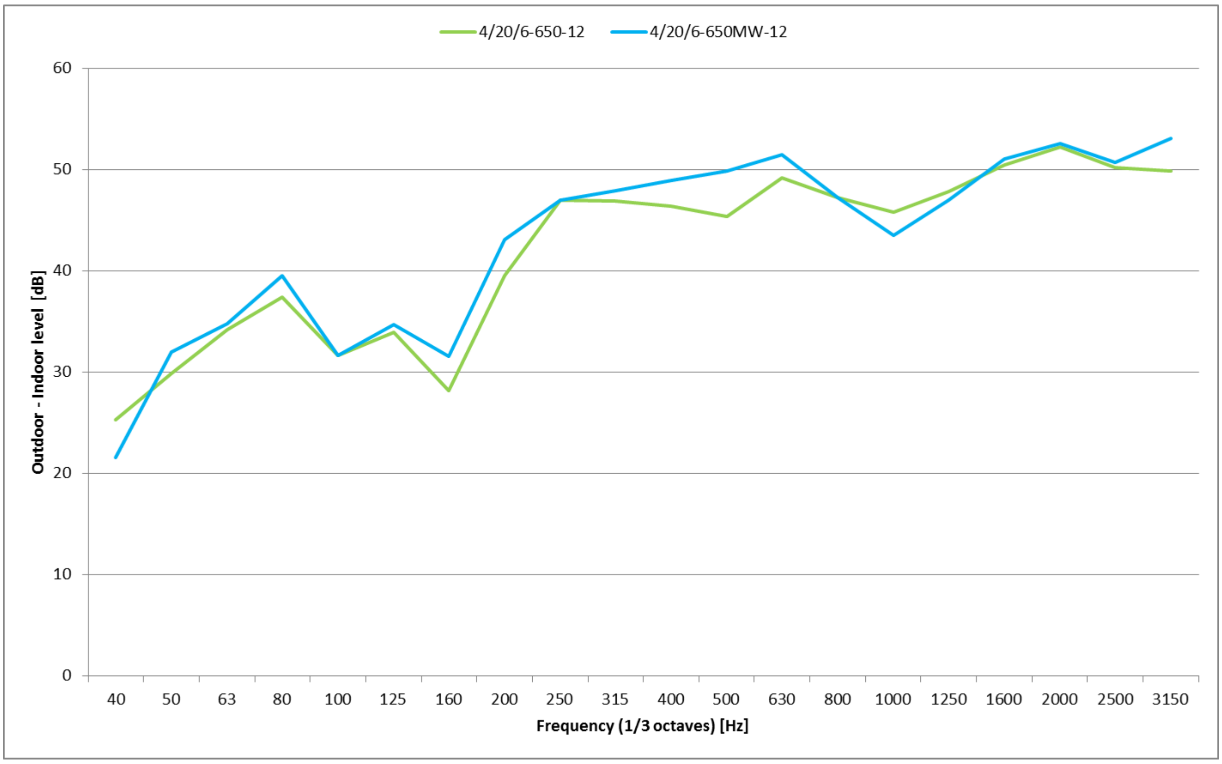

Figure 6.2.2

Measurement results: mic. position I2 – 1/3 octave bands

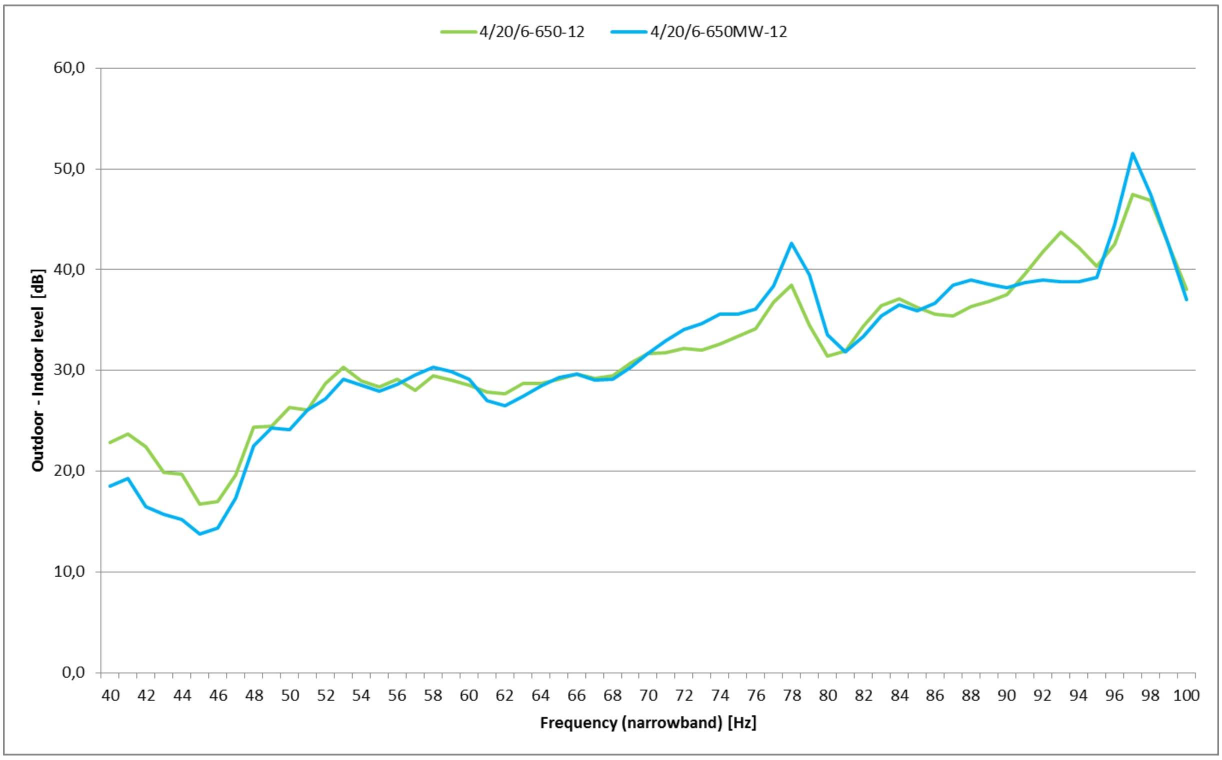

Figure 6.2.3
Measurement results: mic. position I1 – narrowbands (1 Hz)

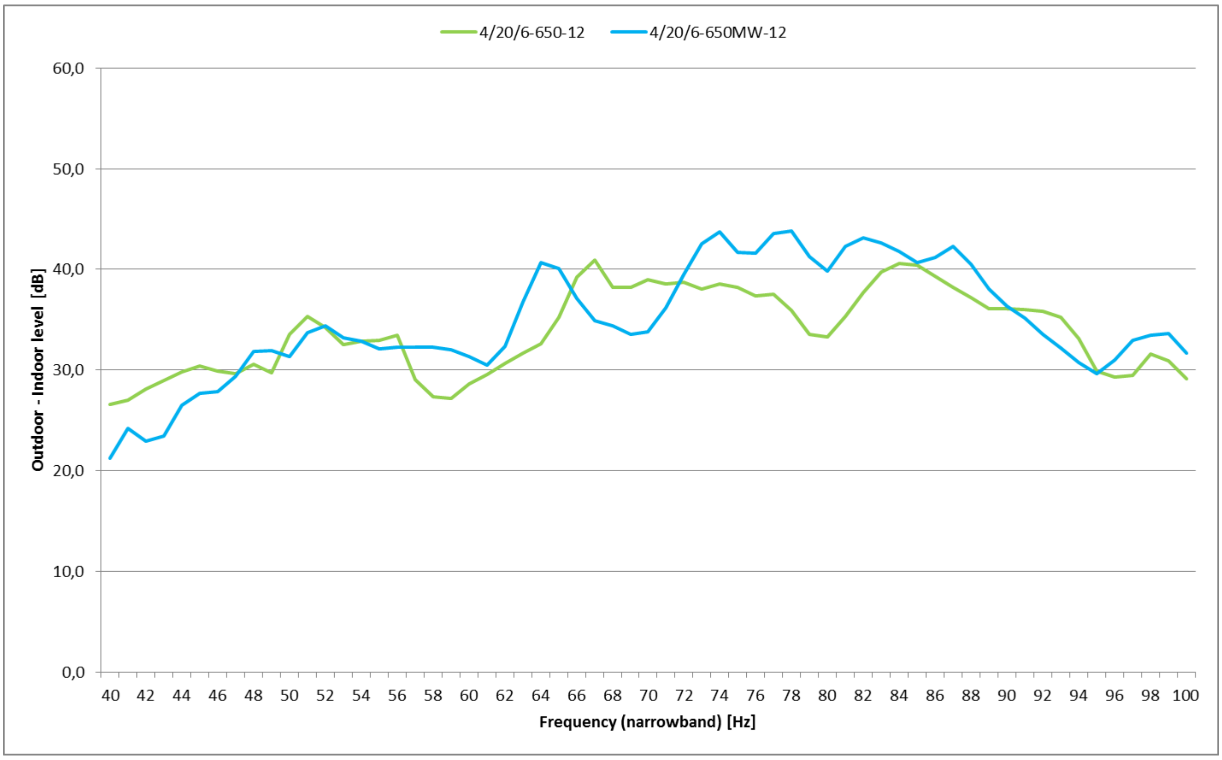

Figure 6.2.4
Measurement results: mic. position I2 – narrowbands (1 Hz)

7 CONCLUSIONS

In the months M25 to M36, on site measurements were performed on double façades. The results of these measurements are presented in the present deliverable 5.5.1.

Six different setups have been installed and measured:

Setup	Inner side (existing window)			Cavity [mm]	Outer side
	Glass pane 1 [mm]	Cavity [mm]	Glass pane 2 [mm]		Glass pane 3 [mm]
1	4	20	6	-	-
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3	4	20	6	650	12
4	4	20	6	650MW[1]	12
5	4	20	6	1000	12
6	4	20	6	1300	12

Table 7.1 Measurement setups

Figures 7.1.1 to 7.1.4 show the results from the measurements on site for the six different setups. The results are expressed as the difference between the outdoor and the indoor noise level:

- The outdoor noise level is the average of the noise levels measured in the two outdoor microphone positions (E1/E2).
- For the indoor noise level, no average is made: the results are given for the indoor microphone positions I1 and I2 separately.

The results are given:

- In 1/3 octave bands between 40 and 3150 Hz;
- In a narrowbands analysis between 40 and 100 Hz with a resolution of 1 Hz.

Tables 7.2.1 and 7.2.2 give the value of the increase in insulation value (in dB) averaged for the two microphone positions for a number of frequencies compared to setup 1 (no glass pane):

[1] Setup 4 is identical to setup 3, but the cavity is lined with mineral wool with a thickness of 60 mm.

	1/3 octave band frequency [Hz]				
increase in insulation value [dB]	40	50	63	500	1000
setup 1 vs. setup 2 (4/20/6 vs. 4/20/6-300-12)	-	2	4	16	6
setup 1 vs. setup 3 (4/20/6 vs. 4/20/6-650-12)	6	5	2	12	7
setup 1 vs. setup 4 (4/20/6 vs. 4/20/6-1000-12)	5	6	3	10	8
setup 1 vs. setup 6 (4/20/6 vs. 4/20/6-1300-12)	5	5	4	13	6
setup 3 vs. setup 4 (4/20/6-650-12 vs. 4/20/6-650MW-12)	-	-	-	4	-

Table 7.2.1 Increase in insulation value in dB – 1/3 octave bands

	narrowband frequency [Hz]		
increase in insulation value [dB]	40	50	60
setup 1 vs. setup 2 (4/20/6 vs. 4/20/6-300-12)	2	6	6
setup 1 vs. setup 3 (4/20/6 vs. 4/20/6-650-12)	8	8	7
setup 1 vs. setup 4 (4/20/6 vs. 4/20/6-1000-12)	8	9	5
setup 1 vs. setup 6 (4/20/6 vs. 4/20/6-1300-12)	7	9	6
setup 3 vs. setup 4 (4/20/6-650-12 vs. 4/20/6-650MW-12)	-	-	-

Table 7.2.2 Increase in insulation value in dB – narrowbands (1 Hz)

Following conclusions can be drawn from the measurement results:

- Adding the glass pane at the first distance (300 mm) gives an increase in the insulation value in the 1/3 octave bands of 50 Hz, 63 Hz and > 250 Hz. At 50 and 63 Hz, the value of the increase is 2 to 4 dB. In narrowbands, the increase in insulation value can be detected for frequencies up to 65 Hz;
- Increasing the cavity depth give increasing insulation values for the low frequencies (1/3 octave bands of 40 and 50 Hz) up to 5 or 6 dB;
- The insulation values in the 1/3 octave band of 63 Hz does not improve by increasing the cavity depth;
- Increasing the cavity depth also does not influence the insulation values for the higher frequencies (> 250 Hz);
- Figures 7.1.3 and 7.1.4 (narrowbands) show resonance problems for frequencies between 70 and 85 Hz. This is due to a combination of the dimensions of the receiving room and the frequencies of the sound;
- Adding absorption in the cavity hardly improves the insulation values for frequencies < 100 Hz and > 800 Hz;
- For frequencies between 100 and 800 Hz, there is an improvement of up to 4 dB by adding absorption in the cavity.

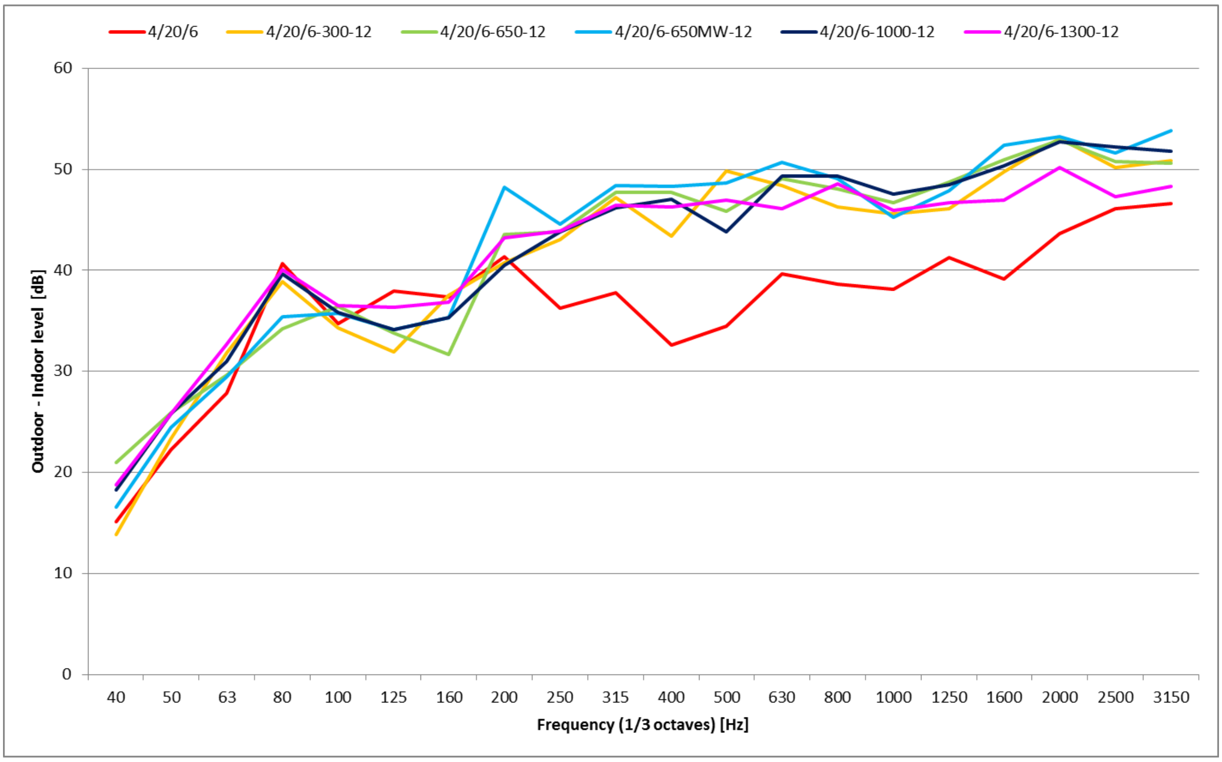

Figure 7.1.1

Measurement results: mic. position I1 – 1/3 octave bands

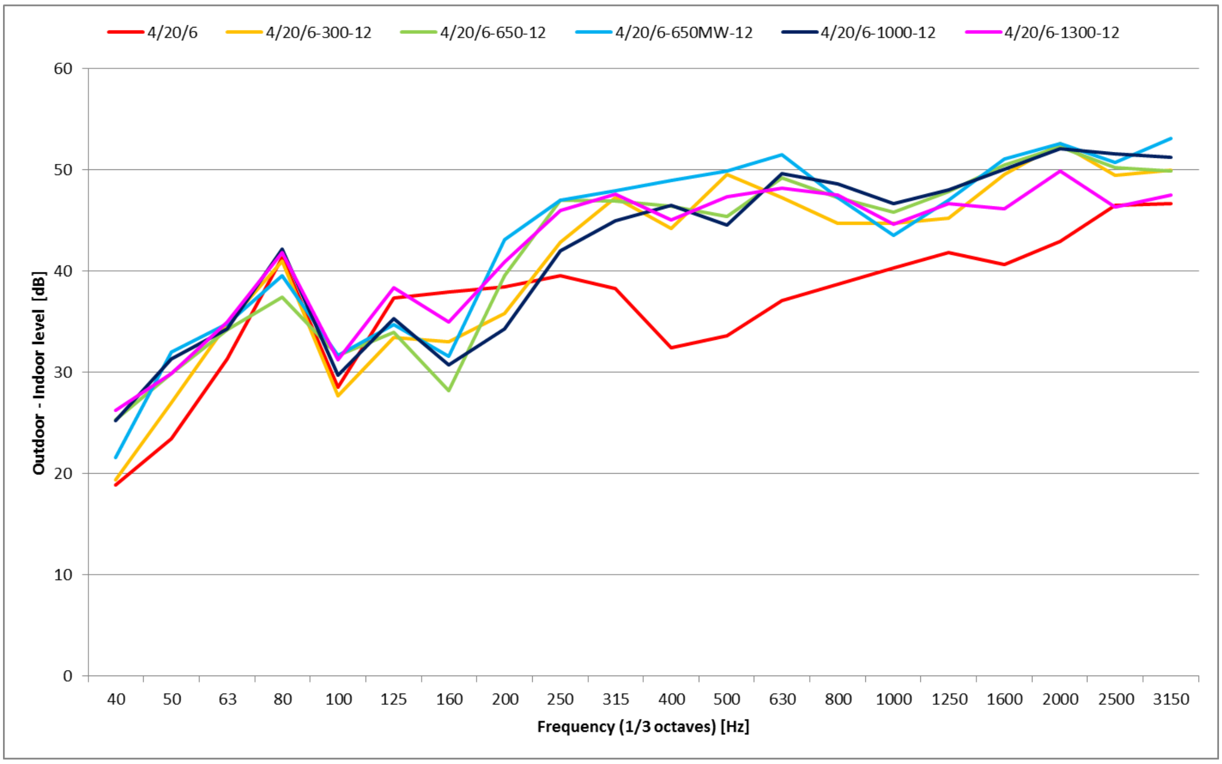

Figure 7.1.2

Measurement results: mic. position I2 – 1/3 octave bands

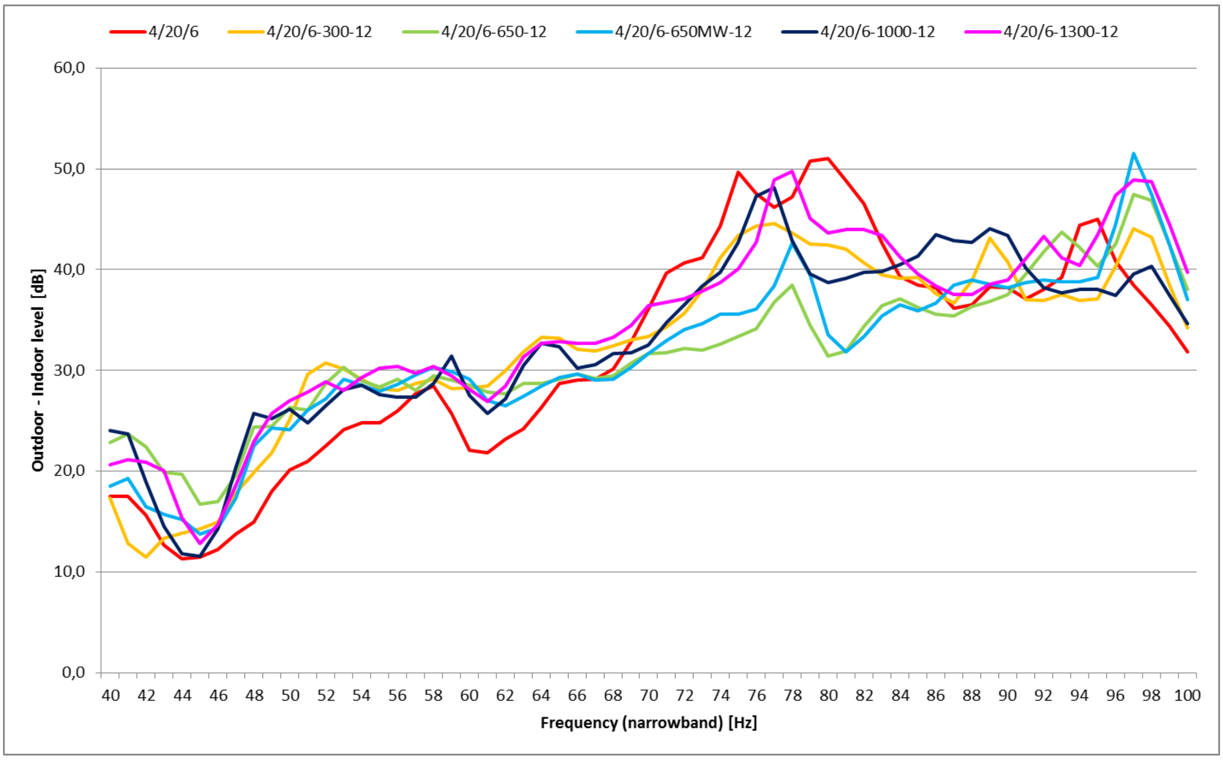

Figure 7.1.3

Measurement results: mic. position I1 – narrowbands (1 Hz)

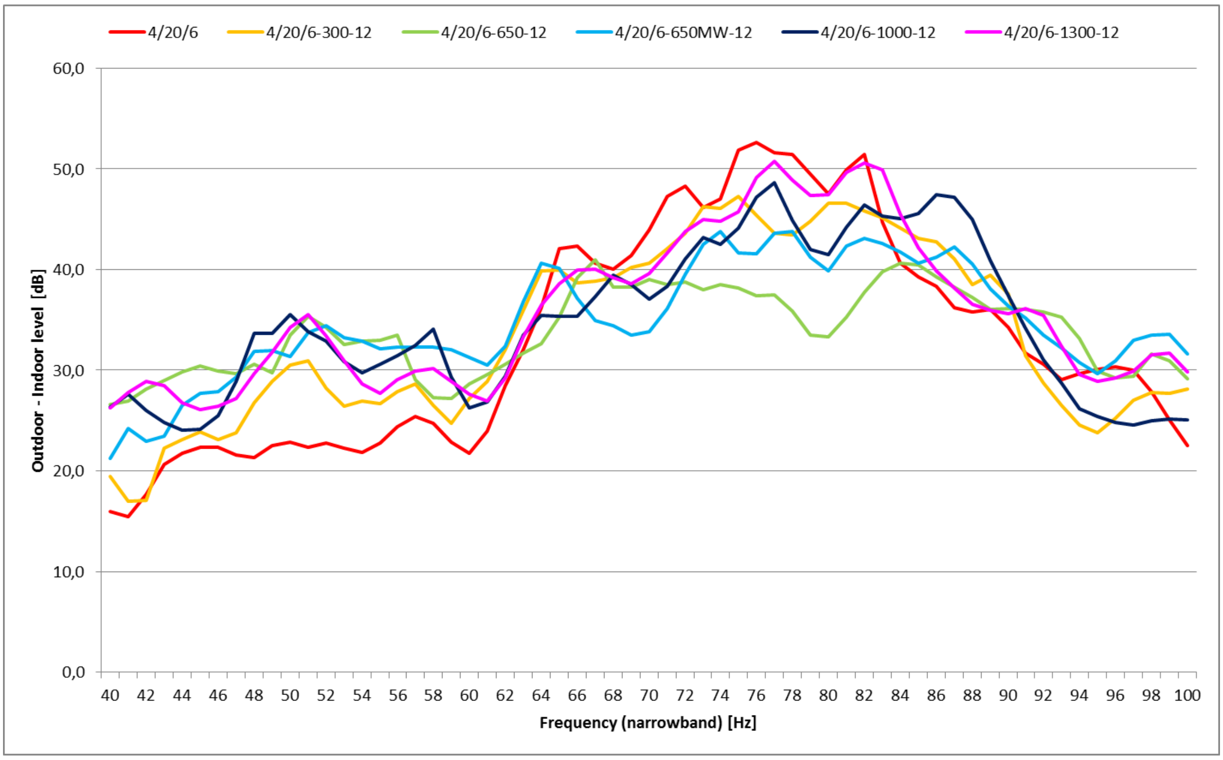

Figure 7.1.4

Measurement results: mic. position I2 – narrowbands (1 Hz)