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Acoustic Characterisation of an Air-To-Water Heat Pump for Different Operating Conditions: Inter-laboratory Results

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Abstract

Since the last 5 years the European heat pump market is showing an accelerated growth of outdoor air source heat pumps. The noise emitted by heat pumps is recognised as a drawback of the technology, especially during non-steady state operation of the heat pump.
Within Annex 51 "Acoustic Signatures of Heat Pumps" of the IEA HPT TCP, a dedicated task is the experimental investigations on acoustic performance of air-to-water heat pumps. The measurements of several laboratories on a unit, according to several operating conditions, on standard conditions (EN 14511), part-load conditions (EN 14825) and ERP (EN 12102-1) are compared. Under some conditions, some frost/defrost cycles occur, and a focus is set on the spectrum and sound level changes that can be observed between these cycles. The paper also presents some data about the acoustic directivity of the unit.

Keywords: acoustic emission; inter-laboratory test; heat pump; acoustic test;

1. Introduction

The primary aim with Annex 51 "Acoustic Signatures of Heat Pumps" of the IEA HPT TCP is to further increase the acceptance of heat pumps for comfort purpose with respect to the noise and vibration emissions.

The overall objective of this collaborative work is to gather the knowledge and expertise of the participants in order to forward this knowledge with dedicated recommendations for low-noise heat pumps to different target groups such as manufacturers, acoustic consultants, installers, standardization bodies and policy makers.

To reach this goal, different reasons to reduce sound emissions depending on countries (regulation), locations and applications have to be gathered and understood. The main influencing factors to the acoustic signature of these units will be identified. Collecting and combining research results in these fields on the different implementation levels (component, unit and application level) will finally lead to directions for improved components, units and control strategies including guidelines, as well as training and inputs to future standards.

The work of Annex 51 is divided into six tasks, from standard and legislation aspects to acoustic behavior of individual heat-pump sources (components) and noise synthesis, noise emission for neighborhood, psychoacoustics, etc. One of these tasks is dedicated to the measurement of the heat-pumps noise levels: water heater, air-to-air and air-to-water heat-pumps.

This paper focuses on the acoustic measurement of a split air-to-water unit circulating in six European laboratories, and running on several operating conditions, leading to different sound power levels which are analyzed and compared. In addition, the unit polar directivity is also measured and the effects on the noise between the defrosting phases and the consequences of frosting on the sound level is addressed.

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Regarding the expertise in terms of testing of heat pumps, as Annex 51 gathers experts from the major testing laboratories as well as the convenor of the European standardization committee on acoustics for HP (CEN/TC 113 WG9) and considering the new standard EN 12102-1 which is applied in this project, no specific bibliography was conducted for that task.

It has to be noted that many round robin tests are regularly performed within laboratories for ISO 17025 accreditation but without any public data. The European project ECOTEST, aiming at assessing the reproducibility of the standards used for Ecodesign regulations by means of round-robin tests on different types of heat pumps was conducted exactly at the same time than the Annex 51 task. The results of ECOTEST on the acoustic tests will be considered once publically available, if any relevance for this Annex.

2. Sound power levels of heat-pumps in steady-state conditions

2.1. Program

The EN 12102-1 standard specifies the main rules for implementing an acoustic measurement, especially on the installation aspects of the unit, whatever the operating conditions. A measurement program (cf. Table 1) has been defined for the unit, and each laboratory carried out all or part of this program, with thermodynamic measurements in parallel to the acoustic measurement.

The EN 12102-1 Annex A.4 gives the conditions to determine the sound power level of variable speed units for compliance with Ecodesign and Energy labelling regulations (cf. configuration #5 of Table 1).

Table 1. program of tests with the thermodynamic settings and specific settings for the selected air-to-water heat pump

Nr.	Standard	Condition	Air dry bulb (wet bulb) temperatures (°C)	Water inlet/outlet temperatures (°C)	Setting from manufacturer table	Set temperature	Fan	Mode	Liquid circulator setting
1	EN 14511	standard rating	7(6)	30/35	1	30	Auto	Heat (Sun)	max.
2	EN14511	standard rating	7(6)	30/35	1	30	Auto	Heat (Sun)	2
3	EN 14511	standard rating at max frequency	7(6)	30/35	10	21	Auto	Heat (Sun)	max.
4	EN 14825	C	7(6)	*/27	12	29	Medium (3 bars)	Heat (Sun)	max.
5	EN12102-1 A.4	reaching the same capacity as test C	7(6)	30/35				Heat (Sun)	max.
6	EN 14825	D	12(11)	*/24	11	30	Medium (3 bars)	Heat (Sun)	max.
7	EN 14825	B	2(1)	*/30	13	28	Medium (3 bars)	Heat (Sun)	max.
8	EN 14825	A/F (Tbiv)	-7(-8)	*/34	14	27	Medium (3 bars)	Heat (Sun)	max.
9	EN 14825	A/F (Tbiv) and maximum frequency	-7(-8)	*/34				Heat (Sun)	max.
10	EN 14825	E (TOL)	-10(-11)	*/35	15	25	Medium (3 bars)	Heat (Sun)	max.

2.2. Heat-pump under test

A split air-to-water heat-pump was selected as it is representative of a large share of the European market. The unit under test was provided by an European manufacturer: this inverter unit using R410A has a rated heating output of 8 kW according to its label. The outdoor unit size is approx. 800 x 600 x 300 mm.

2.3. Laboratories

This unit circulated in 6 European laboratories, carrying out acoustic and thermodynamic measurements:

- AIT (Wien, Austria),
- CETIAT (Lyon, France),
- DTI (Aarhus, Denmark),
- Fraunhofer ISE (Freiburg im Breisgau, Germany),
- Politechnico Milano (Milan, Italy),
- RISE (Borås, Sweden).

These laboratories implemented the heat pump in different measuring environments, some in a reverberant room, some others in a climatic chamber used as a hard wall room or as a free field room. The measurement techniques are various, from ISO 3741 in reverberant room and ISO 3743-1 or ISO 3747 (with engineering grade) in hard-wall room (usually a climatic chamber), and ISO 3744 for other environments. They all fulfilled the EN 12102-1 “class A” measurement requirement, which implies ambient conditions to be controlled, and the use of an acoustic standard with at least engineering grade.

One of the laboratories uses a mesh of 55 microphones around and above the unit, allowing directivity measurement.

Several laboratories investigated short time steps acoustic measurements (with less than the 30 seconds average used for standard measurement) to observe the noise variation when frosting and defrosting cycles occur.

Fig. 1. Examples of the heat-pump installation in a test room
(left: reverberant room, right: climatic chamber)

2.4. Inter-comparison results and analysis

Even though the tests results for all the conditions listed in Table 1 can not be presented, it can be said that in most of the cases, the laboratories found similar results. The differences that can occur are acceptable, given the variety of test environment and acoustic test methods. When some larger difference appeared, it was often due to a difficulty of adjusting operating condition rather than an acoustical measurement problem.

The first condition to be tested by 6 laboratories is the standard rating condition, as given in EN 14511 condition (configuration #1) which results are presented in Fig. 2

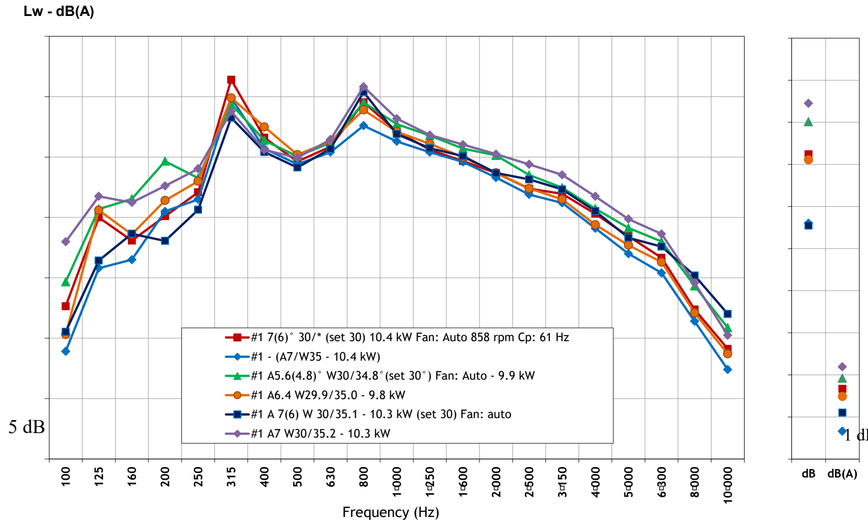

Fig. 2. Spectrum of A-weighted sound power levels for Standard rating conditions EN 14511 (#1) from 6 laboratories

For this operating condition, the spectra are close in the middle range of the spectrum, and the peaks at 315 and 800 Hz are well observed by all laboratories (their origin has not been studied, not being part of this work). As usual, larger differences appear at low frequencies, due to modal behavior of the rooms. The overall dB(A) value remains in a range of 1.4 dB(A). The thermodynamic results are also in a narrow range, from 9.8 to 10.4 kW.

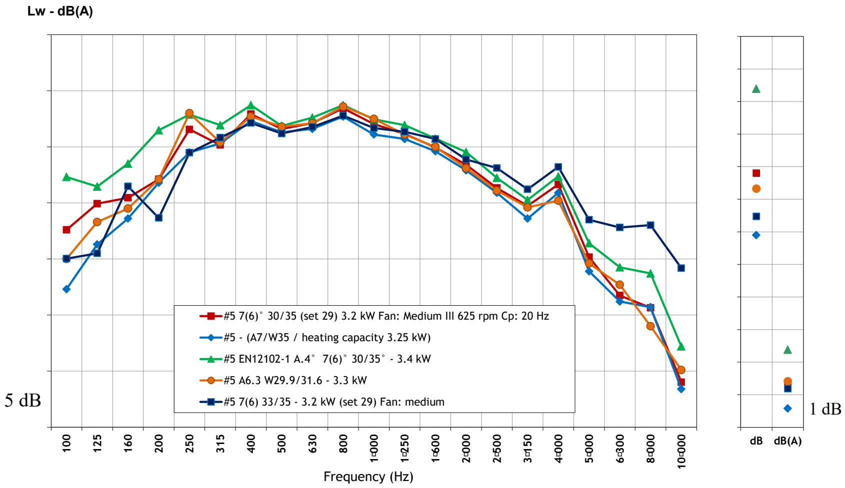

Fig. 3. Spectrum of A-weighted sound power levels for EN 12102-1 7(6)° 30/35°
same capacity as for the previous EN 14825 (C) from 5 laboratories

The EN 12102-1 condition requires to set the unit to the same heating capacity as observed for the C point of EN 14825, by reducing the compressor frequency and/or the water temperature difference ΔT if necessary. This procedure is sometimes difficult to achieve as the setting parameters are not reachable, or even though, the requested capacity can not be achieved.

The Fig. 3 shows results from 5 laboratories, leading to convergent results, for the middle range of the spectrum. The low and high frequency ranges exhibit some discrepancies for some laboratories (not investigated in the scope of this study), but the overall dB(A) value remains in a 1.5 dB(A) range. The measured capacity remains in a 0.2 kW range, from 3.2 to 3.4 kW.

2.5. Operating conditions vs sound power levels

The results of one laboratory which measured the rotation speed of compressor and fan are used to show the differences in sound power levels according to the operating conditions.

Different operating conditions lead obviously to variable sound power level and different spectrum shapes. In the present case, the standard rating condition (configuration #1) has a peak at 315 Hz band which disappears for the same condition but with the max frequency setting of compressor and fan. In spite of an average difference of 1.5 to 2.5 dB over the spectrum, the overall value only differs by 0.8 dB(A).

The noise levels for the configuration #6 and configuration #5 are significantly lower, respectively -13 and -10 dB(A) compared to the standard rating conditions (#1).

The noise is more linked to the rotation speeds of the compressor and the fan, than to the heating capacity of the unit, for which no linear relationship can be found for all the laboratories. Fig. 4 shows that configuration #5 is louder by 2.8 dB(A) than #6, due to the higher fan rotation speed (625 vs 558 rpm), despite a lower capacity. Although the two configurations have the same fan rotation speed, configuration #3 is louder by 1 dB(A) than #7, because compressor rotation frequency is 81 Hz instead of 34 Hz.

For all laboratories, configuration #3 (EN 14551 at maximum frequency) gives the highest observed sound power level from all configurations. The negative outdoor air temperature conditions lead to a sound level very close value to the value obtained with configuration #3. For the sake of simplicity, and to avoid acoustic measurement at negative temperatures, this easy-to-implement condition could be considered if the highest sound level would have to be declared. It has to be noted that this value would only be representative of a short period of the heat pump operation.

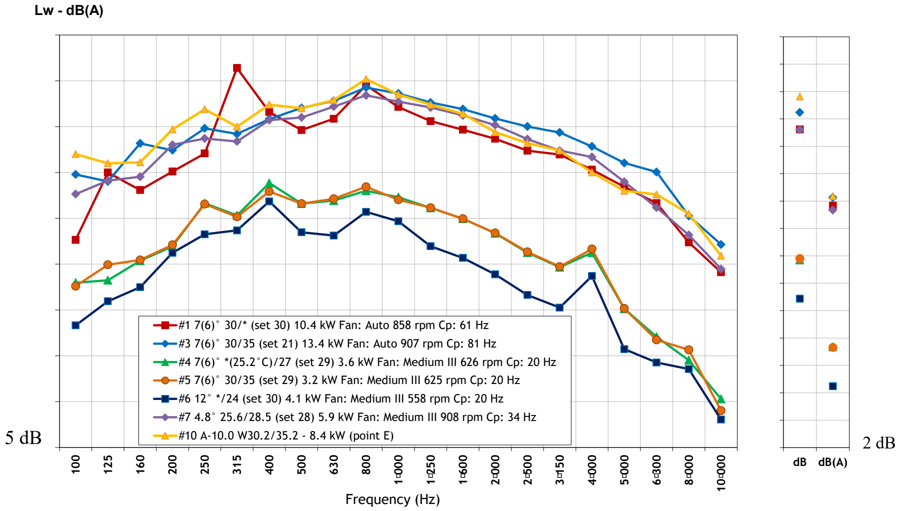

Fig. 4: Spectrum of A-weighted sound power levels for different operating conditions of the heat pump

For the acoustic value measured according to EN 12102-1 Annex A.4 (configuration #5), laboratories found out the procedure difficult to understand and not easily implemented for setting the unit (the heating capacity has to be same than for C point, the compressor frequency being the main parameter to adjust, then the outlet water temperature if necessary). The sound power level obtained is very close to the one obtained for EN 14825 point C (configuration #4). For the 5 laboratories that perform both tests, the overall difference is between 0 and -0.3 dB(A) only. A proposal could be to replace configuration #5 by the configuration #4 for achieving better reproducibility among laboratories.

3. Directivity

One laboratory implemented measurements with a dodecagonal polar frame (approx. diameter 2 m) around the outdoor unit, with 55 microphones. The data from 12 microphones, height 75 cm (third row from the floor, see the yellow arrows for 2 microphones on Fig. 5), allows the plot of the relative directivity diagram, presented in A-weighted overall level on Fig. 6 (an offset was applied to the acoustic data to show directivity values centered on zero).

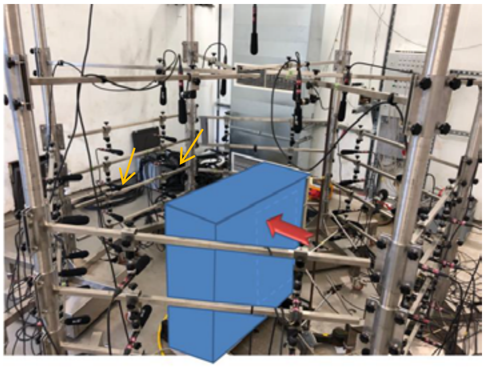

Fig. 5.Dodecagonal frames around the units with microphones

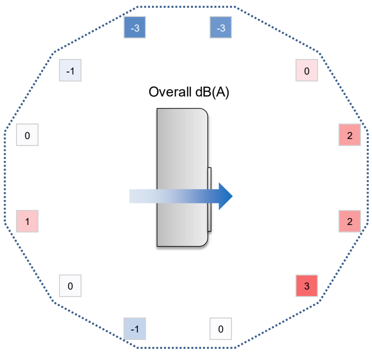

Fig. 6. Directivity for the overall A-weighted sound pressure level at 75 cm height

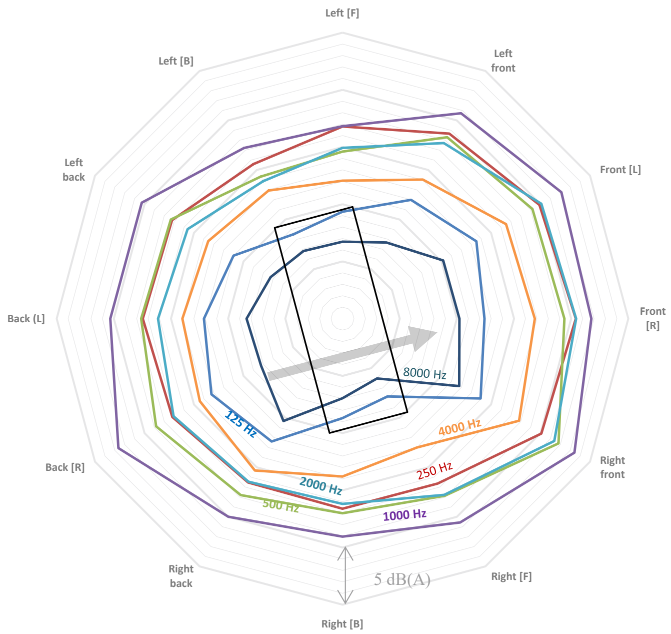

Fig. 7. Directivity for each A-weighted octave band

The directivity diagram in Fig. 7 shows the acoustic radiation directivity of the unit for each A-weighted octave band. Due to the fan located on the right of the casing, the maximum sound level is emitted in this direction ("right front"), and a little bit less on the rear side. The minima can be found on right and left sides, where there are only blind faces. For each octave band, Table 2 gives the amplitude of variation, and the position of the loudest and the quietest microphone.

Table 2. Amplitude of variation of sound pressure level around the unit

Freq.	**125 Hz**	**250 Hz**	**500 Hz**	**1000 Hz**	**2000 Hz**	**4000 Hz**	**8000 Hz**	**Overall**
Max – Min (dB)	6.1	4.8	7.5	6.6	7.5	5.8	5.7	6.2
Max position *	Right front	Front [R]	Right front	Right front	Right front	Right front	Right front	Right front
Min position *	Right [F]	Left [B]	Left [B]	Left [F]	Left [B]	Left [F]	Right [F]	Left [B]

** according to Fig. 7*

As expected the radiation is not omnidirectional, but the directivity amplitude is not huge, with a maximum range of 7.5 dB, meaning a ± 3.75 dB(A) around the mean arithmetical value. The octave bands for which the directivity is the most important are also those which contribute the most to the overall level. Overall range (including the full band) is ± 3.1 dB(A) around the mean arithmetical value.

In the case of an outdoor unit installation close to a neighborhood, this directivity should be considered in order to orientate the quietest side in front of the neighbor. Nevertheless, the effect of this directivity tends to reduce at longer distance.

4. Transient effects (spectral, sound power level)

The experiments also focused on the variation of sound power level when the heat pump operates with frost/defrost cycles. The sound level is rarely measured during this phase as it is generally out of the scope of standardised condition required for national legislations or certifications. In this condition, it is then continuously measured with a short time step (around 1 s) over a series of frost/defrost cycles. According to the temperature conditions, these cycles may have different duration, from 75 minutes to 120 minutes. The variation of acoustic emissions during these phases seems to be repeatable in shape as shown in Fig. 8.

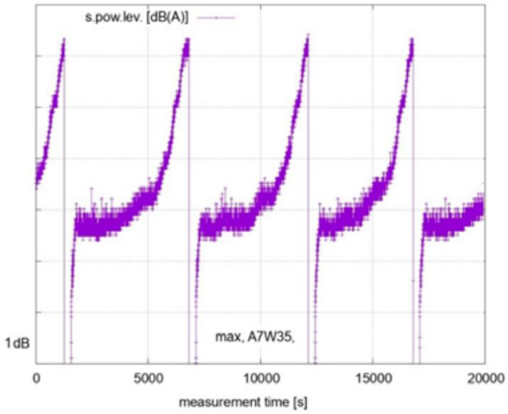

Fig. 8. Time dependent A-weighted sound power levels over 5h30 – configuration #3: EN 14511 freq. max

The simplest analysis for this unit shows that its sound power level measured (averaged over a few seconds) is always lower than the one measured during frosting (almost-steady state operation), without consideration of annoyance which would be studied using a psychoacoustic approach. That is why the acoustic behaviour during the defrosting phase is not investigated in the present paper.

Fig. 9 shows the variation of A-weighted sound power level according to time in seconds, for each octave band and for the overall levels during the frost and the defrost cycle. It can be seen that the overall value slightly increases with the frosting, for almost all frequency bands, except 4000 and 8000 Hz. The most contributing bands to the overall A-weighted value are 1000, 500 and 2000 Hz.

The frosting of the unit leads to an increase up to 3.5 dB(A), before the unit switches to the defrosting cycle. The spectrum at the end of frosting (arrow D) can be compared to the "dry" heat exchanger configuration (arrow H) on Fig. 10. The spectra of Fig. 10 correspond to the arrows time positions on Fig. 9.

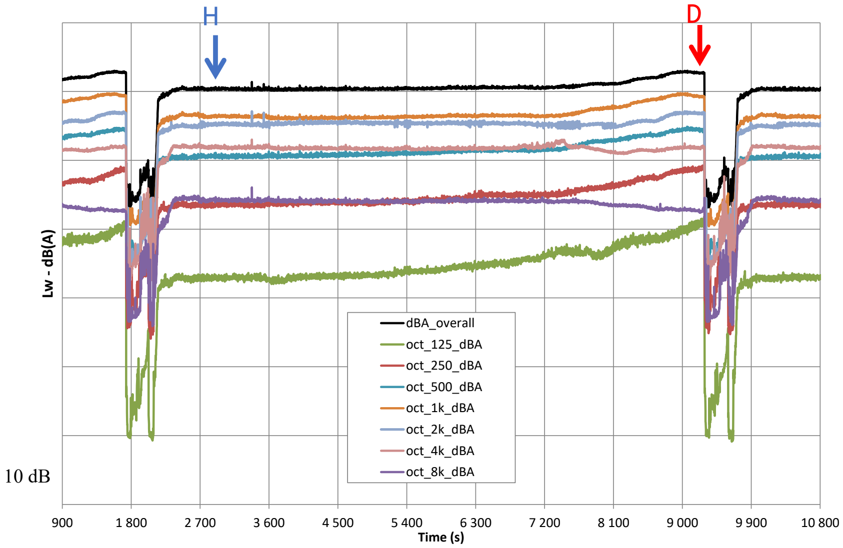

Fig. 9. Time dependent A-weighted sound power levels (in octave bands) between two defrosting phases configuration #3: EN 14511 frequency max

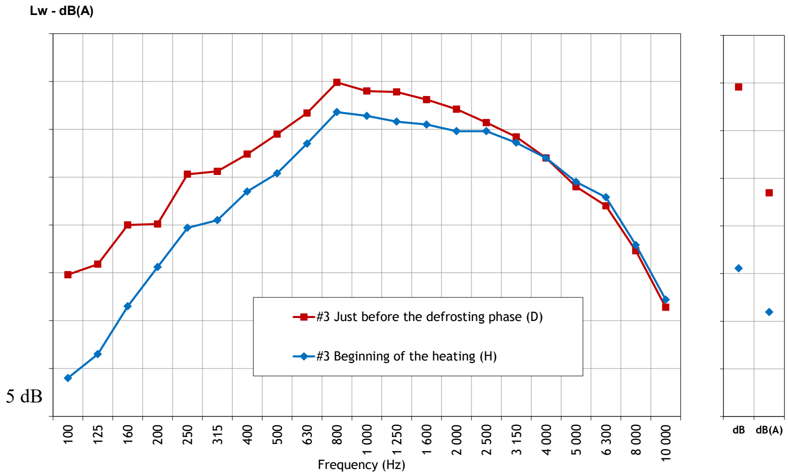

Fig. 10. Comparison of sound spectra before and after defrosting phase (cf. arrows on Fig. 9)

A similar increase of sound power level was observed for the configuration #7 (EN 14825 point B) condition, with a smaller effect on the overall increase, which is around 2 dB(A).

Fig. 11 shows the same quantities as Fig. 9, for negative outdoor air temperatures, leading to different behaviors of the sound power level. These levels are steadier, without noticeable increase before the defrosting starts, even though some accidents on frequency band may occur, but without larger influence on the overall level (see changes at 1800 s). However, this overall level quickly reaches the same magnitude than the one observed at the end of heating of Fig. 9 - arrow "D").

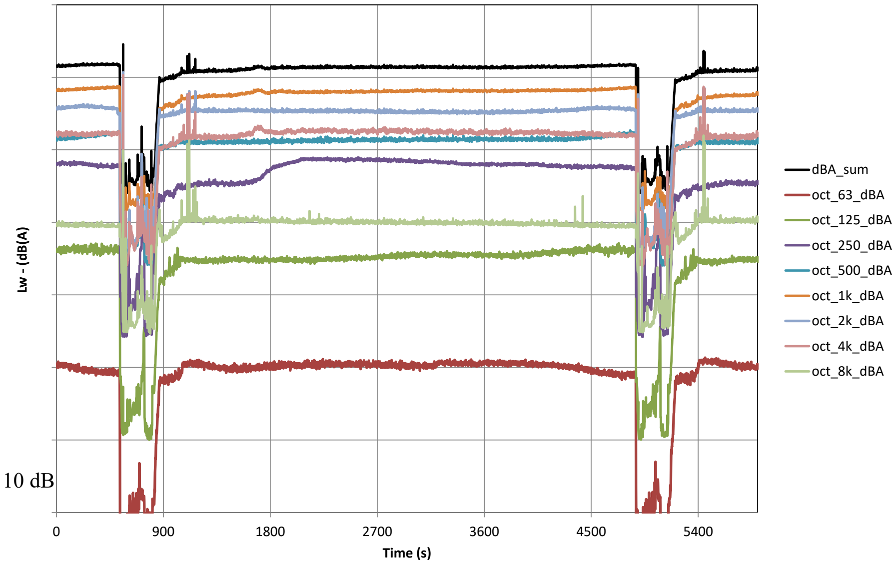

Fig. 11. Time dependent A-weighted sound power levels (in octave bands) between two defrosting phases configuration #8: EN 14825 -7(-8) */34

Conclusions

Acoustic tests have been performed on a split air-to-water heat pump, circulating through six European laboratories, for several operating conditions. The comparison of sound measurements shows a good agreement between results for standard operating conditions (EN 14511 and EN 12102-1). The EN 12102-1 Annex 4 used for Ecodesign compliance requires a unit setting not easy to understand and a clarification from the European Commission could be helpful.

The polar directivity appears to exist with a moderate amplitude (6.2 dB(A) for the overall A-weighted value, and 7.5 dB(A) for middle frequency octave bands), which can be used for an optimized orientation of the outdoor unit in order to limit the noise for the neighborhood. Additional measurements done on the non-steady period between the defrosting phases show that the frosting may increase the sound power level by 3.5 dB(A) for positive outdoor temperatures.

As part of the Annex 51, the results from these round robin tests will be of much help for:

- achieving a better understanding by the manufacturers of the acoustic behaviour of heat pumps in relation with climate conditions
- providing input for the revision of acoustic product standards such as EN 12102-1
- preparing recommendations for installers, namely on the sound directivity
- a better understanding by the policy makers of the complexity to tackle sound power level as it is often a compromise with energy efficiency of the heat pumps.

The results will provide input in order to select the most relevant operating point of the heat pumps and to define corresponding sound power level requirements in ErP regulations.

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