Technology Collaboration Programme
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Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 51

Acoustic Signatures of Heat Pumps

Final Report – Part 8

2.3 Seasonal Sound Power Level Air-to-Water Heat Pump

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Preface
This project was carried out within the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP), which is a Technology Collaboration Programme within the International Energy Agency, IEA.

The IEA
The IEA was established in 1974 within the framework of the Organization for Economic Cooperation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster cooperation among the IEA participating countries to increase energy security through energy conservation, development of alternative energy sources, new energy technology and research and development (R&D). This is achieved, in part, through a programme of energy technology and R&D collaboration, currently within the framework of nearly 40 Technology Collaboration Programmes.

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The Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) forms the legal basis for the implementing agreement for a programme of research, development, demonstration, and promotion of heat pumping technologies. Signatories of the TCP are either governments or organizations designated by their respective governments to conduct programmes in the field of energy conservation.

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For further information about the Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP) and for inquiries on heat pump issues in general contact the Heat Pump Centre at the following address:
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2.3: Seasonal Sound Power Level

Air-to-Water Heat Pump

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Date: November 2020	Final Version, Review: 04

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1 INTRODUCTION

This Task 2 of the Annex 51 pursues several objectives:

First, to perform a Round Robin Test between the laboratories to:

- Check that the measurements give close results ;
- Get a feedback on the standards implementation.

These data and results are available in the reports 2.1 and 2.2 of the Task 2.

And then, to provide input to other Tasks of the Annex, e.g. noise levels during the unsteady running conditions (frosting/defrosting), noise levels at non-standard rating conditions:.

- Task 4: Analysis of the effect of operating conditions of heat pumps on acoustic behavior
- Task 5: Heat pump installation and effects on surrounding environment
- Task 6: Improved measuring techniques and description of the acoustic performance

This report 2.3 describes the calculation of a Seasonal Sound Power Level (SL_w) calculated from the results of the laboratories on the air-to-water heat pump (RRT1).

2 SUMMARY OF RRT1: AIR-TO-WATER HEAT PUMP

The test program included several operating conditions, not usually used for acoustic characterization.

The first one is based on EN 14511-2 operating conditions (#1), with a modulation of circulator (#2), and at maximum compressor frequency (#3).

The next operating point (#4) is at the part load condition C from EN 14825

The operating point (#5) is performed according to EN 12102-1 Annex A.4, i.e. in the EN 14511-2 conditions while the heating capacity measured at part load condition C shall be obtained. This requires to set the unit at a frequency that allows to reach this capacity r, and if necessary and to adjust the water flow rate while maintaining the outlet water temperature.

The next conditions encompass the EN 14825 conditions:

- Condition D: smallest part load capacity (#6),
- Condition B: where defrost would is expected to occur (#7)
- Conditions A/F: at which the unit is operating at full load (#8 and #9)
- Condition E: investigating the operating limit of the unit (#10).

Table 1 describes these different test conditions and the corresponding settings provided by the manufacturer.

Table 1: operating conditions of the RRT1 on the air-to-water unit

RRT1 Programme : Measurement Points									
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.

(*) The water flow rate determined from test # 1 shall be used with the indicated outlet water temperature

3 SEASONAL SOUND POWER LEVEL

For the air to water heat pump, the knowledge of the noise levels measured for different operating conditions of EN 14825 allows considering the calculation of a "seasonal" acoustic value.

The Seasonal Coefficient of Performance SCOP is representative of the efficiency of a unit over the average climate. This climate is described as a series of bin temperatures with their corresponding occurrences between -10°C and +15°C.

COP values at the temperatures of -7, +2, +7 and 12°C are used to calculate this SCOP by linear interpolation between the two closest temperatures and weighting according to bin temperature occurrence.

The distribution of temperatures in the average climate is given in Figure 43. The total of hours is 4910, representing 56 % of the full year (8760 hours).

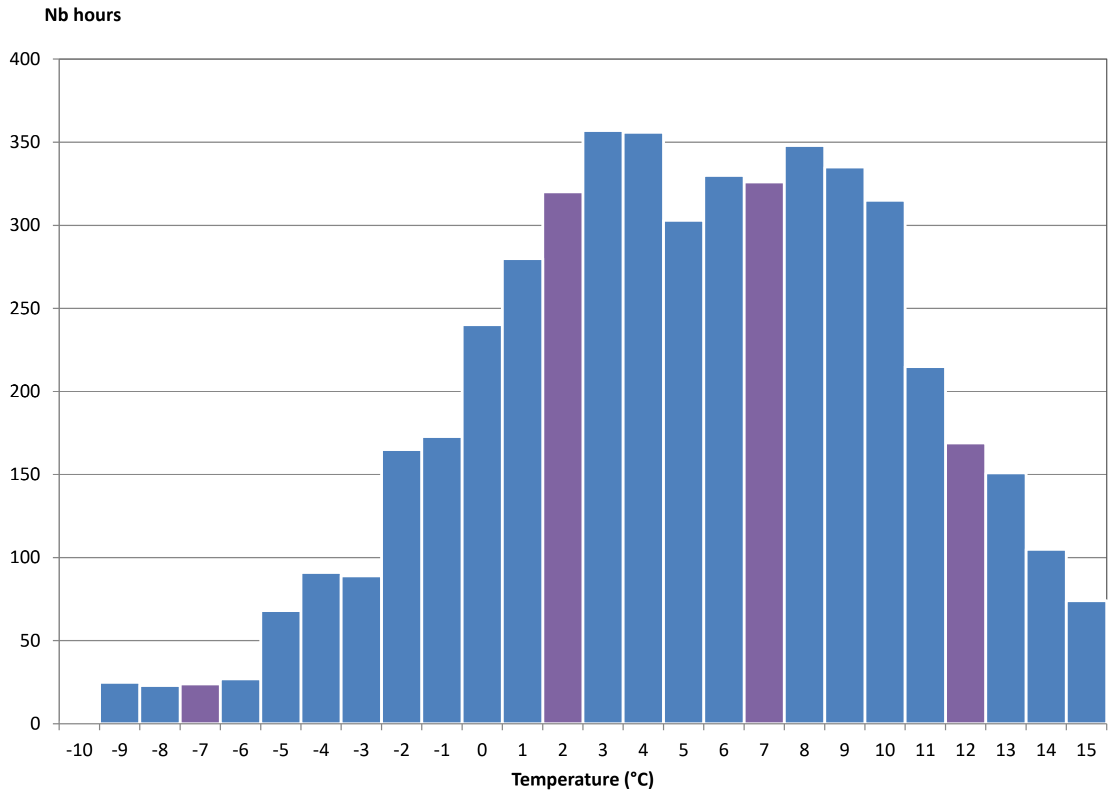

Figure 1 : number of hours for each step of temperature for average climate between –10 °C and +15 °C

With the measured sound power levels at the 4 target temperatures (–7, +2, +7 and +12 °C), several approaches are possible to calculate a seasonal sound level. In all cases, each sound level of each temperature is weighted by the number of hours, with a weighted logarithmic average, similarly to the noise exposure of workers.

$$SL_w = 10\ Log\left[\left(\frac{1}{\sum N_i}\right)\sum_i \left(N_i \,.\, 10^{Lw_i/10}\right)\right] \qquad (1)$$

Where SL_w is the seasonal sound power level, N_i is the number of hours associated to its sound power level Lw_i.

The data are only available for 4 temperatures[1].

<u>Approach by ranges:</u>

One approach is to attribute one sound level for a range of temperature, e.g. the sound values at -7 °C attributed to the range [- 10 ° to -3°], then the sound values at + 2°C are attributed to the range [-2 ° to 4 °], then 7° for [5 ° to 9 °], and finally 12 ° for [10 ° to 15 °].

[1] The sound level is also known at -10°C, but considering that there is very few hours of operation at this temperature, and that the acoustic measurement is tricky, it is not taken into account here.

The measured values are in red in the table of Figure 2. They are extended on the temperature ranges as described above. The right column entitled "relative weight" gives the results of the intermediate calculation used in (1):

$$10\ Log\left[\left(\frac{1}{\sum N_i}\right) N_i \,.\, 10^{Lw_i/_{10}}\right]. \qquad (2)$$

The logarithmic sum of the values in this column gives the SL_w, the weighted average sound power level which is here 66.5 dB(A).

Outdoor air temp. °C	Hours	Lw(A)	Usual operation
Tj	h/j	dB(A)	Relative weight
-10	1	71.5	34.6
-9	25	71.5	48.6
-8	23	71.5	48.2
-7	24	71.5	48.4
-6	27	71.5	48.9
-5	68	71.5	52.9
-4	91	71.5	54.2
-3	89	71.5	54.1
-2	165	68.9	54.2
-1	173	68.9	54.4
0	240	68.9	55.8
1	280	68.9	56.4
2	320	68.9	57.0
3	357	68.9	57.5
4	356	68.9	57.5
5	303	60.1	48.0
6	330	60.1	48.4
7	326	60.1	48.4
8	348	60.1	48.6
9	335	60.1	48.5
10	315	58.1	46.1
11	215	58.1	44.5
12	169	58.1	43.4
13	151	58.1	43.0
14	105	58.1	41.4
15	74	58.1	39.9
Total hours	4910	66.5 dB(A)	

Figure 2 : calculation of a seasonal sound power level – based on ranges

The right column gives weighted values for each temperature, showing their contribution to the overall result. The colors show that values in the range [+1 to +4 °C] are the most contributive due to the combination of a large number of hours of operation and a high noise level. On the contrary, even if the noise level at colder temperatures is higher, it is associated to a few hours of operation of the unit, then does not really contribute to the overall value.

Approach by interpolation of sound levels:

Another strategy is to apply the same approach as in EN 14825 for SCOP determination, with a linear interpolation between the sound levels, represented by the gray gradient on Figure 3. Below -7 °C and above + 12 °C, the values remain constant.

Outdoor air temp. °C	Hours	Lw(A)	Normal operation
Tj	h/j	dB(A)	Relative weight
-10	1	71.5	34.6
-9	25	71.5	48.6
-8	23	71.5	48.2
-7	24	71.5	48.4
-6	27	71.2	48.6
-5	68	70.9	52.3
-4	91	70.6	53.3
-3	89	70.3	52.9
-2	165	70.1	55.3
-1	173	69.8	55.2
0	240	69.5	56.4
1	280	69.2	56.7
2	320	68.9	57.0
3	357	67.1	55.8
4	356	65.4	54.0
5	303	63.6	51.5
6	330	61.9	50.2
7	326	60.1	48.4
8	348	59.7	48.2
9	335	59.3	47.7
10	315	58.9	47.0
11	215	58.5	44.9
12	169	58.1	42.7
13	151	58.1	41.9
14	105	58.1	39.5
15	74	58.1	36.8
Total hours	4910	66.2 dB(A)	

Figure 3 : calculation of an seasonal averaged sound power level – based on interpolation

Using the same set of measured values, the overall result is now 66.2 dB(A), which is close to the 66.5 dB(A) from the previous method.

Due to the smoother behavior of the sound level with interpolation, and for consistency with EN 14825 SCOP calculations, this method is preferred.

Note: the "relative weight" column now shows that the main contributing values are centered on 2 °C, due to influence of both duration and sound level.

Two other characteristics of the unit operation have also to be taken into account: the On/Off cycling at warmer temperatures and the defrosting process at lower temperatures.

On/Off cycling

The On/Off cycling occurs at high outdoor temperatures where the heating capacity of the heat pump even at its lowest frequency is much higher than the required heating loads. From heating capacity results we know that this On/Off cycling at least occurs at temperatures equal or above 12 °C.

The unit does not run continuously and is "off" during a percentage of time. During these off periods, the sound power level can be set to 0 dB(A) to express its silence. The data presented in the Figure 3 already show that the range 12 – 15 °C does not really contribute to the overall result (one remind that the logarithmic sum gives the prevalence to higher values). In this present case, adding periods during which the unit is stopped will not change the overall result, because the initial result of 58.1 dB(A) @ 12 °C is not contributing to the overall value, due to low sound level and small number of hours of operation.

Anyway, to improve the approach, it is interesting to calculate the ratio of capacity required for these specific conditions. Some assumptions are done, assessing 15 % of stop condition for 12 °C, 22 % for 13 °C, 35 % for 14 °C and 50 % for 15 °C. These values could be refined, but they would have no influence as the sound levels at higher temperatures are usually lower than at colder temperatures. It could be different if the calculation was done for a "warmer" climate, for which the number of hours associated to these temperatures would be higher.

Defrosting

The second characteristic to consider is the defrosting. During this phase, the averaged sound power level which has been measured is much lower, approx. 15 dB(A) less than without frosting). The duration the defrosting cycles has been measured between 5 to 6 minutes. The time between two defrosting cycles (when the unit starts until it stops) is between 88 and 130 minutes, depending on the ambient conditions and the configuration of the unit (Figure 4). Considering that the ratio of defrosting duration depends on the outdoor air temperature, ratios between 5 and 10 % of time, between -10 °C and 4 °C are assumed. Above 4 °C, no defrosting is arbitrary considered. This can be easily changed in the calculation if other units behave in different ways.

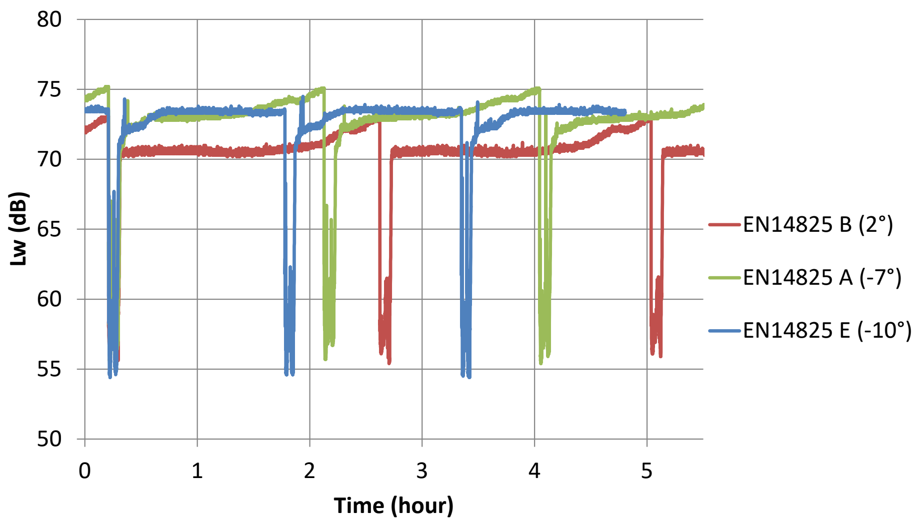

Figure 4 : frosting/defrosting cycles for different temperature conditions

Including these two considerations of the heat pump operation, considering that the sound power level of the unit stopped is 0 dB(A) and is 50 dB(A) during defrosting, the final overall averaged sound level is now **66.0 dB(A)**. This small decrease is only due to the arbitrarily defined defrosting time during which the unit radiates less noise (130 hours cumulated, approx. 4 % of the total time and 7% of the time between -10° and +3°).

Figure 5 shows the calculations, and a new column for the contribution of each king of operation. The "special operation" deals with cycling and defrosting. One can see that it does not contribute with values very far from the max of the "normal operation" which culminates at 57.

Outdoor air temp. °C	Hours	Lw(A)	Normal operation	Special operation	Stop/defrost ratio time
Tj	h/j	dB(A)	Relative contribution		Defrost
-10	1	71.5	34.4	4.3	4%
-9	25	71.5	48.4	18.3	4%
-8	23	71.5	48.0	17.9	4%
-7	24	71.5	48.2	18.1	4%
-6	27	71.2	48.4	19.6	5%
-5	68	70.9	52.1	23.6	5%
-4	91	70.6	53.1	24.9	5%
-3	89	70.3	52.7	24.8	5%
-2	165	70.1	55.0	28.2	6%
-1	173	69.8	55.0	28.4	6%
0	240	69.5	56.1	29.9	6%
1	280	69.2	56.4	31.2	7%
2	320	68.9	56.7	31.8	7%
3	357	67.1	55.4	32.8	8%
4	356	65.4	54.0		
5	303	63.6	51.5		Lw defrost
6	330	61.9	50.2		55.2
7	326	60.1	48.4		
8	348	59.7	48.2		Lw Stopped
9	335	59.3	47.7		0
10	315	58.9	47.0		
11	215	58.5	44.9		Time stopped
12	169	58.1	42.7	-22.9	15%
13	151	58.1	41.9	-21.7	22%
14	105	58.1	39.5	-21.3	35%
15	74	58.1	36.8	-21.2	50%
Total hours	4910	66.0 dB(A)	66.0	39.1	

Figure 5 : averaged sound level with cycling and defrosting taken into account
Defrosting averaged sound power level ~55 dB(A)

If the sound level during a defrosting cycle is increased from 55 to 65 dB(A), it has still no influence on the SL_W which remains at 66 dB(A), since the sound power level in operation of 71.5 dB(A) in this range of temperatures remains much higher.

If the sound level during a defrosting cycle is increased to 70 dB(A) (then close to the 71.5 dB(A) at this operating condition), the overall value goes increases to 66.2 dB(A), as in Figure 3. This is as if there was no defrosting cycle.

It's only with a quite unrealistic value of 80 dB(A) associated to defrosting cycle that a significant influence can be observed (Figure 6), with an increasing overall sound level, reaching **68.1 dB(A)**. The column "special operation" increases a lot, mainly due to the high sound level much more than the duration of operation. It reaches 64.1 dB, becoming almost as contributing as the "normal operation" data.

Outdoor air temp. °C	Hours	Lw(A)	Normal operation	Special operation	Stop/defrost ratio time
Tj	h/j	dB(A)	Relative contribution		Defrost
-10	1	71.5	34.4	29.3	4%
-9	25	71.5	48.4	43.3	4%
-8	23	71.5	48.0	42.9	4%
-7	24	71.5	48.2	43.1	4%
-6	27	71.2	48.4	44.6	5%
-5	68	70.9	52.1	48.6	5%
-4	91	70.6	53.1	49.9	5%
-3	89	70.3	52.7	49.8	5%
-2	165	70.1	55.0	53.2	6%
-1	173	69.8	55.0	53.4	6%
0	240	69.5	56.1	54.9	6%
1	280	69.2	56.4	56.2	7%
2	320	68.9	56.7	56.8	7%
3	357	67.1	55.4	57.8	8%
4	356	65.4	54.0		
5	303	63.6	51.5		Lw defrost
6	330	61.9	50.2		80.2
7	326	60.1	48.4		
8	348	59.7	48.2		Lw Stopped
9	335	59.3	47.7		0
10	315	58.9	47.0		
11	215	58.5	44.9		Time stopped
12	169	58.1	42.7	-22.9	15%
13	151	58.1	41.9	-21.7	22%
14	105	58.1	39.5	-21.3	35%
15	74	58.1	36.8	-21.2	50%
Total hours	4910	68.1 dB(A)	66.0	64.1	

Figure 6 : averaged sound level with cycling and defrosting taken into account
Defrosting averaged sound power level ~ 80 dB(A)

It is now possible to compare these results with the ones obtained according standard rating conditions.

Fehler! Verweisquelle konnte nicht gefunden werden. Table 2 shows the results calculated from the set of data measured by the 4 laboratories in these EN 14825 conditions. The overall values measured for EN 14511 and EN 12102-1 are also given for comparison. Of course, the input data are slightly different according to laboratory, but the relative results are consistent.

The difference between Seasonal Sound Level SL_w and EN 14511 is between 2.2 and 3.4 dB(A), whilst the difference with EN 12102-1 is between -5.7 and -6.7 dB(A).

Table 2: input data and results for 4 laboratories (defrosting at ~ 55 dB(A))

	Lab 1	Lab 2	Lab 3	Lab 4	Average
	Lw dB(A)	**Lw dB(A)**	**Lw dB(A)**	**Lw dB(A)**	**Lw dB(A)**
EN 14825 point A (-7 °C)	**71.5**	**68.2**	**68.0**	**70.2**	**69.5**
EN 14825 point B (2 °C)	**68.9**	**67.2**	**68.1**	**68.6**	**68.2**
EN 14825 point C (7 °C)	**60.1**	**57.0**	**57.5**	**58.7**	**58.3**
EN 14825 point D (12 °C)	**58.1**	**54.4**	**55.1**	**56.3**	**56.0**
Seasonal Lw dB(A)	**66.0**	**63.7**	**64.3**	**65.3**	**64.8**
EN 12102-1 "acoustics"	**60.3**	**57.2**	**57.6**	**58.7**	**58.4**
Difference	*-5.7*	*-6.4*	*-6.7*	*-6.6*	***-6.4***
EN 14511 A7(6) W30/35	**68.2**	**67.1**	**67.5**	**68.0**	**67.7**
Difference	*2.2*	*3.4*	*3.2*	*2.7*	***2.9***

The calculation of a SL_w is interesting as it clearly demonstrates (for this heat pump) that the averaged sound power level for the average climate is much higher than the noise measured according to the operating conditions given by EN 12102-1 Annex A.4, i.e. the sound level for air at 7(6) °C and water at 30/35 °C, but at the same capacity than the declared capacity at EN 14825 point C[2].

This encourages considering a change in the definition of the measurement conditions for the acoustic point.

Table 3 shows that the noise level measured at EN 14511 conditions (#1) seems to be more realistic, as it is very close to the EN 14825 Point B at 2 °C (around or less than 0.6 dB difference) which has been identified as the "key point" in a seasonal sound power level approach.

Table 3: results at EN 14825 point B and EN 14511 conditions for 4 laboratories

	Lab 1	Lab 2	Lab 3	Lab 4
EN 14825 point B (2 °C)	68.9	67.2	68.1	68.6
EN 14511 condition	68.2	67.1	67.5	68.0
Difference	*0.6*	*0.1*	*0.6*	*0.6*

Sound testing at EN 14511 conditions rather than at EN 14825 Point B at 2 °C will allow all sound techniques specified in EN 12102-1 as it is an "easy to implement" operating condition (no negative temperature, no frosting). These are positive points to move towards comparable results

[2] These conditions are the required conditions for sound power level according to ErP regulation 813/2013 for air-to-water heat pumps

4 CONCLUSIONS

For the first time, sound power levels of an outdoor unit heat pump has been determined for several operating conditions according to EN 14825 points A to E. In the same approach than for the SCOP calculation, a seasonal sound power level SL_w can be calculated, using the number of hours for each temperature of the average climate to weight each sound level for the overall average over the heating season.

The sound data measured at -7, 2, +7, +12 °C outdoor temperature are used, and for temperatures for which there are no acoustic results, a linear interpolation is applied to the acoustic values. Then a logarithmic weighted average is calculated, using the number of hours of operation for each bin of outdoor air temperature over the average climate, and the sound power level measured or interpolated at each bin temperature. The On/Off cycling above 12 °C and the defrosting cycle effects have also been taken into account, leading to a marginal decrease of the resulting overall sound power level .

As for any weighted average, the results are strongly impacted by the combination of the two main parameters, the number of hours and the associated sound level. A high sound level with only a few hours will not strongly contribute to the SL_w. With the logarithmic nature of the sound levels, the higher values are more dominant than for algebraic calculation, meaning that the lower sound levels will be less contributing.

From these calculations, a comparison can be done with the sound power level measured according to EN 12102-1 which is 6 to 7 dB(A) lower than the seasonal approach value , indicating that this EN 12102-1 operating condition may be not representative.

The EN 14511 standard rating condition 7(6) /30-35°C seems to be an interesting candidate condition as it gives quite close sound power levels, only 2 or 3 dB higher than the SL_w. This EN 14511 test condition is easy to implement. Moreover, it could avoid performing the tests according EN 14825 at different outdoor air conditions, those below 7 °C being difficult or impossible to maintain in acoustic test rooms. This EN 14511 standard rating condition seems to reflect a more representative acoustic behavior of the heat pump than the present EN 12102-1 Annex A.4.

A modification of the EN 12102-1 condition is desirable, both because it does not seem to be representative and because it is difficult to understand and implement in its current definition. The EN 14511 standard rating condition seems to be a good compromise between accuracy/reliability of the test and representability of the sound power level of the heat pump over the heating season.

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