Technology Collaboration Programme on Heat Pumping Technologies (HPT TCP)

Annex 51

Acoustic Signatures of Heat Pumps

Executive Summary

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Acoustic Signatures of Heat Pumps

IEA HPT Annex 51

IEA HPT Annex 51
Executive Summary and Documents Guide

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Introduction

Reduction of acoustic emissions is important to further **increase the acceptance of heat pumps** as air-to-water, water-to-air, air-to-air and brine-to-water (ground source) units (referred to as "units" in the following text). To increase this acceptance and minimize noise annoyance more focus has to be put on the acoustics emissions at steady state and transient behaviour of acoustic signatures during different operating conditions (e.g. icing, de- frosting, capacity control, cooling mode).

Depending on end user (owner or neighbour), noise is an indoor and/or an outdoor issue. From an acoustic perspective, both new and retrofit markets are important to be considered, as those heat pumps provide a convenient and effective way to exploit the potential energy savings.

Acoustic emissions have to be accessed in a hierarchical approach considering the following levels:

- **Component level** - Low noise components (e.g. fans and compressors)
- **Unit level** - System approach of combining the components, unit control, transient acoustic features.
- **Application level** (building/neighbourhood, including smart grid, psychoacoustic effects & acoustic propagation)

Furthermore, Education and training are very important aspects in heat pump acoustics (placement, noise reduction measures, modes of control and operation) so that bad installations will not go against good acoustic design and construction of the units.

As the current legislation is globally very diverse (also serving the needs of the different locations and countries), the Annex is structured to contribute to guidance and future standards in this field.

This Annex lived through the collaboration from the six countries (given in alphabetical order) Austria, Denmark, France, Germany, Italy and Sweden. All information regarding the IEA HPT Annex 51 "Acoustic Signatures of Heat Pumps" can be downloaded from the IEA HPT Annex 51 Website:

https://heatpumpingtechnologies.org/annex51/

This document contains executive summaries from all seven tasks, which had been followed throughout the duration of the Annex. The deliverable documents together with presentations, the webinar video and additional documents can be retrieved from the Annex 51 website.

Deliverable Documents

The following documents contain the deliverables generated by the IEA HPT Annex 51 team during their collaboration:

E	**IEA HPT Annex 51 Executive Summary and Document Guide – IEA HPT Annex 51 Executive Summary and Document Guide**	*E*
U	**IEA HPT Annex 51 Umbrella Report – IEA HPT Annex 51 Umbrella Report**	*U*
1.0	Deliverable 1.0 – **Introduction – IEA HPT Annex 51 D1.0**	*1.0*
1.1	Deliverable 1.1 – **Measurement Techniques – IEA HPT Annex 51 D1.1**	*1.1*
1.2	Deliverable 1.2 – **Regulations – Countries overview – IEA HPT Annex 51 D1.2**	*1.2*
1.3	Deliverable 1.3 – **Regulations – Synthesis – IEA HPT Annex 51 D1.3**	*1.3*
2.1	Deliverable 2.1 – **Selection of Heat Pumps for Round Robin Tests** – Market figures – **IEA HPT Annex 51 D2.1**	*2.1*
2.2	Deliverable 2.2 – **Round Robin Tests – Air-to-Water Heat Pump** – Heat Pump Water Heater – **IEA HPT Annex 51 D2.2**	*2.2*
2.3	Deliverable 2.3 – **Seasonal Sound Power Level** – Air-to-Water Heat Pump – **IEA HPT Annex 51 D2.3**	*2.3*
3	Deliverable 3 – **Overview on Heat Pump Component Noise and Noise Control Techniques – IEA HPT Annex 51 D3**	*3*
4	Deliverable 4 – **Analysis of the Effect of Operating Conditions of Heat Pumps on Acoustic Behaviour – IEA HPT Annex 51 D4**	*4*
5	Deliverable 5 – **Report on heat pump installation with special focus on acoustic impact – IEA HPT Annex 51 D5**	*5*
6	Deliverable 6 – **Annoyance rating and psychoacoustical analysis of heat pump sound – IEA HPT Annex 51 D6**	*6*
7.1	Deliverable 7.1 – **Educational material on acoustics of heat pumps – IEA HPT Annex 51 D7.1**	*7.1*
7.2	Deliverable 7.2 – **Workshop material and conference contributions – IEA HPT Annex 51 D7.2**	*7.2*

Task 1 "Legislation and standards"

Deliverable 1.0 – **Measurement Techniques** – **IEA HPT Annex 51 D1.1**	*1.0*
This document in its first part describes the physics of the acoustic phenomenon, with a brief definition: - of the quantities (pressure, power and sound intensity); - of the methods of propagation of sound outdoors; - of how the sound changes depending on the proximity or distance from the source, or depending on external conditions (wind, thermal stratification, presence of obstacles, diffusion and diffraction phenomena, the ability of some materials to absorb or reflect sound). The second part, on the other hand, focuses on the perception of sound by human beings by answering the question: "how does human beings perceive sound?"	

Deliverable 1.1 – **Measurement Techniques** – **IEA HPT Annex 51 D1.1**	***1.1***
This document shows the measurement methodologies used. This document is also divided into two large parts. The first part describes the instrumentation used in the measurement campaigns. First of all microphones, their functioning, the composition of more complex instruments such as intensity probes and microphone arrays are described, starting from the combination of 2 or more simple microphones. The first part is completed with the description of sound level meters, analyzers and acoustic calibrators. The second part describes: • sound pressure (and sound pressure level) measurements • sound power (and sound power level) measurements • the acoustic mappings, made with intensity probes or with microphone arrays. • psychoacoustic investigations, carried out with special mannequins (HATS, head and torso simulator).	

Deliverable 1.2 – **Regulations – Countries overview** – **IEA HPT Annex 51 D1.2**	***1.2***
The main areas covered are international standards; European directivities and Certification schemes; National laws of EU States. First of all there is a description of the international standards that regulate the problem of noise: • the international product standards EN12102-1 and EN12102-2 are described; • the measurement standards of the sound pressure level: ISO 1120X family; • the measurement standard of the sound power level measurement: ISO 347X family and ISO9614 family. Below there is a description of the European regulations in terms of maximum emission limits and labeling for heat pumps with electric driven compressors (EU 206/2012; EU 626/2011; EU 813/2013; EU 211/2013; EU 814/2013; EU 812/2013) and a brief description of the Ecolabel system. In the document there is also a description of the main certification schemes	

in EU: Eurovent and HP Keymark.

The document continues with a description of the national laws of the EU States considered in the ANNEX51 project.

Deliverable 1.3 – **Regulations – Synthesis** – **IEA HPT Annex 51 D1.3** *1.3*

In this document an analysis has been made between the various national legislative systems which differ in terms of noise. The analyzes were made taking into consideration different areas:

- environmental noise laws (maximum limits allowed indoors or outdoors, homogeneous areas, periods of the day or days of the week considered, penalties for particular sources such as heat pumps in some cases, or for particular types of noise such as impulsive noises repeated and tonal sounds);
- laws on noise concerning buildings (in some cases maximum limits of systems are defined);
- limits regarding the Safety area (maximum limits allowed in the workplaces).

Different nations currently have different approaches. Not all nations divide the national territory into different areas, but even in the absence of areas (such as in France for example), there are still very restrictive limits, especially for the noise allowed inside homes.

The analysis shows that even when the approaches are similar, different methods of measurement are often adopted to determine the noise annoyance. This annoyance is then defined starting from different descriptive indices. An example concerning heat pumps is for example the penalty due to the identification of tonal sounds: this is foreseen in different countries, but each country has a different method for the calculation and application of this descriptor which in some cases heavily penalizes models of heat pumps for which the frequency of the compressor and its harmonics overlaps that produced by the rotation of the fan. But this does not happen with all descriptors used.

Task 2 "Report on Laboratory Tests on Air-to-Water Heat Pump and Heat Pump Water Heater"

Deliverable 2.1 – **Selection of Heat Pumps for Round Robin Tests** – Market figures – **IEA HPT Annex 51 D2.1** *2.1*

Initially titled "Definition of heat pump units to be covered by the study" the task was heavily extended by covering the laboratory tests and analyzing the results. Therefore, the Deliverable 2.1 includes the market figures, the selected units and considerations for establishing a test program.

Deliverable 2.2 – **Round Robin Tests – Air-to-Water Heat Pump** – Heat Pump Water Heater – **IEA HPT Annex 51 D2.2**	2.2

For the decarbonization of the heating and cooling of residential buildings, heat pumps are considered as an advantageous solution. But the sound level they produce can sometimes be considered as disturbing or annoying and are a real hurdle to their deployment.

In one hand, the regulation is an effective way to provide a fair framework. The labeling helps the user to know the associated sound levels. It also defines the identical operating points at which to carry out the tests. In the other hand, the test standards allow the use of units under controlled operating conditions to get reliable and comparable results. These test standards are written as precisely as possible, to avoid interpretations (which are still possible).

Task 2 of Annex 51 has 2 objectives:

- to compare the results obtained between laboratories to check, after comparison of the results, whether the test methods are clear or whether they need to be improved.

- to provide input data for other tasks of Annex 51.

Interlaboratory tests

The tests are carried out on 2 types of heat pumps: an air-to-water heat pump and a heat pump water heater (HPWH). The test standards for the purely acoustic part are respectively EN 12102-1 and -2. They give requirements on how to set up the machine and measure sound levels. The operating points can be varied.

The acoustic tests are carried out on the air-water heat pump with a focus on the outdoor unit, containing the compressor and the fan which are the main noise sources. About ten operating points are defined, with conditions of EN 14511 but also operating points of standard EN 14825 (points A to F), and finally the "acoustic" point described in Annex A of EN 12102-1. A measurement protocol is also drawn up and supplied to laboratories to eliminate the simplest points of misunderstanding. The tests are carried out partially or completely by the 7 laboratories participating in Annex 51. On the most usual point of EN 14511 A7 (6) °C and W30-35 °C), the results compare well despite the wide variety of environments and measurement techniques. For some test points less usual for acoustic tests, some more important deviations could have been found without it being possible to analyze their origins, due to lack of sufficient data.

For the tests on the HPWH, an inlet/outlet ducted unit on the outdoor air, the objective was mainly to perform standardized measurements according to the new standard EN 12102-2 (being published). Only a few laboratories were able to participate due to the complexity of the implementation of this device. Most of the results are consistent.

The results are often convergent, which is a positive indicator. These deviations will be useful for the standardization committees to improve the drafting of standards, during revisions for example.

Input data

Taking advantage that the heat pump is being tested in laboratories, the usually untested configurations in acoustics (typically the operating conditions of EN 14825 for the "average" climate) provide additional information regarding the noise levels at various operating points. The primary relationship between noise and fan rotational speed can be highlighted, followed in second order by compressor rotational speed.

Continuous acoustic measurements with a very short time step were made during the icing and defrosting phases, showing that for positive temperatures, the icing led to an increase in noise of nearly 3 dB(A). In addition, the defrost is also described with precision, the different phases are clearly observable.

Directivity tests are also carried out with measurements all around the unit, showing differences of ± 3 dB depending on the measurement direction, these differences being important to be exploited when the sound levels radiated in the vicinity are to be calculated.

All these investigations deserve to be repeated on other types of machines to be able to confirm (or not) the observed trends.

Deliverable 2.3 – **Seasonal Sound Power Level** – Air-to-Water Heat Pump – **IEA HPT Annex 51 D2.3**	*2.3*
Finally, from the data measured in the different operating conditions of EN 14825, a "seasonal sound power level" calculation was carried out, using the meteorological data of the "average" climate, associated with the annual operating times of the heat pump at each temperature. This calculation shows that, on this unit, the seasonal noise level is close to that measured at 2 °C (considered as the barycenter of the climate for the acoustics). But this temperature is difficult to obtain in purely acoustic rooms and it generates icing both for the unit and for the measurement instrumentation. The operating point of EN 14511 then gives results closer to this seasonal sound power level than the specific acoustic point of Annex A of EN 12102-1. These results are providing some input for a possible revision of the standard.	

Task 3 "Identification of noise at component and unit levels and noise control techniques"

Deliverable 3 – **Overview on Heat Pump Component Noise and Noise Control Techniques** – **IEA HPT Annex 51 D3**	*3*
Heat pumps are more and more used in densely populated areas, which increases the need for quite heat pump design. The Task 3 report of the Annex 51 gives an overview on heat pump component noise and the fundamentals of noise control techniques. The aim of the report is to provide information and insights on the characteristics of different air and structure borne noise sources and an overview of various noise control measures, which can be applied in the design of quiet heat pumps. First, the function and the working principle of heat pumps is explained briefly. This builds the basis for understanding why and how the different components of heat pumps generate noise. The main noise sources, the fan and the compressor, are discussed in more detail, but also secondary sources and transmission paths are addressed. The block diagram in Figure 1 shows	

how the noise sources can be divided into two groups: the primary or main noise sources, such as the fan and compressor, and the secondary sources, such as valves or heat exchangers, which occur due to the self-noise of the refrigerant and the air flowing through the system or the interaction between the compressor and the pipework and between the heat exchanger and the fan.

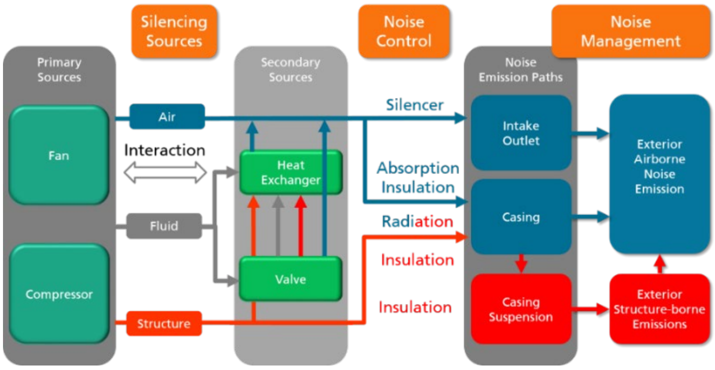

Figure 1: *Primary and secondary noise sources in a heat pump and main airborne and structure-borne transfer paths to the exterior.*

The most efficient method to reduce noise emissions is to suppress the noise generation at the source. In heat pumps, this can be achieved by using more quiet properly dimensioned compressors or fans. The next best way to reduce emissions is to decouple the main noise source from the rest of the heat pump. For example, using elastic mounts to fasten the compressor to the heat pump frame can greatly reduce the vibrational power transmitted into the frame. Any source may transmit airborne or structure-borne noise via a number of different parallel paths. Hence, the further away from the sources, the more difficult it is to control noise transmissions efficiently. If noise control measures at the heat pump are not efficient enough, it may be necessary to protect the surrounding with additional expensive retrofit solutions such as noise barriers or acoustic housings.

The acoustic emissions of heat pumps can be influenced by many design parameters and varies greatly between various operation conditions. The report gives an overview on the principles of passive and active noise control from which specific noise control measures can be derived for different heat pump components and transmission paths. Any heat pump component may transmit airborne or structure borne noise via a number of different parallel paths. To reduce the noise emissions from heat pumps efficiently, all noise paths need to be treated according to their dominance and contribution. The noise emissions from fans for example, are dominated by aeroacoustics sources and can be reduced or modified by changing the fan blade geometry or by using flow grids to optimise flow conditions.

Measures to reduce **fan noise** can be an installation of a diffusor which minimises exit losses improves the fan efficiency. Further, a relevant topic for heat pump manufacturers is the interaction between the fan and the heat exchanger and how they influence the acoustic behaviour of each other. Several parameters, such as the distance between the components or the angle of the heat exchanger, can have an influence on the fluid flow and on the aeroacoustic emissions. The previous named noise generation mechanisms can be summarised as airborne noise. The term “airborne” noise refers to the sound that is transmitted through the air. A significant part of heat pump noise is emitted to the outside via openings, e.g., the air inlet on the suction side and the air outlet on the pressure side. There are various passive control techniques which can be applied on heat pumps to reduce the transmission and emission of airborne noise. In practice, there are three main noise control techniques to reduce sound emission: sound absorption, sound insulation and sound attenuation. **Fehler! Verweisquelle konnte nicht gefunden werden.**a) illustrates the principles of these three techniques, showing where and how they may be applied in machine acoustics.

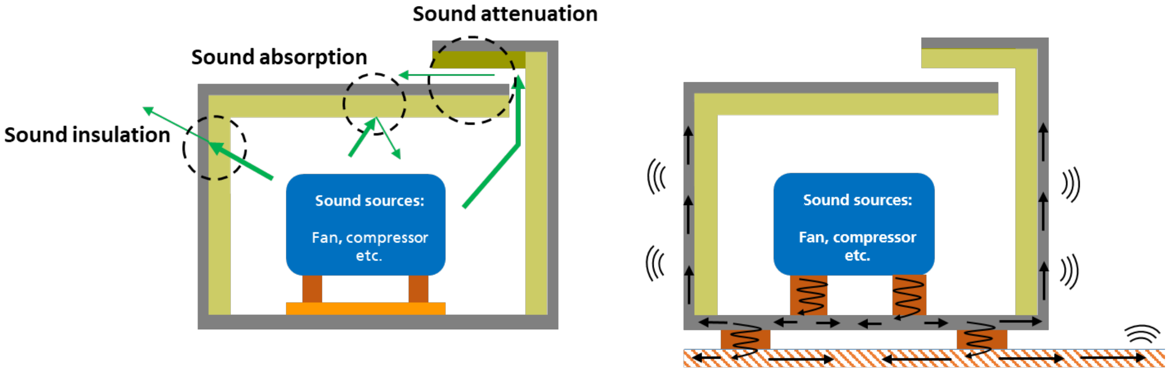

Figure 2: Methods to influence the sound emission of a noise source, e.g. heat pump or motor.

The second main noise source in a heat pump is **the compressor**. The vibro-acoustic of refrigeration compressors comprises several phenomena playing major roles, the origin of which is linked either to the dynamic behaviour or internal or external acoustics. The vibratory behaviour is linked to the movement of the motor itself, the second phenomena is linked to the projection of coolant against the upper part of the dome located downstream of the compression chamber. The meaning of structure born noise, generated by the compressor is of great practical importance. On the one hand, the product designers have to think about the appearance of the casing, on the other hand, they have to consider the vibration properties of the material that is used. In the casing, vibration is generated through vibrating components, such as the compressor and, more or less, the fan. Further, transmission paths, such as fluid pipes or structure parts, are the reason for noise transportation to the heat pump casing (see Fehler! Verweisquelle konnte nicht gefunden werden.).

In the report, active noise and vibration control (ANC and AVC) techniques for treating airborne and structure borne noise are also briefly introduced. However, to date there are no off-the-shelf ANC or AVC solutions available for heat pumps. Towards low frequencies, the effectiveness of passive acoustic treatments is limited. Due to the long acoustic wavelength at low frequencies, conventional airborne noise control concepts are heavy and require a large installation space. For applications with weight restrictions and where the installation space is limited, active noise control (ANC) approaches can be an alternative.

Finally, if the heat pumps themselves do not meet the requirements, retrofit solutions are required. Typical retrofit solutions are so-called acoustic housings. In addition to noise reduction, these housings can protect heat pumps or air conditioning systems from other environmental influences or vandalism.

Task 4 “Analysis of the effect of operating conditions of heat pumps on acoustic behaviour”

Deliverable 4 – **Analysis of the Effect of Operating Conditions of Heat Pumps on Acoustic Behaviour – IEA HPT Annex 51 D4**	*4*
Heat pumps being identified as a key element in the long term decarbonization of the heating sector, understanding and improving their acoustical behaviour becomes crucial to ensure their widespread acceptance, especially in densely populated areas. To this effect and in conjunction	

with the content of other tasks, this task addresses three topics:

1. First, the coupling of energetic and acoustic heat pump models are reviewed.
Such approaches allow for an efficient and accurate evaluation of the dependency between states of operation and their resulting noise, including transient or cyclic evolutions like frosting. Thus, individual components can be sized accordingly, economically accounting for acoustics at early stages of development. Furthermore, the heat pump control strategies and operating envelopes can be adjusted through simulation (possibly in real time), in order to reach a combined optimization that best suits both energetic and acoustic needs.

2. Sound emissions during heat pump transient processes are identified and discussed. Those can be short-term events (seconds to hours), such as start-stop behavior of the compressor, load changes and inverter modulation, frosting/defrosting (in the case of air heat pumps), domestic hot water tapping or other changes in external conditions. Some long-term phenomena (months to years) such as the ageing of grommets can also impact sound emissions.
Even though transient noises prove to be quieter than steady noises near full capacity, they remain very relevant as they tend to draw more attention through their suddenness and possible evolutive or tonal character. Corresponding noise control measures are further investigated within Task 3.

3. Finally, it is reported on the dependency of heat pump noise emissions on the type of heat source, heat sink, the operating conditions/load levels and the control strategy. Each of those influences are exemplified through experimental comparisons. Further results with a similar scope can be found in the Task 2 report.

A proper understanding of relations between heat pump types and sizes, their states of operation and their subsequent acoustic behaviour is essential to minimize noise disturbances. Pursued efforts in acoustical engineering, at component, unit and set-up levels, should pave the way for more comprehensive early stage design processes, including virtual prototyping and reliability engineering.

Task 5 “Heat pump installation and effects on surrounding environment”

Deliverable 5 – **Report on heat pump installation with special focus on acoustic impact – <u>IEA HPT Annex 51 D5</u>**	***5***
Air-to-water heat pumps are also often chosen where space is limited or where there are obstacles in the building regulations. Compared to air-to-air heat pumps, water, which is more suitable for this purpose, is used for heat transfer. A permit is not required. The disadvantage of the air-to-water heat pump is its comparatively low efficiency and increased noise emissions. The latter are mainly caused by the motor of the air intake fan and by the compressor. The aim of this work thesis is therefore to select and place air-to-water heat pumps in such a way that the sound pressure level in the surrounding houses is kept low.	

In the following chapters, light will be shed on several topics surrounding the placement of heat pumps.

This report presents a selection of tools, which are used for calculating sound pressure levels. This includes simple formula based tools, which are often available online on websites of heat pump manufacturers or heat pump association. Examples shown include a Swiss, German and Austrian version. Two-dimensional visualization is based on the same formulas, but allows the user to see the sound pressure levels in a horizontal plane surrounding the freely placeable heat pump. All these tools neglect - apart from the corner- and wall-placement "penalties" - absorbtion, reflection or frequency dependencies in the calculation. The underlying formula is very ease and can be calculated by hand. To include the effects of directivity and frequency behaviour as well as absorption and reflection a much larger computational effort would have to be made. Some approaches, which try to shed light on these effects are visited next. Advanced sound propagation tools like CadnaA, SoundPlan, NoiseD3D, Mithra-SIG, IMMI, Olive Tree Lab Suite and OpenPSTD are listed. The full three-dimensional calculation of sound propagation is of course possible solving the acoustic wave equation using e.g FEM and BEM.

The virtual placement of heat pumps using augmented reality is presented. This includes a description of acoustic measuremnets of noise sources, the aurealisation approach and the methods for calculation sound propagation. The app is realized by a modeling and mapping approach and hardware and software for visualization and acoustics are described.

The acoustic interaction of multiple heat pumps including reduction measures is analysed using primarily the tool IMMI. First, the terraced housing estate chosen for a exemplary study is presented including the description of heating load, hot water provision, heating demand and the analysis of the neighbouring sites. The maximum sound propagation is calculated using IMMI following ÖNORM ISO 9613-2 and ÖNORM S 5021. Several scenarious have been compared: One heat pump per household, one heat pump per house and a local heating supply scenario. In all cases heat pump selection and placement are outlined. Results are compared using a method introducing penalty points on all defined immission points (doors, windows, borders). For a promising case, calculations have been repeated introducing noise barriers into the calculation. Time of day dependent sound propagation have been visited to introduce user profiles of the different buildings. Alternative tools like OpenPSTD and Olive Tree Lab Suite and the involved options are described.

The report additionaly is working on the analysis of unit placement, indoor & outdoor sound propagation. This includes the description of different installation locations and linked sound pressure maps showing the propagation of noise in various scenarious. A table summarizing the sound pressure level, which can be expected depending on the heat pump position is given.

We outline the potentail of sound absorption at nearby surfaces and tabulates the reduction effects of various measures taken. Finally common unclever decisions in heat pump placement are visited such as wrong locations, roof installation, the (unforeseen) development of the neighbouring properties, the selection of improper sound absorbing measures and finally the installation of further units in the neighbourhood.

Task 6 "Heat pump installation and effects on surrounding environment"

Deliverable 6 – **Annoyance rating and psychoacoustical analysis of heat pump sound – <u>IEA HPT Annex 51 D6</u>**	***6***
Noise from heat pumps has a potential to cause annoyance of owners and neighbours, the degree of which is influenced by several factors. Factors like the acoustic characteristics of the noise, the installation and placements of the heat pump unit and individual's sensitivity to noise. To further increase the acceptance of heat pumps it is important to reduce this noise induced annoyance. In order to achieve this, detailed knowledge of how acoustic parameters influence the annoyance is necessary. Noise regulations are commonly focused on the A-weighted level, but other acoustic parameters may better explain the level of annoyance. These parameters could be the presence of low frequency noise and tonality, which the A-weighted level inefficiently assess. Common parameters used to assess the subjective perception of noise is loudness, sharpness, roughness, and tonality. These parameters have been developed to better explain the sensation of sounds. A way to assess the annoyance of noise sources is to perform listening tests. In this way it is possible to gain knowledge of the acoustic parameters that influence the annoyance. A possible drawback of these tests is that it often requires to use short sound stimuli, making it difficult to assess long term annoyance. A desired result is an annoyance index that show how different acoustic parameters explain the assessed annoyance response. Development of an annoyance index of heat pump noise could be beneficial when setting regulatory demands for heat pump noise. In task 6 of Annex 51, a listening test was performed on an Austrian and Swedish listening panel. Both panels were presented with the same set of sounds and the same test set up. The sounds investigated were recorded on the outdoor unit of an air-to-air heat pump at different operating conditions at different positions around the unit. All recordings were equalized to the same A-weighted level to investigate the effects of other parameters on perception. From the study a model of an annoyance index was derived, which showed dependence on several parameters to have a sufficiently reliable model. The single best descriptor was roughness, but the model was improved by adding sharpness, loudness, and, to a minor degree, tonality. This shows that the perception of the heat pump noise is rather complex. Further, the sound rated as the most annoying was the condition with the lowest compressor speed. This condition also has the lowest fan speed, which also additionally might influence the perception. This report additionally present results from previous studies dealing with different aspects of heat pump noise. A Swedish study investigated the perception of noise from ground source heat pumps. The sounds investigated were recorded on three units at different compressor speeds. Sounds were again equalized for the A-weighted level. The results showed that the participants preferred sounds with higher compressor speed. The sound from the compressor is not surprisingly the dominant noise source due the absence of fan noise (compared to an air source heat pump). But the variation in acoustic characteristics due to the variation in compressor speed seem to be of importance. An Austrian study investigated the effects of different noise mitigation measures on perception. Recordings were done in a climate chamber with absorbing walls and a reflecting ground. In this experiment the sound samples were not equalized. Acoustic data showed a considerable directionality of the different measures which was also present in the perception	

data. As a consequence, no overall effect of the measures was observed although there were effects depending on the emission direction. Interestingly, the A-weighted level was the variable which best explained the perception data whereas loudness explained less variance. Combining different variables, the best model contained A-level, loudness, and loudness level as well as sharpness and roughness with the latter four explaining an additional 10% of the variance. Overall, the results show that, in addition to the A-weighted level other acoustical parameters such as loudness, roughness, and sharpness may help to better model the perception of heat pump noise. Furthermore, the directional effects observed indicate, that the placement of heat pumps could have a relevant effect on how annoying people perceive the unit.	

Task 7 "Heat pump installation and effects on surrounding environment"

The dissemination task consists of two deliverables:

- 7.1 Educational material on acoustics of heat pumps V02
- 7.2 Workshop material and conference contributions

Deliverable 7.1 – **Educational material on acoustics of heat pumps** – **IEA HPT Annex 51 D7.1**	*7.1*
In the 7.1 deliverable document "D7.1 Educational material on acoustics of heat pumps" four guides are included: - Control the noise – a guide for installing air for water heat pumps - Heat pumps & environment acoustics - Heat pumps & recommendations for installation - Heat pumps - study of the risk of noise pollution in the vicinity The first guide is based on a documentation produced for the Danish Energy Agency. The three consecutive documents are based on fiche technquies from AFPAC, the French heat pump association. The original documents are available on the Annex 51 Website https://heatpumpingtechnologies.org/annex51/. **Control the noise – a guide for installing air for water heat pumps** covers an introduction to heat pumps discussing noise/sound authority, noise from air to water heat pumps (noise creation, noise measurement, influence of operation conditions, noise regulations), noise distribution (outdoor noise, indoor noise), calculation models (noise data, operating conditions, sound calculation tool), noise reduction, good installation (vibration sources and distribution cannels, rules of thumb regarding vibration isolation), control measurements, npise reduction (noise shields, noise gates, cabinet vibrations, cabinet noise) and examples (unappropriate placement, good and bad placements, control measurment of noise). **Heat pumps & environment acoustics** covers definitions of sound power and sound pressure, the calculation method of adding sound sources, recommendations for the implementations (location, reflection of emitted noise, reflection of received noise, directivity of ventilations, distance to property lines, installation under windows), reminder on the regulation of	

neighbourhood noise, application examples and emergence calculation (outdoor measurement, measurement inside buildings. **Heat pumps & recommendations for installation** covers supports (concrete base, metal frame), network design rules (design principles, wall crossings), the pipes (direct expansion, water pipes), air networks (vibration transmission through ducts, noise transmission through ducts, radiation of noise through the walls of the duct, design principles), acoustic attenuation devices (absorbers on walls, sound barrier, enclosures) and maintenance. **Heat pumps - study of the risk of noise pollution in the vicinity** covers measurements of residual noise without heat pumps, acoustic emergence, manufacturer documentation, conversion of acoustic power / pressure, place of installation (location, reflection of emitted noise), location of measurement and the measurement of acoustic emergence (absorbent on wall, sound barrier, enclosure).	

Deliverable 7.2 – **Workshop material and conference contributions** – **IEA HPT Annex 51 D7.2**	*7.2*
The 7.2 deliverable document, "7.2 Workshop material and conference contributions" lists all workshop presentations, the various conference presentations, contains the links to the webinar video and concludes with a list of publications which have been prepared by the Annex 51 partners throughout the Annex 51 duration.	

Administrative Topics

- Project duration: April 2017 – December 2020
- Operating Agent: Christoph Reichl, AIT Austrian Institute of Technology, christoph.reichl@ait.ac.at
- Participating countries: France, Sweden, Austria, Italy, Germany and Denmark
- Further information: http://heatpumpingtechnologies.org/annex51/ and Research Gate https://www.researchgate.net/project/IEA-HPT-Annex-51-Acoustic-Signatures-of-Heat-Pumps

Acknowledgements & Outlook

This summary should not end without huge acknowledgments to all contributors within IEA HPT Annex 51. This has to be especially emphasized, as the last part of the Annex has been transformed to an online adventure due to the COVID-19 crisis, which also forced us to change the initially planned workshop at the Mostra Convegno Conference to a webinar. Acoustics of Heat Pumps will surely remain a topic of wild discussion and we are sure, that we can continue our way together to **increase the acceptance of heat pumps** by continuously removing the barriers one after the other. Enjoy the 500+ pages of documentations, the presentations, papers and last but not least the webinar.

All the best,

your IEA HPT Annex 51 Team.

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