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Simulation of noise propagation of outdoor HVAC/R unit in surrounding space

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ABSTRACT

The proposed paper will describe how acoustic simulation technique will improve the quality of installation of outdoor HVAC units and its acceptance.

The HVAC/R outdoor units are thermodynamic machines having 2 major sources of noise, a refrigerant compressor and a fan to move the air and make the thermal exchange. The installation of such equipment in urban area becomes more challenging due to restricting regulation and neighborhood acceptance. Furthermore, a modification of the installation after commissioning is not easy and certainly costly. A system manufacturer can now use acoustic solver to predict the sound propagation of a unit, anticipate various configuration of field installation and provide recommendations to contractor. The objective is to minimize the claims for noise and improve the quality of installation and acceptance of HVAC outdoor units.

Keywords: HVAC Unit, Directivity, Testing, Simulation

I-INCE Classification of Subject Number: 50

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1. INTRODUCTION

In our day to day life of citizen, each of us is exposed to thermodynamics machines: the heat pumps (and more specifically the residential heat pump) that provide human comfort at home by heating the space and the domestic hot water, and the so called condensing units that are providing the necessary cooling to protect the food (and – also very important – minimize the food waste with a better supply chain – remember that 1/3 to ½ of produced processed food is going to waste).

Both systems are using the outdoor air to exchange heat. The condensing unit is rejecting the heat from food inside display cases or food disposals, into the ambient air using an evaporator equipped with a fan to force the convection.

The heat pump shares the same working principle of the condensing unit but works basically in the opposite direction: the heating capacity is pulled out from the ambient air to heat up space of domestic water.

The capacity exchange with ambient air induces the unit to be placed outdoor, open to fresh air. While this is not causing any problem where the houses or retails are largely spaced, the situation becomes quickly complicated in cities with higher density of population. This leads to shorter distance between the outdoor units and living space that can easily generate annoyance. The local regulations for noise emission have been established to protect the wellbeing (or even the health of people) and comfort of the resident.

Noise limits L_{Aeq} dB(A)	Day (6/7-22 h)	Night (22-6/7h)	Remark
Austria	50	55	
Belgium	40-60	30-55	Range represent the variation according to the zone measurement : • industrial • commercial • residential
Denmark	40-70	35-70	
Finland	45-55	40-50	
France	50-55	40-45	
Germany	45-70	35-70	
Italy	45-65	35-65	
Portugal		< 45-55	
Spain	55-65	40-55	
Sweden	50-55	40-45	

Figure 1: overview of noise limits in Europe [1]

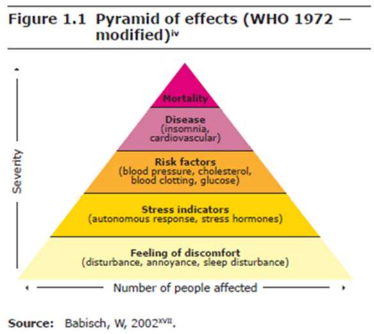

Figure 2: Effects of noise exposure by World Health Organisation [2]

The primary focus of the authorities is clearly a mitigation of noise generated by transport (Roads, highways, airports, railways). But as component or system manufacturer active in heating or cold chain, we are more and more facing problematic of the difficulty to install equipment due to the obligation to respect the noise legislation.

Our first responsibility is to optimize the system to reduce noise emission but also to better understand the context of use and installation. Specifically, the noise emission characteristics of the equipment must be investigated in order to help and support a trouble free installation.

In this article, we will focus on units that are outdoor and using ambient air. There are other technologies using different sources like water, ground to exchange energy. Those are not part of the discussion.

Figure 3: installation of condensing unit of the shop roof and at proximity of the neighborhood – proximity with living place created troubles and action was required to minimize noise from the units.

2. Condensing unit: description of the machine, the application

The condensing unit can be installed indoor or outdoor. The indoor units can only be installed into large space with enough ventilation or roof covered: large garage, access area for services, ...

The outdoor units are typically installed on the roof of retail: gas station, food retails, bakeries, butcheries, caterings and restaurants, convenient store.

Figure 4: indoor condensing unit [3]

Figure 5: Outdoor condensing unit - the components are inside a housing protecting to weather conditions [3]

Both are sharing the same working principle and components:

- Condenser: the heat transported by the refrigerant is rejected at condenser through forced convection (this component gives the name of condensing unit)

- The fan forces the air in the condenser to cool down the refrigerant. Nowadays, the fans have variable speed controls to adapt the speed of the fan with the need of cooling capacity required

- A compressor that compress the refrigerant from low temperature, low pressure to high pressure and high temperature.

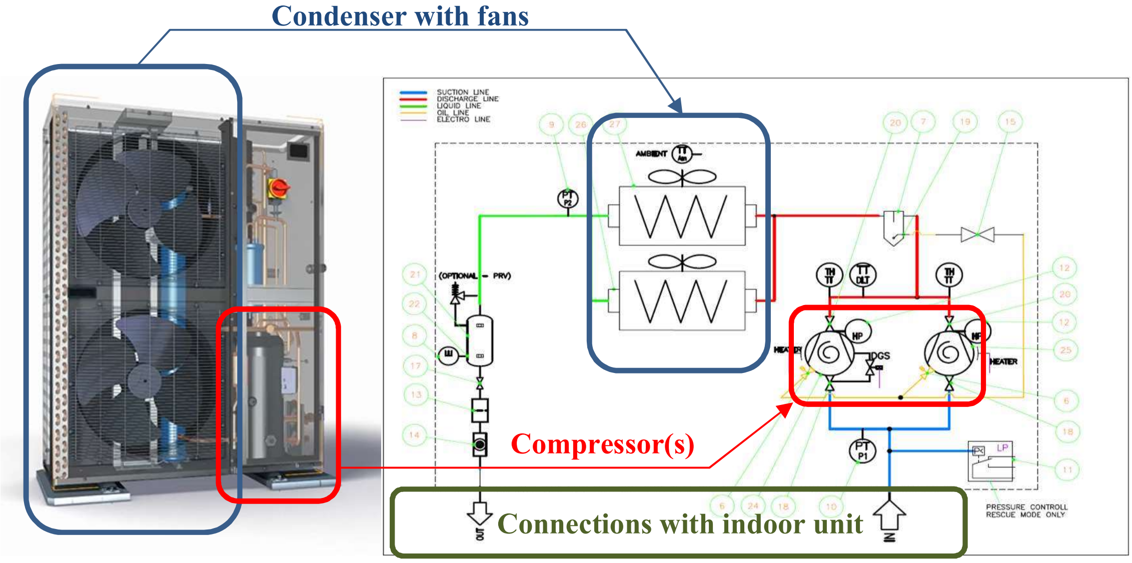

Figure 6: Semi open view of condensing unit [3] *Figure 7:schematic representation of outdoor condensing unit [3]*

The outdoor unit is connected with 2 refrigerant lines to the display case or other equipment containing the food, inside the shop. This display case has a second heat exchanger, called evaporator, and fans used to extract heat from fresh goods and from air in their surrounding.

Figure 8: indoor unit in the shop area (display case) [3]

The indoor module must stay cooled during days and night as the shop manager doesn't remove the material when shop is closing. This means that a certain amount of cooling capacity is still required after 10 pm, and the outdoor unit might continue to operate overnight. Of course, the required capacity is reduced and the up-to-date system can adapt the compressor and fan speeds to match this need and minimize the noise emission.

3. Condensing unit : Installation in the field

The development of the small retails in cities is part of a context of re-urbanization, change in the transport modes, limitation of the extension of commercial areas close to highways and major roads. This is a trend of shortening the distance between the fresh goods and population.

The condensing units of those shops and services are thus installed in the direct vicinity of the residential places with apartments and houses. This proximity can lead to annoyance and infringement of outdoor noise regulation. The situation can consequently force the owner to pay a penalty and to modify the installation to comply with the local regulations. The modification is costly, typically as expensive than the unit itself, explaining why end users are reluctant to make this unpredicted investment.

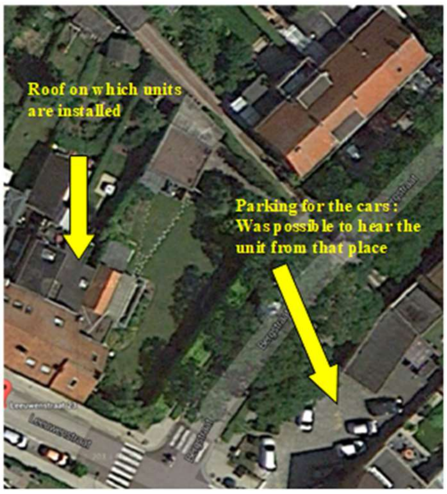

Figure 10: Condensing units installed on the roof of bakery causing noise problems in the neighborhood. Wall behind the unit direct the noise towards a parking place and houses around [3]

Figure 9: Installation of the condensing unit in an vehicle access to a parking [3]

4. Noise characteristics of an outdoor condensing unit

The major noise sources of a unit are the fan blowing air across the condenser and the compressor. The acoustic characteristics of those 2 sources are definitively different: the fan is broad band noise while the compressor is a rotating machinery with fundamental and harmonics frequencies having amplitude that are modulated by the dynamic response of the structure and the operating conditions of the system (basically the operating temperature of the display case and ambient air). Beyond those primary noise sources, the piping and unit housing can be excited by the compressor: vibration due to residual unbalancing and gas pulsation. The units are now equipped compressors and fan with variable speed to better adapt the cooling capacity to the need. This feature provides a better energy efficiency and allow to manage a night mode that limits the rotational speed of the fan and compressor beyond 10 pm.

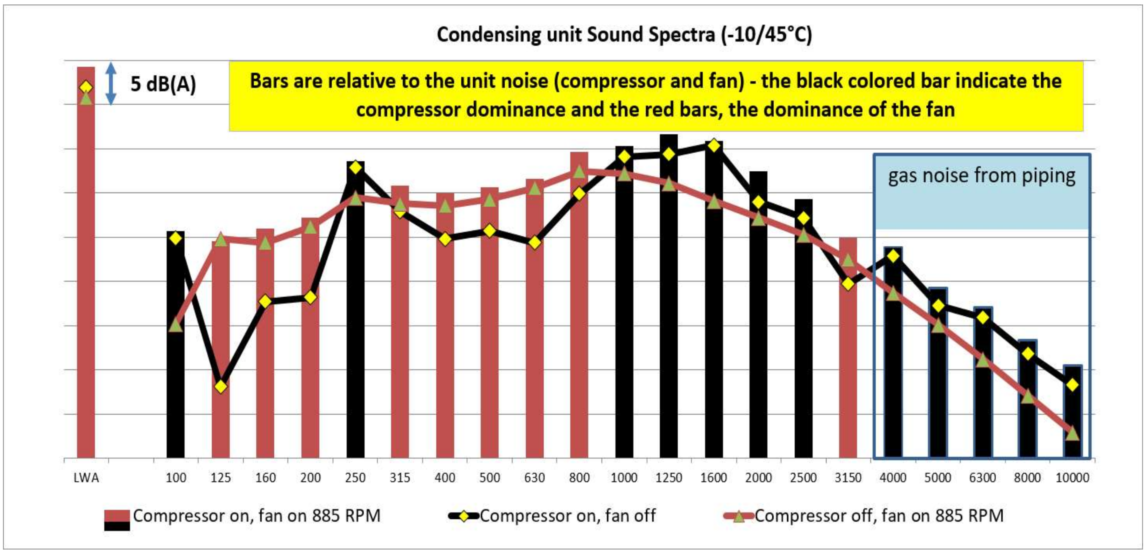

Figure 11: Sound spectra of outdoor condensing unit ZXME-040 from Emerson [3]

A second important noise characteristic is the native directivity pattern (independent of the surrounding) of the unit that is caused:

1. Position of components in the frame: typically, the compressor is located along one lateral side and the heat exchanger occupy the rest of the foot print
2. The fan intrinsic directivity due to direction of the flow

The directivity is an extremely important parameter when it comes to measure the unit in the field to verify the compliance with the regulation or when it is required to apply sound barriers.

The orientation of the fan is therefore a dominant factor of the unit directivity. We can find 2 types of unit design in the market: the first one and most popular is a mounting of the fan on the vertical panel (horizontal axis) blowing air horizontally in front of the unit– Second one with the fan that is mounted on top of the unit blowing air upwards. It is evident the distribution of noise emission will be totally different between those 2 designs and the way to mitigate the noise level must be adapted to the unit design. We see here the need of accurate information about not only the noise level of the unit but also of the direction of the noise propagation for the contractor who has to perform the installation in a certain environment: a good set of information will ease the selection of the unit in respect to the application and configuration of the installation, but also the preparation of the surrounding in advance avoiding costly modification after commissioning to unacceptable noise level.

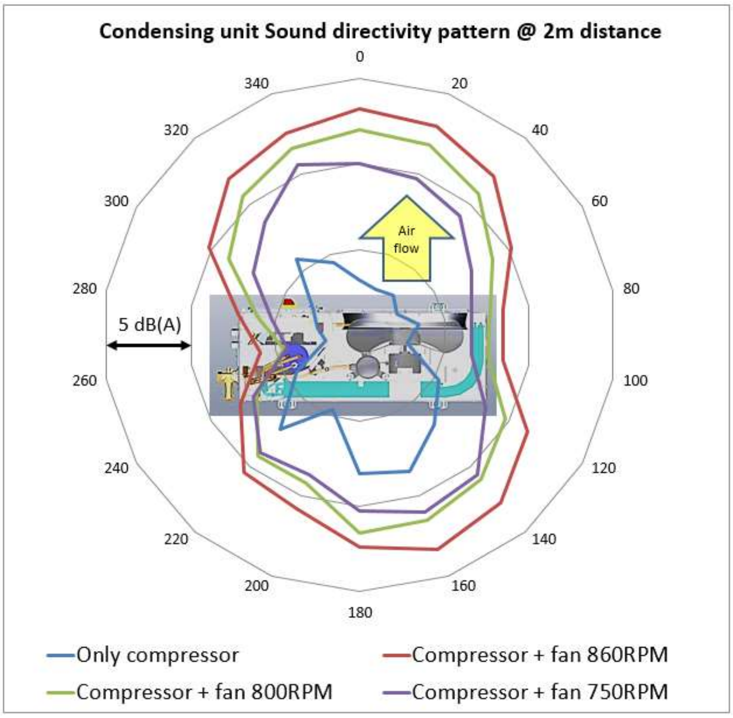

Figure 12: Unit sound directivity of a condensing unit with horizontal fan axis [3]

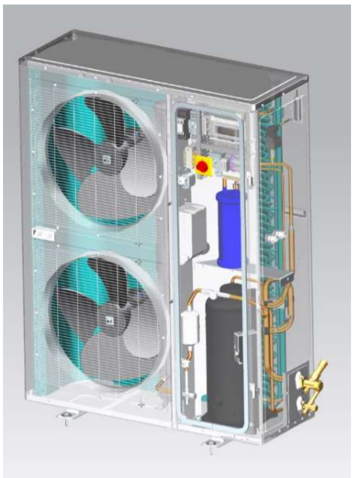

Figure 13Unit ZXLE-075E

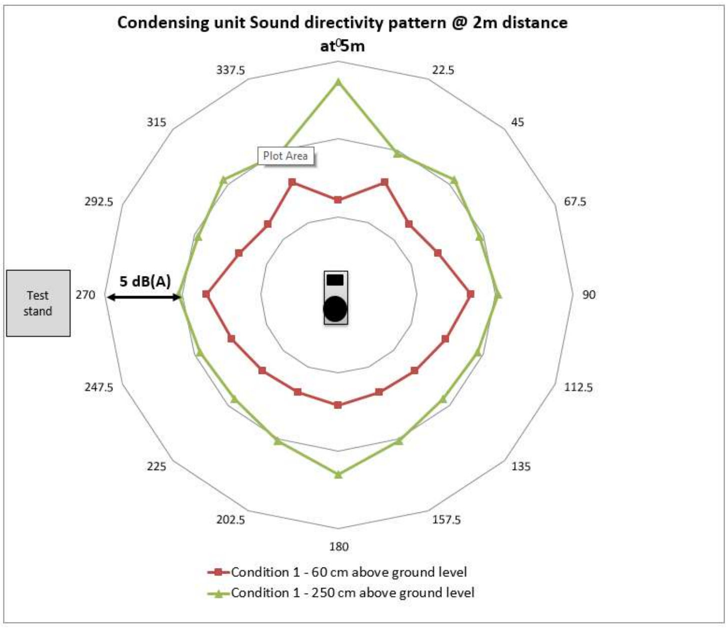

Figure 14:Unit sound directivity of a condensing unit with Vertical fan axis

Figure 15: unit OME-4MTL-07X

3. Measurement of unit and publication of the noise level

The sound level of unit is usually expressed using either the sound power level or sound pressure level. We must admit that the way the sound data are usually presented might be either confusing due to a lack of required information or insufficient:

- The sound power level is defined at a specific operating condition (that should be clearly indicated and is usually relevant for the application). But it doesn't provide understanding of how the unit will distribute the acoustic energy in the surrounding. Additionally, the sound power level is not a metric that can be directly used to verify the compliance with noise regulation like sound pressure. A conversion will be necessary.
- Sound pressure level is a more suitable metric to consider for the outdoor unit as it is the parameter prescribed by the legislation. However, this metric must have a clear identification of the distance, operating condition (like for the sound power level) and the surrounding layout (is it pure free field, over reflecting plan, on floor along a wall, in a corner), represented by directivity index of the installation space.

The sound pressure level is the most suitable metric and therefore is largely used by the manufacturers to communicate the sound performance at given operating conditions and distance. A short review of Original Equipment Manufacturer shows a large variety of how the specifications are presented: sound pressure at 1, 3, 10 m – full free field, or free field over reflecting plan. Furthermore, the native directivity pattern of unit is absent despite this characteristic might lead to a variation of 5 dB(A) between the noisiest and the quietest location of measurement when positioning the sound level meter around the unit – at a given distance.

The today's practice at Emerson is to make a measurement of the sound power level of the unit in the sound room (semi-anechoic) and calculate the average sound pressure assuming a homogeneous distribution of the acoustic energy around the unit.

$$\text{Sound Pressure Level} = \text{Sound Power Level} + 10 \text{ Log } (Q/(4 \pi r^2) + 4/R)$$

- r = distance between the measurement point and source assuming r significant larger than the dimensions of the source
- R = Room coefficient. 4/R is neglectable in our case
- Q =directivity pattern (Free-Field: Q=1 / Over reflecting floor: Q = 2 / Along wall : Q = 4 / in a corner: Q = 8)

In fact, proposing a measurement of the sound pressure level of units at 5 or 10 m from the source is challenging because either it requires extremely large sound rooms that are expensive and for which it is hard to demonstrate an acceptable return on investment (Note that the OEM are generally on intense cost pressure to stay competitive) or outdoor measurement that are technically complicated (the evaporator part has to be installed to operate the condensing unit) and requires a large open space with a low sound level.

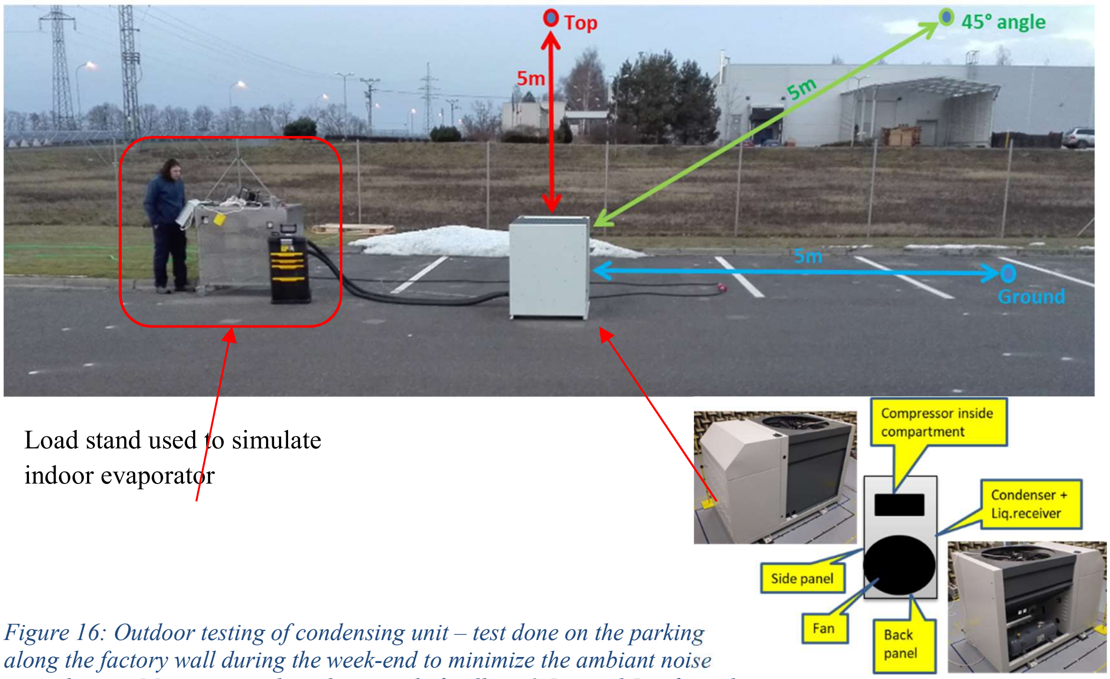

Figure 16: Outdoor testing of condensing unit – test done on the parking along the factory wall during the week-end to minimize the ambiant noise perturbation. Measurement have been made finally at 2.5 m and 5 m from the source.

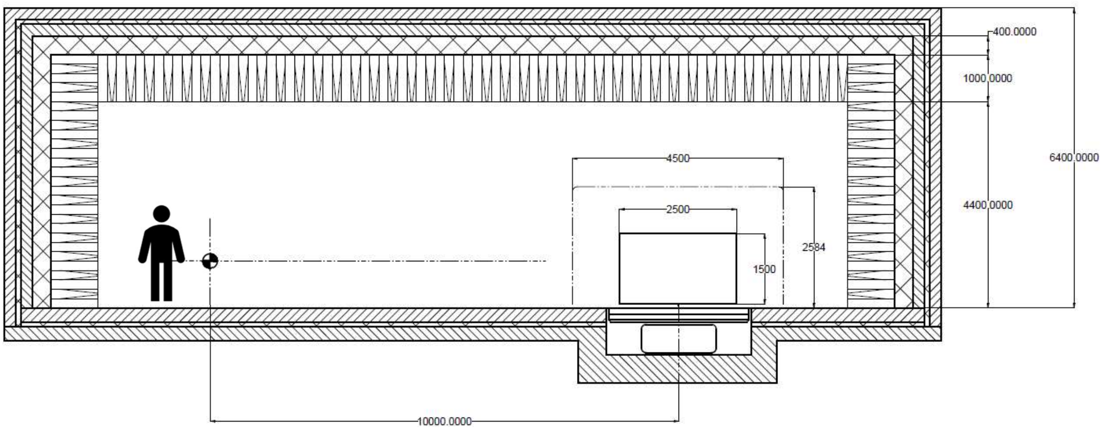

Figure 17: Schematic of semi anechoic sound room for sound pressure measurement at long distance (5 to 10 m) from the source-Side view

4. Solution with simulation

It is now clear that there is a need for accurate characterization of the acoustic performance and directivity pattern. But this task is really challenging only by experimentation.

Therefore, it has been decided to investigate a hybrid approach where the near field sound measurement of unit will be used as input to simulate the noise propagation of the said unit in surrounding space. The technical details of the method are presented in an associated paper [5].

The advantage of the hybrid method mixing measurement and simulation is to achieve a good analysis of the sound field generated by the unit without the need to create a numerical model of the unit itself which can result in an ambitious task. Additionally, the measurement of real unit will represent the true acoustic emission without assumptions. The downside is of course the necessity to have a physical unit operating in the sound lab and perform an intensive session of sound measurements. This hybrid method can be considered as an intermediate step between the testing and the complete digitalization of the problem.

The first step of the methodology is to make the sound measurement in near field. The unit will me mapped with a fine grid size to capture enough special description of the acoustic emission. One fixed microphone will be used as phase reference. The test is done in a semi-anechoic chamber, over reflecting floor. The condensing unit is hooked up to the system that generate the load of the evaporator and guaranty a stable condition during the test.

Figure 18: measurement of the outdoor condensing unit in semi-anechoic sound room with free field microphones

In total there more than 1400 measurement points done by a set of 4 microphones scanning a virtual box of 1200 mm x 600 mm x 960 mm around the unit.

The data are the used as inputs in to extract the pellicular mode of the numerical model built in Actran ©, calculate the emission factor and recompute the complete acoustic emission of the units.

From this point it will be possible to make a series of sensitivity analysis:

- Generate the native directivity pattern of the unit (overall or per frequency)
- Impact of the configuration where unit is installed: floor, wall, corner
- Prediction of the acoustic efficiency of the sound barrier according to the dimensions, and distance

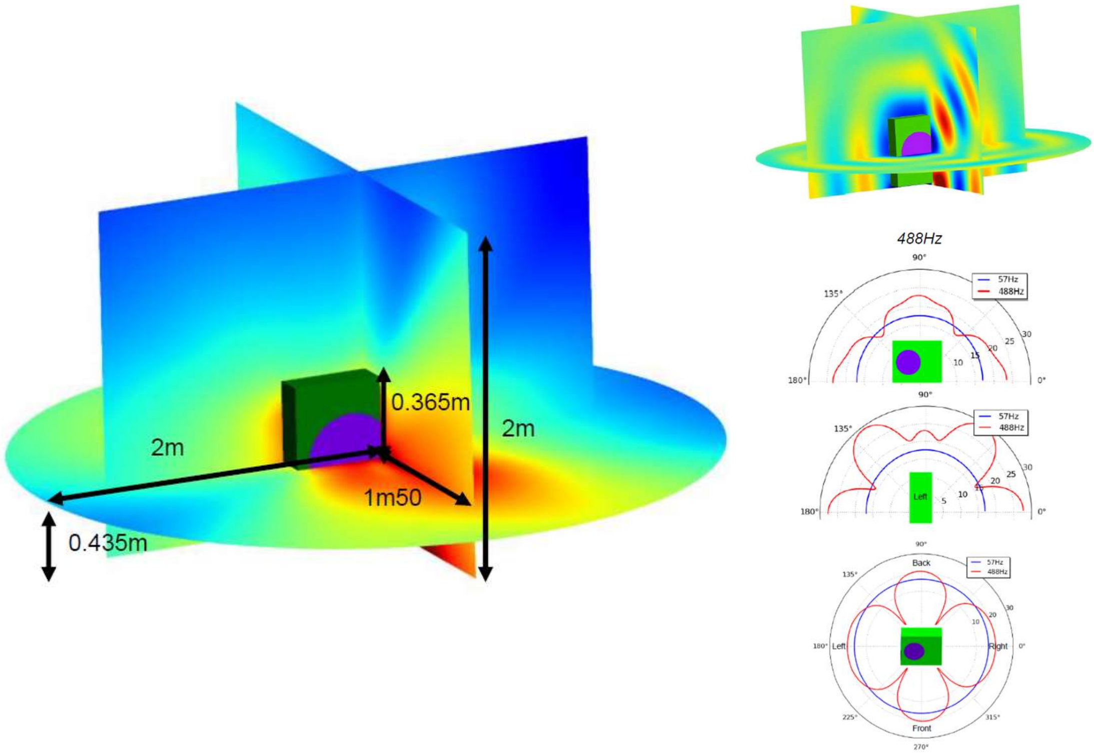

Figure 19: Example of the simulated propagation of the sound around the condensing unit

5. Conclusions

The noise pollution is becoming an increasingly important parameter for human wellbeing and comfort. Regulation, legislations, European directive are enforcing equipment manufacturers to minimize the impact of operation of machines on people. This is going with the re-urbanization of cities bringing the resident closer to sources of noise

For equipment and component manufacturers involved in the cold chain management, the noise of the condensing units must be reduced as much as possible to guaranty the acceptance and avoid annoyance leading to complains, and later, call to justice court.

Despite an important work on the unit with optimized fans, compressor, housing, heat exchanger, the level of noise can still be too important. Then it will be required either to change the location or orientation of the installation or to apply an acoustic protection. Ideally, this should be planned at the definition of the specification to minimize the cost by suppressing trial and error process.

The responsibility of the manufacturers is to integrate this need of adequate information inside the system development to address the questions from the contractor or architects.

The proposed method is new and benefit from the last development of numerical tools. Today we still do significant amount of testing and assumptions on sound directivity pattern, but we can predict that the testing will be enhanced by modeling of components allowing a complete numerical twin of the real unit. This will make possible on one side more optimization and improvement of the machine itself and on the other side the generation of useful information, guideline and recommendation for contractors. And at the end improve the acceptance of outdoor units by minimizing the complains about noise with a better quality of installation.

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