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Acoustic Assessment and Design of Acoustic Protection for Heat Pumps

Akustické posouzení a návrh protihlukových opatření u tepelných čerpadel

The paper deals with the acoustic assessment and design of acoustic protection for an actual heat pump system for a residential building with a shop installed in the courtyard of an older residential building. The heat pump system is used for the cooling and heating of the residential and non-residential premises, hence the night operation of the heat pumps, which is subject to stricter hygiene limits on noise. The installation of the units and the construction were already under implementation, therefore, there was little room for acoustic design adjustments.

Keywords: *heat pumps, noise, residential courtyard, design of acoustic protection*

Článek se věnuje akustickému posouzení a návrhu akustických opatření u reálné soustavy tepelných čerpadel pro bytový dům s prodejnou instalované ve vnitrobloku starší bytové zástavby. Soustava tepelných čerpadel slouží pro chlazení a vytápění bytových a nebytových prostor, tudíž byl vyžadován i noční provoz tepelných čerpadel, na který se vztahují přísnější hygienické limity hluku. Instalace jednotek a stavba byly již v realizaci, tudíž nezbývalo příliš možností pro návrhy akustických úprav.

Klíčová slova: *tepelná čerpadla, hluk, obytný vnitroblok, návrh protihlukových opatření*

INTRODUCTION

Nowadays, heat pumps (HP) are used as a part of air conditioning and heating systems, not only for the commercial sphere, but also in the communal sphere for family and residential buildings. Noise from heat pumps is assessed by hygienic noise limits, e.g., in the protected outdoor area of buildings (up to 2 m from the windows of protected rooms), in this case, especially residential buildings. The hygienic noise limits for these sources according to [4] are the level $L_{Aeq,8h}$ = 50dB for 8 consecutive noisy and consecutive hours of the day and $L_{Aeq,1h}$ = 40 dB for one of the loudest hours of the night. In addition, if a noise component is present, 5 dB is subtracted, thus $L_{Aeq,8h}$ = 45 dB for the day and $L_{Aeq,1h}$ = 35 dB for the night.

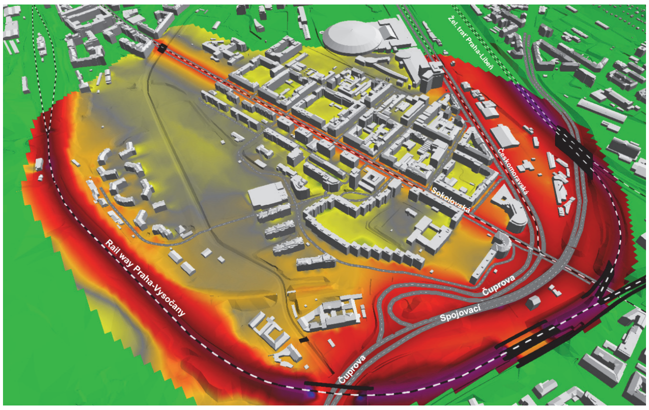

Figure 1 An example of a 3D view of the real computational situation of traffic noise sources with the display of noise bands, see [3].

The cooling or heating designer solves the design of the heat pumps in terms of thermal requirements, but often neglects the acoustic assessment. There are cases when an acoustics issue comes up only after the installation of the heat pumps and once the noise is noticed on site. In such cases, however, there are no longer many possibilities to reduce the noise. The danger of installing heat pumps in terms of acoustics occurs especially when it is not possible to install the equipment outside a protected area e.g., on the roof, but it is necessary to install the equipment, for example, in the interior of a residential building. There is very low background noise in the inner courtyard, and an inadequate noise source can be easily demonstrated by on-site measurements.

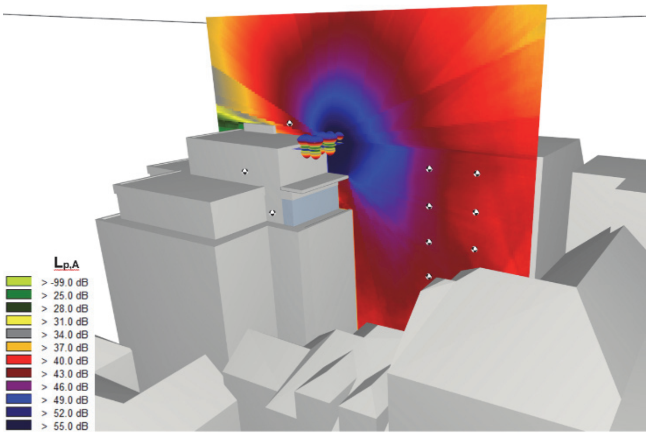

Figure 2 A 3D view of a computational model showing the distribution of the noise field around the cooling unit installed on the roof near the protected area, see [3].

For acoustic assessment, a number of computational software products exist today, whose differences mainly lay in the possibilities of entering more complicated geometric situations, the possibility of entering parameters for sound characteristics of the materials, the directionality of the sources, and in the computational methodology also. The more sophisticated the software is, of course, the more expensive it is, so it is always necessary to assess each situation and make decisions as to how large the monitored area will be and what details are decisive for assessing the noise. These may include reflections from the facade, the frequency composition of the sound, the proximity of the point to the source and the size of the sound source, its directivity, and the number of resources to be considered in the model. It is not possible to use the same approach for the acoustic assessment of, e.g., traffic noise in the city, see Fig. 1, or to provide a detailed explanation of the noise propagation from the cooling unit to the protected area near the installation, see Fig. 2. Also, a completely different approach is required for a noise source model, such as aerodynamic noise. Physical principals must be simulated there. The model simulates noise generation by solving fluid mechanics equations, which describe fluctuations of air mass, and subsequently describe sound propagation by wave equations, see [5] and [8]. This detailed access, when the sound propagation is described by wave and fluid mechanics equations or detailed measurement around the source [6] and [7], is not convenient for practical application due to the huge demands on the solution time.

A HEAT PUMP AIR/WATER PROBLEM FROM A NOISE POINT OF VIEW

The main source of air/water heat pump noise is the axial fan at the condenser section and the compressors, which are mostly installed in one compact outdoor unit. The noise generated by the unit is composed of medium and higher frequencies generated by the axial fan, which can be effectively dampened by absorption, and lower frequencies occurring at the compressor section, which are difficult to dampen. It is not necessary to invest in a less noisy unit because the fans are designed for certain conditions in terms of air flow and transport pressure only. If the load is in the form of a cover or noise suppression device, the unit can no longer overcome the pressure loss and loses functionality. It may be more advantageous to install a more powerful and noisy unit, which can withstand the intake and displacement of the additional pressure loss, to dampen the sound with absorption dampers, which are acoustically, significantly more efficient than the silent unit. The manufacturer usually reports noise from the unit without load. If the pressure drop, in the form of silencers, is added to the heat pump intake and discharge, the whole noise generation system will be re-tuned. In general, the noise generated by the unit will increase but noise components in the noise spectrum may be generated also. This means that the resulting noise must be considered with the noise component at the reference point, i.e., by 5 dB more stringent than the normal hygienic noise limits in the protected outdoor area of buildings, i.e., $L_{Aeq,8h}$ = 45 dB per day and $L_{Aeq,1h}$ = 35 dB per night, see [4]. Another difficulty in selecting a unit is often that the reported noise at a certain distance from the unit in the manufacturer's catalogue applies to the free acoustic field. However, if the unit is inserted into a wall, a corner or even a canopy, the noise may increase by 8 dB. In addition to the sound pressure level at a certain distance from the unit, it is also necessary to check the sound power level, which actually testifies to the device parameters and reliably defines its noise level. Another difference between the catalogue and real acoustic emissions of the HP could be that producers present data of the HP for nominal conditions, according to the European norms [1] and [2], which is not with the HP at full power.

DESCRIPTION OF THE SOLVED SITUATION

The solved heat pump installation is located in the interior of a residential building of a listed building in the city centre, similarly as was solved in [9]. The original design for effective acoustic modifications was an air/water heat pump installed in an inner courtyard only, in the canopy with one free side for air exchange, see Fig. 3. The heat pumps provide air conditioning for the interior of the flats, heating and air conditioning to the shop and cooling the server technology in the adjacent building. The total installed cooling power, resp. heating, is about 190 kW. There are 6 heat pump units in total. The internal space of the canopy, including the walls and the roof, is covered with mineral insulation thickness of. 60 mm + a non-woven fabric on the surface. The inside height of the canopy is approximately 3.6 m, above the upper planar unit is the height of 1.2 m of free space. At maximum operation of all refrigeration units (6 pieces), the air flow through the fans is 60,000 m³/hour. The closest window of the living room from the free opening of the canopy is 6 m away. The noise of the cooling units, see Fig. 3, is L_{WA} = 64 dB, L_{WA} = 72 dB and L_{WA} = 79 dB for 1 unit, 1 unit and 4 units, respectively. The smallest heat pump on the left in Fig. 3 has a fan wheel vertical to the ground (a classic split unit with the exhaust on the sides). Other larger heat pumps have an axial fan wheel in the horizontal plane at the top (the exhaust at the top), the compressor is at the bottom, similar to Fig. 4. The heat pumps are installed outside the residential building, so the propagation of vibration (structural noise) from the heat pumps to the inside of the residential building was not solved. The pipeline network dilatation from the construction of the building can also be a difficult problem as well [10].

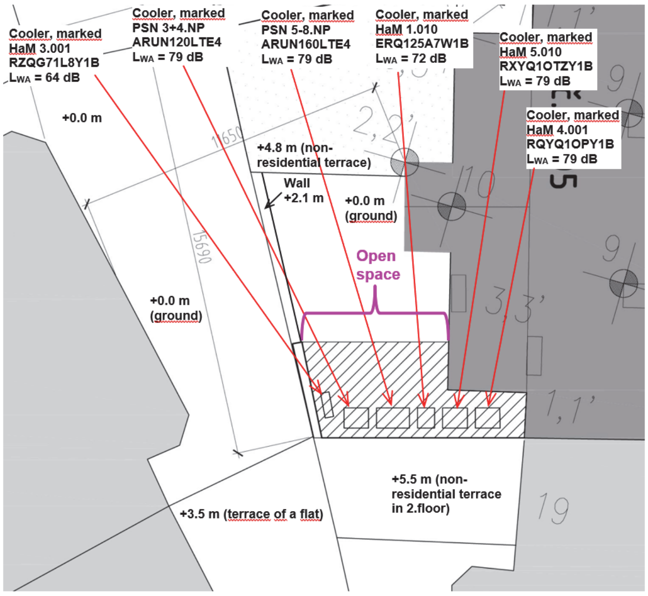

Figure 3 Situation of the heat pump installation in the assessed courtyard.

DESCRIPTION OF THE CALCULATION MODEL

The noise calculation was taken using the CADNA R software (Datakustik GmbH). It is a planar model of calculation with the base plane at the surface level of the courtyard. The area of the model was limited to the interior of the project only - the closest protected area of the building to the noise sources - the cooling unit in the courtyard shed. The computational model includes the entire courtyard and parts of the adjacent buildings, an area of 36 x 60 x 40 m (width x length x height - court-ceiling of the computing area). The boundary areas of the computational area are considered without reflection and perfectly absorbed - the space behind the boundary surfaces continues. The surface of the individual buildings - facades of the buildings, the surface of the courtyard is considered reflective – they are mainly concrete, brick and glass surfaces. The solved installation of the heat pumps is located in the courtyard of the residential building. The calculation is performed in the frequency range of 31.5 to 8000 Hz. The uncertainty of the calculation is 2 dB.

In the computational model, it is always necessary to consider how real sources of noise will be entered. If the calculation is to investigate short distances from the source, i.e., the case solved, the real noise source needs to be described in detail by alternative theoretical sources (point, area, volume), with due consideration being given to the directionality of the noise sources. It is always necessary to check that the logarithmic sum of the sound power levels of all the theoretical noise sources is at the level of the real noise source. When simulating the sound pressure levels at a certain distance (at the calculation point) and the overall sound power level (sum of the replacement sources of noise) in the octave frequency spectrum must be checked, and not only to control the total values of the theoretical noise only. In the calculation, it can easily occur that the replacement of real sources with theoretical and tuning calculations will lead to another definition of the noise spectrum of the theoretical source, although the overall sound power level or power level in the model with the measured data from the manufacturer will be the same level.

If larger distances are resolved, real sources can be replaced by a less accurate description, i.e., only point sources that are the easiest to calculate. The more theoretical the model will try to describe the real source of noise, the more complex and the longer it will take. In assessing the noise of the above-mentioned situation in the courtyard, it was necessary to replace the real sources of noise with real sources as much as possible, see Fig 4.

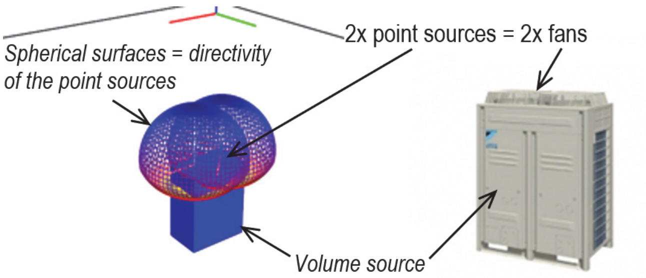

Figure 4 Comparison of the actual noise source – the actual heat pump on the right with the theoretical one on the left, used in the calculation model of the heat pump installation in the courtyard

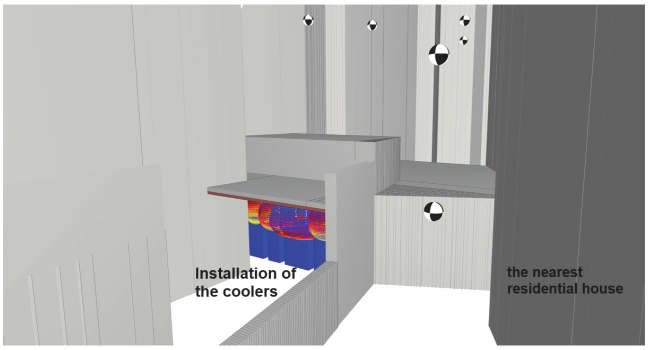

Figure 5 The 3D view of the calculation model with the installation of the HP in the canopy before the modifications

The description of the heat pump noise sources can be made as follows: The theoretical volume source replaces the basic dimensions of the HP unit, the body of the unit in which the compressor part of the cooling/heating cycle is located (the dominant area of noise emission is at low frequencies and the directionality is evenly distributed throughout). The point sources of noise replace the axial fan in the upper plane of the unit, the dominant area of radiation is in the region of the middle frequencies and it is the directional source of the noise dominant in the direction of flow, in the hemisphere direction from the upper plane of the unit. The smaller cooling/heating unit of a split-type HP with a vertical fan can only be replaced by a vertical surface source and there is no need to define the directivity also, since this unit is significantly quieter than the other heat pumps, and will not have a significant effect. Fig. 5 shows a 3D view of a computational model showing the theoretical sources of noise replacing the real heat pumps.

VALIDATION OF THE CALCULATION MODEL

Since the installation of some of the heat pumps had already been completed, it was possible to verify the correctness of the calculation model. During the noise measurement, the heat pumps of Figure 6 were in operation, the units were running at full power. Other units were out of order (they were disconnected or switched off, but were present at the installation site). The control points, i.e., MP no. 1 to 3, were selected around the installation site and adjacent objects. Table 1 shows the measured and calculated values of the A-weighted equivalent sound pressure level from the operation of the selected heat pumps.

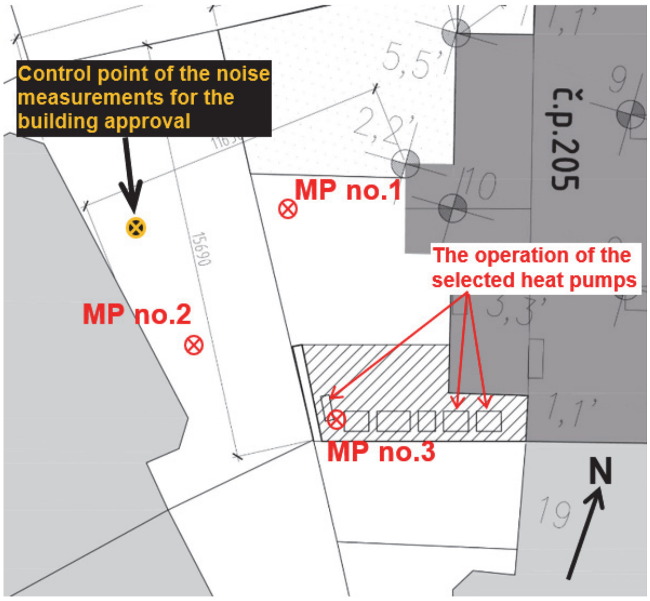

Figure 6 The noise measurement situation for verifying the computational model and control point of the noise measurements for the building approval, see the article's conclusion

Table 1 Verification of the calculation model - full power of the cooling units shown in Figure 6

Measurement point (MP)/ calculation point (CP)	**Measured $L_{Aeq,T}$ (dB)**	**Calculated $L_{Aeq,T}$ (dB)**
MP no.1 – before the installation of the heat pumps	58.6 ± 2 dB	58.8 ± 2 dB
MP no.2 – 1 m in front of the nearest residential building facade, window level 1st floor	51.0 ± 2 dB	51.9 ± 2 dB
MP no.3 – above the roof canopy of the coolers installation	51.3 ± 2 dB	50.5 ± 2 dB

The differences between the measured and calculated A-weighted equivalent sound pressure level in Table 1 are up to 0.9 dB. The justification may be that the model considers the pure courtyard space, that is, only the building construction of the facades of the buildings and any walls. The model does not take the presence of building material or scaffolding into account that was present on site during the control measurement of the noise.

RESULTS OF THE CALCULATION BEFORE ACOUSTIC ADJUSTMENTS

The sum of all the heat pumps at full power, i.e., approx. 190 kW, representing the highest daily operation of the heat pumps, generates noise at the nearest residential building (about 6 m beside the canopy, further north of MP no.2) at the level $L_{Aeq,8h}$ = 56 dB, see the noise field in Fig. 7 and 8. For the night reduced regime of the HP (operation of parts of the limited power units only, a total of about 50 kW), the noise level $L_{Aeq,1h}$ = 51 dB was calculated for the neighbouring residential object, see the noise field in Fig. 9 and 10. The hygienic noise limits of $L_{Aeq,8h}$ = 50 dB per day and $L_{Aeq,1h}$ = 40 dB for night are significantly exceeded, not to mention the possibility of the presence of a noise component in the noise spectrum.

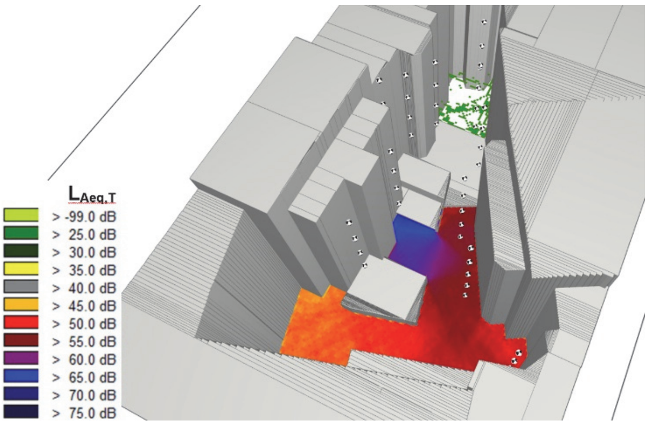

Figure 7 Noise field at 3 m above the ground before adjustments for maximum HP operation (in the daytime)

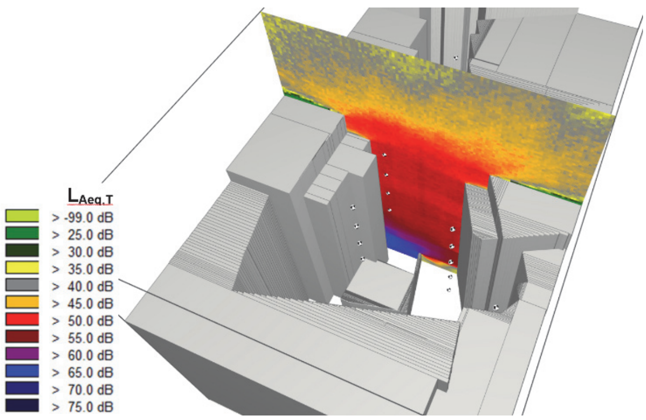

Figure 8 Noise field in the vertical plane before adjustments for maximum HP operation (in the daytime)

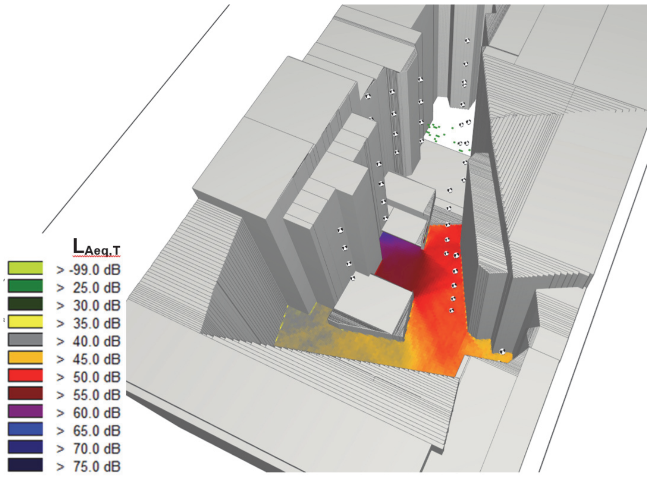

Figure 9 Noise field at 3 m above the ground before adjustments for reduced HP operation (at night)

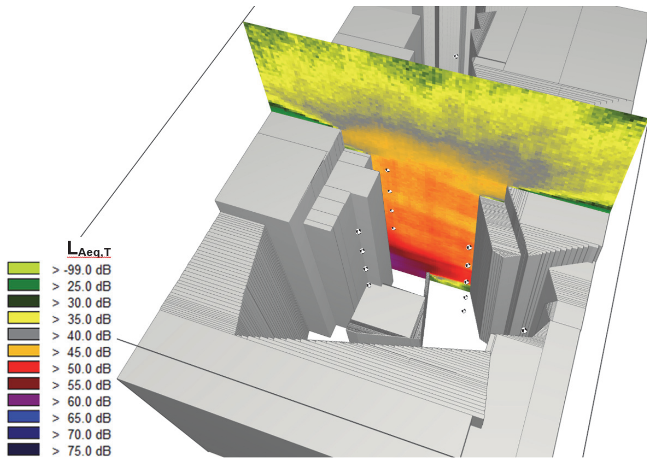

Figure 10 Noise field in the vertical plane before adjustments for reduced HP operation (at night)

PROPOSAL FOR ACOUSTIC ADJUSTMENTS AND NOISE EVALUATION

Due to the already finished work of the canopy and the location of the HP in its position, it was no longer possible to carry out larger structural modifications. The limitation was also due to the fact that the planned HP installation was a long-discussed solution with conservationists. So, the only solution was to use the free space between the heat pumps and the end of the canopy. The solution, see Fig. 11, was the horizontal distribution of the open canopy's opening to the bottom of the intake's opening and the expansive upper opening. The intake has a dimension of 4x2 m (width x height), a top exhaust port of 5x1.5 m. The holes were completely cross-sectioned with cell silencers measuring 250x500x1500 mm with a leading edge on each side, see the section in Fig. 11. The induced pressure loss at a full flow rate of 60,000 m^3/h is 18 Pa and 21 Pa at the intake. An arch was created above the HP fans for a better exhalation.

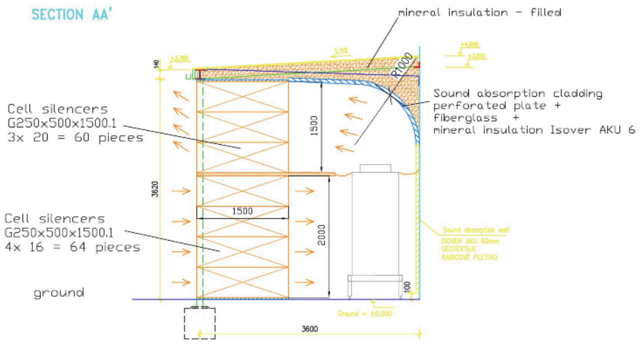

Figure 11 Section of the canopy with acoustic modifications in the form of cellular silencers.

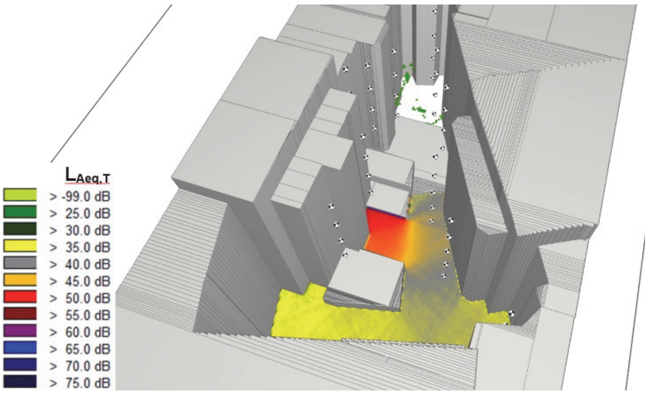

Figure 12 Noise field at 3 m above the ground after acoustic modifications, maximum HP operation (at night)

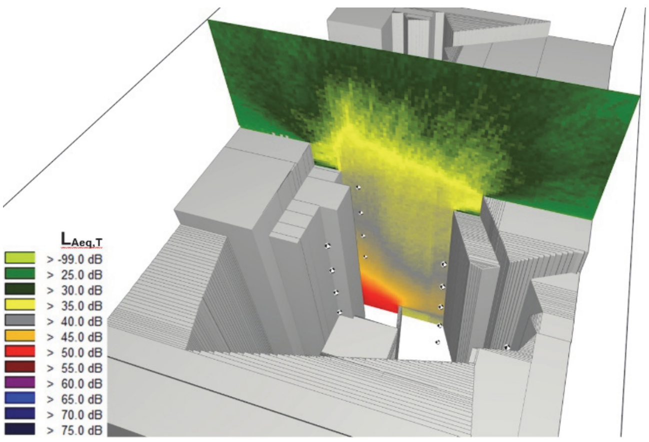

Figure 13 Noise field in the vertical plane after acoustic modifications, maximum HP operation (in the daytime)

Problems of the HP installation could arise during heating, because the freezing air generated by the fans can cool down the courtyard. But the basic solution with a canopy only (without buffers) was chosen by the builder in the early phase of the project and were discussed with heating and cooling professionals.

The calculation results for the sum of all the heat pumps at full power, i.e., approx. 190 kW, are at the level $L_{Aeq,8h}$ = 42 dB at the nearest residential building (approx. 6 m beside the canopy, further north of MP no.2), see the noise field in Fig. 12 and 13. For the night reduced mode, the noise level was calculated at $L_{Aeq,1h}$ = 33 dB in the next residential object, see noise field in Fig. 14 and 15. The hygienic noise limits of $L_{Aeq,8h}$ = 50 dB per day and $L_{Aeq,1h}$ = 40 dB for night operation are also met as well as with the assumption that the noise component of the spectrum is present.

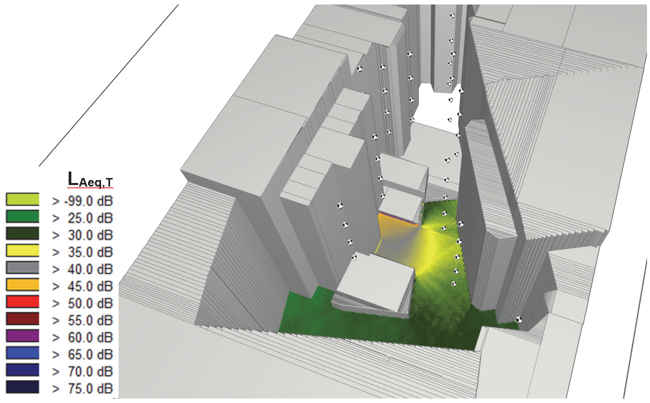

Figure 14 Noise field at 3 m above the ground after acoustic modifications, reduced HP operation (at night)

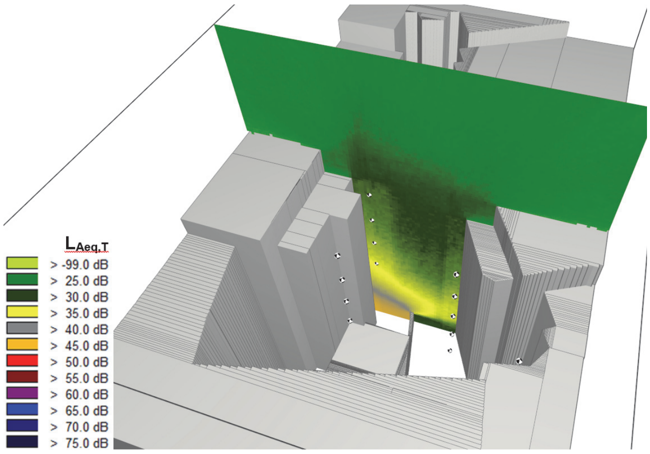

Figure 15 Noise field in the vertical plane after acoustic modifications, reduced HP operation (at night)

CONCLUSION

The results of the calculation after the acoustic protection were verified by noise measurements for the building approval at the control point approx. 6 m beside the canopy, further north of MP no.2, see Fig. 6. Table 2 shows the results of the noise measurements for the building approval and the calculated values of the A-weighted equivalent sound pressure level from the operation of the selected heat pumps.

Table 2 The results of the noise measurements for the building approval and calculated values from the day and night operation of the heat pumps, at the control point see Fig. 6.

Operation of the heat pumps	Measured $L_{Aeq,T}$ (dB)	Calculated $L_{Aeq,T}$ (dB)
DAY OPERATION – $L_{Aeq,8h}$	35.7 ± 1.8 dB	41.3 ± 2 dB
NIGHT OPERATION – $L_{Aeq,1h}$	32.5 ± 1.8 dB	33.3 ± 2 dB

The measured noise values are demonstrably in compliance with hygienic noise limits, according to [4]. For the day regime, the measured noise value is significantly lower than the calculated value, as the set daily heat pump regime for which the system is actually approved does not represent the maximum power of all the heat pumps of the daily programme. On the contrary, the measured noise value for night regime, where significantly stricter hygienic noise limits apply, corresponds to the calculated value, which is the same as the night operating conditions for the final approval and actually corresponds to the simulated mode.

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NOMENCLATURE

$L_{Aeq,T}$ A-weighted equivalent sound pressure level [dB]