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Research Article

Research on Noise Reduction Scheme of Heat Pump Unit in a Square

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Heat pump unit is a host device located in the central air-conditioning terminal, providing cold and hot water. Heat pump unit has the advantages of energy saving, environmental protection, easy maintenance, and so on. It is adopted to solve the problems of refrigeration and heating in ventilation and air conditioning from many engineering projects in China. When the equipment is turned on, however, the high noise generated by the heat pump unit has a very negative impact on the life and work of the surrounding residents. Therefore, noise reduction is needed to improve the environment quality. In this paper, the noise of the air-cooled heat pump unit of the square area in Shanghai was detected, the noise source was analyzed, and the corresponding noise reduction scheme was proposed. After the completion of the scheme, measurements indicate that A-weighted sound pressure level is less than or equal to 60 dB (A) during the day and less than or equal to 50 dB (A) at night, which meets the relevant national noise limit emission standards and conforms to the second-class quality standard of the acoustic environment.

1. Introduction

Statistics released by China's ministry of ecology and environment protection show that, by February 2019, the hotline 12369 had received noise pollution accounted for 32 percent of reports. Noise has gradually become one of the biggest public hazards in recent years [1–5]. Among them, the impact of the heat pump unit on the surrounding environment is a universal environmental pollution problem that the city faces and needs to be solved [6, 7]. Effective control noise is, therefore, very urgent and necessary.

The air-cooled heat pump unit is widely used in the projects with its advantages, such as dual functions of cooling and heating, simple operation, convenient management, and maintenance [8, 9]. In order to reduce the noise of the heat pump unit and thus providing a more comfortable living environment for people, a reasonable implementation scheme should be adopted in several projects. In this paper, the acoustic environment of the heat pump unit of the square in Shanghai is taken as the main research area. First, the sound environment is tested. Then, according to the noise evaluation standards in China [10–12], a reasonable implementation scheme is developed and given to solve the noise disturbance of heat pump units in the square.

2. Methods

2.1. Project Overview. The air-cooled heat pump unit equipment (model: AEH1080E, unit weight: 6900 kg, rated refrigeration/heat: 180/179 kw, China) has a total of four units and a supporting water pump, which are located in the iron fence area beside the road in a square. The main body of the equipment is 2,300 mm away from the other side enclosing wall, and the height of the wall is 1,900 mm. The ground between the wall and the main part of the equipment is mainly paved with equipment pipelines. The heat pump unit has 40 fans at the top, the chassis is not fully closed, and

the compressor is all supported on the steel frame. The heat pump unit is surrounded by high-rise residential buildings, only 8 m from the nearest west side residence as shown in Figure 1.

The units operate 24 hours without stopping. When the equipment is in operation, the sound pressure level is high. When the noise generated by the heat pump unit exceed the emission limit of the corresponding area stipulated in the national standard "acoustic environment quality standard" (GB-3096, China), effective measures should be taken immediately to reduce the noise.

2.2. Noise Sources. From the analysis of the overall structure of the heat pump unit, the noise radiated by the equipment during operation can be divided into two parts. When the heat pump unit is running, its steel structure will have a slight vibration, and this vibration will produce noise; the other is generated by the compressor and the exhaust fan of the heat pump unit. The latter may be the main part of the noise of the heat pump unit.

According to the field investigation, the noise area emitted by the heat pump unit is very large. Because the two sides and the top of the unit emit noise outwards, the noise of the heat pump unit is open. In addition, the compressor is supported fully on the steel frame, and the noise of the heat pump unit also spreads down from the bottom.

2.3. Acoustic Measurements. In order to evaluate the acoustic quality of the square and to solve the noise disturbance of heat pump units, acoustic measurements were carried out. A hand-held analyzer type 2250 (Brüel & Kjær Sound & Vibration Measurement A/S, Nærum, Denmark) was used in this study. This sound level meter was calibrated before measurement. The noise measured values were characterized by equivalent continuous A sound pressure level (see equations (1) and (2). The time recording characteristic of the instrument was "slow" response. 100 values were read continuously. The interval of reading the instantaneous value of the measuring point was 5 seconds. In order to improve the precision, several cares were taken, such as good weather conditions. The measurement time, place, and temperature were accurately recorded. In this current study, the temperature measured was 20 to 26 degrees Celsius, and the weather was clear. In addition, the microphone diaphragm of the sound level meter should be clean during measurement. In order to reduce the influence of wind on noise measurement results, when the wind speed is greater than 3 m/s, the microphone should be timely covered with a windshield; when the wind speed is greater than 5 m/s, the measurement should be stopped immediately. During measurement, the microphone should be far away from other reflective surfaces, and the vertical distance from the ground should be greater than 1.2 m. Finally, safety should be observed during measurement to avoid obstructing the passage of vehicles and pedestrians.

When the four heat pump units are all working, the noise of the unit itself and the interior of the west residential building is measured at eleven o'clock in the day time. The measurement points and test data are shown in Tables 1 and 2, respectively.

2.4. Theoretical Model of Sound Source Attenuation. The attenuation of point sound source can be given by the following equation:

$$L_A(r) = L_A(r_0) - 20\log\left(\frac{r}{r_0}\right) - \Delta L, \tag{1}$$

where $L_A(r)$ is A-weighted sound pressure level (SPL (A)) at r distance from the sound source, in units of dB (A). $L_A(r_0)$ is the A-weighted sound pressure level at the point r_0 and $r_0 = 1$ m from the sound source, in units of dB (A). ΔL is the amount of attenuation caused by various factors, including shielding, air absorption, and ground effect, and the unit is dB (A).

In the current study, noise sources are varied. According to the superposition theorem of sound sources, the equivalent sound pressure level at any point in the sound field can be given by the following equation:

$$L_{\text{eqA}} = 10\log\left(\frac{1}{N}\sum_{i=1}^{N} 10^{(L_{Ai}/10)}\right), \tag{2}$$

where L_{eqA} is the equivalent A sound pressure level in dB (A). L_{Ai} is the ith A sound pressure level in dB (A). N is the total number of sources.

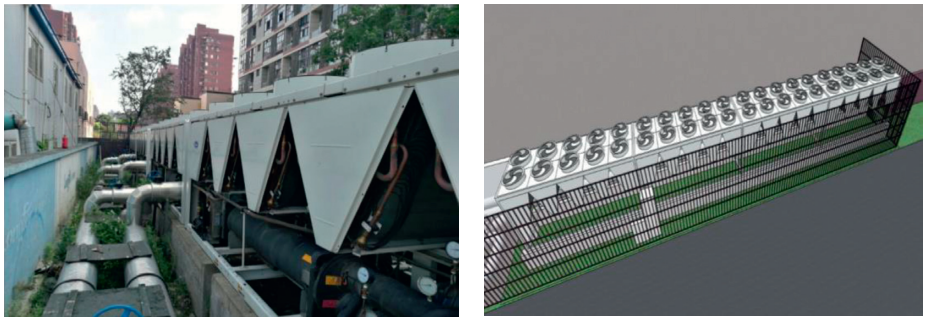
2.5. Noise Reduction Measures. For noise reduction of the air-cooled heat pump unit, we mainly design a closed noise reduction structure, that is, steel structure beams and columns are designed on the periphery of the heat pump unit, and the sound insulation plate is used to seal the air-cooled heat pump unit on three sides, forming a large sound insulation space. At the same time, the muffler is installed in the inlet and outlet of the heat pump unit to avoid secondary noise pollution.

In order to prevent the vibration of the heat pump unit and the pump from being transmitted to other places through the pipeline, we installed the vibration absorption and vibration isolation devices at the base of the heat pump unit and the inlet and outlet water pipes, respectively, and installed the vibration absorption support at the main pipeline.

3. Results and Discussion

3.1. Sound Pressure Level. Before noise modification, the measurement data of sound pressure level of the noise from heat pump units are shown in Table 1, and the measurements of equivalent sound pressure level in the west residential building with windows closed are shown in Table 2.

In Table 1, it can be found that the noise generated by the air-cooled heat pump unit during operation is about 80 dB (A), and the maximum noise value reaches 92 dB (A). The huge noise generated by the heat pump unit causes noise pollution to the adjacent floors and affects the lives of the residents.



(a) (b)

Figure 1: The air-cooled heat pump unit before noise reduction treatment: (a) left, photograph; (b) right, schematic diagram.

Table 1: Sound pressure levels of the noise from heat pump units before noise modification.

Serial number	Noise source	Measuring point	Sound pressure level (dB) (A)
1	Heat pump unit	Next to the unit	89
2	Heat pump unit outlet	Beside air outlet	92
3	Water pump	Near the water pump	84
4	Heat pump unit and water pump	In front of the residential building on the south side	74
5	Heat pump unit and water pump	In front of the west side residential building	72
6	Heat pump unit outlet	West side residential building 4-5 floors outside the window	77
7	Heat pump unit outlet	South side residential building 4-5 floors outside the window	75

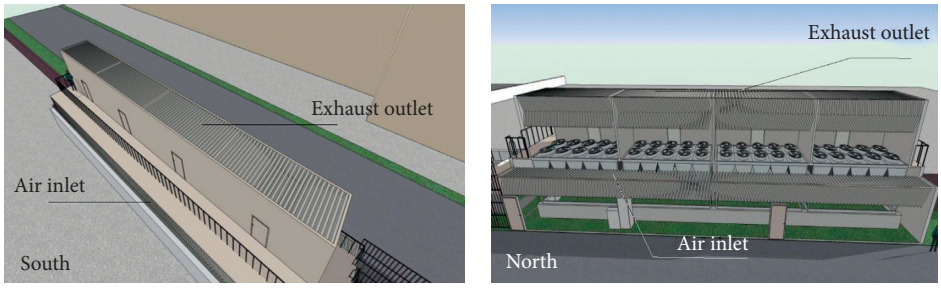
Table 2: Sound pressure levels in the west residential building with windows closed before noise modification.

Measuring point	Time (s)	Leq, T (dB) (A)	Frequency (Hz)						
			125	250	500	1k	2k	4k	8k
8F, room 831	37	46.3	56.2	52.3	38.8	31.9	35.6	23.8	19.3
8F, room 822	45	46.3	54.5	51.6	40.8	38.4	36.2	24	19.8
7F, room 731	51	49.1	57.4	54.7	43.6	41.7	40.2	27.3	21.5
7F, room 722	33	48.9	58.4	55.9	41.7	35.3	35.5	29.1	23.9
6F, room 622	30	50.9	49.7	48.2	39.2	36.9	36	27.3	22.5
5F, room 522	30	49.7	47.3	46	37.8	41.9	39.4	29.5	22.8

As can be seen in Table 2, the noise generated by the heat pump unit presents a mid-low frequency characteristic. Because the low-frequency noise has strong penetration, wide frequency band, slow distance attenuation, and wide influence range, the fifth and sixth floors are the areas most affected by the noise. The equivalent sound pressure levels are 49.7 dB (A) and 50.9 dB (A), respectively. To create a comfortable living environment, noise must be controlled.

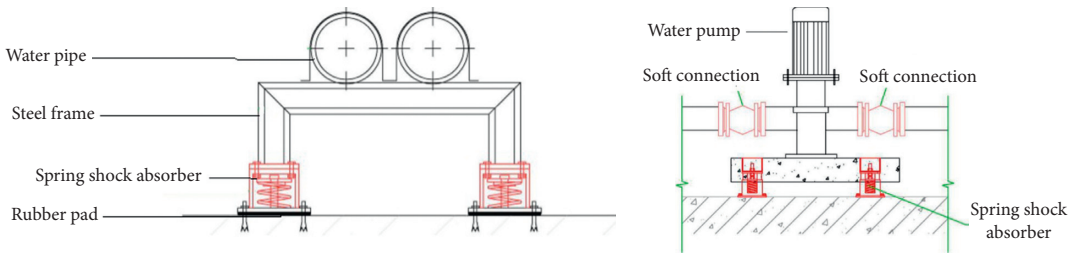
3.2. Overall Noise Reduction Scheme. Generally, there are three ways to consider for noise reduction of the heat pump unit: first, sound source management. Because the unit is not easy to reform, sound source management has operational disadvantages, and it is difficult to achieve; second, the noise transmission way to control, such as sound insulation, noise reduction, and vibration reduction methods for noise control; and third, on the receiver side, the noise-sensitive people should wear earmuffs and other labor protection measures to indirectly prevent and control noise [13, 14]. In the current study, the second noise reduction method is adopted.

Considering that the noise mainly comes from the compressor and the exhaust fan during the operation of the heat pump unit, the exhaust air of the heat pump unit, and the running water pump, we use the overall sound insulation cover design for the heat pump unit, that is, the heat pump unit area is closed and isolated. In order to facilitate the ventilation and heat dissipation of the equipment, we set up an inlet and outlet air channel on the sound insulation cover and further apply a muffler in the inlet and outlet air channel for noise elimination. The schematic diagram of the sound shield for the heat pump unit is shown in Figure 2. It should be mentioned here that, in order to improve the sound insulation effect of the sound enclosure, sealing materials are



(a) (b)

Figure 2: The schematic diagram of the sound shield for the heat pump unit.



(a) (b)

Figure 3: The schematic diagram of vibration isolation of the water pipe and the water pump.

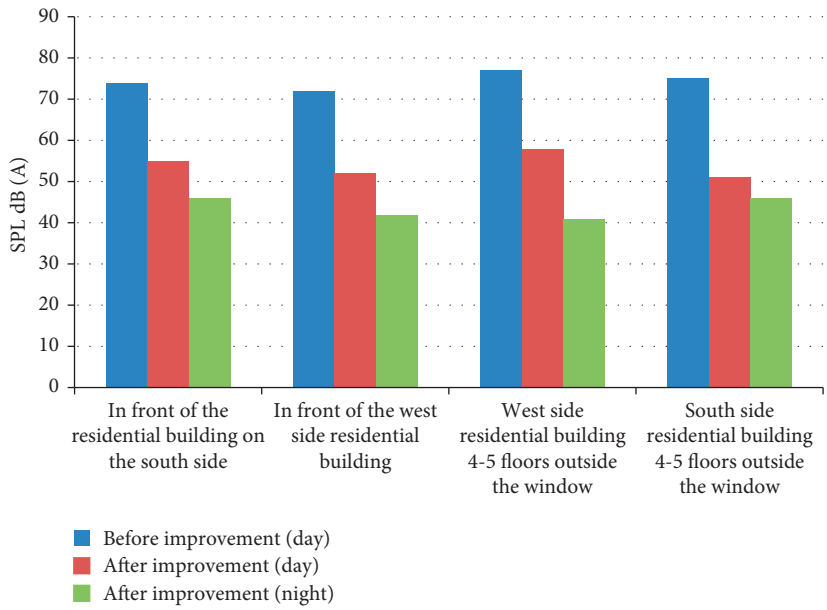


Figure 4: Sound pressure levels of the noise outside the window of the building before and after improvement.

used between the sound enclosure modules. In particular, when installing the sound insulation cover, rubber damping pad should be installed between the module and the ground to prevent rigid sound transmission.

As for the air inlet design, due to the limited space in the region, a vertical direct-insert muffler with a size of 1,500 mm * 1,000 mm is adopted for the air inlet on the south side and the north side of the unit, which is installed at a tilt of 15°, as shown in Figure 2. In this way, the labyrinth channel is formed to ensure that the heat pump unit can enter the air and achieve the best noise reduction effect. Considering the top air exhaust muffler, we use half bending muffler insert and use professional sound-absorbing wall to block the equipment exhaust outlet. In this way, after the exhaust area of each equipment is separated by the sound-absorbing wall, the exhaust air of the heat pump unit will form an independent space. The lower part of the independent space is the slow flow area of exhaust air, which is mainly used for static pressure and rectification of the exhaust

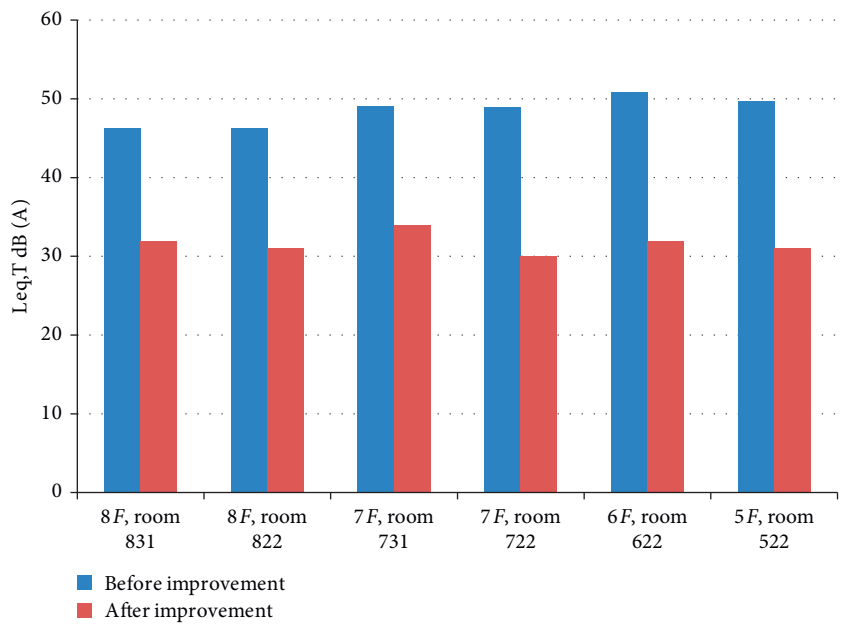


Figure 5: Sound pressure levels in the west residential building with windows closed before and after improvement.

air. The upper part is the muffler channel composed of two-sided metal perforated plate filled with environmentally friendly sound-absorbing cotton, which has dual functions of resistance muffler and reactive muffler. For the muffling of the top exhaust air, we adopt the half-folded muffler insert, which has been proved to be effective in multifrequency and wide-band muffling. The upper and lower parts constitute the exhaust muffler of the heat pump unit (noise attenuation: 24 dB (A)), which can effectively control the influence of exhaust noise on the surrounding environment.

As shown in Figure 3, in order to prevent the noise from being transmitted to other places through the pipe vibration, we install the vibration absorption and vibration isolation devices on the base of the heat pump unit and the inlet and outlet water pipes, respectively. To overcome the vibration of the heat pump unit, the concrete approach is to add a steel frame base on its side and then to install a spring shock absorber with deformation of 50 mm under the steel frame base. Meanwhile, 25 mm spring shock absorber is installed in the ground riser of the heat pump unit. The spring shock absorbers are all provided with 8 mm thick shock absorbent rubber pads. To reduce the vibration of the water pump, a spring shock absorber should be added on the side of the base of the steel frame. Soft connection is installed on both ends of the inlet and the outlet, and the concentricity should be adjusted [15, 16]. Current practice shows that these methods are very effective in reducing noise transmission.

Before and after improvement, sound pressure levels of the noise outside the window of the building are shown in Figure 4. The noise interference generated by sound superposition outside the window of the affected building is no more than 60 dB (A) during day time and no more than 50 dB (A) at night. In the west residential building, the sound pressure levels after closing the window are shown in Figure 5. It can be found that the sound pressure level is less than or equal to 35 dB (A) after noise improvement.

4. Conclusions

The noise of the air-cooled heat pump unit of a square area in Shanghai was detected, the source of the noise was analyzed, and the corresponding noise reduction scheme was proposed. Noise reduction construction was carried out with the scheme. The scheme is simple in construction and nice in design. After the completion of the scheme, the heat pump unit has smooth ventilation and heat dissipation and runs normally. Measurements indicate that the designed schemes meet the relevant national noise limit emission standards, which conform to the second-class quality standard of acoustic environment (SPL (A) ≤60 dB (A) during the day and ≤50 dB (A) at night) in China. In addition, on the premise of ensuring the noise reduction effect, the scheme can be well integrated with the environment and has a good landscape effect.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

All authors declare no conflicts of interest regarding the content and implications of this manuscript.

Acknowledgments

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