Investigation on thermal environment improvement by waste heat recovery in the underground station in Qingdao metro

Jianwei Liu¹, Jiaquan Liu², Fengyin Wang¹, Cuiping Wang¹*

¹Energy Engineering Institute, Qingdao University, Shandong Province, China, 266071
²Enviormental and Energy Management Department, School of engineering and applied science, The George Washington University, USA

*Corresponding author’s email: cpw_qdu@qdu.edu.cn

Abstract. The thermal environment parameters, like the temperature and air velocity, are measured to investigate the heat comfort status of metro staff working area in winter in Qingdao. The temperature is affected obviously by the piston wind from the train and waiting hall in the lower Hall, and the temperature is not satisfied with the least heat comfort temperature of 16 ℃. At the same time, the heat produced by the electrical and control equipments is brought by the cooling air to atmosphere for the equipment safety. Utilizing the water-circulating heat pump, it is feasible to transfer the emission heat to the staff working area to improve the thermal environment. Analyzed the feasibility from the technique and economy when using the heat pump, the water-circulating heat pump could be the best way to realize the waste heat recovery and to help the heat comfort of staff working area in winter in the underground metro station in north China.

1. Introduction
The metro construction industry is developing very quickly in China; and the metro cities are more and more. But the capital cost, energy consumption and energy conservation potential and energy saving methods are causing increasingly attention. The energy consumption is very great when the metro running. According to the actual statistics, the running energy consumption is about 590.6kW/km[1], and among which the ventilation and air conditioning system consumes about 40%. But in the winter, many waste heat produced by the communication and power transformation equipment must transfer to atmosphere by convection cooling air from fans, while the air temperature in staff area is always very low[2]. If the waste heat from the equipment rooms is recovered and transfer to the staff area, to improve the thermal comfort of staff, it is very significant for the metro energy saving.

In this paper, the thermal environment parameters were measured and analyzed, to evaluate the thermal comfort of staff area in winter, and to calculate the possible heat recover and to analyze the feasibility of waste heat transfer to staff area. In the winter of China north, like the coastal city of Qingdao, the cold climate is always longer, so the thermal environment and heat comforts are very important and necessary to be investigated, for the metro staff health and energy conservation. The piston wind effect is also considered in this paper, though the train’s to and fro is in the lower layer, as shown in Fig.1 of waiting hall, the effect is obviously occurred in the Hall layer, and has influence to the staff working area.
2. Measurement of heat environment parameters

NO.3 line has been running now in Qingdao for one year, the subway station of WUSI Square and LICANG are the test sites during the coldest three months in this winter.

![Figure 1. The metro station vertical view](image)

2.1. Test sites and test aim

The measurement contents included temperature distribution, air flow velocity in Hall region; and the heat flux production in communication equipment room, comprehensive monitor room and transformation rooms; and then the length and width size of the Hall entrance and exit, tickets sale area, information area, security check area to calculate the heat load distance to arrive the heat comfort. There are wall-mounted sensors for the temperature and humidity, and its data are transfer to the monitor room. For the hall height is very higher than working staff, the heat comfort for staff should not judged by the data of monitor room. So the difference between the measurements with the wall-mounted sensor’s data is also the gist to judge the real heat comfort and the necessary of improvement of thermal environment. So the measurement height is 1.5m, reflecting the staff real feeling.

2.2. Measuring apparatus

a. Temperature data acquisition instrument, AGILENT 34970A, the accuracy is 0.001 °C.
b. Hot wire anemometer, SZX9-KA23, it can show the velocity and temperature and pressure. The accuracy of velocity test is 0.01 m/s, and the accuracy of temperature test is 0.1 °C.
c. Heat flux analyzer, the accuracy is ±2%.

3. Experimental results

3.1. Difference between the wall-mounted sensor with the measurement

The difference between the monitor data from wall-mounted sensor with the measurement data, is shown in Fig.2. The monitor data is higher than the measurement data for the wall-mounted sensor is nearer to the soil layer, and its temperature is the heat exchange result of soil with air flow in Hall. But the measurement data is just from the height of 1.5m distance to the ground. It is the convection heat exchange result of piston wind with the indoor air. The two temperature data are all increasing with the time, but the monitor data affect less influence from the piston wind, so it is not responding to the real feeling of the staff. The staff always feels the piston wind and the fluctuation temperature.
3.2. Piston wind effect
At a security site, the detail measurement of the air temperature fluctuation with the piston wind[3], is shown as Fig.3.
When the piston wind is coming, the air temperature is decreasing, for the pumping cold air. The train drives the cold air in tunnel out to the waiting hall and then to Hall layer when it is coming to the station; and pump the colder air from the station entrance (outside) into the Hall when the train leaves the station. So the air temperature in the Hall is especially affected by the pumping when the train left and the entered colder air. One of the methods to improve the heat comfort could be preventing the pumping colder air entering the Hall.

4. Heat load computation
From the measurement, the mean temperature of the staff working area in Hall in winter is just 12\textendash}13\textdegree C, whose is not satisfied with the heat comfort temperature of generally accepted 16\textdegree C at least, so there need supplement heat. But as said in Introduction, the metro running energy consumption is so great that it is not accepted to supply heat to Hall by more energy consumption in winter. If the temperature of just at the staff working area not the whole Hall, rise to the 16 \textdegree C, according the sizes of working are in WUSI station Hall, 44kW heat load should be supplied.

5. Feasibility analysis of the waste heat recovery to working area by heat pump
5.1. The heat flux measurement in equipment rooms
There are more than 10 rooms for varies equipment in WUSI station. The total mean heat flux produced by equipment is 38-120kW. For the room temperature arrives to 28\textendash}32\textdegree C, the cooling air fan
is stared and the 2.23 m$^3$/s air flow rate used to cool the equipment. The convection heat exchange makes the air outflow rise to 26 °C from 10°C and then emitted to atmosphere. So the hot air flow could be the heat source for the waste heat recovery. The water-circulating heat pump could recover heat from the low temperature heat source, and transfer the more heat to the staff working area, including the consumed power convert to heat. The co-efficient of performance of this heat pump could reach to 4.9 [4], so the input power is not large, 9 kW. The cooling water flowrate is 1.67 kg/s and the heating water flowrate is 1.05 kg/s. So the system transfer the waste heat to supply the heat to staff working area, which improved the heat comfort of metro staff in winter.

5.2. Introduction of the water-circulating heat pump system
The heat pump system is shown in Fig.4. The circulating water in heat pump absorb the heat $Q_1$ from the return cooling air, and along with the input power to drive the compressor in heat pump, the $Q_2$ heat supplement to the staff area to heat the indoor circulation air. $Q_2=Q_1+P$. The heat release ways would be determined in CFD[5-6] for optimization.

![Figure 4. Water-circulating heat pump system to recover the waste heat](image)

5.3. Economic analysis
The heat pump system adds two circulating pumps, one circulating air fan, and a heat pump unit. According to the power consumption (running cost) and the capital cost, the economy comparison could be drawn, compared with the traditional central heating method in China under the same heat comfort conditions. According to the water and air circulating flowrate, the water pump of 1.5kW is chosen and the fan of 5kW is chosen. Along with the heat pump of 9kW consumption, the running time in winter is 873h, so the running power cost is about 5500RMB, less than 1000 $, it is superior to the central heating method, whose cost each winter is about 13000 RMB.

6. Conclusions
The measurement of temperature and air velocity in the metro staff working area in winter, show that the air temperature is not satisfied with the heat comfort though the air velocity fluctuation is not large by the piston wind effect. At the same time, the equipment (including the communication equipment, the power transformation equipment, and comprehensive control equipment) rooms release a large amount of heat and need to be cooled. So the waste heat could be transferred to the staff working area by the water-circulating heat pump to improve the heat comfort. The technique and economy of the
waste heat recovery system are all feasible for the metro running energy conservation and thermal environment improvement.

7. References
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