Research on Evaluation Method of Gas Environment in Metro Station

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Abstract. With the development of rail transit, subway has become one of the main means of transportation in most cities. However, the particularity and tightness of the subway station, the continuous growth of passenger traffic has also brought some negative environmental problems, such as the comfort and safety of subway station staff and passengers. In this paper, a comprehensive evaluation model of gas environment for metro station is proposed. The micro environment quality evaluation index of metro station is divided into two parts, one is the air quality evaluation index, the other is the thermal comfort evaluation index. From the construction and calculation of these two indexes, the comprehensive evaluation of gas environment of metro station is realized. In order to verify the applicability of the proposed method, we collected the environmental parameter data of six subway stations and evaluated them by using the environmental assessment method. The results show that the proposed method can not only realize the evaluation and monitoring of the station environment, but also has great significance for the improvement and decision-making of public transport environment.

Keywords: Subway station, Microenvironment, Comprehensive environmental assessment.

1. Introduction

In cities, subway is one of the most effective public transportation methods to solve the problem of traffic congestion. At the same time, with the development of the subway, the number of passengers is also increasing. Since most subway stations are located in underground space, the ventilation conditions are poor, and pollutants are easy to deposit in the station, which will have a negative impact on the health of passengers, such as NH₃, VOCs, and NO₂. Therefore, it is necessary to analyze the environmental trend of subway stations and establish a relatively accurate model to evaluate the environmental parameters of subway stations [1-3]. The environment of rail transit system has become the focus of domestic and foreign scholars because of its special air tightness and a small amount of exchange with the outside air. Subway thermal environment and gas environment related to human comfort have received extensive attention. Zhu Jianming from Beijing Jiaotong University analyzed the environmental conditions of Beijing subway and the temperature field distribution of the tunnel, and established a heat transfer model using various conservation equations, and analyzed the heat generation of the train and the thermal parameters of the tunnel. At the same time, the temperature field in the
station is numerically calculated. Simulation calculation and verification [8]. In 1976, the US Department of Transportation, through experimental research, proposed the heat flow index RWI and heat loss rate HDR, which can be used to evaluate the thermal comfort of rail transit. Abbas Pour, M and Jafari, Jordan carried out the actual measurement of thermal environment parameters on the platform and carriage in Tehran metro station in Iran, collected the condition of air conditioning and passenger flow, RWI was used for comfort evaluation, and drew the conclusion that the thermal environment of metro station was acceptable to the state [10].

At present, there is no systematic and comprehensive research and evaluation model for the air environment of subway stations, and there is also a lack of research on the formulation of pollutants and pollutant standards. This paper proposes a new method Comprehensive environmental friendliness evaluation method. The evaluation research mainly focuses on the two indexes of thermal comfort index and air quality index. PMV thermal model combined with meteorological parameters was used to obtain the thermal comfort evaluation index. A comprehensive air quality index model was used to calculate the air quality index by combining the monitoring parameters and standards of toxic and harmful gases. The comprehensive environmental friendliness of rail transit stations can be evaluated comprehensively through the above two kinds of evaluation indexes.

2. Data acquisition and processing of environmental parameters in subway station

In view of the environmental monitoring of the station, the main focus is the detection of gas content. The pollutants in the environment mainly include PM10, PM2.5, oxygen, ammonia, formaldehyde, carbon monoxide, carbon dioxide, nitrogen dioxide, sulfur dioxide, organic volatiles and so on.

2.1. Equipment introduction

The data collection in this study was carried out using air detection equipment, as shown in Figure 1. The equipment can monitor more than a dozen environmental parameters such as temperature, CO2, O2, wind speed and humidity.

![Figure 1. Integrated monitoring equipment.](image)

In this test, the thermal comfort meter is used to test and record various environmental and thermal comfort indicators in the station. The parameters that can be tested include environmental temperature, pressure, relative humidity, black ball temperature, dew point temperature, air flow rate and other indicators. At the same time, the changes of various indicators in the test period can be recorded. The overall appearance and interface function of the thermal comfort meter are shown in Figure 2:
2.2. Data acquisition of subway environmental parameters
The research is divided into two stages. The first stage is from May 3, 2020 to June 22, 2020. There are 6 subway stations including Guanzhuang station, Andingmen station, Beitucheng station, Xitucheng station, Huixin West Street north exit station and Qingnian Road station. 13 kinds of environmental parameters (PM10, PM2.5, NH3, CH2O, Co, NO2, SO2, TVOC, CO2, O2, temperature, humidity and wind speed) are continuously tested. The test period of gas environmental factors is 8:00 a.m. to 22:00 p.m., once every 2 minutes.

In the second stage, from September 22, 2020 to September 27, 2020, 13 environmental parameters (PM10, PM2.5, NH3, CH2O, Co, NO2, SO2, TVOC, CO2, O2, temperature, humidity and wind speed) of Xitucheng station were measured successively. The test cycle of gas environmental factors is from 7:00 a.m. to 23:00 p.m., once every two minutes.

3. Environmental assessment model
Thermal comfort evaluation index involved in the test parameters include: temperature, humidity, wind speed. The test parameters involved in the air quality evaluation index include: PM10, oxygen, carbon monoxide, formaldehyde, VOCs, SO2, NH3, CO2, NO2.

3.1. Thermal comfort model
Danish professor grid based on the human body thermal comfort equation, the establishment of a famous PMV (Predicted Mean Vote, hereinafter referred to as Expected Mean Vote) thermal comfort prediction evaluation model (ISO7730 international standardization method)[4],the model considering the metabolism of human body, clothing thermal resistance, air temperature, flow, humidity, and the influence of such factors as to calculate the value of human body thermal comfort PMV value, and is used to quantify the degree of hot and cold of environment [5].

PMV model can predict PMV under the influence of human metabolism, clothing thermal resistance, ambient air temperature, flow rate, humidity and other factors. The calculation formula of PMV is as follows:

\[
PMV = \left(0.303e^{-0.36M} + 0.0275\right) \cdot \left[(M - W) - E_{ak} - E_{c} - E_{fr} - E_{dr} - E_{r}\right]
\]

\[
= \left(0.303e^{-0.36M} + 0.0275\right) \cdot \left[(M - W) - 3.05 \times 10^{-3} \cdot \left[5733 - 6.99(M - W) - p_{a}\right]\right]
\]

\[
-0.42 \cdot \left[(M - W) - 58.15\right] - 1.7 \times 10^{-5} \cdot M \cdot (5867 - p_{a}) - 0.0014 \cdot M \cdot (34 - t_{a})
\]

\[
-3.96 \times 10^{-8} \cdot f_{cl} \cdot \left[(t_{da} + 273)^4 - (t_{r} + 273)^4\right] - f_{cl} \cdot h_{c} \cdot (t_{da} - t_{a})\right)\]

The calculation formula for the outer surface temperature of clothing is as follows:
The calculation formula of convective heat transfer coefficient is as follows:

\[
t_{tM} = 35.7 - 0.0275 \cdot (M - W)
\]

\[
-I_{cl} \left\{ 3.96 \times 10^{-8} \cdot f_{cl} \cdot \left[ (t_{cl} + 273)^4 - (t_r + 273)^4 \right] + f_{cl} \cdot h_c \cdot (t_{cl} - t_a) \right\}
\]

The calculation formula of convective heat transfer coefficient is as follows:

\[
h_c = \begin{cases} 
2.38(t_{cl} - t_a)^{0.25} & \text{when } 2.38(t_{cl} - t_a)^{0.25} > 12.1 \sqrt{v_d} \\
12.1 \sqrt{v_d} & \text{when } 2.38(t_{cl} - t_a)^{0.25} < 12.1 \sqrt{v_d}
\end{cases}
\]

Where: M -- Metabolic rate, W/m²; W -- People do work outside, W/m²; Icl-- Dress heat resistance, (m²·K) /W; Pa -- The partial pressure of water vapor in the surrounding air, Pa; ta-- air temperature around human body, °C; tcl--The outer surface temperature of human clothing, °C; tr-- Mean ambient radiation temperature, °C; fcl--Coefficient of clothing area; hc -- Convective heat transfer coefficient, W/(m²·K).

The 7-point scale for evaluating human comfort is shown as follows: hot +3, warm +2, slightly warm +1, moderate 0, slightly cool -1, cool -2, and cold -3.

Table 1. ASHRAE is a seven-point scale for human thermal comfort.

| Thermal comfort   | Scale |
|-------------------|-------|
| hot               | +3    |
| warm              | +2    |
| slightly warm     | +1    |
| normal            | 0     |
| slightly cool     | -1    |
| cool              | -2    |
| cold              | -3    |

The M value of human metabolic rate can be determined according to international standards. While the crowd waited, they moved quickly from the platform above to the subway platform. In this case, the human metabolic rate falls between the international definition of mild to moderate activity. The photoactive metabolic rate was 115W/m², and the medium active metabolic rate was 145W/m². In this study, we determined a metabolic rate of 120W/m² for waiting personnel.

3.2. Air quality evaluation model

In the air quality evaluation, oxygen (oxygen partial pressure ≥13.5kPa, TBT1932-2009 passenger train health and monitoring technical requirements) is only used as an indicator parameter of ventilation volume, and does not participate in the evaluation. In this way, the air quality evaluation parameters include: CO₂, carbon monoxide, formaldehyde, organic volatile VOCs, SO₂, NH₃, NO₂, PM10.

There are two kinds of air quality evaluation: single index and total index. Single index refers to a single pollutant or parameter in the air component to reflect the air environmental quality of the "grading index", or called sub-index, with symbol II. The total index refers to the "comprehensive air quality index" under the co-existence of a number of pollutants in all air components. The general index is composed of several single pollutant "classification indexes" according to certain principles, and is used to evaluate the total quality of the air environment formed by the combined action of each major "classification indexes".

In order to reflect the different degree of impact of various pollutants on the environment, the weighting method of each parameter is adopted according to the harm of each pollutant to human health.
or air environment. There are three types of AQI: ratio simple superposition AQI, ratio arithmetic mean AQI and both the highest score index and the average score index. In this study, the last type of air environment quality index was used to evaluate the cabin air environment. This formula is called Shen's index, which takes into account not only the average score index but also the highest index. The calculation formula is as follows:

$$\text{AQI} = \sqrt{(\max(\frac{c_1}{c_{max1}}, \frac{c_2}{c_{max2}}, ..., \frac{c_i}{c_{maxn}}))^2 + \left(\frac{1}{n} \sum_{i=1}^{n} \frac{c_i}{c_{maxi}}\right)^2}$$

(4)

Where: $C_i$ -- the actual concentration of the $i$ harmful gas in the cabin; $C_{max}$, $i$ -- the maximum allowable concentration of the $i$ harmful gas in the cabin; $n$ -- type of harmful gas. The larger $i$ is, the worse the air quality is, and vice versa.

Due to the low concentration of pollutants in the air environment, there will be no significant impact on human health in the short term. When the index method is used to evaluate the indoor air environment quality, it is generally believed that the sub-index and comprehensive index below 0.50 is a clean environment, and the qualified rate is the highest. A level of 1.00 indicates light pollution, while a level of 2.00 or above indicates heavy pollution. According to the comprehensive indicators, the air quality grade can be divided into five grades, as shown in the table below.

| AQI grade | evaluate   | Impact on human health                                      |
|-----------|------------|-------------------------------------------------------------|
| ≤0.5      | I          | clean suitable for human life                                |
| 0.5~1.0   | II         | unpolluted, environmental pollutants do not exceed the standard, and human life is normal |
| 1.0~1.5   | III        | light pollution, at least one environmental pollutant exceeds the standard, general will not occur acute and chronic poisoning |
| 1.5~2.0   | IV         | medium pollution, generally, 2-3 environmental pollutants exceed the standard. There was no obvious harm to the health of the population, but the sensitive people suffered seriously |
| >2.0      | V          | heavy pollution, generally, 3-4 environmental pollutants exceed the standard. There is no obvious harm to the health of the population, and the sensitive people may die |

3.3. Air quality assessment in subway stations

Divide the air quality simulation results by the upper limit value 2 of concentration level in Table 2, multiply by 0.8, and then add the PMV divided by the value calculated by the upper limit value 3 of comfort level in Table 1 multiplied by 0.1 to get the comprehensive environmental quality. The calculation formula is as follows:

$$\text{EQI} = \frac{A Q I}{2} \times 0.8 + \frac{P M V}{3} \times 0.1$$

(5)

Where: AQI is air quality index and PMV is thermal comfort index.

The comprehensive environmental index EQI was defined, and the thermal environmental index PMV and air quality index AQI were combined to reflect the overall environmental quality of the station. PMV parameter curve is obtained from the above section, and EQI can be calculated according to the value of AQI. The air quality results within 5 hours of the test are shown in the figure below:
4. Analysis of evaluation results

In order to realize the comprehensive evaluation of the environmental quality of the station, this chapter analyzes and evaluates the air environmental quality index and the thermal comfort function PMV index in the station, and finally adds the given weight to obtain the final comprehensive index of the station environment, which is used to evaluate the station environment. Conduct a thorough assessment.

The analysis and evaluation process are as follows:
1. Calculate the air quality index AQI;
2. Calculate the thermal comfort index PMV;
3. Weighted summation to obtain the comprehensive environmental quality index EQI.

4.1. PMV analysis

A thermal comfort questionnaire was conducted at each station, and a 1-hour black bulb thermometer test and wind speed test were conducted. Table 3 shows the air temperature, relative humidity, black bulb temperature, wind speed and clothing thermal resistance of 5 subway stations. These values were substituted into the calculation formula of PMV to obtain the thermal comfort data of the six stations, as shown in Table 3.
**Table 3.** Average values of environmental parameters of five subway platforms.

| station              | Guanzhuang | Anding | Beitucheng | Huixinxijiebeikou | Qingnian |
|----------------------|------------|--------|------------|-------------------|----------|
| Air temperature      | 25.45      | 25.8   | 26.33      | 28.54             | 28.4     |
| relative humidity    | 22.1       | 59.5   | 47.2       | 50.6              | 51.43    |
| Black ball temperature| 25.47     | 26.13  | 26.59      | 28.69             | 28.68    |
| wind speed           | 1.5        | 1.5    | 1.5        | 1.7               | 1.7      |
| clothing insulation  | 0.7        | 0.7    | 0.8        | 0.5               | 0.7      |
| Hot vote             | -0.115     | 0.068  | 0.571      | 0.188             | 0.875    |
| PMV                  | -0.14      | 0.058  | 0.402      | 0.311             | 0.855    |

The thermal comfort of Guanzhuang station and Xitucheng station is between "normal" and "slightly cool". The thermal comfort at other stations ranged between "normal" and "slightly warm." Qingnian Road subway staff should reduce the temperature of the air conditioning, reduce the temperature in the subway station. For Xitucheng station, the subway staff should appropriately raise the temperature of the air conditioning. In summer, the temperature inside the subway platform is generally "warm". At the same time, it can be analyzed that the value obtained from the passenger thermal questionnaire is close to the calculated thermal comfort value.

### 4.2. AQI analysis

**Table 4.** Concentration of 13 environmental parameters in a day at five platforms

| Environmental parameters | unit | minimum | Maximum | Mean ± variance | Maximum allowable concentration |
|--------------------------|------|---------|---------|----------------|---------------------------------|
| NH3                      | ppb  | 4       | 33      | 17.48±1.50     | 0.2mg/m³                        |
| CH2O                     | ppb  | 9       | 60      | 30.91±10.65    | 0.12mg/m³                       |
| TVOC                     | ppb  | 10      | 112     | 65.75±37.88    | 0.6mg/m³                        |
| NO2                      | ppb  | 2.1     | 34.5    | 5.56±2.93      | 0.24mg/m³                       |
| SO2                      | ppb  | 0.9     | 4.4     | 2.1±0.6        | 0.5mg/m³                        |
| CO                       | ppb  | 36      | 63      | 46.46±6.54     | 10 mg/m³                        |
| CO2                      | %    | 0       | 0.08    | 0.023±0.02     | 0.15%                           |
| O2                       | %    | 20.6    | 21.2    | 20.98±1.08     | -                               |
| PM10                     | mg/m³| 0.003   | 0.15    | 0.06±0.03      | 0.25mg/m³                       |
| PM2.5                    | mg/m³| 0.002   | 0.12    | 0.05±0.027     | 75μg/m³                         |
| temperature              | °C   | 25.1    | 29.1    | 26.85±1.75     | 22-28°C                         |
| humidity                 | %RH  | 11.6    | 56.3    | 43.7±11.01     | 40-80%                          |
| wind speed               | m/s  | 0       | 0.8     | 0.14±0.15      | 0.5m/s                          |

The concentrations of CH2O, TVOC, NH3, SO2, NO2, PM10, PM2.5 and CO obtained in this test were substituted into Equation (4) to obtain the air quality index of the five subway stations (Figure 4). Among the five stations, Guan Zhuang Station has the best air quality, which is Grade I, while all other subway platforms have Grade II air quality. Guan Zhuang station has the smallest passenger flow and good air circulation, and its air quality is better than other stations. The air quality of the five monitoring stations was Grade I and Grade II. The results show that the air quality in the platform of Beijing subway is better.
5. Conclusions
In this paper, a method for evaluating the gas environmental parameters of subway stations is proposed. The comprehensive evaluation index EQI is obtained by weighting the thermal comfort index and air quality index, so as to evaluate the subway microenvironment quality more comprehensively. The realization of typical pollution situation assessment can provide analytical means for the environmental design of the station and the operation strategy of environmental control equipment.

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