Study on Air Quality Characteristics of Subway Stations Using Sensor Module

Choon-Keun Bong, Young-Gu Kim, Kyu-Young Song, Jung-Eun Oh, and Yoon-Kwan Kim

***Abstract*—This study developed an environment monitoring system in order to construct a data base for understanding the actual conditions and improving problems about the air quality of subway stations, and used this device to understand the air quality of the station and analyzed the changes according to the number of passengers to execute a preliminary review related to their interrelationship. As a result of measuring the air quality of the ticket barrier and the platform of the subway station as well as outside of the station using the monitoring system, the ticket barrier and platform showed an outcome difference of similar patterns while the range of fluctuation for the platform was larger than the ticket barrier. During rush hours, the effect, according to entering passenger cars, showed to be insignificant and some sections were measured to have exceeded the indoor environment standard. This signifies that maintaining air quality during rush hours is especially crucial. In addition, during lunch hours when the number of passengers is relatively small and fixed, it overall showed to maintain a simple concentration below the indoor environment standard. Accordingly, in these times, lowering the rate of operation of conditioning equipment to minimize power and reduce the use of unnecessary energy is found to be needed.**

***Index Terms*—Air quality, investigation and analysis, subway station, underground environment.**

I. Introduction

Air quality of the underground environment has been one of the core environment-related problems for the past several decades. Therefore, related institutions and self-governing bodies are leaning their efforts toward modernizing the management systems of underground stations and underground shopping complexes [1]. Due to recent increases of activity time in underground spaces as well as an increase in the interests of the citizens of the environment, it is essential for the introduction of a transparent management system through real-time constant monitoring not only for processing contamination and ventilation, but also for the environmental factors. Accordingly, the Ministry of Environment is striving to prepare measures including establishing plans such as a five-year subway station air quality improvement plan from 2007 to 2012. Particularly, the subway is a representative of public transportation with on average of over several million passengers daily, thus it is inevitable that the operation of subways will expand in the future and consequent number of passengers will increase as well. Therefore, air quality problems of subway stations are very important to the health management of citizens. Nonetheless, research and management about the subway environment are in a deficient state as of now [2]. Existing research and investigations about subway stations analyzed air quality based on units of time and months. For rush hours, there is a need to consider the fast fluctuating characteristic of passengers to analyze the air quality in minutes.

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This study investigated the number of train operations and passengers of each passenger car categorized by different time periods in order to establish a data base to grasp the current conditions and improve the problems of air quality of subway stations. Furthermore, the temperature, relative humidity, PM10, and CO_2 of the open air, ticket barrier, and platform were measured in minutes using a real-time monitoring device to analyze the changes according to the number of passengers and understand the air quality of subway stations in Seoul and ultimately perform a preliminary review of the according interrelationship.

This is judged to be a useful data when the future subway indoor air quality plan is established [3].

II. Research Methods

A. Research Subject and Time

To measure the air quality of subway stations, 2 environment monitoring devices were installed like Fig. 1 beside the second basement level ticket barrier and third basement level platform of Gwanghwamun located within Seoul and the temperature, relative humidity, CO_2, and PM10 were measured for approximately 50 days from November 1 to December 21 of 2012.

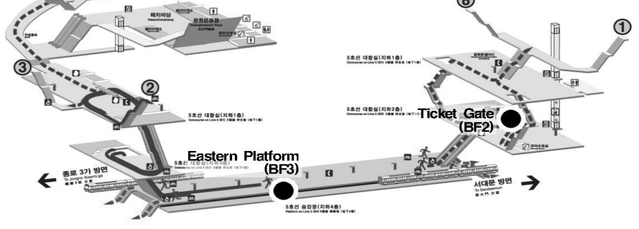

Fig. 1. Monitoring system installation locations

The surrounding regions of Gwanghwamun station are mostly composed of commercial areas, thus there are a lot of floating populations, and population movement is concentrated during rush hours leading to a clear change in the number of passengers; therefore, it was decided to be suitable for the subject of the study.

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Meanwhile, open air was only measured during a fixed time period during the weekdays and weekends in order to measure the data value for comparing the measurement outcomes of platforms and ticket barriers.

The environment monitoring device was installed inside the punching plate that has a smooth air flow but can prevent the contact of an outsider, and a notebook, UPS, and WiBro communication module were allocated on its bottom.

Fig. 2. Environmental monitoring instruments installed in subway station in Seoul.

B. Research Method

A real-time monitoring device that uses a sensor module was developed and used in order to measure the temperature, relative humidity, PM10, and CO_2 of the air and the subway station.

When developing a system for easily monitoring contamination of the underground environment, an environment measuring device that includes a sensor is the primary component in managing the air quality of the underground environment. It is largely composed of sensor and transmitter, MCU: Micro Control Unit, RS485, and Power[4], [10]. In this study, spatial conditions and characteristics were considered to develop and apply a miniaturized, lightened device of low-power consumption, and it is composed of sensor nodes, a gateway, a database server, and a management program (Fig. 3).

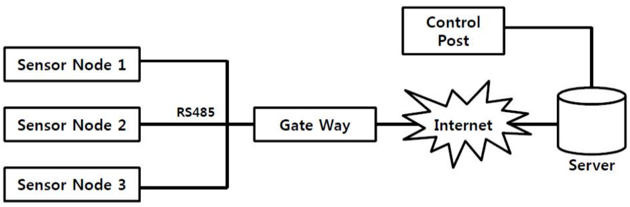

Fig. 3. Environmental monitoring system architecture.

TABLE I: SENSOR SPECIFICATIONS.

Channels	Sensor Type	Range	Accuracy	Response Time
Temperature	Semi conductor	-40~123℃	+/-0.3℃	<4sec
Relative humidity	Semi conductor	0~100%	+/-1.8%	<4sec
CO_2	NDIR	0~10,000ppm	2ppm	<40sec
PM10	Light Scattered	1~500㎍/m^3	1㎍/m^3	<1min

The measurement sensor applied to this device measures temperature, relative humidity, PM10, and CO_2, and the method and specifications of each sensor are as shown in TABLE I. Also, a transmitter was installed on each sensor for amplification and conversion of data.

The composition of a sensor measuring device include an environment measuring sensor, a transmitter for outcome value amplification and analog-digital conversion, a central processor device, a communication module, a display panel, and a switch. A distribution diagram is shown in Fig. 4. Current and voltage generated from each sensor are designed to be conveyed to the transmitter attached to the sensor and to the communication module through the digital conversion process of amplification and analog data.

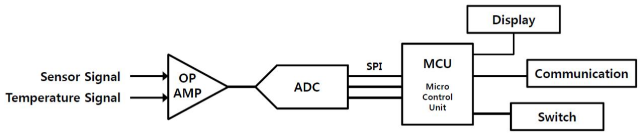

Fig. 4. Block diagram of sensor board

The control center is composed of Selector and MCU that sequentially send data received from each individual sensor. The CPU used for MCU used a processor module STM32F103 that is able to fulfill the function of controlling the display and communication with analog-digital conversion device and measuring device boards. It is composed of a signal to begin operation (Keys), communication with the measuring device board (UART), temporary storage (Memory), and communication check lamp (LED). The distribution diagram with the surrounding composition devices are like Fig. 5[5].

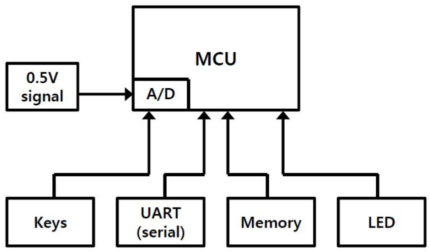

Fig. 5. MCU processor module

The data measured from 2 installation spots are transmitted to the gateway using RS485 wireless communication and the received data are sent to a notebook connected to the environment measuring device to safely save the data. The collection of data was done in units of minutes and a UPS (line stabilizer) was installed to allow a stable power supply in case of power failure.

In addition, a management program was developed for the analysis and display of each module' s management and data of the environment monitoring system. The software is largely composed of a section that sets and modifies the factors including measurement locations and input variables, a section that prints the measurement outcomes, and a section that uses the saved database to verify, modify, delete, and print the preliminary statistical data. Measuring devices for each sensor node were designed to allow registration of install locations and measuring instrument names ofmeasuring instruments and communication settings[6], [11] such as communication port, Baud rate, and Data bit.

The data collected from sensor nodes of environment measuring devices for each location were designed to be sent and saved in the database in real time through the internet network. It was also designed to allow checking of the time received and measured value of the collected data categorized by environment factors (Fig. 6).

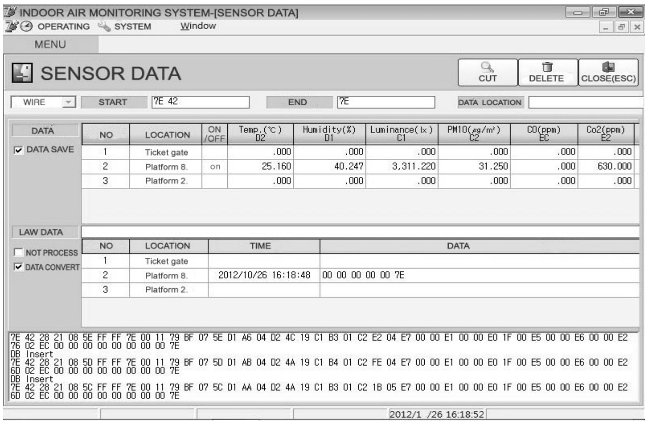

Fig. 6. Management program of environmental monitoring system.

Before installing in Gwanghwamun station, the monitoring device was tested using the standard gas and dust measuring device(Grimm 1108). The measurement range of environmental factors were deemed applicable to the subway station with temperature sensor ranging from -40~123℃ and humidity sensor ranging from 0~100%. Also, with CO_2 sensor measuring between 0~10,000ppm and PM10 sensor between 1~500μg/m^3, it received reliable data close to the indoor environment standard value of multiuse facilities. Furthermore, communication between the environment measuring device and gateway are linked in real time to allow checking of saving data almost in real time within 1 second of delay time.

III. Results and Considerations

A. Subway Operation and Passengers

Seoul subway is being used mainly as a means of commuting to and from work[3], [8]. When looking at the time-based changes of Gwanghwamun station passengers like Fig. 7, it shows a tendency of passengers increasing beginning at 6AM when people head off to work and reaches its highest mark around 8~9AM then gradually decreases. Based on around 6PM when workers leave work, another large rising curve appears and a relatively large population movement continues until after 11PM.

Also, the surrounding areas of Gwanghwamun station are mostly composed of commercial areas so the number of passengers getting off the subway was far more concentrated during the time when people head to work and conversely, the number of passengers getting on the subway was concentrated during the time when people leave work. These characteristics are judged to vary depending on the characteristics of the area in which the station is located, and various consequent analysis and management will be essential.

Fig. 8 represents the daily subway operation frequency of Gwanghwamun station and it shows a similar pattern to the time-based changes of subway passengers' graph. The operation interval during rush hours when people head for or leave work was adjusted to be shorter leading to more frequent operation.

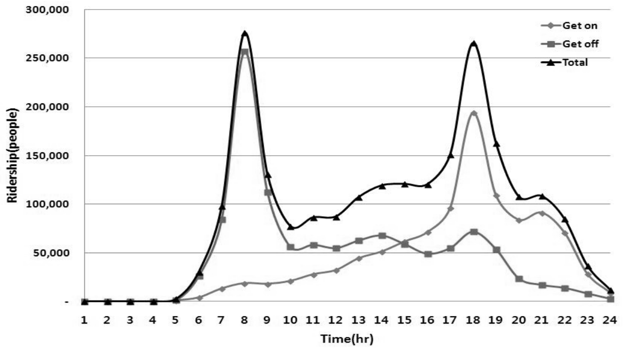

Fig. 7. Time-based changes of subway passengers.

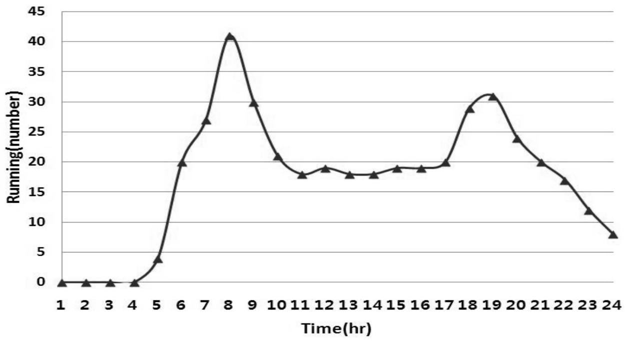

Fig. 8. Time-based subway operation frequency.

According to preceding research results, subway passengers, underpass floating population, ventilation system, natural ventilation (air entrance), train wheel abrasion, rail abrasion, brake abrasion, power supply line abrasion, and train drift are being reported as the primary air quality factors within the subway station. These factors were investigated with the main cause of the most important contaminant within the subway station, PM10 [3].

B. Air Quality Measurement Outcome of the Subway Station

The result of measuring the air quality through the monitoring system of the ticket barrier and platform in Gwanghwamun station showed that in the case of temperature, PM10, and CO_2, the ticket barrier and platform represented a higher value than the open air, and relative humidity was measured higher in the open air compared to the ticket barrier and platform. This appeared to have showed a higher concentration because, compared to the smooth air flow of the open air, ticket barriers and platforms do not have an easy circulation of air due to their underground characteristics. Relative humidity decreases according to the operation of the heating system. Also, the characteristics of measurement value were analyzed based on the data of the station with a broad range of fluctuation according to the similar measurement outcome patterns ofboth the ticket barrier and platform in all items including temperature, relative humidity, CO_2, and PM10.

The reason the platform has a broader range of fluctuation than the ticket barrier is judged to be due to the fact that the ticket barrier is influenced more by the open air. Circulation and dilution of air are realized and fluctuation of environmental factors is relatively higher than the ticket barrier due to the train and the number of passengers of the platform. The air quality of the subway platform in TABLE II, measured through the monitoring system, is showing values lower than the indoor environment standard values with average temperature 10.1℃, average humidity 26.3%, average concentration 523.0ppm, and PM10 average concentration 81.70$\mu g/m^3$. However, when the minute-based measurement values rather than the average values were analyzed(Fig. 9), some sections were shown to exceed the indoor environment standard values for dozens of minutes during rush hours.

TABLE II: THE MEASUREMENT RESULTS OF PLATFORM

Channels	Average	Max.	Min.	S.D
Temperature(℃)	10.1	14.1	5.6	2.1
Relative humidity(%)	26.3	34.8	19.9	4.3
CO_2(ppm)	523.0	831.7	382.5	135.1
PM10($\mu g/m^3$)	81.7	147.1	41.3	30.4

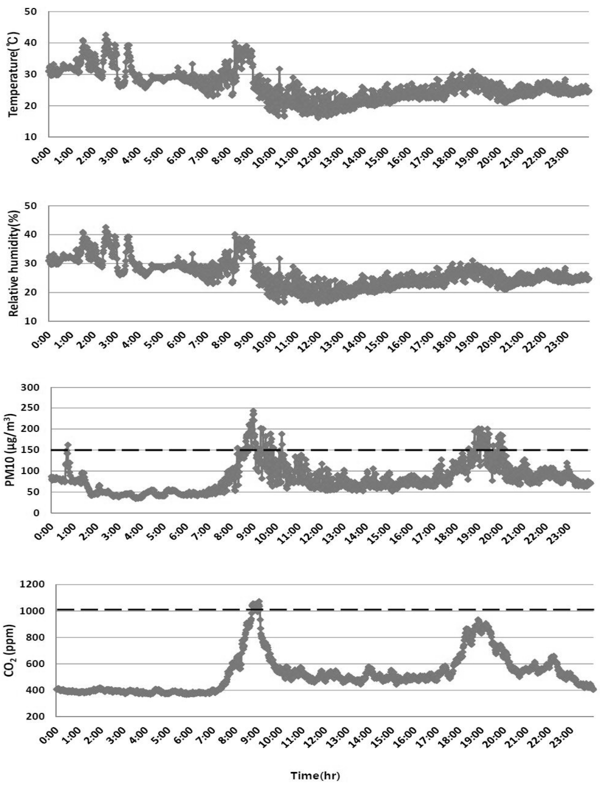

Fig. 9. Measurement results for platform.

The results of measuring the air quality of Gwanghwamun station platform showed that outcomevalues of rush hour are higher than other time periods as shown in Fig. 9. The far bigger outcome values during rush hour suggest that the number of subway passengers and operation frequency have a significant effect on air quality, and these patterns show a similar image in the subway passenger and subway operation frequency graphs.

Particularly, PM10, and CO_2 increased proportionally to the number of passengers and operation frequency, and temperature did not drop easily due to the characteristic of the platform not allowing easy inflow of outside air. Also, relative humidity fluctuated due to a variety of factors, and it was difficult to find a correlation with the number of passengers and subway operation frequency.

According to the efforts to improve the air quality of subway stations including strengthening tunnel management and installing screen doors, HCHO and CO_2 concentrations were investigated to show a slightly decreasing tendency every year after 2000, but PM10 represents a concentration value close to the standard value, thus a counter management plan is being demanded[3].

C. Operation Time-Based Air Quality Characteristics

In order to analyze the changes in air quality according to the number of passengers and trains entering the station, platform air quality measurement outcome of the morning hours with many passengers and lunch hours with far less number of passengers was measured through the environment monitoring system and analyzed like TABLE III. When the average concentration and R^2 value of each factor of the morning hours and the lunch hours was compared, R^2 value and average concentration of the morning hours was far higher and the lunch hours maintained the lowest concentration of the day excluding early morning hours before the subway begins operation.

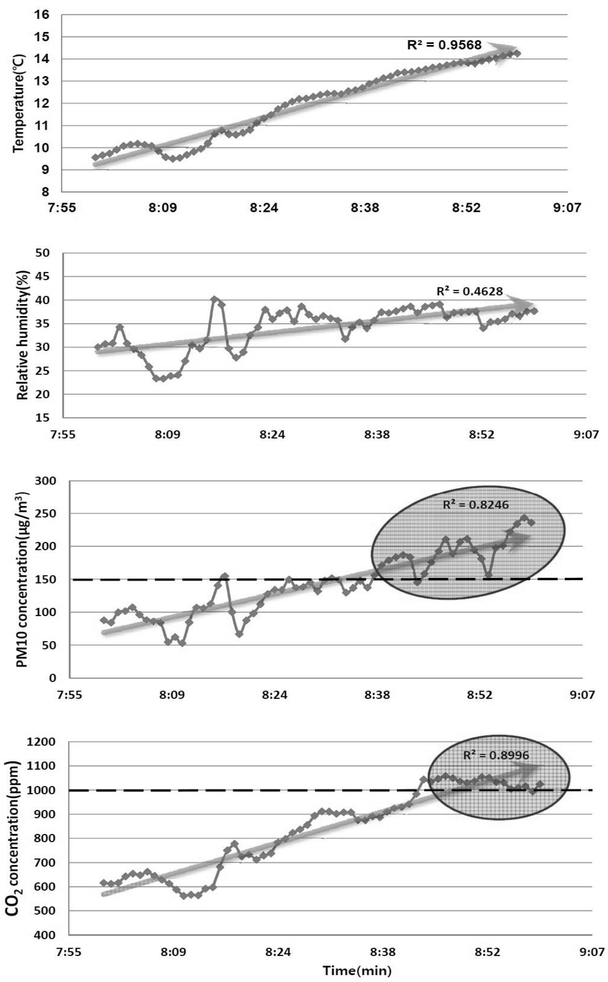

Fig. 10. Results for platform during the morning rush hours (8:00~9:00).

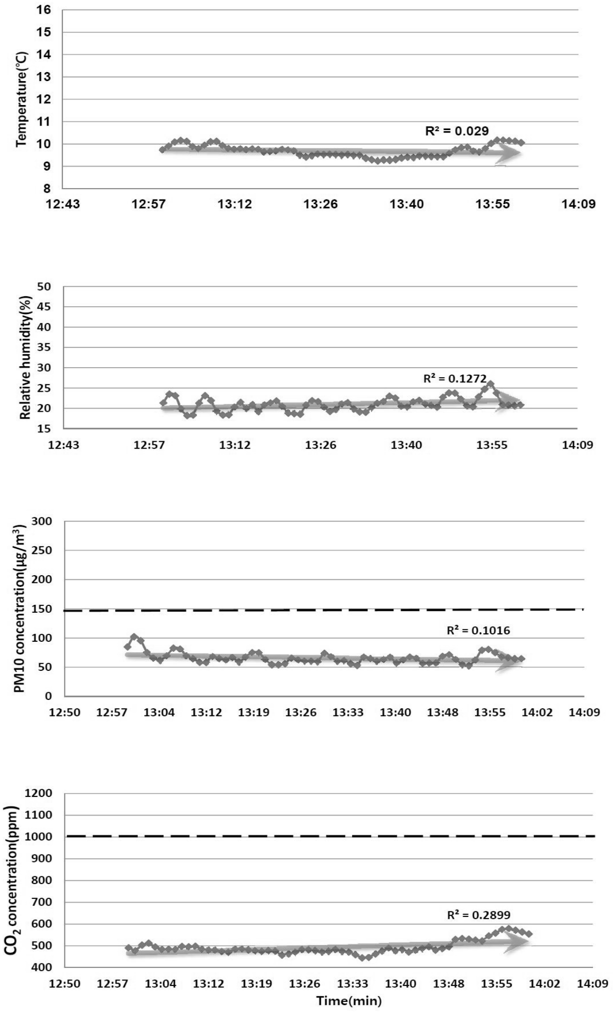

Fig. 11. Results for platform during the lunch hours (13:00~14:00).

TABLE III: COMPARED TO MORNING HOURS AND LUNCH HOURS

Channels	Morning hours		Lunch hours	
	Average	R^2	Average	R^2
Temperature(℃)	11.9	0.9568	9.7	0.029
Relative humidity(%)	34.1	0.4628	21.0	0.1272
CO_2(ppm)	835.3	0.8246	494.0	0.1016
PM10(㎍/m^3)	142.3	0.8996	65.9	0.2899

In the case of the morning hours with a large number of passengers, the influence of trains entering the station was insignificant compared to the influence of the number of passengers, and some sections showed exceeding the indoor environment standard values (Fig. 10). In addition, during the morning hours, despite the circulation of air due to conditioning equipment, contaminant concentration gradually increased according to the rapidly increasing passengers. Therefore, there is a need for special interest and effort in air quality maintenance of rush hour with a lot of population movement. In the case of lunch hours with a relatively fixed and small number of passengers, temperature, humidity, CO_2, and PM10 all showed a fixed pattern according to the entrance of trains into the station, and overall maintained a plain concentration below the indoor environment standard values. Therefore, it is necessary to lower the rate of operation of conditioning equipment during lunch hours to minimize electricity and reduce the use of unnecessary energy [9].

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