Asian Journal of Atmospheric Environment
Vol. 2-1, pp.60-67, June 2008

How about the IAQ in Subway Environment and Its Management?

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ABSTRACT

The spatial limitations of urban environments in general lead to invention and design of a wide range of underground transportation systems such as subways, underground roads and paths, etc. Among them, the application of subway systems in metropolitan cities is most commonly observed to ease those confronted difficulties on this purpose. It in turn leaves passengers and workers to be exposed to indoor air potentially polluted by various sources existing in this underground environment. Specifically when considering the IAQ in a subway station, there exist many IAQ-related parameters to be counted either as individual or as integrated exposures.

In this study, a model system has been developed to manage the general IAQ in a subway station. Field survey and CO_2 measurements were initially conducted to analyze and understand the relationship between the indoor and outdoor air quality while considering the internal pollution sources such as passengers, subway trains, etc. The measurement data were then employed for the model development with other static information. For the model development, the algorithm of simple continuity was built and applied to model the subway IAQ concerned. In this paper, the recent updated draft version of model developed will be reported and demonstrated.

Key words: Indoor air quality, Subway environment, Train-induced wind, Source contribution

1. INTRODUCTION

It has been frequently reported and well known that people in modern societies spend more than 80-90% of time a day in indoor environment. Among various types of indoor spaces, residential buildings, offices, schools, etc. are the primary spaces and cabin spaces for public transportation are the secondary. Fig. 1 presents the daily lives of Korean, U.S., German. As shown, people spend most of time in indoor environment, which is common among the countries. For German, they stay outdoor longer than Korea or U.S. It is found that people experience the cabin air quality in transportation for approximately 1.1 hour in average.

As a reference, the intensities of air pollution are 1.56 g/capita · km, 2.74 g/capita · km, 0.008 g/capita · km for passenger car, bus, subway, respectively. It is also reported that passenger car, bus and subway consume 546 kcal/capita · km, 251 kcal/capita · km, 100 kcal/capita · km, respectively. From this, we can conclude that the subway is the most environment friendly way of transportation, especially in the public transportation sector.

Table 1 summarizes the pattern of public transportation of seoul in recent years. In 2006, subway occupies 34.8% of public transportation, bus 27.7%, passenger car 26.3%, taxi 6.3%, and other miscellaneous 4.9%. According to the public transportation policy in Seoul, subway will take the role of 49% out of total public transportation in the future. It subsequently requires more ventilation and energy to maintain the indoor air quality in subway environment. Normally underground subway stations are ineffective for natural ventilation, compared to ground subway stations. The air pollutants delivered into underground stations could be easily trapped and accumulated. The high concentration of fine dust in tunnels is frequently transported into platform by subway trains, which makes the station indoor air quality (IAQ) worse.

In this study, the underground subway station, which is quite different space from other ground spaces, is focused. Various IAQ factors for underground subway environment are primarily reviewed with corresponding control measures. The management strategies based on the field measurement and analysis are also suggested.

2. IAQ FACTORS IN SUBWAY STATION

As described previously, it is common to expand the role of subway in public transportation, which requires to increase the frequency of train operation and the number of train. It in turn may cause to degrade the IAQ level in subway environment. Recently the indoor air in a subway station is separated by installing screen doors in platform, which prevents the air exchange between subway station and tunnel and worsens the air quality in subway tunnel. The air pollutants from ground transportation are also easily delivered into the subway environment through on-road ventilation opening. To protect the subway environment from this, it is required to have optimized ventilation systems for platform and subway tunnel and to install air cleaning device to on-road ventilation openings with optimized design.

2.1 Structures of Subway Station

A subway station has three major compartments in common; ambient on the ground, concourse in the first basement, and platform and tunnels in the second basement in subway in Fig. 2. For easy access and convenience, subway stations are usually constructed every 0.8-1.0 km in urban area and 1.5-3.0 km in suburban area. Based on the station location, it is also classified into elevated station, ground station, and subway station. In urban area, the subway station is the most common to avoid space limitation for construction.

Considering the type of platform, stations are also classified into island platform (b) and sided platform (a) in Fig. 3. As shown, the island platform has railways on both sides and a sided platform has only a single railway.

2.2 Conditions of Subway Operation

In the manual of subway operation, the operation condition is instructed according to the location between neighbouring stations, operation schedule, etc. Fig. 4 shows the diagrams for subway operation. Currently the subway train is being operated at the maximum speed of 70 km/hr. As reported previously, moving train in subway tunnel generates train-induced wind (TIW) which delivers and exchanges air between station and tunnel. It was also found that the amount of TIW was in the similar range to the mechanical ventilation in the subway station studied (Song, 2004).

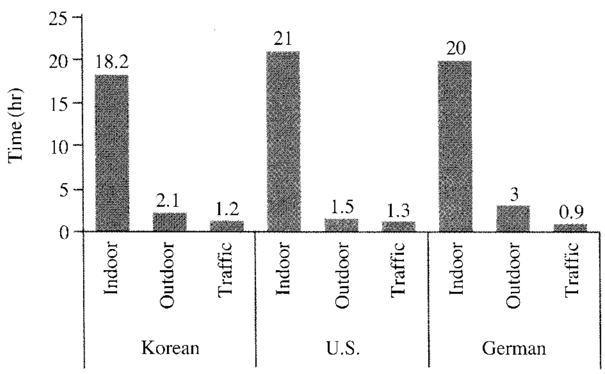


Fig. 1. Daily lives of Korean, U.S., German.

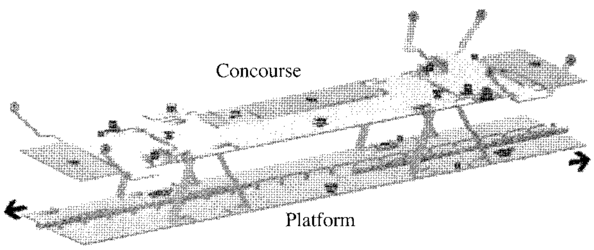
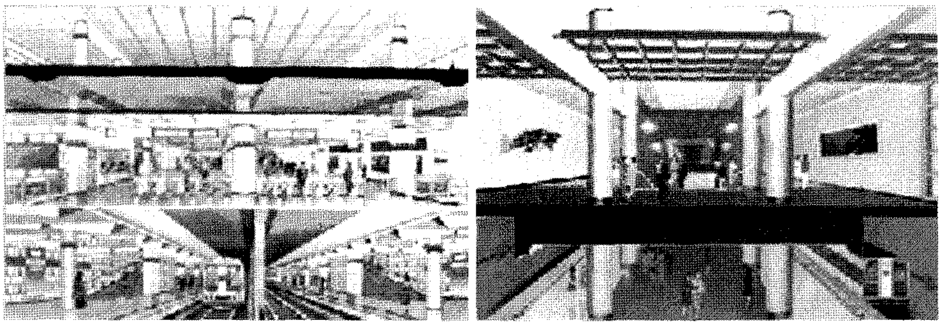


Fig. 2. Typical structure of subway station for field measurement.

Table 1. Public transportation in Seoul (2007).

Year	Total	Subway	Bus	Taxi	Car	Other
2003	100 (%) 2,938 (million people/day)	35.6 1,046	25.6 752	7.1 209	26.4 775	5.3 156
2004	100 (%) 3,034 (million people/day)	35.8 1,086	26.2 795	6.6 200	36.4 801	5.0 152
2005	100 (%) 3,086 (million people/day)	35.9 1,108	26.8 827	6.2 191	26.3 812	4.8 148
2006	100 (%) 3,139 (million people/day)	34.8 1,092	27.7 869	6.3 198	26.3 826	4.9 154



(a) Sided platform (b) Island platform

Fig. 3. Type of platform in a subway station.

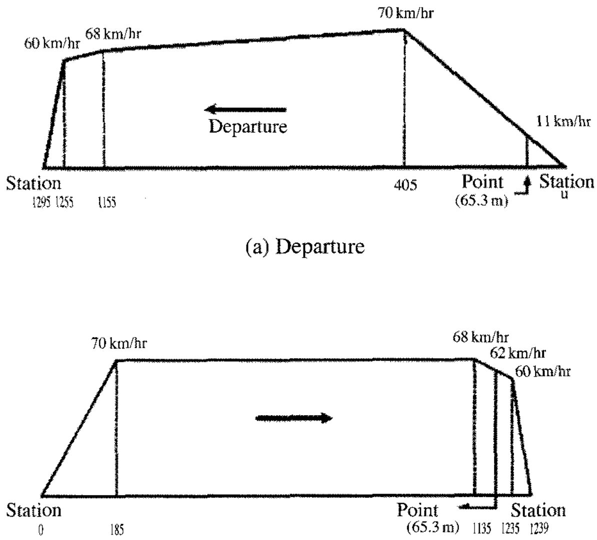
2. 3 Design of On-road Ventilation Opening

In principle, the height of the ventilation opening needs to be high as much as possible so that the air pollutants from transportation can be avoided for ventilation. Due to the limitation of local condition, however, tower type (1.2 to 2 m high) and ground type (0.3 m high) are common. The ground type of ventilation opening has the advantage to avoid blocking the scenary of shops, etc. It may not be applicable for the case of narrow side walk. Tree leaves, cigarette butt, etc. could be easily entered, which affects the air quality of ventilation opening. People could be also be suffered from the discomfort condition caused by train-induced wind (TIW) (Lin *et al.*, 2008; Kim and Kim, 2007; Yuan *et al.*, 2007; Kim *et al.*, 2004).

For the case of tower type ventilation opening, it is normally installed above 1.5 m height. This type is beneficial to take fresh air into ventilation opening, compared to the ground type. The exhausted air is also expected to have better dispersion. The dimension can be reduced by increasing the operation wind speed, but it has a certain space requirement, which may cause inconvenience to pedestrians. When designing ventilation opening in subway, the dimension is determined by the wind velocity. Usually the tower type is preferable but the ground type is also selected depending on the site condition. In this case, the wind velocity in the ground type ventilation opening needs to be maintained below 3.5 m/s.

2. 4 Ventilation System for Subway Tunnel and Station

In subway system, the air exchanges between subway tunnel and station are occurred, which has the influence of tunnel air onto the station air, including temperature, humidity, air quality, etc. It also implies the demand of the ventilation for tunnel air. Ventilation in subway tunnel is operated either naturally or mechanically. Natural system is frequently applied in early stage, but mechanical system becomes dominant in recent years. The mechanical system is often adopted to deal with emergency cases (e.g. fire) and compensated by natural ventilation, i.e. train-induced wind.



(a) Departure

(b) Arrival

Fig. 4. Operation modes of a subway train.

When considering the characteristics of station, a transit station is quite different from other normal station. Currently these subway stations are managed while being classified into normal and intensified groups. An individual station has the unique management strategy counting passengers, subway operations, ventilation, etc. For subway ventilation, push-and-pull system installed to the ceiling is operated in subway concourses. This scheme aims to make dilution ventilation and to reduce the air pollution level afterwards. However it might be possible to degrade passengers' comfort, as well known in previous studies.

For platform, fresh air is supplied from the ceiling

Table 2. Form of ventilation opening.

Classification	Tower type	Ground type
Summary	G.L.+1,500 mm height	G.L.+300 mm height
Wind speed in ventilation opening	5-7 m/sec	5 m/sec
Surface wind speed in ventilation opening	5-10 m/sec	3.5 m/sec
Advantage	• An inflow of fresh air • Inflow the prevention of pollutant • Minimizing pedestrian's displeasure • Curtailment of expenditure	• Enhance urban view and minimize pedestrian's displeasure • Ease the complain in the surrounding for ventilation opening
Disadvantage	• Degrading urban view • Hinder of passable • Complain in the surroundings of ventilation openings	• Environmental degradation by air pollution influx • Cause displeasure to pedestrian by discharged air pollutant
Application	Mainly applied to the supply opening	Mainly for the place where the tower type is not applicable

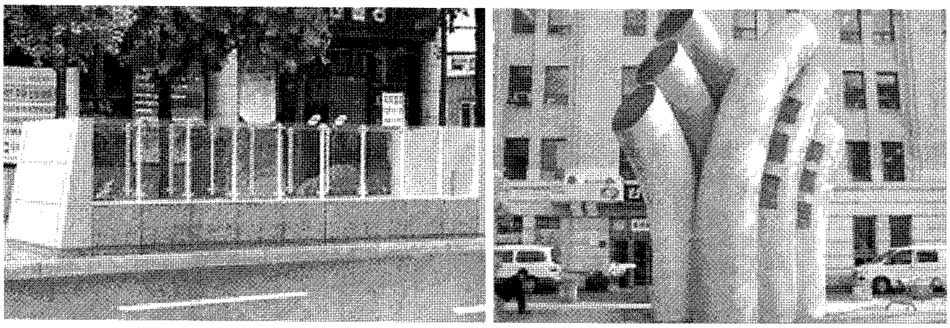

(a) Ground type (b) Tower type

Fig. 5. Various types of ventilation openings.

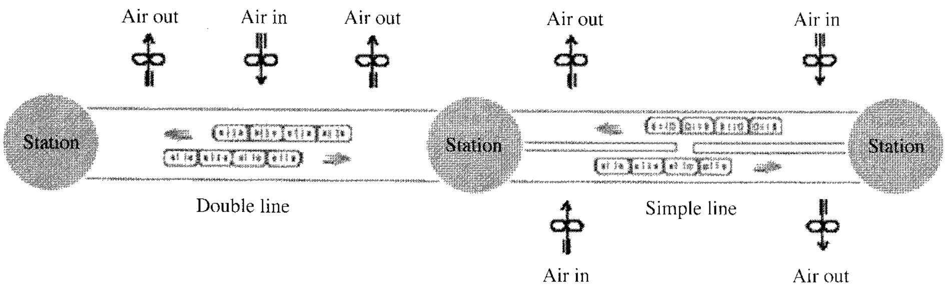


Fig. 6. Ventilation in subway tunnel.

and indoor air is exhausted through the opening under the platform. The air in platform, however, is significantly affected by train-induced wind. It was found that the amount of train-induced wind generated by subway train is similar to the subway ventilation. The recent introduction of screen door is beneficial to improve the air quality in subway platform. It degrades the air quality in tunnels while reducing ventilation by train-induced wind (Kazuhiro, 2006; Rie *et al.*, 2006; Ke *et al.*, 2002).

3. SUBWAY AIR QUALITY AND CONTROL

3.1 Air Quality in Subway Station

Fig. 7 presents the time-serial data for passengers and subway service. Bi-model distribution with the peaks during commuting time zones in the morning and the evening is observed. The train operation in (b) well copes with the demand in (a). According to the field measurement of subway IAQ in Fig. 8, the

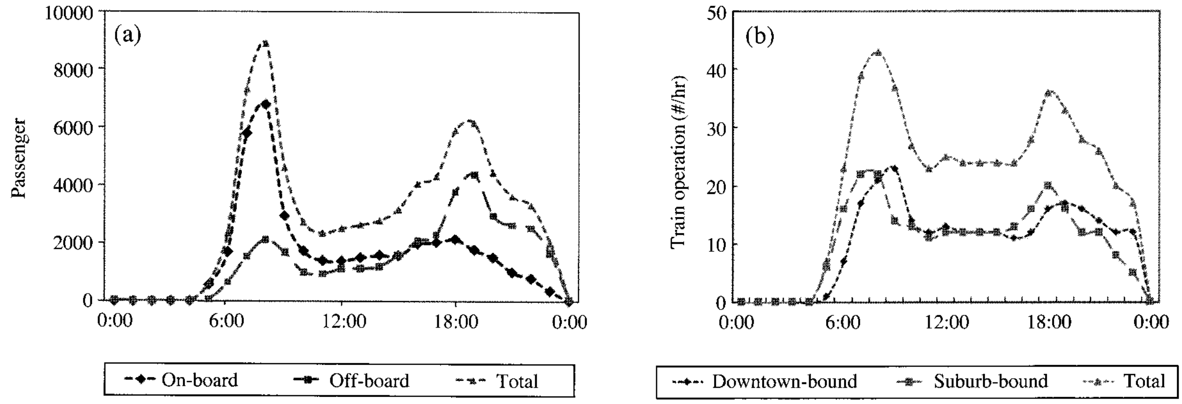


Fig. 7. Time-serial variation of passenger (a) and subway service (b).

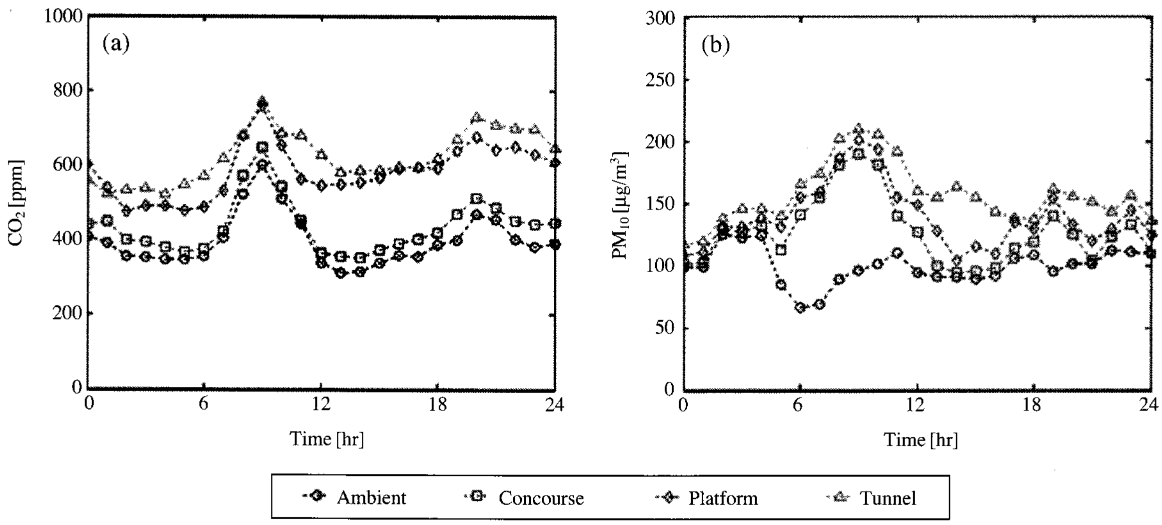


Fig. 8. Daily variation of CO_2 (a) and PM_{10} (b) in the subway station.

peaks during commuting time zone in Fig. 7 are closely reflected. As shown in Fig. 8 (a), the CO_2 in tunnel marks the highest concentration, and then platform, concourse, and ambient as in order. From this, it is found that the major source of CO_2 in subway environment is passenger, i.e. human breathing. For PM_{10} concentration in (b), the tunnel marks the highest value, and then platform, concourse, and ambient as in order. It indicates that the dust generated in tunnel is accumulated (Seoul Metropolitan Subway Corporation, 2003).

3.2 Source Contribution in Subway IAQ

From previous study, the factors for subway IAQ are categorized into three groups. The first one is originated from outdoor soil, the second one is combined outdoor source including oil combustion and road dust, and the third one is from the abrasion of break and electrode. Fig. 9(a) and (b) display the source contribution of subway IAQ in concourse and platform. "Out door source" is the biggest contributor in the concourse air and "ferrous related" is the biggest in the platform. It also implies that the air quality in the concourse and the platform have different source characteristics, which in turn requires to propose different IAQ control strategies. The source contribution of "ferrous related" becomes even bigger in (c) for the tunnel air (Song, 2004; Seoul Metropolitan Subway Corporation, 2003).

3.3 Current Control Approach for Subway IAQ

As described so far, the IAQ in subway environment has a large number of factors including pass-

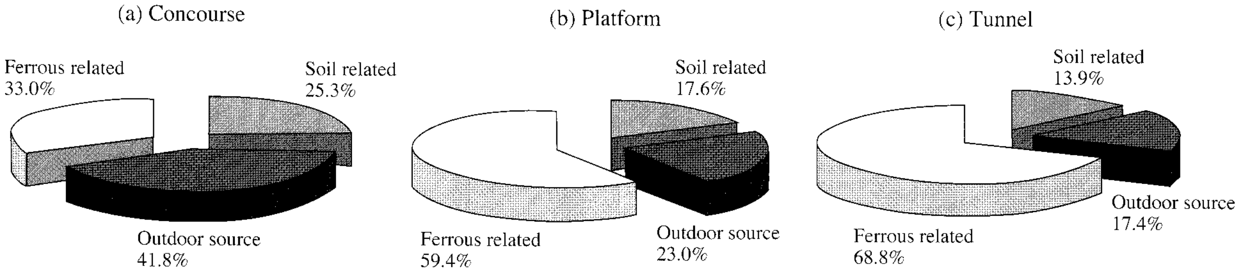


Fig. 9. Source contribution of PM_{10} in the subway.

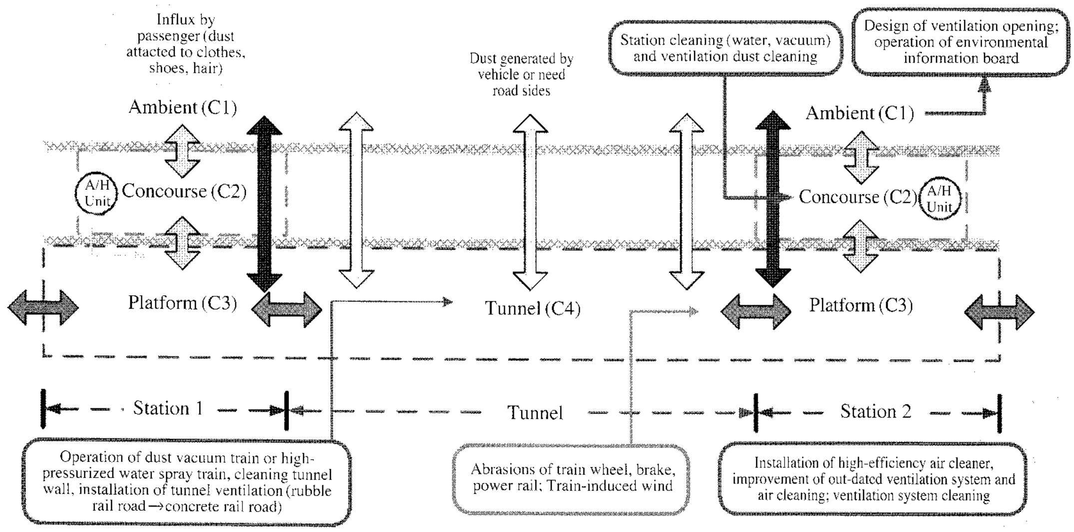


Fig. 10. Current manage-ment for subway IAQ.

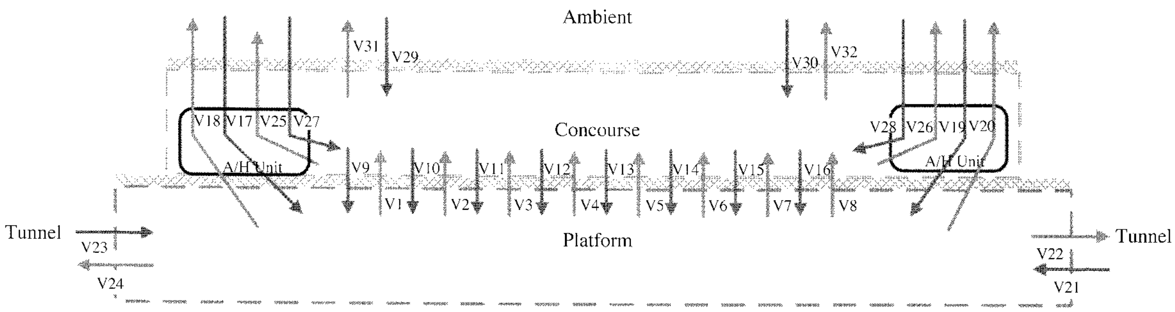


Fig. 11. Schematic diagram for the IAQ consideration in the subway station.

engers, workers, station structure, air pollution characteristics, ventilation, etc. Especially the on-road ventilation opening connecting the tunnel air to ambient air is easily exposed to the vehicle air emission. Currently, subway management in Korea identifies the emission sources and prepares corresponding countermeasures. As summarized in Fig. 10, various efforts have been made individually, but the systematic approach to cover the general air environment in subway has not been suggested yet unfortunately. Reviewing the individual approach, the outdoor electronic bulletin board is operated to inform the subway air quality level to the public and cleaning work is carried out throughout the station to improve aesthetic appearance.

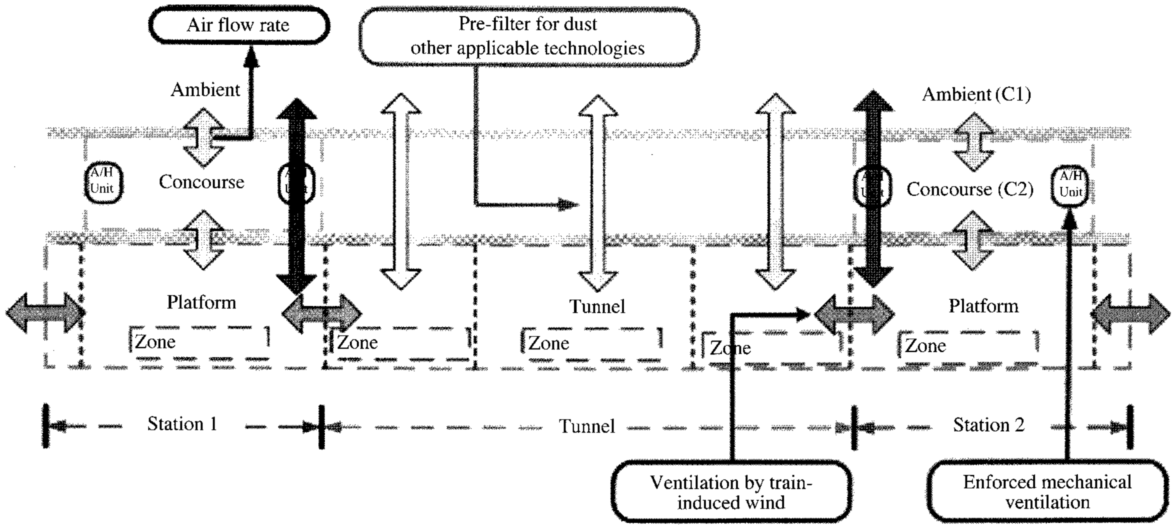


Fig. 12. Total system for IAQ management in a subway station.

In platform, out-dated ventilation system and air cleaner are replaced and high efficiency air purifiers are applied to ventilation opening so that the fresh outdoor air free from outdoor air pollution can be intaken to the subway environment. In tunnel, rubble rail-bed is replaced by concrete to reduce the suspended dust. Cleaning train using vacuum or high-pressure water spray is also operated to remove dust from tunnel.

4. Systematic IAQ Management in Subway Environment

As the subway is taking more and more role in public transportation, the important of subway IAQ has been further emphasized regarding the public health. This, in turn, leads a wide range of efforts to improve or maintain the IAQ in subway environment better than before. As reviewed in the paper, however, those efforts have been performed individually in different time frames. Also the different IAQ characteristics of each subway station has not been carefully and sufficiently considered in the initial planning stage.

From the study, the conclusion to manage the subway IAQ is drawn as follows:

Each subway station has different characteristics for its IAQ, which needs to be fully understood and to be considered in the IAQ designing stage. The IAQ factors are station structure, surrounding environment, passenger, etc.

As described earlier, the ventilation system in subway environment has the essential function to supply fresh air into the subway and to dilute and remove air pollutant from the subway environment. Therefore the ventilation system needs to be designed and reviewed as in Fig. 11 while counting every possible air exchanges, ie. train-induced wind or screen door, etc.

Based on the characteristics, the major source contribution most be identified. The counter measures are prepared for corresponding pollution sources carefully. Each part of a station, e.g. concourse, platform, tunnel, has different IAQ characteristics including source contribution.

Finally, the total system for IAQ management in a subway station, as shown in Fig. 12, must be setup and operated to cope with time-various changes in passengers in a day, in seasons, etc. The system has to have the functions to monitor the IAQ in a station to propose the optimized control strategy, and to control each IAQ component practically (Song *et al.*, 2008, 2004; Song, 2004).

ACKNOWLEDGEMENTS

The authors acknowledgement the financial supports from the Ministry of Environment, South Korea and Seoul Metro.

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(Received 6 May 2008, accepted 4 July 2008)