Air Exchange and Ventilation in an Underground Train Station

Mikael Björling[1*]

[1] University of Gävle, Faculty of Technology and Environment, Department of Buldings, Energy, and Environment, 801 76 Gävle

[*]*Corresponding email: Mikael.Bjorling@hig.se*

SUMMARY
The indoor air climate of an underground train station was investigated during two days in January 2008. The underground platform was accessed from ticket halls on each side with air volumes of 1 000 m^3 and 1 430 m^3, respectively. The station platform air volume was approximately 14 300 m^3. Air from the outside could enter either via the ticket halls or via the train tunnels from ventilation towers situated on each side of the platform area. The local mean age of air was determined in several locations at different heights using pumped sampling and homogeneous emission of PFTs. In addition, the temperature and relative humidity was measured at selected locations. The average air exchange rate per hour (ACH) was found to be 3.62 h^{-1}, ranging from 4 h^{-1} at rush hours to slightly more than 3 h^{-1} at night and in the middle of the day. The largest ACH (4.5 h^{-1}) was found at rush hour in one of the ticket halls, corresponding to a flow rate of 75 000 m^3/h. The lowest ACH (2.8 h^{-1}) was found in the other ticket hall at night, corresponding to a flow rate of 47 000 m^3/h. In the middle of the station platform the ACH was lower than the ACH at the platform ends.

KEYWORDS
Tunnel, PFT tracer gas, homogeneous emission technique, multi-zone model, relative humidity.

1 INTRODUCTION

The ventilation of large premises is a challenge. The airflows in these systems can consist of a complicated array of inlets, outlets, and inter-zonal flows that may be difficult to analyse. The homogeneous tracer gas emission technique is one way to simplify measurements of some ventilation parameters. In this technique, it simply suffices to measure the local concentration of the tracer gas to evaluate the local mean age of air. The technique has also been used in a similar project to measure the ventilation of road tunnels (Bring et al, 1997). By using several different tracer gases, it is also possible to investigate the flows inside the premises (Etheridge and Sandberg, 1996). This study was performed to map the ventilation flows in an underground train station as a part of the documentation in a larger project with the aim of redesigning the underground train system.

2 MATERIALS/METHODS

Measurements have been performed on the 2 and 3 of January 2008 in four time periods each ranging approximately one and a half hour (Period 1: night 22:00 – 23:40, 2/1; 2: morning (8 am) 08:00 – 09:40, 3/1; 3: noon 11:40 – 13:20, 3/1; and 4: evening (5 pm) 16:20 – 18:00, 3/1). The infiltrated ventilation air was measured using the homogeneous emission tracer gas technique described in NORDTEST Standard VVS 118 (1997) and ISO 16000-8 (2005). Two different perfluorocarbon tracers (PFTs), perfluorobenzene (tracer A) and perfluorotoluene (tracer B), were used. For the tracer gas emission we have chosen to use passive tracer gas sources (Stymne and Boman, 1994). For the experiment 2000 single tracer gas sources were grouped in perforated boxes and distributed in the morning of the 2 of January. The homogeneous emission tracer gas technique requires the emission of tracer gases to be proportional to the volume of each zone. A schematic layout of the underground station with its air flows is shown in figure 1. The natural division of the underground train station is into three zones: the two ticket halls and the platform area. In each of the ticket halls only tracer gas B was emitted from boxes in 5 positions. In the platform area only tracer gas A was emitted from 18 boxes hanging at a height of 4 meters over the platform level. In each measurement period samples were obtained in triplicates using simultaneous pumped sampling for 20 minutes onto charcoal tubes with calibrated and programmable SKC sampling pumps. There were 3 measuring points in each of the ticket halls, and 5 measuring points evenly distributed on the platform. All measuring points were situated at heights close to 2.5 meters. Temperature and RH were measured in the ticket halls (close to the stairs), at the platform ends and in the middle of platform, with a frequency of one value every 2 minutes. Outdoor temperatures and RH were obtained as three hour averages from the nearby SMHI weather station at Observatorielunden. The train frequency was also recorded during the measurement periods.

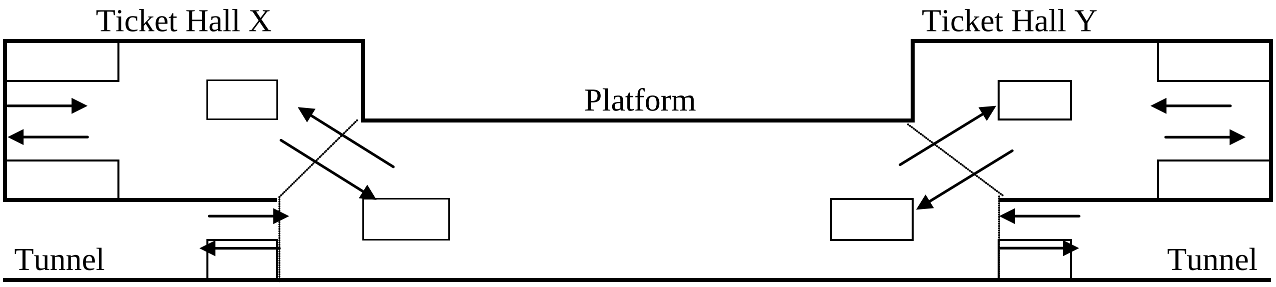

Figure 1. Schematic design of the underground station. The ticket halls are in direct contact with the outside air. On either side of ticket halls, the tunnels are in contact with the outside air via ventilation shafts. Therefore the platform may receive fresh air either via the ticket halls or the tunnels.

3 RESULTS

Ventilation system description

The ventilation of the underground train station (figure 1) is affected by the train traffic in the tunnels and by natural ventilation. There is no forced ventilation system. Fresh air may enter the system either via the doors in the ticket hall or via ventilation shafts connecting the tunnels to the street level. The ventilation shafts are located in the tunnels, on either side of the platform, just after the point where the tracks separate to arrive on either side of the platform. Trains act as pistons in the tunnels to transport air from the tunnel and the ventilation shafts into the platform area. Natural driving forces lead to transport of air through the doors of the ticket halls and the ventilation shafts in the tunnels. Natural ventilation is thus affected both by the outdoor conditions and the frequency of door openings. Ticket hall X is busier and has more doors than ticket hall Y.

Temperature and relative humidity

The temperature and relative humidity variations for the two ticket halls are shown in Figure 2. The corresponding variations for the platform and outdoors are shown in Figure 3. January 2 was moderately cloudy with 0.7 mm precipitation and wind speeds 1-3 m/s whereas January 3 was cloudy with 1.1 mm precipitation and wind speeds 1-7 m/s. Figures 2 and 3 clearly show that ticket hall X is busier and has longer periods where doors are constantly open so that the values approaches the outdoor conditions, whereas ticket hall Y and the platform is moderately affected.

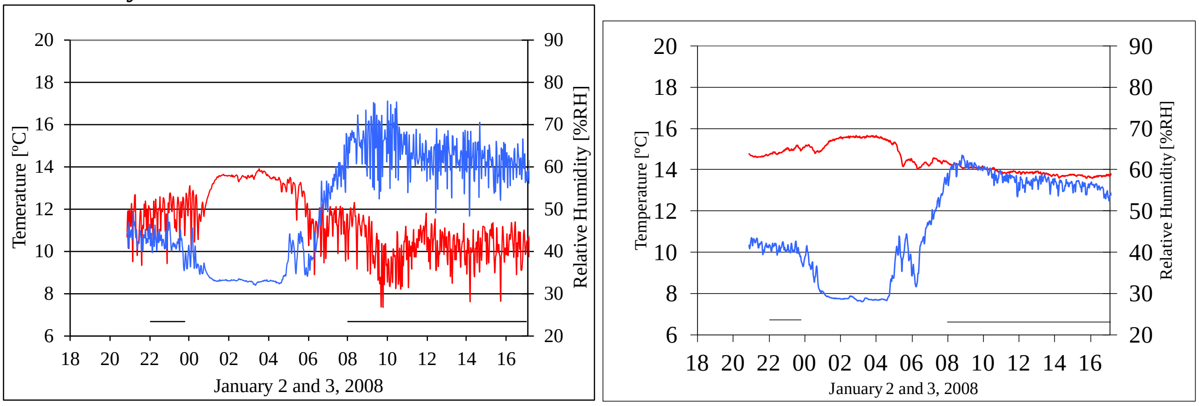

Figure 2. Temperature (red) and relative humidity (blue) in ticket hall X (left) and ticket hall Y (right). Measuring periods are marked.

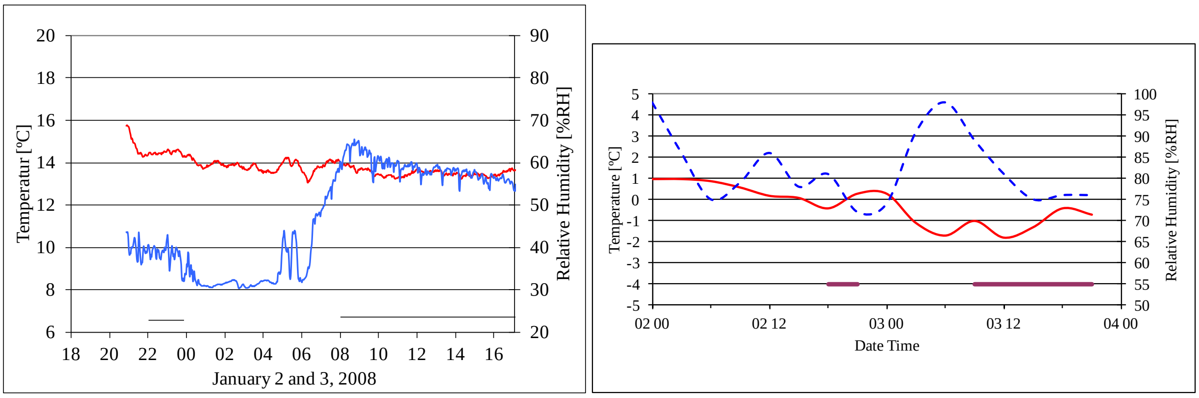

Figure 3. Temperature (red) and relative humidity (blue) in the middle of the platform (left) and outdoors (right). The measuring periods are marked.

Determining the local mean age of air

The natural ventilation variable measured by the method is the local mean age of air τ [h] (Stymne and Boman, 1994). The local age of the air, since it entered the system depends on the local mixing conditions. Older air means less efficient removal of contaminants and supply of fresh air. Since we label the air in the system with two different tracer gases, A and B, the local mean age of air is given by

$$\tau_i = \tau_i^A + \tau_i^B = c_i^A / k_A + c_i^B / k_B \qquad (1)$$

where c_i^x is the concentration of tracer gas x [g·m^{-3}]and k_x is the emission rate of tracer gas x per volume [g·h^{-1}·m^{-3}]. The concentration is given by

$$c_i^x = M_x / \kappa / T \qquad (2)$$

where M_x is the mass of tracer gas x collected in the samplers [g], κ is the air sampling rate [m^3·h^{-1}], and T is the sampling time [h]. The mass collected is measured using a gas chromatography technique. The results of the measurements are presented in Figure 4 for all the measuring periods. The relative rush hours at 8 am and 5 pm stand out as the age of the air is clearly less than during noon and night for all measuring points. The influx of fresh air is larger for the rush hour periods compared to noon and night. This may partly be due to the larger number of trains (Table 1) and partly because the doors in the ticket halls are open for longer periods during rush hour. The air generally is older toward the middle and the Y side of the platform. The middle of the platform is least affected by the rush hours. In spite of the fact that ticket hall X is busier than Y, their local mean ages do not differ much. A quick analysis of the two tracer gas concentrations in the ticket halls shows that ticket hall X has a larger influx of old air from the platform area than ticket hall Y.

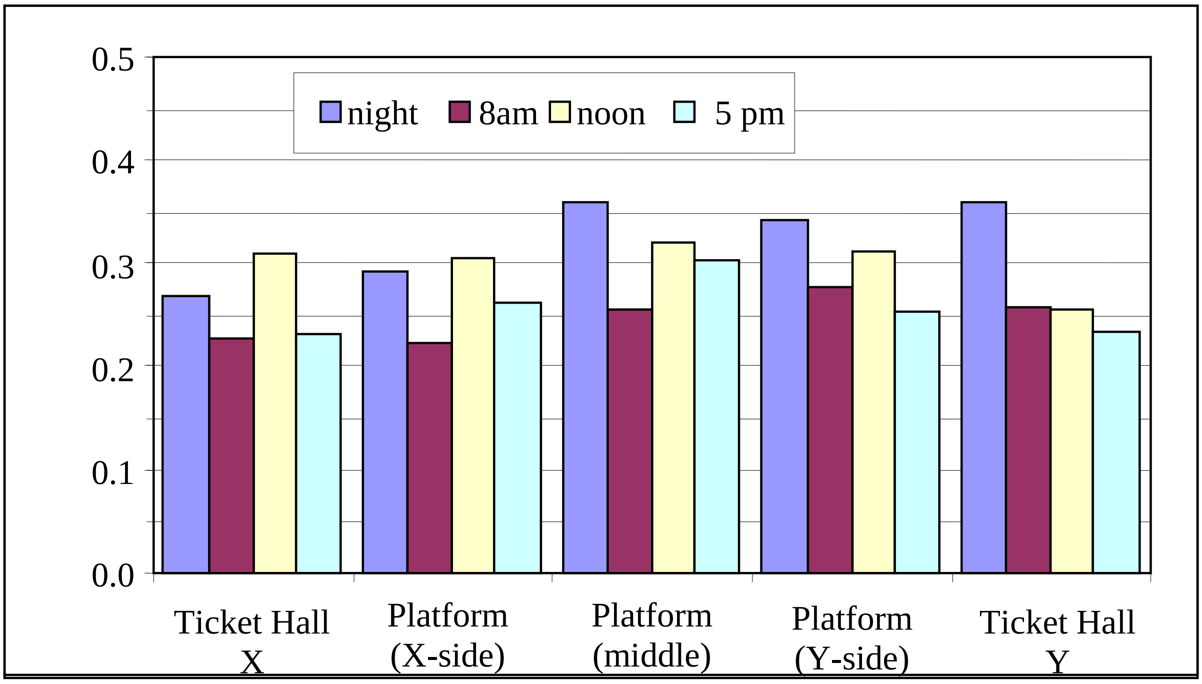

Figure 4. The local mean age of air, τ [h] measured at selected points for each of the measuring periods (see legend).

Table 1. Number of trains in each direction during the measuring periods

period	X-direction	Y-direction
night	12	12
8 am	21	15
noon	18	17
5 pm	23	21

The local air change rate and the total inflow of air

In steady state conditions, the local air change rate ACH [h^{-1}] can then be obtained as the inverse of τ. In Figure 5, the calculated results are presented with error bars. The same local trends as for the local mean age are observed. The measured local air change rates are nearly double the recommended air change rates for residential buildings, i.e. twice per hour. Except for the morning rush hour, the middle of the platforms is the least ventilated spot. The total air flow rate Q_{tot} [$m^3 \cdot h^{-1}$] is given by the total room volume divided by the average τ for the exiting air (Etheridge and Sandberg, 1996). Since there are many exit points in the system measuring in all of them is difficult. However, we may estimate the τ for the exiting air by the volume-weighted average of the local mean ages. These estimates are presented in Table 2. As expected the total influx of air into the underground train station is quite large and is the largest during rush hours. The average air exchange rate per hour (ACH) was found to be 3.62 h^{-1}, ranging from 4 h^{-1} at rush hours to slightly more than 3 h^{-1} at night and in the middle of the day. The largest ACH (4.5 h^{-1}) was found at rush hour in one of the ticket halls, corresponding to a flow rate of 75 000 m^3/h. The lowest ACH (2.8 h^{-1}) was found in the other ticket hall at night, corresponding to a flow rate of 47 000 m^3/h.

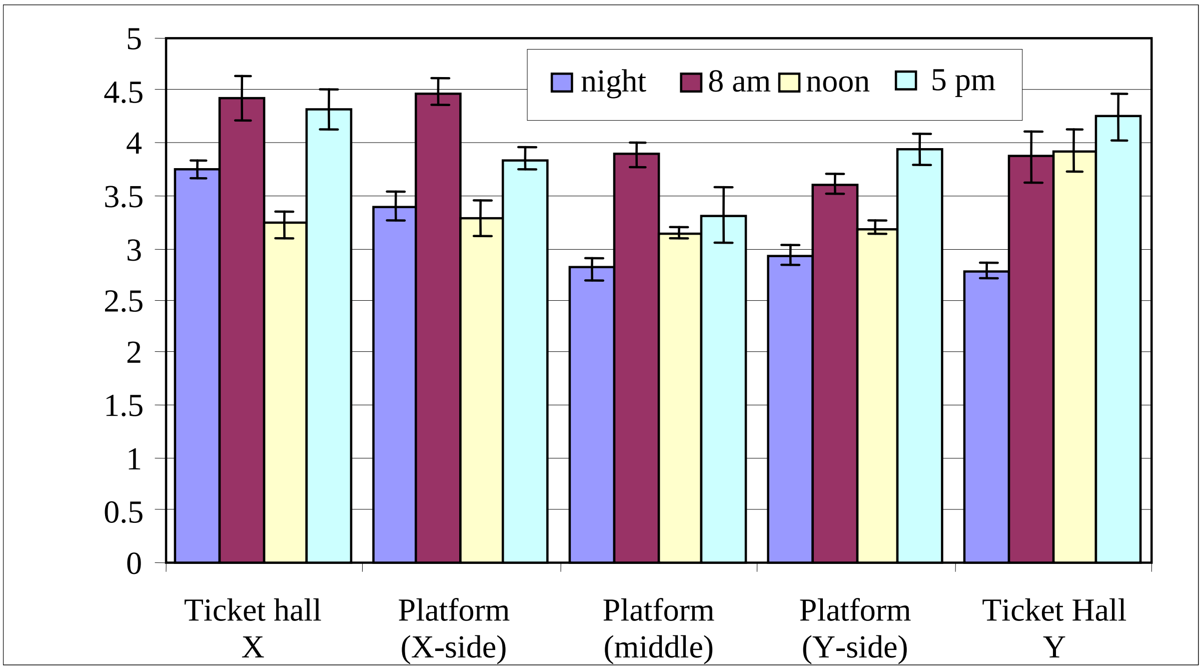

Figure 5. The local air change rate, ACH (h^{-1}) measured at selected points for all the measuring periods (see legend). The error bars are also given.

Table 2. Volume-weighted averages of the local mean ages of air and the estimated total airflow into the system.

		$\tau_{average}$ [h^{-1}]			
Measuring Object	volume [m³]	night	8 am	noon	5 pm
Ticket Hall X	1000	0.27	0.22	0.31	0.23
Platform	14300	0.33	0.26	0.31	0.27
Ticket Hall Y	1500	0.36	0.26	0.26	0.24
Total	16800				
Volume Averaged Mean Age		0.33	0.26	0.31	0.26
Estimated Total Airflow[m^3 h^{-1}]		52000	64000	55000	64000

4 DISCUSSION

The measuring periods were chosen to compare periods of less frequent travel with the relative rush hours in the morning and afternoon. However, at the dates of the measurements, one may expect rush hour to be less intense than a normal work day since many people may have chosen to remain on Christmas vacation. The ventilation increases during rush hour but the reasons for that must be investigated further. Is it mainly due to the increased frequency of door openings or to the increased frequency of trains that could lead to a greater influx of fresh air from the tunnel ventilation shafts? We are also able to see local patterns of mixing conditions. The middle of the platform appears to be the most stationary part of the air. Using two different tracer gases will also enable a further study of the internal flows in the underground train station. Such a quantitative study requires a more lengthy analysis and will be published in a subsequent paper (Björling, 2012). However, by inspection we could conclude that a large contribution to the local mean age of air in the busier ticket hall X come from the influx of older air from the platform area.

5 CONCLUSIONS

We show that determination of the local mean age of air can be used to study the mixing conditions in an underground train station. In turn we can evaluate other important parameters such as the local air change rate as well the total influx of fresh air. Using different tracer gases also enable us to draw some conclusions concerning the internal inter-zonal flow patterns. However, because our multi-zone system is underdetermined since we only use two different tracer gases the analysis is necessarily incomplete. Some additional quantification of the internal flows is nevertheless possible from the measurements but requires a more lengthy analysis and some extra assumptions.

ACKNOWLEDGEMENT

Hans Stymne and Carl-Axel Boman (Pentiaq AB), and Bengt Christensson (IVL) are acknowledged for assistance. AB Storstockholms Lokaltrafik (SL) is gratefully acknowledged for financing the study.

6 REFERENCES

Axley, J.W. 1989. “Multi-zone dispersal analysis by element assembly”, Building and Environment. 1989;24: 113-130.

Björling, M. 2012 To be submitted to Tunnelling and Underground Space Technology.

Bring, A. Malmström, TG. and Boman, CA. 1997 “Simulation and Measurement of Road Tunnel Ventilation”**,** Tunnelling and Underground Space Technology, vol. 12, No. 3, pp 417-424.

Etheridge, D. and Sandberg, M. 1996. ”Building Ventilation Theory and Measurement”. John Wiley

ISO/DIS 16000-8. 2005. “Indoor Air – Part 8: Determination of local mean ages of air in buildings for characterizing ventilation conditions”, International Organization for Standardization.

NORDTEST. 1997. “Ventilation: Local mean age of air – homogeneous emission technique”. Nordtest Method: NT VVS 118, Nordtest, Finland.

Stymne H. and Boman CA. 1994. "Measurement of ventilation and air distribution using the homogeneous emission technique - a validation". Healthy Buildings '94, Proc. of the 3rd International Conference, vol. 2, pp 539-544, Budapest, Hungary.