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Assessment of Indoor Air Quality(IAQ), Comfort and Safety in Metro Subway Station

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Abstract : With ever increasing number of citizen using subway stations everyday, safety, health and comfort of passengers and occupants (mostly metro personnel) have become important social issues. Considering the fact that various physical variables and pollutants such as particulate, VOCs and biological agents are closely related to indoor air quality (IAQ) which may cause health problems, a method of quantitative assessment using information-theoretic measure on such variables needs to be devised and implemented for comfort, health and safety of passengers and occupants in the subway station. A basic framework for assessing indoor air quality (for comfort and health) and safety in subway station is suggested. In particular, application of information-theoretic measure for the assessment of indoor air quality, comfort and safety in subway station is discussed. Some examples are presented as well.

Key words: subway, indoor air quality, comfort, health, safety, information

1. Introduction

With increasing number of citizen using subway stations everyday, safety, health and comfort of passengers and occupants (mostly metro personnel) became an important social issue. For example, fire accident in 2003 in a subway station in the city of Daegu in Korea which killed nearly 200 passengers indicates that any means to assess the level of safety must be given a priori in ensuring the safety of passengers. A method to assess the level of the indoor air quality (IAQ) as well as the safety needs to be devised and implemented in securing clean and safe indoor environment and saving lives of passengers particularly in case of fire. Previous study indicates that particulate in indoor air in subway station appears, as expected, to be denser than in outdoor air. Tunnel and platform are the weakest locations for the health of passenger. Attention on IAQ in passenger lounge area must also be given in view of health because metro personnel usually occupy this area for many hours of a day[1, 2, 3, 4].

This study discusses application of information-theoretic measure to assess the indoor air quality (therefore, comfort and health) and safety of passengers and occupants. The idea is based on the general principles of design and their applications to quantification of uncertainty in IAQ and safety involved in the physical variables and pollutants, etc. Examples are then given.

2. Performance Level of Indoor Air Quality

Standard definition of IAQ that is specific to subway environments is not available. However, in terms of ensuring the safety, health and comfort of passengers and occupants in a more generic building environment, IAQ can be defined as the physical, chemical and biological properties that indoor air must have in order

- dnot to cause or aggravate illness in the passengers or occupants, and
- to secure high level of safety, health and comfort to the passengers and the occupants in the performance of the designated activities for which the station has been intended and designed.

2.1 Physical properties

The possible performance levels for indoor air quality in a building environment are given as the exposure values of the following physical variables[5]:

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- Radon
- Electromagnetic fields
- Chemical agent

The guideline for exposure values of these physical variables is not available.

2.2 Particulate matters

WHO suggested that even very low level of particulate in the air (e.g., 10-20 micro gram/m^3, PM_{10}) is associated with an increased health risk in the population. WHO recommends to keep the exposure values as low as reasonably achievable. Table 1 shows the regulatory values of particulate matters adopted for outdoor air by US-EPA. They represent figures that ought not to be exceeded in any indoor condition.

2.3 VOCs (Volatile Organic Compounds)

In an attempt to define comfort target values for total VOCs and subgroups of VOCs, tentative values were proposed by Seifert[6]. These values are not the absolute figures and must be taken as indicative values and used in the order of magnitude level. The guideline of pollutant in the air is given in Table 1 for a generic building environment and these values can be used for subway environment.

2.4 Environmental Tobacco Smoke (ETS)

ETS is a complex mixture of thousand chemical substances in particulate and vapor phase. There is no evidence for a safe exposure level.

2.5 Biological agents

It has been shown with relatively good certainty that building-related moisture and microbial growth increases the risk of respiratory symptoms, respiratory infections allergy and asthma. Also, toxic mechanisms may be involved, especially in connection with toxin producing fungi and bacteria. There is, however, no evidence for a safe exposure level.

3.Performance Level of Comfort

3.1 Thermal Comfort

The environmental variables which constitute the thermal environment are temperature (air, radiant, surface), humidity, air velocity and personal variables (clothing

Table 1. Guideline values of pollutant in the air

Pollutant	Values (mg/m^3)	References
CO	10 (8 hrs) 30 (1 hr) 60 (30 min) 10 (15min)	WHO, 2000
NO2	0.2 (1 hr) 0.04 (annual)	WHO, 2000
Particulate matter		
PM	No guideline value recommended	WHO, 2000
PM_{10}	0.05 (annual) 0.15 (24 hrs)	US EPA, 1996
$PM_{2.5}$	0.015 (annual) 0.06 (24 hrs)	US EPA, 1996
Ozone	0.12 (8 hrs)	WHO, 2000
VOCs		
Toluene	0.26 (1 week)	WHO, 2000 WHO, 2000 Seifert, 1990
Benzene	UR: 6×10^{-6}	
TVOCs	0.3	
Aliphatic hydrocarbons	0.1	
Aromatic hydrocarbons	0.05	
Halogenated hydrocarbon	0.03	
Terpene	0.03	
Esters	0.02	
Aldehyde and ketone (excluding formaldehyde)	0.02	
Formaldehyde	0.1 (30 min)	WHO, 2000

Table 2. Ventilation rate for offices depending on the pollution load in three categories (CEN 1752) [7]

Category	Occupants only		Low-polluting materials		High-polluting materials	
	l/sm^2	Cfm/ft^2	l/sm^2	Cfm/ft^2	l/sm^2	Cfm/ft^2
A, High	1	0.20	2.0	0.40	3.0	0.60
B, Medium	0.7	0.14	1.4	0.28	2.1	0.42
C, Basic	0.4	0.08	0.8	0.16	1.2	0.24

with activity level). The requirements for acceptable thermal climate are given in such standards and guidelines as EN ISO 7730, CR 1752 and AHSRAE 55-92[7].

The interaction between IAQ and the thermal comfort is, in general, less recognized. However, changing the temperature and the humidity of the indoor air may change IAQ in two ways: Temperature and humidity of the air have direct impact on the perception of the air quality, thus decreasing the acceptability of the air with increasing air temperature and humidity. Dry and cool air also has an important impact on the amount of energy used for ventilation. Reducing temperature from 22°C to 202°C and humidity from 50% RH to 4% RH can lead to reduction of ventilation rate from 10 to 3.5 l/s per person in an office space.

3.2 Ventilation

Ventilation has to be adequate to remove and dilute the indoor pollutants and provide acceptable level of contamination in the indoor air. The relationship between the ventilation rate and the pollution load is given in Table 2. Carbon dioxide concentration is, in general, used to surrogate the ventilation rate.

4. Information-theoretic Measure to Assess The Level of Comfort and Safety

The concept of entropy was first introduced in statistical thermodynamics by physicist Boltzman to quantify the uncertainty involved in the system[8-9]. Such uncertainty stems from the randomness of the process or the system. Let $x(n)$ be a state of some process that has a set C of possible states. Let Ψ be the set of all possible probability densities q on C such that and $q(x \in C) \geq 0$

$$\int_C q(x)dx = 1 \tag{1}$$

The entropy of a process with the probability density q is represented as:

$$E[q] = -\int_C q(x)\log q(x)dx \tag{2}$$

The entropy is a measure of the amount of information produced by a random process $x(n)$, or a measure of uncertainty in a random process. The larger value of entropy corresponds to more uncertainty in the process.

Consider in Figure 1 where the performance of the process is quantified in view of the safety. Safety/comfort range signifies the tolerance associated with process variables. System range designates the capability of safety/comfort process (in terms of tolerance) and the current performance of designed processes. Common range is the overlap between the safety/comfort range and the system range.

Figure 1 implies how much of safety requirements are satisfied by the current performance of the designed process (system range).

The probability of achieving the particular safety/comfort requirement i and the information content are then defined, respectively, by:

$$q_i = \left(\frac{System\ Range}{Common\ Range}\right)_i \tag{3}$$

$$E[q_i] = \log\left(\frac{1}{\frac{Common\ Range}{System\ Range}}\right)_i = \log\left(\frac{System\ Range}{Common\ Range}\right)_i \tag{4}$$

Information content is a measure of the probability of success of achieving the specified requirements in safety/comfort process in subway station or a measure of uncertainty in insuring safety/comfort in subway station. It is independent of specific nature of process variables such as physical variables, pollutants and etc.

If the safety range does not overlap with the system range (operation range), indoor environment in subway station does not reflect the safety/comfort requirements at all. If the safety range covers the entire system range, all the safety/comfort requirements are satisfied by the process variables in indoor environment. One way of reducing uncertainty (information contents) in safety/comfort is to increase the common range. This implies that one has to try to satisfy all safety/comfort requirements specified by the safety range with process variables.

5. Examples

5.1 Comfort

In order for passengers and occupants feel comfortable, temperature and humidity must be within the narrow range (band). Too high temperature above may indicate a fire. Attention on IAQ, especially the humidity in passenger lounge area must be given because metro personnel usually occupy this area for many hours of a day. Too low or high humidity also harms the health of personnel. These restrictions lead to a configuration that a safety/comfort range has a certain band along the system function as in Figure 1. Typical temperature range for health and comfort of users lies between 18~28°C (comfort range). Any temperature below or above this range will lead to uncertainty in comfort. CO_2, VOC, chemical agents, some of biological agents are, however, must be kept as low as possible or reasonably achievable. In this case, a safety/comfort range has a certain upper limit (maximum exposure value in terms of the safety and comfort) along the system function as in Figure 2. The maximum CO_2 level allowed in practice is 1000 ppm.

Thus, the safety/comfort range may be bounded along the system function (the value of physical variable, temperature in Figure 1) or have an upper limit (limit on CO_2 level in Figure 2).

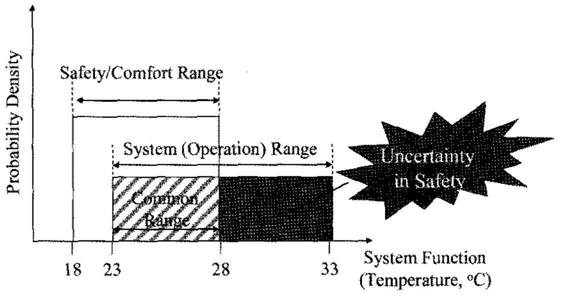

Fig. 1. Probability distribution of a system function (temperature) that has a band.

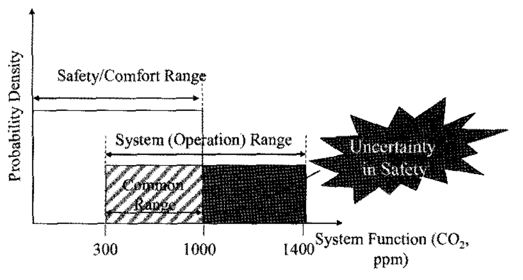

Fig. 2. Probability distribution of a system function (CO_2 level) that has an upper limit.

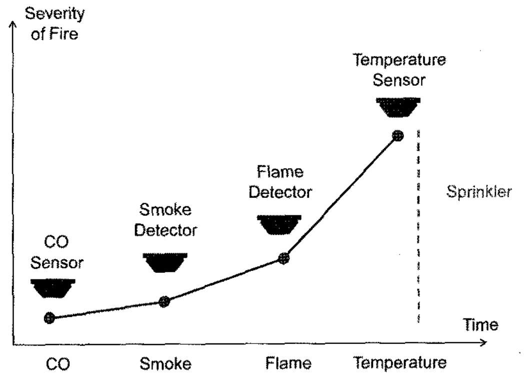

Fig. 3. Sequential development of fire, its characteristic features and relevant detection mechanisms.

5.2 Fire Safety

Figure 3 shows the sequential development of fire, its characteristic features and relevant detection mechanisms. Figure also indicates that due to its sequential nature and independent characteristics sensors/detectors and relevant information differ in time. CO sensor is effective in the initial stage of fire, then smoke and flame detection follow and temperature monitoring is finally used to confirm the fire.

In terms of assessing the indoor air quality for the comfort of passengers and safety in view of fire, either two (or multiple) sensors can be used independently for each purpose or a single sensor can be used for both purposes. Figure 4 shows such a case that a single sensor is used for both purposes but the systems operation range is different for each case. In this case, system function (physical variable) for comfort management is also used as system function for assessment of safety in

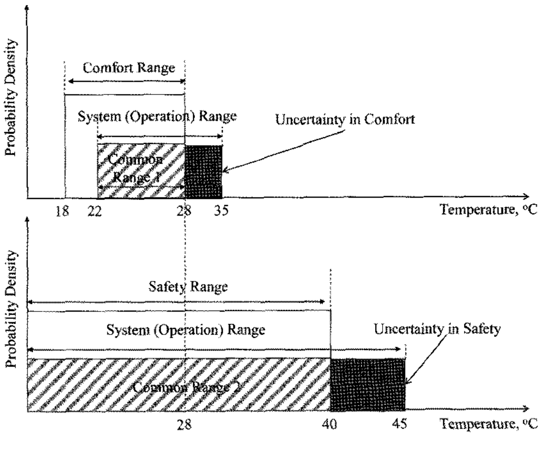

Fig. 4. Probability distribution of a system functions for the case where system function (temperature) for comfort management is used as system function for assessment of safety in fire and the systems operation range is different for each case.

fire and. When a single system parameter is used to monitor comfort of passengers and detect fire in sequence, the uncertainty must be taken into account separately. Temperature, for example, may provide information on both comfort of passengers and fire. The temperature range for comfortable environment in subway station is limited by both lower and upper bounds. If temperature rises beyond the threshold value (or safety range) for detection of fire, 65o C for example, it is an indication of fire and uncertainty increases beyond this value.

5.3 Total uncertainty due to multiple physical variables

If two independent physical variables are used in sequence to detect fire, probability distribution of a system function would be separated accordingly. The total uncertainty in the process is simply the sum of uncertainty associated with each physical variable, provided that each event is probabilistically independent of each other. For two physical variables, the total uncertainty is:

$$E_{total} = log\left(\frac{1}{q(e_1,e_2)}\right) = log\left(\frac{1}{q(e_1)}\right) + log\left(\frac{1}{q(e_1)}\right) = E_1 + E_2 \qquad (5)$$

The indoor air then must be managed in such a way that the total uncertainty in safety in Eq(5) is minimized.

6. Conclusions

A basic framework to assess the indoor air quality in terms of comfort, health and safety of passengers and occupants in subway station was suggested. In particular, application of information-theoretic measure to assessment of indoor air quality (therefore comfort and health) and safety in subway station was discussed. The suggested framework was designed to deal with various physical variables to quantify the uncertainty involved in the indoor air in subway station. Examples show that integration of monitoring data and assessment of IAQ in subway stations is as a whole possible, thus raise the efficiency and the effectiveness of management of indoor air and safety particularly in fire in subway station.

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