INTERNATIONAL JOURNAL OF
ENERGY AND ENVIRONMENT

Volume 1, Issue 4, 2010 pp.697-704
Journal homepage: www.IJEE.IEEFoundation.org

Recommended concentration limits of indoor air pollution indicators for requirement of acceptable indoor air quality

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Abstract
Object and goals of indoor air pollution control with ventilation may influence improvement of indoor air quality, building energy consumption and even carbon emissions. Indicators of indoor air pollution caused by occupants-related sources and building-related sources were chosen based on sources emitting characteristics, pollutants composition, indicator choosing principles and indoor air pollution situation in China. Then the recommended concentration limits of indicators were given for unadapted and adapted persons according to logarithmic index evaluation method, combined with percentage of dissatisfaction and joint effect of indoor air pollution caused by these two kinds of sources.

Keywords: Indoor air quality, Occupant-related sources, Building-related sources, Indicator, Concentration limit.

1. Introduction

Indoor air environment (IEA) is one main exposure for human beings. There exists very close relationship between indoor air quality (IAQ) and occupants comfort and health. For one hand, IAQ, i.e. pleasant or unpleasant odor dominates the psychological reaction of occupants to indoor air environment at some extent, and it may even lead to physical hazard, e.g., there is mounting evidence that exposure to indoor air is the cause of excessive morbidity and mortality [1]. For another hand, indoor air pollution is one kind of low concentration pollution and concentration of most indoor air pollutants generally didn't surpass the limit of related indoor air quality standards [2-3]. Without surpass doesn't mean indoor air has good quality and symptoms of sick building syndrome (e.g., irritation of the eyes, blockened nose and throat, headaches, dizziness, lethargy, fatigue irritation, wheezing, sinus, congestion, dry skin, skin rash, sensory discomfort from odors and nausea et al.) still occur commonly. In fact, exposure to indoor low concentration air pollution chronically may make occupants neurological disorders and immune function weak, which induce kinds of symptoms eventually [4]. Furthermore, the influence process of this pollution is from occupant psychological feeling to subjective reaction and to physical symptoms.
While, how to control indoor low concentration air pollution? Is it necessary to make indoor air pollutants concentration become zero? Of course, it is not. Actually, improve perception and acceptability of indoor air quality is a proper act to control this pollution at present, namely, controlling indoor odor level and making occupant obtain comfortable psychological feeling when exposing to indoor air. Ventilation, that provides outdoor airflow, is one important method to improve IAQ and keep occupant comfortable and healthy [5]. However, how much outdoor airflow is enough for this purpose is one

critical problem, which affects improvement of indoor air quality and building energy consumption [1], especially for high occupant density building space, e.g. theatre, bazaar, library and so on.

Indoor air pollution load and goal of indoor air quality improvement are two important factors determining the requirement of outdoor airflow. In order to obtain the load and establish reasonable goal to meet acceptable indoor air quality requirement, indicators of indoor air pollution caused by occupant-related sources and building-related sources were selected according to sources emitting characteristics, pollutants composition, indicator choosing principles and indoor air pollution situation in China at present and their recommended concentration limits were determined with the joint effect of indoor air pollution caused by these two kinds of sources in actual building room in this study.

2. Composition of pollutants and indicators

2.1 Composition of occupant-related pollutants

Occupant-related sources contain human breath and skin metabolism and the pollutants they produce include inorganic component (e.g. carbon dioxide) and organic component (e.g. acetone, one of human VOCs), the composition of which can be seen in Table 1 [6].

Table 1. Occupant-related sources and their potential pollutants [6]

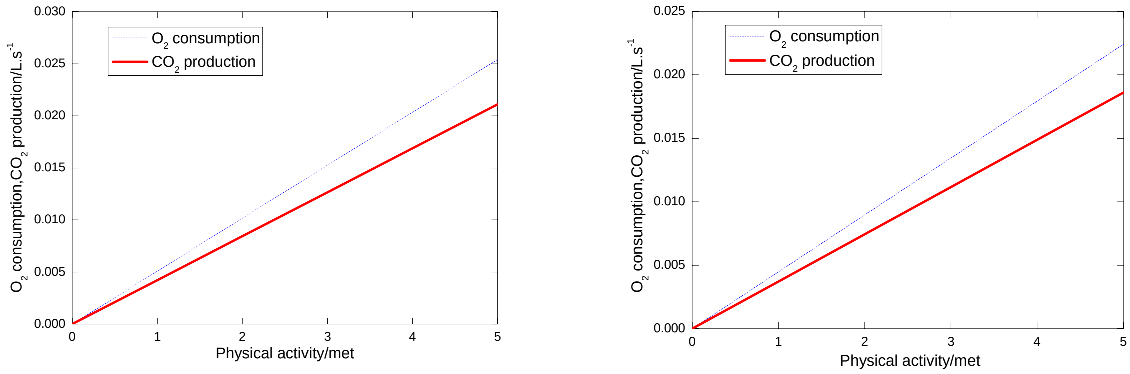
Sources	Inorganic component	Organic component
Human breath	carbon dioxide	isoprene
	moisture	acetone
	ammonia	ethanol
	sulfured hydrogen	acetaldehyde
	carbon monoxide	acetic acid
		allyl alcohol
		amyl alcohol
		butyric acid
		diethylketone
		ethyl acetate
		ethyl alcohol
		methyl alcohol
		phenol
		toluene
Skin metabolism	carbon dioxide	acetone
	ammonia	toluene
	carbon monoxide	methane
	ammonia	

Carbon dioxide and human VOCs are main pollutants released by occupant. The carbon dioxide is one production of human metabolism, emission quantity of which mainly depends on human oxygen consumption [7]. While there is one close relationship among human oxygen consumption, level of physical activity and DuBios surface area. According to Chinese civil physique monitoring bulletin in 2005, average height of Chinese adult males and females are 1.69m and 1.57m respectively, average weight of Chinese adult males and females are 67.23Kg and 56.55Kg respectively, average body surface area of Chinese adult males and females are 1.77m^2 and 1.56m^2 respectively. Therefore, the carbon dioxide emission quantity of Chinese adult males and females can be obtained respectively for different physical activity, seen Figure 1(a b).

Compared to the mechanism of carbon dioxide emission, influencing factors of human VOCs emission are multiple, besides human oxygen consumption, even including human race, diet, personal hygiene and health [6]. Breathing process is one main source of human VOCs and production of human VOCs in breathing process contains that from pulmonary inhale and that from endogenous synthesis. Therefore,

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online)

the production of human VOCs depends on pulmonary inhale rate, endogenous synthesis rate and metabolic discharge rate.



(a) Chinese adult males (b) Chinese adult females

Figure 1. Carbon dioxide emission quantity

2.2 Indicator of indoor air pollution by occupant-related sources

Due to complicated composition of occupant-related pollutants, it's necessary to choose one or more indicators for determination of outdoor airflow to improve indoor air quality at present. However, how to choose reasonable indicators? There are some guidelines for indicators choosing [8], including that indicators should reflect level and characteristics of indoor air pollution effectively, produce a prompt response to the variation of sources emission intensity and provide proper guidelines for the determination of outdoor airflow rates and ventilation strategy. Of course, simple and inexpensive to measure is necessary.

It can be seen from the emission mechanisms of carbon dioxide and human VOCs that there exists difference in the degree of accordance with the indicator guidelines for them. First, it's very difficult to quantify the emission of human VOCs accurately at present, which makes it not accord with the basic condition as one indicator. While carbon dioxide may reflect the variation of sources emission intensity (occupants quantity) promptly, quantification of which is feasible and reliable, although it's not harmful at indoor usual concentration level. Therefore, carbon dioxide can be used as one effective indicator for indoor air pollution caused by occupants.

2.3 Composition of building-related pollutants

Building-related sources contain building materials, decoration materials and furnishing and so on, the potential pollutants of each source were given in Table 2.

Table 2. Building-related sources and their potential pollutants[9]

Sources	Potential pollutants
Shell and façade construction	Asbestos may be found in cement roofing, shingles and siding.
Concrete	Concrete sub flooring in a finished building may be uneven and require applications of floor leveler before the interior floor material is applied. These products may contain odorous chemicals such as phenol and phenoxyethanol. In other cases, floor sealants were placed directly on the concrete, either as finish paint or as a moisture seal. These sealants typically have very high VOC emissions. Though concrete is usually one of the best materials for people who are chemically sensitive, occasionally chemicals such as fungicides, germicides and insecticides are added, which could possibly off gas into the building.

ISSN 2076-2895 (Print), ISSN 2076-2909 (Online)

Wallboard or drywall	These materials can contain formaldehyde and other aldehydes. They also can be the source of odors. These materials are very adsorptive and can collect chemical odors and fumes from other sources such as paints and adhesives.
Insulation	Formaldehyde may be found in foam and fiberglass insulation. Fibers, including fiberglass or asbestos, also may be found in insulation.
PVC	Polyvinyl chloride is by far the most common plastic used in construction. In 1992, 6.3 billion pounds of this resin were used. Polyvinyl chloride also is commonly used in flooring.
Paneling	Aldehydes, such as formaldehyde, may be found in decorative paneling made of pressed wood products. The manufacturing of plastic paneling typically results in solvents being trapped in the plastic. In addition, heptachlor, a pesticide added to prevent mold growth, has been detected in these materials
Wood	Formaldehyde may be found in some plywood and particleboards.
Paints, coatings, sealants, adhesives	These are used to bond, seal, coat or finish building materials and may be significant sources of VOCs, solvents and odors.
Roofing	Flat roofs require applications of asphalt and tar that contain VOCs and are a significant source of odors. Some membrane roofing systems used on shopping malls and commercial office buildings can off gas formaldehyde, VOCs, ammonia and amines. Emissions from these materials can infiltrate the building through open crack and crevices.

2.4 Indicator of indoor air pollution by building-related sources

According to large numbers of surveys and tests, formaldehyde (HCHO) is widely found in building-related sources in China, e.g. decoration material, bond, finishing material and so on [10]. For another thing, it appears frequently in building room and its sources release slowly, which has long influence. Moreover, the stimulation and toxicity of HCHO are strong and it’s very easy and cheap to detect. All of those make HCHO be suitable for reflecting and evaluating indoor air pollution caused by building-related sources as an indicator in China, although total of all volatile organic compounds (TVOC) has been accepted as an evaluation index in some other countries.

3 Recommended concentration limits of indicators

3.1 Evaluation method

Concentration limits of indicators may determine the goal of indoor air quality improvement and influence the requirement of outdoor airflow. However, the existing environment standards mainly consider about the objective relationship between indicators concentration and human physiological health, but little about human psychological sensations (percentage of dissatisfaction, PD). As a result, although the indicators concentration conforms to the standards, the PD is still very high. Therefore, it’s very meaningful to improve acceptable level of indoor air quality by considering human psychological sensations and establishing reasonable indicators concentration limits. For another hand, there exists joint effect of indoor air pollution caused by occupant-related sources and building-related sources in actual building room. With superposition impact (e.g. agonism) [11], the joint effect should be considered for determination of indicators concentration limits.

The relationship between human response and indicators concentration can be established with logarithmic index evaluation method. According to Weber-Fechner law, that response is proportionate to the logarithm of stimulus, the following equations can be obtained [10, 12].

$$I_{\mathrm{CO_2}} = 90 \log \frac{C_{\mathrm{CO_2}}}{485} \quad (1)$$

$$I_{\mathrm{HCHO}} = 67\log\frac{C_{\mathrm{HCHO}}}{50} \tag{2}$$

As far as human psychological sensation is concerned, the joint effect of indoor air pollution caused by these two kinds of sources can be seen as one superposition relationship. Berglund B., Berglund U. [13] and Mats JO [14] reported that odor pollutants mixtures that are homogeneous may be modeled as vector addition for the joint effect. That’s to say, the comprehensive logarithmic index can be acquired according to the following method.

$$I = \sqrt{I_{\mathrm{CO_2}}^2 + I_{\mathrm{HCHO}}^2 + 2I_{\mathrm{CO_2}} I_{\mathrm{HCHO}} \cos\alpha} \tag{3}$$

where α is the interaction constant of these two kinds of sources. When α is zero, the joint effect becomes maximum additive relationship, which is accepted in many researches and standards (e.g. ASHRAE standard 62.1).

For another thing, the relationship between human psychological sensation (PD) and comprehensive logarithmic index can be seen as one linear relationship, according to large numbers of subjective and objective tests. Therefore, the following equations can be established for unadapted persons and adapted persons respectively [11].

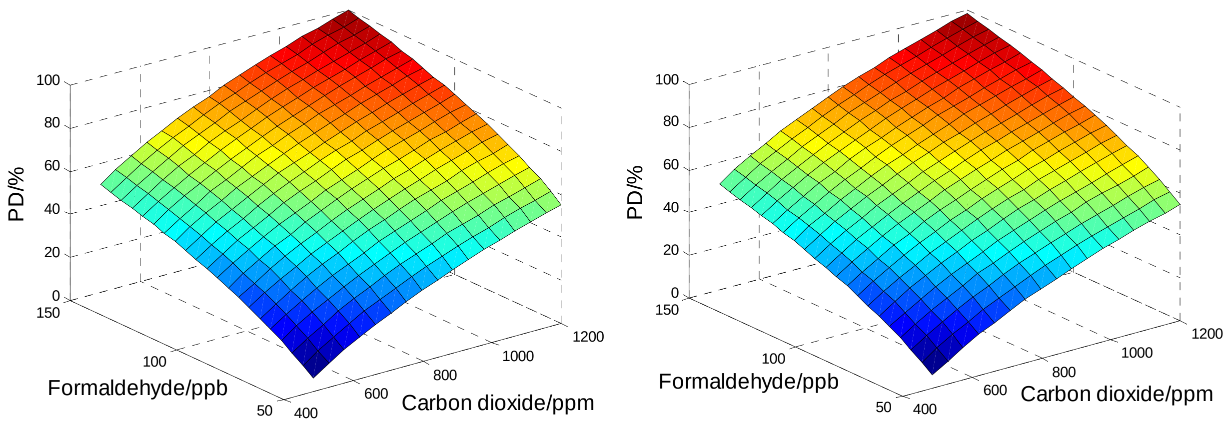
Unadapted persons $$PD = 1.39I + 5.98 \tag{4}$$

Adapted persons $$PD = 1.37I + 5.98 \tag{5}$$

3.2 Results and discussion

For different additive relationship, including maximum adding (α=0), moderate adding (α=45º) and minimum adding (α=90º), the recommended indicators (carbon dioxide) concentration limits can be obtained according to equations (1) ~ (5), seen Figure 2(a b), Figure 3(a b) and Figure 4(a b).

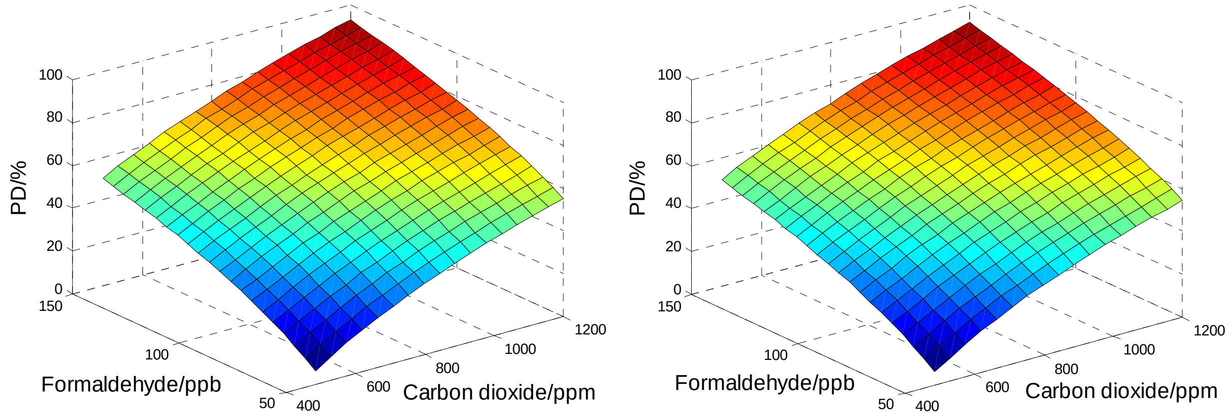
It can be found from Figure 2(a b), Figure 3(a b) and Figure 4(a b) that the recommended concentration limits of carbon dioxide and formaldehyde are less than those in Indoor Air Quality Standard of China, when PD=20%. Moreover, rise of formaldehyde or carbon dioxide concentration may make the recommended concentration limit of carbon dioxide or formaldehyde decrease accordingly, as a result of the joint effect.



(a) unadapted persons

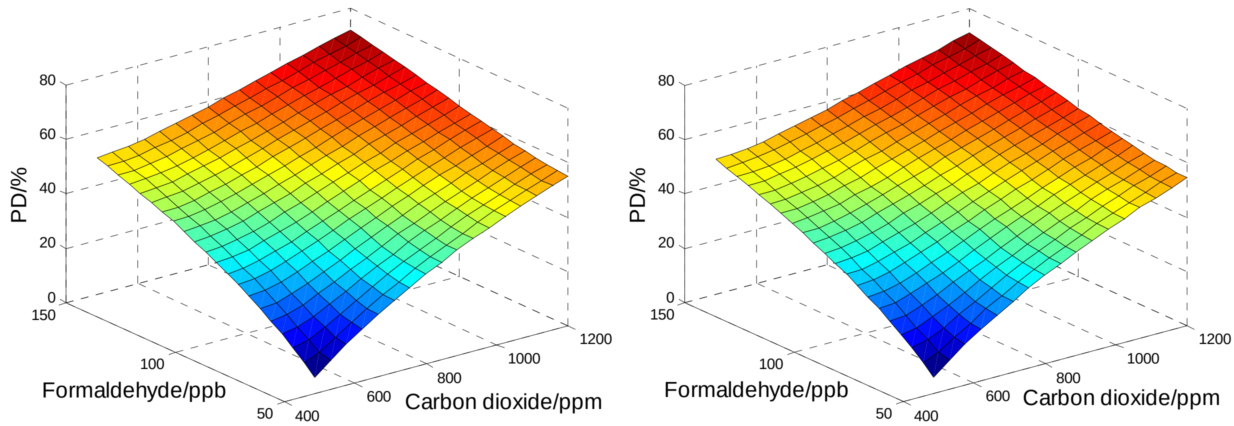
(b) adapted persons

Figure 2. Maximum adding



(a) unadapted persons (b) adapted persons

Figure 3. Moderate adding



(a) unadapted persons (b) adapted persons

Figure 4. Minimum adding

Secondly, there exists difference between the recommended concentration limits of carbon dioxide and formaldehyde for unadapted persons and those for adapted persons. When PD=20% and formaldehyde concentration is 55 ppb for the same additive relationship, the difference for carbon dioxide recommended concentration limit is about 0.4%. While PD=20% and carbon dioxide concentration is 620 ppm for the same additive relationship, the difference for formaldehyde recommended concentration limit is about 0.5%. Moreover, the difference may become more obvious when formaldehyde or carbon dioxide concentration increases for the same additive relationship, when PD=20%. For another hand, the difference may rise when additive relationship varies from maximum adding to minimum adding for the same formaldehyde or carbon dioxide concentration, when PD=20%.

Thirdly, when PD=20% and formaldehyde concentration is 55 ppb, the difference between recommended concentration limit of carbon dioxide for maximum adding and that for moderate adding is about 1.5%, while it may reach to 6.2% between that for maximum adding and that for minimum adding. While PD=20% and carbon dioxide concentration is 620 ppm, the difference between recommended concentration limit of formaldehyde for maximum adding and that for moderate adding is about 0.6%, while it may reach to 13.2% between that for maximum adding and that for minimum adding. Moreover, the difference may be more apparent between different adding when formaldehyde or carbon dioxide concentration rises.

4. Conclusion

Indicators of indoor air pollution caused by occupant-related sources and building-related sources have been chosen based on sources emitting characteristics, pollutants composition, indicator choosing principles and indoor air pollution situation in China at present. With the joint effect of indoor air pollution caused by these two kinds of sources, the recommended concentration limits of indicators have been obtained according to logarithmic index evaluation method, the results are very useful for determination of outdoor airflow to meet requirement of acceptable indoor air quality.

Acknowledgements

This study is supported by National Science Foundation of China (project No. 50908163). The authors would like to acknowledge Mr. K.S. Li and Institute of HVAC&GAS Engineering for their kind assistance in this research.

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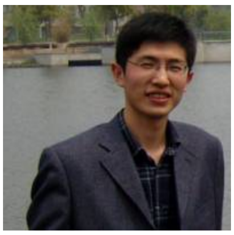

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