Total Volatile Organic Compound (TVOC) as Index of Indoor Air Quality and Its Measuring and Evaluation

Masahiro Hori

General foundation, Japan Dust-Control Association, 1-9-13 Akasaka, Minatoku, Tokyo 107-0052
TEL/FAX: 03-6802-8691/8692, E-mail: horim@pka.biglobe.ne.jp

(received on 20th July, 2019, accepted on 22nd November, 2019)

Abstract

This review describes the definition of TVOC, measuring method, biological influence, standard value, effect and the defect, significance of existence and how to use it. The process for which TVOC has been used as an indoor environment quality index is also explained. TVOC was proposed as an index which showed the possibility of the pollution influence. It was also proposed as the overall, simple notation of VOCs of which many kinds existed in the indoor air. TVOC has been used in a lot of the research. However, the defect as the index that showed the contaminated level was pointed out by existence of small amount stimulus ingredients missed by a present VOC/TVOC measuring method. TVOC can’t be a toxic academic index essentially. On the other hand, because a lot of VOCs coexists, to which the standard value is not set yet, TVOC has the practical meaning as an environmental protection index to achieve the decrease of the VOC risk through the monitoring of VOC concentration and the evaluation of source such as construction materials.

Keywords: Air quality, Index, TVOC, Measuring

1. Introduction

Total volatile organic compound “T (Total) VOC” has come to be used as a pollution index of volatile organic compounds (VOC) that has become a focus of attention as indoor environment becomes a problem. TVOC has been proposed as a comprehensive shorthand notation for VOCs that can be easily detected in several tens or more types, but there is a lot of criticism in relation to sick house symptoms, and the validity of the guideline value (index) itself is also questioned. The practicality of the on-site measurement method is also a problem. In this review, it is gathered up about the definition of TVOC, the measuring method, effects and defect, and guidelines values. In addition, there is the usage of TVOC, TVOC concentration level and characteristics, the history of TVOC and various problems that we still have, such as what to measure instead of TVOC, and how to handle VOCs with low toxicity.

2. Definition of VOC and TVOC

Contaminants that may be present in the indoor air are classified into carbon dioxide, nitrogen oxides, inorganic gases such as ozone, dust and organic compounds containing suspended microorganisms. The organic compounds are classified into gas of low-boiling substance groups that always exist in gaseous state such as methane, fluorocarbons, mercaptans and amines and vapor groups such as organic solvents, and the latter can be further classified as volatile organic substances. Many kinds of VOC are often expressed as VOCs, because they are so many types of compounds as compared to inorganic gases and dust. The total amount of such VOCs is TVOC. Examples of VOCs detected in Japan include compounds as shown in Table 1 (Ministry of Health, Labor and Welfare: MHLW 2000) (JIS 2005) (Arashitani 2009). WHO (WHO 1989) classifies organic pollutants by boiling point (Table 1), but the boiling point range is from 50 to 100°C to 240 to 260°C (vapor pressure: 10 to 10^{-2} kPa). Although there is no meaning in the strict classification, and it may be for convenience, the reason that it was deliberately designated as VOC is because VOC with a boiling point of 50°C or less in the indoor environment is highly volatile, and the boiling point is high and the
vapor pressure is high. It is considered that SVOC ($10^{-2}$ to $10^{-8}$ kPa), which has high boiling point and extremely low vapor pressure, has low volatility and a low quantitative contribution to TVOC. The criteria of the Architectural Institute of Japan in 2010 (AIJ 2010) follows that of WHO.

In order to know the concentration of individual VOCs, they are collected by adsorption and analyzed by gas chromatography, and the results (chromatograms) are used to characterize and quantify VOCs (Maroni et al. 1995a, US EPA 1984). It is impossible to identify 250 to 900 kinds of the VOCs (USEPA 1984) by ordinary measurement, and it is too complicated to describe all the components even if possible, so it was proposed as a simplified title method using the sum of VOCs (Molhave, 1996). In addition, since this shows an overall image of VOCs that cannot be shown in the representation of only some of the major VOCs, TVOC can be said to be a comprehensive notation. The interpretation of TVOC varies from the measurement method or the analysis method at the time of qualitative determination. The first report on this in Japan is the “Report of the Sick House Problem Study Group of MHLW (MHLW 2000), but here it is based on the concept of the TVOC decision procedure of the European Commission Joint Research Center (ECJRC 1997). The abstract defines the individual compounds that make up the TVOC, and should be constructed in a way that is as close as possible to the total VOC concentration and that will be useful for assessing air quality, specifically as many compounds as possible were identified (at least the top 10 substances), and the total unidentified VOC was converted to toluene, and the sum of the identified substances and the sum was used as TVOC. It is recommended that what is identified be 2/3 or more of the whole (1 mg/m$^3$ or less at 1/2), and it is also required to clarify the VOC list to be included in the TVOC calculation and compounds representative of each chemical classification. In addition, when you look at the progress after that, although the analysis above this level was conducted in the research referred in this review, at many sites, only the 6 VOCs for which the guideline value was set by the study meeting, the TVOC measurement values could not be obtained or were made public.

In ISO 16000-6 (2011), the total of VOCs from n-hexane to hexadecane (having 6 to 16 carbon atoms) is regarded as TVOC on the chromatogram (however, VOCs outside this range that cannot be ignored can also be considered). Further, in the chamber test method (JIS 2009) of JIS, the one in which the whole range of VOC in the same range is converted to toluene is referred to as TVOC. Although the definition of the Building Society standards conforms to WHO, the operation adopts toluene conversion with emphasis on simplicity rather than accuracy in view of the fact that TVOC is not a toxicological standard value but a concentration management target (AIJ2010).

### 3. Measuring method

VOC is usually expressed as weight concentration ($\mu$g/m$^3$, mg/m$^3$) and TVOC as its sum. Although the definition by boiling point was described above, it is necessary to clarify the relationship with the measuring method because the TVOC value can be known only by chemical measurement. The TVOC measuring method

| Classification by functional group   | Main compounds *                                               |
|--------------------------------------|----------------------------------------------------------------|
| Aromatics                            | Benzene, toluene, xylene, ethyl benzene, trimethyl-benzene and styrene |
| Chain-hydrocarbons                   | Hexane, Nonane, Decane, trdecan, tetradecane, dimethylpentane   |
| Cycloalkanes                         | Cyclopentan, Cyclohexane                                        |
| terpene                              | Pinen, Limonen                                                  |
| Alcohol                              | Ethanol, 1-butanol.                                             |
| Glycol /glycol ether                 | Methoxyethanol, butoxyethanol                                   |
| Aldehyde                             | Pelargonic aldehyde, Decanal,                                   |
| Ketone                               | Acetone, Methyl ethyl ketone,                                   |
| Halogenated hydrocarbon              | Chloroform,1,1,1-trichloroethane, trichloroethylene, p-dichlorobenzene |
| Ester                                | Ester ethyl acetate, butyl acetate                              |
| Other                                | 2-benchel frane                                                |

*An isomer is transcribed together.*
is roughly divided into a method of collection/gas chromatography analysis and a simple method of which results are obtained at the place. (Hori, 2001) (Fujii, 2000). Sampling is important in order to obtain statistical representative values in environmental measurement (Koshi, 1976) (Hori 2006). The method is adopted in various standards including sampling after 5 hours by closing the window also for VOC / TVOC (ISO 2007) (JIS 2005).

3.1. Gas chromatography method

The concentration of VOC was often less than 1 mg/m\(^3\) in indoor environment (Hori 2001), so sample air is sucked with pump through a porous polymer (Tenax, Carbotrap, Carbocieve) (JIS 2005a) (Maroni et al., 1995b) or activated carbon (JIS 2005), and VOC in the air is collected. Passive samplers are not used unless most VOCs are identified and their uptake rates are known (AIJ 2010). VOC is separated with thermodesorption or solvent extraction from the adsorbents was injected into a gas chromatography, and determined by its chromatogram. The sum of quantity of VOC is TVOC.

The value of VOC may be affected by three factors in addition to the identification rate of VOC (the percentage of the peak area of VOC identified to the whole peak area in chromatogram): The ability in collection-retention of an adsorbent (JIS A 2007), abstraction ability of a solvent (BMTC 2006) (JIS 2005b), characteristics of detector in gas chromatograph (Hori, 2001) (MHLW 2000b). When high concentration VOCs are identified, the identification rate becomes high. The identification rate in a resident environmental research of the Ministry of Health Labour and Welfare (46 ingredients of standard substance) was about 50%. It became 80% or more using 70 standard substances in the subsequent survey (Jinno 2006). The sampling operation of activated carbon is easier to use than that of Tenax (Hori 2001), but it’s certain VOC is less than 90% in the abstraction rate (BMTC 2006) and the recovery may be lower than that of Tenax (Zorn, 2008).

A mass spectrometer (the whole ion current) and FID (hydrogen flame ionization detector) are often used as a detector, but the sensitivity (the ion current value per the unit concentration) is different depending on the kinds of VOC.

When the rate of unidentified VOC is high in mass spectrometer or VOC is converted in toluene, the difference of the TVOC with TVOC where much of VOC was identified becomes high in the sample that has a lot of VOC different from toluene in the sensitivity (Interim Report 2001). On the other hand, the precise is more than mass spectrometer in FID where the sensitivity is proportional to the number of carbon of VOC mostly (Hori, 2001). A TVOC monitor with an adhesion column and FID is used. The column separates VOC from VVOC of the methane (about 1.3 mg/m\(^3\)) and the butane with which coexists in the atmosphere (Fujii 2000).

3.2. Simple method

The simple method is a method in which the TVOC value is directly indicated, and can be measured quickly and easily in the field, so it is also called a field measurement method. The main detection principles in practical use and their features are shown in Table 2. Although the sensitivity characteristics for VOCs differ depending on the detection principle, they are relative concentration meters because they differ considerably depending on the same principle and the type of VOC.

In recent years, small and light-weight PID and semiconductor methods are mainly used as TVOC meters, and toluene is usually used as a standard gas (Hori, 2001). Among them, only FID has low sensitivity in direct measurement (Hori, 1999), but it can be applied to on-site measurement by heating and desorbing the one that has been adsorbed and concentrated by Matsumura et al. (Kawaguchi 2008).

On the other hand, the composition ratio (not concentration) of VOCs in the indoor environment always differs depending on the specifications, time elapsed after construction, usage after entering (such as bringing in furniture), and the simple method differs in sensitivity depending on the type of VOC. In principle, it cannot be used to measure the absolute concentration (mg/m\(^3\)) even if it is converted to toluene unless this

| Classification of VOC | Boiling point | Examples |
|-----------------------|--------------|----------|
| High Volatile (VVOC)  | Less than 50-100°C | Mercaptan, Butane |
| Volatile (VOC)        | 50-100°C ~ 240-260°C | Toluene, Decane |
| Semi-volatile (SVOC)  | 240-260°C ~ 380-400°C | Ethyl-phthalate, Organophosphorus compound |
| Particulate (POM)     | More than 380°C | Tar, SVOC adsorbed on Particulates |
“composition ratio is similar” (Hori, 2001). The conversion factor is the ratio of TVOC by the indicated value of the simple method to it by gas chromatography analysis, but in an environment that satisfies conditions such as time-lapse changes at different times within the same building, a good correlation can be seen between the both method (Noguchi 2011). Although the example which calculated required the conversion factor in some real environment was shown in Table 4, it may not correspond also in new construction. Therefore, in the case of using the simple method, it is necessary to use a conversion factor obtained by performing parallel

| Detection principle | Feature |
|---------------------|---------|
| Photo-ionization (PID) | Ion electric currents of VOC ionized by ultraviolet rays is measured. Its undergo influence of the humidity, but a hydrogen source is unnecessary. |
| Semiconductor | The increment of the metal oxide surface current by contact of reductive VOC is measured. The output is revised for straight line in calibration and its undergo influence of the humidity. |
| Photoacoustic (PAS) | A molecule quiver of VOC which absorbed infrared rays is measured. |
| Hydrogen flame ionization (PID) | CH ion electric current in hydrogen flame is measured. The output has mass proportion and doesn't undergo influence of the humidity, but a hydrogen source is necessary. Combination with concentration is needed because of low sensitivity. |

### Table 3 The detection principle used for TVOC simple measuring method (Hori 1999)

| Name | Maker | Detection principle | Indication | Example of conversion factor | References |
|------|-------|---------------------|------------|------------------------------|------------|
| TVOC meter | N | Semiconductor with filaments | Relative | 8 in average | Soda 2003 |
| TVOC monitor | F | Semiconductor with WO₃ | Toluene conversion | 0.48-0.62, 0.55 in average* | Kawaguchi 2008b |
| Multi-gas monitor | I | PAS | Methane conversion | 0.45 | Soda 2003 |
| Odor sensor | N | Semiconductor with filaments | Toluene conversion | 1.05 in average ** | Yamaguchi 2006 |
| TVOC monitor | R | PID | Toluene conversion | 0.49-2.1*** 1.0 in average | Noguchi 2011 Takagami 2006 |

1) The target house is a new house (immediately after completion) except TVOC monitor
2) The conversion factor: B/A is obtained by performing each monitor (A) in parallel with gas chromatography analysis sample (B), the number of samples is different .
3) The background value (the reading of the monitor for clean air differs according to the principle) is corrected.

* Several dozens % of para-dichlorobenzene in residential rooms,
** Concentration 500 μg/m³ or more: 0.84-0.98, 0.91 in average ; 500 μg/m³ or less: 1.04-1.5, 1.31 in average
*** Including new and used houses, laboratory, new nursery school
measurement with TVOC obtained by gas chromatography for similar environmental air (AIJJb 2010).

In recent years, there have been many studies on the practicality of high sensitivity PIDs (Nozaki, 2002). In Singapore, TVOC is measured by PID in which toluene is used as a standard substance (see Table 6). However, since the influence of humidity is also large in addition to the sensitivity difference between VOCs, the difference with the TVOC determined by Tenax-gas chromatography is large (Dong 2005) (Kim 2009). The semiconductor method is advantageous for TVOC compared with other principles, and the sensitivity is also high, so it has been previously studied as an indoor air quality monitor (Hori 1990) (Kawaguchi 2005) (Kuze 2004) (Yamaguchi 2006), and a ventilation system (Yokoyama 2009) (Yanagisawa 2010) has been in practical use. Systems that combine semiconductor sensors and separation columns have been developed to address the large sensitivity difference between VOCs and the large influence of humidity. On the other hand, research and development of TVOC meters aiming at overcoming these two drawbacks are also being conducted (Yanagisawa 2010).

4. Human effects and reference values

Molhave et al. indicated the quantity-effect relationship (Table 5) as a hypothesis from the literature values on the health effects of air quality toxicity (Molhave 1996). Multifactorial exposure levels mean discomfort under certain conditions, and a gas chromatograph with FID is recommended for measurement of TVOC. On the other hand, Seifert determined the

| Concentration          | Effect                        |
|------------------------|-------------------------------|
| 200 µg/m³ or less      | Comfort level                 |
| 0.2~3mg/m³             | Multifactorial exposure level |
| 3~25mg/m³              | Discomfort level              |
| 25mg/m³ or more        | Toxicity level                |

Table 5 Hypothetical quantities of TVOC-effect relationships (Molhave 1996b)

| Country                  | Source                                      | Concentration          | Effect                                      |
|--------------------------|---------------------------------------------|------------------------|---------------------------------------------|
| Germany                  | Federal Environment Agency 1999             | 10000~25000 µg/m³      | (Temporary at the time of renovation)       |
|                          |                                             | 1000~3000 µg/m³        | (Long-term residence)                       |
|                          |                                             | 200~300 µg/m³          | (Maximum long-term average goal)            |
| Finland                  | Indoor Air Quality Climate Society 2001    | S1 : 200 µg/m³         | (Best air quality*)                         |
|                          |                                             | S2 : 300 µg/m³         | (Good air quality)                          |
|                          |                                             | S3 : 600 µg/m³         | (Satisfied air quality)                     |
| Norway                   | Ministry of Health and Welfare 1999        | Avoid unnecessary exposure|
| UK                      | Ministry of Health 2004                    | If a value of 1mg/m³ or more and symptoms of sensation or irritation are reported, conduct surveys and measures for contamination |
| Australia                | National Health and Medical Research Council 1993 | 500 µg/m³ (Average exposure time: 1 hour) |
| Singapore                | Ministry of the Environment 1996           | 3ppm (Measurement by PID, Reference: toluene) |
| China                    | Hong Kong Special Administrative Region 2003 | Best : 200 µg/m³ (Mean exposure time: 8h) |
|                          |                                            | Good : 600 µg/m³ (Mean exposure time: 8h) |
|                          | Directorate General of Environmental Health 2002 | 600 µg/m³ (Average in exposure time) |
| Korea                    | Environment Department 2003                | 500 µg/m³ (Large scale store etc.) |
|                          |                                            | 4000 µg/m³ (Medical institutions etc) |
|                          |                                            | 1000 µg/m³ (Indoor parking) |

* A concentration that meets the needs of residents who suffer from allergies or respiratory diseases.
average value of TVOC from the actual condition survey in Germany (Seifert 1990), and proposed a guideline value of 300 \( \mu g/m^3 \) as a reasonably achievable level. In addition, the provisional target value 400 \( \mu g/m^3 \) of the Japanese Ministry of Health, Labor and Welfare Sick House Study Group is also based on this German method. Later in Germany, two categories according to the required level (RW2: Concentrations related to health effects based on existing toxicology and epidemiological findings, concentrations that would be harmful to susceptible residents living for a long time and we should take countermeasure action immediately. RW1: There is no scientific basis to have health effects even after prolonged exposure, but if this concentration is exceeded it may go above the average exposure concentration which is undesirable for health. Therefore, we should aim to clear this value if possible), and guidelines were proposed for some VOCs (Schleibinger 2003).

As for TVOC, in view of gradually decreasing characteristics (Maroni and Axcelrad, 1995) double levels of guideline values (Table 6) are set according to the time course after completion. Also they individually have 1.5 to 3 times the width, judging from the fact that it is not a toxicological standard (described later) etc., the definition and the measurement method of TVOC is a very reasonable indication. On the other hand, in Japan, Japan's Building Science Association strove to be below 400 \( \mu g/m^3 \) at any stage. In addition, to TVOC, Seifert’s proposal was also evaluated according to different chemical classifications (aliphatic hydrocarbons, aromatic hydrocarbons, terpenes, halogenated hydrocarbons, esters, aldehydes / ketones (except formaldehyde) and other alcohols) (Seifert 1990). In addition to TVOC, the chemical classification of the compound of interest should also be described (Schleibinger 2003). Ikeda et al. investigated the concept and prehistory of regulation in each country and ritual, including TVOC (Ikeda 2005), and found out in the review by Higashi, (Higashi 2005) The guideline values for TVOC in each country shown in Table 6 are extracted from this review.

Narita determined the severity of the symptoms per unit concentration (ppm) (The clinical data of the severity was scored using the worldwide common diagnostic chart (QUEESI) to diagnose the chemical sensitivity) Mucosal symptoms are described as toluene 53 (QUEESI / ppm), formaldehyde 67 and mental symptoms 72 and 57, respectively, which are slightly higher than that of toluene (Narita 2005). However, toluene is only part of the TVOC. On the other hand, according to Kishi et al. (Nishijima 2002), the relative risk that the symptoms increase when the TVOC is 10 times: The odds ratio is as follows (when the number of toluene is 10 times in parentheses). Skin 7.2 (2.2), eyes 11 (3.0), any 5.4 (2.0). When TVOC is high, the possibility that IAQ becomes low so that Molhave may be also pointed out (Molhave, 1996). The following epidemiological investigation of Norback (Norback 1990) et al. in 11 buildings is one such example. The number of people with symptoms increased in proportion to TVOC, and the correlation with TVOC was higher than that of individual chemicals. Higher TVOC increases the possibility of lower IAQ. However, according to this result, it was also reported that at high concentrations, the appearance of symptom was half or less, and at 0.1 mg/ m\(^3\) or below, there were onsets. It should be noted that there is a similar report (Gomes, 2007) of Gomes et al. Furthermore, in Japan, there was a good correlation between VOC and odor intensity in the report (Gomes, 2007) of the National Life Center, which examined VOCs containing formaldehyde generated from bedding.

5. The limit of TVOC

TVOC was originally proposed by Molhave (Molhave 1996) and then by the working group in Europe (ECJRC 1997), but there are few critics of TVOC such as Wolkoff, Anderson (Andersson 1997),, Moschandraes. They say that there is no causal relationship between TVOC and health effects, especially the presence of airway irritation (NLC 2008), (Moschandraes 2004). Becher et al. (Becher 2000) also find that the relationship between VOC exposure and health effects is sparse and inconsistent. The reason is that the TVOC measures only a part of organic compounds although there are odorous components that control indoor air quality and minor unidentified components of irritation (Wolkoff 2001). The following are the problems of measurement methods.

(i) In Tenax collection, intermediate reaction products of aldehydes / percacids such as reaction products (Wolkoff, 2000) and ozone / nitrogen dioxide and unsaturated hydrocarbons such as terpenes (Weschler, 1997), cannot be measured (Weschler, 2000). Unsaturated VOCs can react with ozone coexisting on the Tenax surface (Calogirou 1996) and be underestimated (Singhvi, 1993).

(ii) Odorous substances are often too low to quantify. For example, phenylcyclohexane (0.1 to 0.92 ppb, odor threshold: 0.5 ppb or less) (Kishi, 2009) odor derived from mold (MVOC) such as 1-hexanol 0.69 \( \mu g/m^3 \) (Shibata, et al 2009).

In addition to this, there is a possibility that no compound that affects the living body has been detected yet, and Wolkoff mentions the following substances as organic compounds that may affect indoor air quality (Wolkoff 2001). Acetic anhydride, acrylic acid, amines including t-ammonium. Reaction products of
isocyanates, alkylbenzenes, quinones, phenols, insecticides, mercaptans, mercaptans, dimethylsulfur, terpenes, styrenes, isoprenes and oxidizing substances such as ozone / nitrogen dioxide, non-volatiles such as surfactants alkylbenzenesulphonic acids Substances adsorbed on particles, 2-ethyl-1-hexanol which generated by the reaction between the concrete floor and the plasticizer diethylhexyl phthalate is picked up in Japan.

Wolkoff proposes a comprehensive evaluation of IAQ including SVOC, ozone, nitrogen dioxide, dust, suspended microorganisms etc. instead of TVOC (Tanabe 2006), but it is too complicated to be accepted (Becher 2000). The odorous substances mentioned earlier (low concentration gases with odor threshold close to ppb) dominate the perceived air quality and their psychological impact is large (Wolkoff 2001). The United States Environmental Protection Agency (EPA) also reports that one third of the 4,000 staff members have been particularly sensitive to one or more substances in room air (Becher, 2000). Perceived air quality was taken up from 1990 to 2000 in Japan as opposed to TVOC (Iwasita, 1990) (Kojima 1999). By the way, TVOC is a simple sum of compounds with different molecular weights, but the chemical action is not necessarily proportional to the molecular weight (weight per molecule, up to 3 times difference between VOCs). The expression accuracy of TVOC is low.

The fact that TVOC is not a toxicological standard is emphasized in the guidelines of the Ministry of Health, Labor and Welfare, and also in the Building Society Standard. The weighting between VOCs with different toxicities can be determined by adding (Σ VOCn / Tn) that the synergy can be ignored and each VOCn divided by each reference value (permissible concentration) Tn when the additive property is established (It is good if this value is 1 or less) (AIHA 2009). However, it is not applicable to indoor environment with many VOCs for which the standard value (for example, the guideline value of the Ministry of Health, Labor and Welfare) is not set. Tanabe states the following things: a reasonable re-examination of the TVOC provisional target value of 400 μg/m³ should be made based on interviews at international conferences on indoor environment in Beijing, results of domestic surveys and usage (Tanabe 2006).

6. Utility and usage of TVOC

In many indoor environmental research reports and research papers, TVOC has been used in Japan and the other countries as an indicator that indicates the characteristics of VOC as well as suspended dust and pollutants such as formaldehyde and NO₂ (Arashitani, 2009) (Yoshida 2006) (BMAC 1997) (HHRG 1998) (BRI 1998) (Sowa 2002) (Hougeiri 2009). The TVOC as a management target for the entire VOC was in line with Molhave’s intention that the TVOC is a potential indicator, and the figure of 400 helped to handle complaints. However, on the other hand, it cannot be denied that the figure exceeded the scope of its application and was also used for hazard assessment (Tanabe 2006).

There are countries that do not adopt TVOC (Denmark and the United States) (see Table 6) and countries that were initially adopted but discontinued (Norway), but they are used as guideline values in several countries. In Japan, it is a provisional management target value in the guidelines of the Ministry of Health, Labor and Welfare, and it is as follows in the building environment standard. If this is exceeded, it is recommended that the client be advised of precise measurement and that special measures such as ventilation be taken before entering the house, and the contractor shall clarify the high concentration component and utilize it in the measure.

Chemical substances other than 13 substances (6 VOCs, 6 substances, benzene, trichloroethane, trichloroethylene regulated by air pollution) in the guidelines of the study group on sick house (indoor air pollution) problem of MHLW are used as their substitute substances, and it is increasing. Under such circumstances, the TVOC criteria as a rough indicator, aside from the relevance of 400 μg/m³ is meaningful for risk reduction (Yanagisawa 2010). Since α-pinene that reacts with ozone pointed out by Wolkoff et al. who criticizes the evaluation by TVOC is also a part of TVOC, lowering TVOC where α-pinene is one of the main components should lead to risk reduction. In Japan, some public comments etc. strongly demand the introduction of TVOC.

As mentioned in the simple measurement method, TVOC is easy to apply if the composition ratio of VOC is similar, and TVOC monitor can also be used. TVOC has also been incorporated into the labeling of building materials in Germany as a measure against sources (AgBB 2008) (Klaus 2009) and incorporated into the Japanese Industrial Standard: JIS A 1901 Small Chamber Method (JIS 2009), etc., contributing to the progress of building materials and construction agents. The TVOC monitor (simple method) can also be used to compare regions of indoor sources (Wolkoff 2001). However, the same problem remains with materials and portions having different VOC composition ratios (for example, a decorative board and an adhesive), so in the case of material testing, the TVOC evaluation criteria for each material (monitor and designation of standard substance) are required. On the other hand, high accuracy cannot be expected if the parts have different composition ratios even in the comparison by parts.

TVOC concentration levels and aging changes: The TVOC concentration levels of new buildings in Japan have dropped considerably since the 2000s. For
example, in the 1990s, when indoor environmental problems began to become noticeable in Japan, the TVOC of the apartment complex by RC method in the era of not reducing VOC was 300 mg/m³ immediately after completion, 30 mg/m³ after one month (natural ventilation only) (Kumagai 2001). On the other hand, TVOC in recent years for which measures have been taken were 2 to 9 mg/m³ immediately after completion, and 0.5 to 1.5 mg/m³ after 1 month (Kimura 2009). It is about 1/20 when comparing the both in the data after one month in summer. Since TVOC always changes with time, it becomes a problem in the evaluation of TVOC. According to the guidelines of MHLW, the relationship with the completion date is ambiguous only by applying all to the living environment. On the other hand Molhave claims that TVOC is applicable to both acute and chronic effects of long-term exposure (Molhave, 1996), but it is a stable long-term average value from the determination of the value including 400 μg/m³ in Japan1). In Europe at the time 300 μg/m³ was proposed, 50 times in one week and 10 times in 6 weeks were proposed48), but the German guideline values in Table 5 reflect this effect. The Japanese Building Society’s Standard, which is mainly targeted after the completion of new construction and large-scale remodeling, aims to achieve a clearing of 400 μg/m³. In addition, although the data of change over time is also measured in the previous example, for example, the attenuation rates do not match if the completion time and completion progress are different in addition to the construction method and type of building materials (Mizoguchi 2008).

Relationship with low-toxic VOC: Even if the VOC with a standard value (or unit risk, etc.) clears the standard value, the TVOC does not clear if the concentration of a specific less toxic VOC is specifically high. Consideration to this point is also required by the Ministry of Health, Labor and Welfare’s Guideline 1), and the concept of evaluating TVOC by excluding low toxicity ethyl alcohol derived from relatively high living conditions in Japanese houses is also introduced. On the other hand, terpene type α-pinene is not limited to wooden houses (Tanabe, 2006), but even in RC houses that use wood materials as interior materials, the TVOC often exceeds several thousand μg/m³, so the contribution rate to the TVOC is 25% over (Mizoguchi, 2008). α-Pinen is a natural product and the main component of piton chit, but its concentration in the forest is about 20-200 μg/m³ (Yatagai, 1988). In Germany, 0.2 mg/m³ (Category I) and 2 mg/m³ (Category II) have been proposed as indoor environmental guideline values for terpenes (Sagunski, 2003).

With regard to TVOC, it seems that new developments are not seen even if the trends of the academic society are taken from the proceedings of Indoor Air and Healthy Building from 2006. On the other hand, there are many views that the proportionality with the symptoms of TVOC is weak. In addition, symptoms are said to be due to minor amounts of coexisting irritants. Then, these measurements may be performed together.

Although the toxicological indication of TVOC does not stick to 400 μg/m³, it may be necessary to review it including the relationship with the completion date, in the presence of odor components and VOCs that do not have many reference values that may have synergy, TVOC will continue to contribute to the reduction of VOCs as a simple guideline value for management.

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