A Preliminary Study of a Method to Measure SVOCs Emitted from Electrical Appliances

Janghoo Seo*1 and Shinsuke Kato2

1 JSPS Research Fellow, Institute of Industrial Science, The University of Tokyo, Japan
2 Professor, Institute of Industrial Science, The University of Tokyo, Japan

Abstract
Some types of Semi-Volatile Organic Compounds (SVOCs) that are emitted from plastics used in building materials and household appliances have associated health risks, even at low concentrations. In this study, we proposed a means of determining SVOC emissions for full-scale electrical appliances using the purging flow rate (PFR) – the relationship between the emission rate and concentration. The measurement point used to measure SVOCs was located in the downstream section of the flow. The predicted emission rates for toluene and Di-2-ethylhexyl phthalate from a liquid crystal display television (LCD TV) were 29.87 µg/m²·h and 0.47 µg/m²·h, which equates to the compounds measured from a piece of LCD TV using the micro test chamber method. Results demonstrate that the proposed test method is expected to have practical applications for determining SVOC emissions. However, the PFR simulated by computational fluid dynamics (CFD) analysis was substantially dependent on the CFD analysis boundary conditions in terms of the turbulence intensity or the length scale. In order to measure SVOC emission rates, it is preferable to use an experimental PFR even though CFD analysis is useful for selecting the measurement point by exampling the distribution of the PFR.

Keywords: SVOCs; electrical appliances; purging flow rate; test chamber; emission rates

1. Introduction
A measurement method that assesses emission rates of formaldehyde, other carbonyl compounds and volatile organic compounds emitted from building materials, furniture and electrical appliances in an indoor environment using various test chambers has been developed and proposed in order to improve indoor air quality (ISO 16000-9,10,11, 2006; ASTM D 6670-01, 2001; ECA Report No. 2, 1989; ENV 13419-1, 1999 and JIS A 1901, 2003). On the other hand, although research to measure the emission rates of Semi-Volatile Organic Compounds (SVOCs) has been conducted, it is difficult to accurately evaluate SVOC emission rates, for which no standard test method has been devised.

Some types of SVOCs that are emitted from plastics used in building materials and household appliances have associated health risks, even at low concentrations (WHO, Indoor Air Quality, 1987; Steve M. Hays, 1995; WHO, Flame retardants, 1998; Per Axel Clausen et al., 1997; T. Salthammer et al., 2002; M. Wensing et al., 2005; Per Axel Clausen et al., 2004 and Olaf Wikle et al., 2004). In particular, it is reported that Di-2-ethylhexyl phthalate (DEHP), one of the most commonly used plasticizers, is detrimental to children's asthma and allergic symptoms at home (C.G. Bornehag et al., 2004).

It is difficult to measure SVOC emission rates from building materials or household appliances utilizing the usual test chamber methods, because the boiling points of SVOCs are higher and they are apt to adhere to the surface of the test chamber used (DIN 75201, 1992 and Ellen Katrine Pedersen et al., 2002). In Japan, the micro test chamber method – which employs a thermal desorption method in a test chamber – has been proposed as a measurement method for SVOCs emitted from building materials and household appliances (H. Katsumata et al., 2007 and K. Hoshino et al., 2003). However, it is impossible to measure the emission rates of compounds emitted from full-sized electrical appliances and working electrical appliances using the micro test chamber method because of its small size.

In this research, we propose a way to measure SVOCs emitted from full-size electrical appliances in a large test chamber. The concentration of SVOCs emitted from the electrical appliance is measured downstream of the flow. Since compounds emitted from the test article or appliance only flow parallel to the walls and the test chamber has vertical plug flow, measured concentrations are not influenced by adsorption. In advance, the purging flow rate (PFR) for
the relationship between the emission intensity and the concentration is calculated using computational fluid dynamics (CFD). In the experiment, SVOC emission rates are evaluated from the measured concentration and the PFR simulated by CFD analysis.

By using this proposed test chamber method, we can measure SVOC emission rates using the SVOC concentration at a single point in the chamber, and then the emission rates of SVOCs emitted from full-sized electrical appliances and working electrical appliances will be measured.

2. Principle for Measuring SVOC Emission Rates

The test method proposed for SVOC emission rate measurement uses both experimental and CFD analysis and is carried out in the following next three steps as shown in Fig.1.

Step 1: Calculation of purging flow rate using CFD analysis or experiment

We first suppose that the chemical compounds are emitted from the emission source at a constant rate; emission rate \( q \). CFD analysis is undertaken under the same conditions as the experimental conditions. Then we examine how the emitted compounds are carried and how they are mixed by the air streams in the test chamber. PFR is calculated as per Equation (1) using the concentration analyzed by means of CFD analysis and the emission rate. A schematic of the PFR calculation using CFD analysis is shown in Fig.2.

\[
Q_i = \frac{q}{C_i} \tag{1}
\]

where \( Q_i \) is the purge flow rate \([m^3/s]\) at point \( P_i \), \( q \) is the assumed emission rate \([\mu g/s]\), and \( C_i \) is the concentration \([\mu g/m^3]\) at point \( P_i \) as simulated by CFD analysis.

As mentioned later, not only can the PFR be simulated by CFD analysis using the assumed emission rate, but it can also be calculated using the experimental emission rate \( q \) measured using a one cubic meter chamber.

Step 2: Experimental concentration measurement in test chamber

We measure concentration \( C_i \) experimentally at point \( P_i \) which has a homogeneous distribution of PFR in the test chamber. Namely, point \( P_i \) refers to the location with the slightest gradient of concentration in the test chamber.

Step 3: Measurement of emission rate using PFR and concentration

The emission rate is measured by Equation (2) using the PFR in Step 1 and concentration \( C_i \) in Step 2. It is natural that the PFR measured by the experiment is the same as that simulated by CFD analysis because the CFD analysis is performed under the same conditions in the corresponding experiment.

\[
q^* = Q_i \times C_i \tag{2}
\]

where \( q^* \) is the measured emission rate \([\mu g/s]\) and \( C_i \) is the experimental concentration \([\mu g/m^3]\) on point \( P_i \).

PFR, where PFR means the local purging flow rate, is generally defined as the net rate at which a passive contaminant is flushed out of the volume (chamber) from an arbitrary point (measurement point). That is to say, we can obtain the ratio between the emission rate \((\mu g/s)\) within the chamber and the concentration \((\mu g/m^3)\) at the measurement point by using the PFR \((m^3/s)\).

3. Selection of Concentration Measurement Point

The large stainless steel test chamber that the authors developed is shown in Fig.3. The volume of the test chamber with a vertical plug flow is 19.7 m\(^3\) (2.7 m \times 2.7 m \times 2.7 m). The ventilation system includes a supply opening over the entire floor surface and an
exhaust opening across the entire ceiling. Coarse, medium and high efficiency particulate air filters and chemical filters for gaseous materials are incorporated into the clean supply system. The major adsorbent of the chemical filter is activated carbon. Temperature, relative humidity (RH) and ventilation rate are controlled by filters installed in the HVAC system. The internal surfaces of the test chamber and ventilation duct are made of electro-polished stainless steel to prevent surface adsorption. It is possible to control the air exchange rate of the test chamber from 0.5 to 130 times per hour. An ultrasonic gas flow meter was set to record and monitor the ventilation rate. To minimize background concentrations within the test chamber, extensive ventilation and a temperature of 50ºC were applied before the experiment.

A model appliance with dimensions of 0.5 m × 0.5 m × 0.5 m is installed in the center of the test chamber shown in Fig.3. SVOC emission rates can be evaluated using PFR, which is expressed by the relation between emission intensity of a model appliance and concentration at the specific point that has the slightest gradient of concentration in the test chamber. However, it is possible that the specific point in the test chamber depends on the sample shape or position of the emission source. For use as a standard test method, it is necessary to examine a specific point that can be routinely used. In this study, the specific point in the test chamber depends on the sample shape or position of the emission source. For use as a standard test method, it is necessary to examine a specific point that can be routinely used. In this study, the specific point in the test chamber is determined using PFR simulated by CFD analysis. We examined how the location of the emission face influenced the determination of the specific point as shown in Table 1.

Numerical analysis corresponding to measurement tests of SVOC emission rates was performed. The analytical conditions and analysis model are shown in Table 2. and Fig.3. The analysis was performed under a supply air velocity of 0.045 m/s as the experimental condition. The flow field was conducted by three-dimensional analysis based on a low Reynolds number-type k-ε model; Abe-Nagano model (Y. Nagano et al.). In order to accurately analyze any diffusion in the viscous bottom layer of the boundary layer, the Reynolds number-type k-ε model was used. After analysis of the flow field, the boundary conditions for emissions were given at the surface of the test specimen shown in Table 1. The boundary conditions for adsorption were given at the surface of the test chamber, which is set as zero. SVOCs are generally apt to adhere to the surface of the test chamber so that the saturated adsorption amount \( C_{\text{ad}} \) is assumed to be extremely large in this case. This corresponds to the assumption that the Henry coefficient \( k_h \) in a Henry-type isothermal formula \( (C_{\text{ad}} = k_h \times C) \) is infinite. The transportation of DEHP is expressed and analyzed by Equation (3).

\[
\frac{\partial \overline{C}_o}{\partial t} + \frac{\partial \overline{U}_j}{\partial x_j} \overline{C}_o = \frac{\partial}{\partial x_j} \left( D_o \cdot \frac{\nu_j}{\sigma_j} \right) \left( \frac{\partial \overline{C}_o}{\partial x_j} \right)
\]

where overbar is the ensemble-mean value, \( C_o \) is the concentration of DEHP at a point in space \([\mu g/m^3]\), \( D_o \) is the molecular diffusion coefficient of DEHP \([m^2/s] \),

![Fig.4. Velocity Vectors and Distribution of Concentration of Case 1 (X-Y Section)](image)

![Fig.5. Distribution of PFR (Case 1: X-Y Section \([m^3/s]\))]
$U_i$ is ensemble-mean velocity \([\text{m/s}]\), $v_t$ is the turbulent eddy viscosity \([\text{m}^2/\text{s}]\) and $\sigma_t$ is the turbulent Schmidt number [-].

The diffusion field (transport in the air) was analyzed by the steady method. The mass diffusion coefficient $D_o$ for DEHP in the air was taken as $7.1 \times 10^{-6}$ \([\text{m}^2/\text{s}]\) at 28 °C (Handbook of Chemistry, 1999). The CFD software used for these analyses was Fluent 6.2.

The air velocity vectors and the distribution of concentration within the test chamber are shown in Fig.4. Large volume ventilation formed the laminar flow inside the test chamber except in its center, at which is installed the test specimen, and the airflow in the test chamber was unidirectional. The average velocity within the test chamber was 0.045 m/s. Recirculatory airflow was generated by a stagnant area on the test specimen. As shown in Fig.4., the concentration of DEHP emitted from the test specimen was equally distributed from directly overhead the test specimen to the neighborhood ceiling.

The PFR distribution for Case 1 is shown in Fig.5. The PFR of this area with its homogeneous concentration distribution was $2.75 \text{ m}^3/\text{s}$ or less and was deeply influenced by the supply of clean air (J. Seo et al., 2004). The PFR profiles on Line A (X=0~2.7 m, Y=2.6 m, Z=1.35 m) and Line B (X=1.35 m, Y=0.45~2.7 m, Z=1.35 m) of Fig.3. are shown as Figs.6. and 7. In the case of Line A, the PFR at the center (width X=1.2~1.5 m) of the ceiling in the test chamber was rigidly constant regardless of the location of the emission face. The PFR directly above the test specimen (height Y=0.45~2.7 m) in the test chamber was most equally distributed in the case of Line B. As mentioned above, the measurement point, having a homogeneous PFR distribution in the test chamber, was located in the center of the neighborhood ceiling; X=1.35 m, Y=2.6 m, Z=1.35 m (J. Seo et al., 2004). Generally speaking, the concentration at the point far from the emission source is relatively unaffected by any change in the emission face or source shape because the emitted compounds are mixed with the ambient airflow downstream of the flow, as in this chamber. It was demonstrated that the measurement point did not change though the emission face is located differently. N. Miura et al. reported that the measurement point chosen as above is not affected by the types or shapes of test sample; that is to say, the measurement point was fixed regardless of whether applied to a liquid crystal display television (LCD TV), printer or radio cassette player. However, if the emission rates between faces are different, the distribution of concentrations and the measurement point may be affected, and this has yet to be examined.

From the above results, the relationships between the PFR and the emission rate (or the concentration) can be expressed as Equation (4);

$$Q = \frac{q_{\text{ALL}}}{C_i} \approx \frac{q_A}{C_i} \approx \frac{q_B}{C_i} \approx \frac{q_C}{C_i} \approx \frac{q_D}{C_i} \approx \frac{q_E}{C_i}$$

(4)

where the subscripts shown as \(_\text{ALL},\_A, \ldots, \_E\) refer to the emission faces of the test model as shown in Fig.3.

Equation (4) implies that if the measurement point is far from the emission source, the ratio between concentrations and emission rates is nearly constant and is independent of the location of the emission face. J. Seo et al. (2007) demonstrated that both the PFR of SVOCs and VOCs in this test chamber almost perfectly coincide by using a diffusion-tube with a constant emission flux that can be expressed as Equation (5);

$$Q = \frac{q_{\text{VOC}}}{C_{\text{VOC},i}} \approx \frac{q_{\text{SVOC}}}{C_{\text{SVOC},i}}$$

(5)

where $q_{\text{VOC}}$ is the VOC emission rate \([\mu\text{g/s}]\), $q_{\text{SVOC}}$ is the SVOC emission rate, $C_{\text{VOC},i}$ is the VOC concentration \([\mu\text{g/m}^3]\) at point P, and $C_{\text{SVOC},i}$ is the SVOC concentration \([\mu\text{g/m}^3]\) at point P;

It is shown in Equation (5) that the PFRs of SVOCs and VOCs at the measurement point are nearly identical, which means that the PFR for VOCs can be used as the PFR for SVOCs to measure SVOC emission rates.

4. Method

SVOC emission rates from a LCD TV, which was installed in the center of the test chamber, were evaluated in this study. An LCD TV with screen dimensions of $0.66 \times 0.53$ m$^2$ and a surface area of 0.8m$^2$ is being assessed herein. The test chamber was first conditioned and maintained at 28±0.5°C and 50% RH before performing the experiment. The air
velocity in the test chamber with a vertical plug flow was over 0.045 m/s to minimize the influence from the air surrounding the sampler while sampling was performed. The sampling was carried out using a Tenax-TA at a measurement point (X=1.35 m, Y=2.6 m, Z=1.35 m) with a homogeneous distribution of the PFR in the test chamber. SVOC emission rates from an LCD TV, which was installed in the center of the test chamber, were evaluated in this study. After the test chamber was baked at a high temperature of 250°C, the LCD TV installed in the test chamber was conditioned under 28±0.5°C, 50% RH and a ventilation rate of 0.5h⁻¹, whereupon the experiment was performed. The sampling was carried out using Tenax-TA.

The numerical conditions to calculate the PFR are shown in Table 2, wherein the test specimen is the LCD TV whose dimensions are detailed. A constant emission rate for DEHP from the whole surface of the LCD TV (Cs= flux: 100 µg/m²·h) was assumed as a boundary condition in the analysis of the diffusion field. After analysis of the flow and diffusion field, the PFR is examined using Equation 1 based on the relationship between the emission intensity of the LCD TV and the DEHP concentration at the measurement point (X=1.35 m, Y=2.6 m, Z=1.35 m) in the test chamber.

5. Results of SVOC Emission Rate Measurements

5.1 Calculation of purging flow rate (Step 1)
The calculation results for the PFR at the measurement point (X=1.35 m, Y=2.6 m, Z=1.35 m) are shown in Table 5. When the emission rate of DEHP released from the whole surface of the LCD TV was 100 µg/m²·h, the concentration of DEHP was 1.8 µg/m³ at the measurement point. In this experiment, the PFR used to evaluate the DEHP emission rate of the LCD TV was 1.2×10⁻² m³/s. The measurement point was in a position strongly affected by the supply of clean air and well suited to sampling.

5.2 Experimental Determination of Concentration in Test Chamber (Step 2)
The concentrations of chemical compounds emitted from the LCD TV at the measurement point are shown in Table 6. The concentration of toluene was 0.5 µg/m³, while that of benzene, 1,4-dimethyl; benzene, 1-ethyl-4-methyl; benzene, 1,3,5-trimethyl; and tetracane was below 0.1 µg/m³. The concentration of DEHP, the target compound in this study, was below 0.1 µg/m³. Chemical compound concentrations, as measured in the test chamber except at its center where the test specimen is installed, were equal to the background concentration.
concentration of the test chamber as shown in the analyzed results in Fig.4.

5.3 Predicted Emission Rates from LCD TV (Step 3)

The predicted emission rates for toluene and DEHP released from the LCD TV are shown in Table 7. The predicted emission rate of DEHP was below 0.5 µg/m$^3$·h using the PFR in Step 1 and DEHP concentration in Step 2; the PFR calculated by CFD analysis was 1.2 ×10$^{-2}$ m$^3$/s while the DEHP concentration measured experimentally was 0.01 µg/m$^3$.

A linear relationship is evident in the analysis of the diffusion field for concentration and PFR. The PFR of the VOCs can also be used for the SVOCs to measure SVOC emission rates. Therefore, we can use the simulated PFR to predict the emission rate of toluene using Equation 5. The predicted emission rate of toluene released from the LCD TV was 30 µg/m$^3$·h using a PFR of 1.2×10$^{-2}$ m$^3$/s and toluene concentration of 0.5 µg/m$^3$.

5.4 Emission Rate from LCD TV using 1-m$^3$ Test Chamber

The toluene emission rate from the LCD TV using the 1-m$^3$ test chamber is shown in Fig.8. The emission rate for toluene reaches a steady state some 30 days after the experiment started.

The toluene emission rate from the LCD TV was measured using the PFR (1.2×10$^{-2}$ m$^3$/s) simulated by CFD analysis; 30 µg/m$^3$·h (24 µg/unit·h), while the predicted emission rate for toluene was 65 µg/m$^3$·h (52 µg/unit·h) in the steady state. Furthermore, the PFR measured using the toluene emission rate in the 1-m$^3$ test chamber was 2.9×10$^{-2}$ m$^3$/s as shown in Table 8. This means that the toluene emission rate predicted by this proposed test method is underestimated compared to that predicted when using the 1-m$^3$ test chamber method, which is because the PFR simulated by CFD analysis is underestimated, and the toluene emission rate is influenced by this underestimation in the PFR as shown in Equation 5.

6. Discussion

The emission rate for chemical compounds released from the casing and circuit boards of TVs has been reported based on the micro test chamber method proposed in Japan (Q. Zhu et al., 2003 and H. Katsumata et al., 2007). Emission rates for DEHP released from the TVs were 33~41 µg/m$^3$·h, while the air exchange rate/load factor for the micro test chamber was 0.61 m/h. The emission rates for DEHP used as a plasticizer in the TVs was of about the same order in a comparison between the developed test method and the micro test chamber, even though the TVs used as test samples were different.

To measure emission rates, it is preferable to use the experimental PFR calculated from the emission rate measured using the 1-m$^3$ test chamber. In order to replicate the same conditions between the CFD analysis and experiment, the turbulence intensity or the length scale must be measured by surveying the air velocity of the test chamber, and this has now been performed, because detailed modeling of a test chamber with a porous floor to allow vertical plug flow must be sufficiently expressed. It is also very difficult to model a test specimen with such porosity using CFD analysis. This means that getting a PFR that corresponds to the experiment is not easy, and PFR simulations by CFD analysis may be over- or underestimated. In order to measure SVOC emission rates, it is preferable that an experimentally determined PFR be used.

Concentrations of chemical compounds at the measurement point were very low (1~2 ng) at a sampling rate of 0.05 l/min for 48 and 160 hours as shown in Table 5., because of the large ventilation rate to minimize the influence from the air surrounding the sampler as referred to in EXPERIMENTAL METHODS. In order to concentrate the chemical compounds, if the sampling time is extended or a greater sampling volume is taken, it is probable that the Tenax-TA limits will impinge. Therefore, it is necessary to propose a new sampler instead of Tenax-TA, and a new sampling method has now been developed, the results of which will be reported soon.

7. Conclusions

We proposed and applied a test method to measure SVOCs emitted from full-sized electrical appliances using a vertical plug flow based on both experimental and numerical analyses, and the conclusions of this
paper are summarized below.

1. The vertical plug flow method to measure SVOCs emitted from electrical appliances has been developed. We selected a specific point, with the slightest concentration gradient, by evaluating the PFR in the test chamber in order to measure SVOCs emitted from electrical appliances.

2. The PFR simulated by CFD analysis and the PFR measured by emission rates using the 1-m³ test chamber are used to measure the emission rates. It is preferable to use the experimentally measured PFR even though the CFD analysis is useful to select the measurement point by examining the distribution of the PFR, because of differences between the experimental and CFD analysis conditions in terms of the turbulence intensity or the length scale. In order to replicate the conditions between the CFD analysis and experiment, the turbulence intensity or the length scale must be measured by surveying the air velocity of the test chamber, which has now been performed.

3. It is preferable that CFD analysis is conducted to select the measurement point and an experimentally measured PFR is used to measure SVOC emission rates.

4. This study is now being performed to accumulate more data for SVOC emission rates from various kinds of electrical appliances, and emission rates from printers and radio cassette players as well as LCD TVs have been measured. The results will be reported soon.

Acknowledgements
This study was supported by NEDO (New Energy and Industrial Technology Development Organization, Japan).

References
1) ASTM D 6670-01 (2001) Standard Practice for Full-scale Chamber Determination of Volatile Organic Emissions from Indoor Materials / Products.
2) Carl-Gustaf Bornehag, Jan Sundell, Charles J. Weschler, Torben Sigsgaard, Bjorn Lundgren, Mikael Hasselgren, and Linda Hägerhed-Engman (2004) The Association between Asthma and Allergic Symptoms in Children and Phthalates in House Dust: A Nested Case Control Study. Environmental Healthy Perspectives; 112(14), pp.1393-1397.
3) Clausen PA, and Wolkof P. (1997) Evaluation of Automatic Thermal Desorption – Capillary GC for Determination of Semi-volatile Organic Compounds (SVOC) in Indoor Air. J High Resol Chromatogr, 20, pp.99-108.
4) DIN 75291 (1992) Determination of the windscreen fogging characteristics of trim materials in motor vehicles, DIN-Deutsches Institut für Normung, Berlin, Beuth-Verlag.
5) Ellen Katrine Pedersen, Olav Bjorseth, Tore Svyersen, and Mette Mathiesen (2002) Emissions from heated indoor dust. Environment international, 27, pp.579-587.
6) ENV 13419-1 (1999) Building products – Determination of the emission of volatile organic compounds – Part 1: Emission test chamber method.
7) Handbook of Chemistry (1999) The Society of Chemical Engineers, Japan.
8) H. Katsumata, S. Murakami, S. Kato, K. Hoshino, and Y. Ataka (2008) Measurement of semi-volatile organic compounds emitted from various types of indoor materials by thermal desorption test chamber method. Building and Environment, 43, pp.378-383.
9) ISO 16000 – 9, 10, 11: Determination of the emission of volatile organic compounds from building products and furnishing – Part 9: Emission test chamber method, Part 10: Emission test cell method, Part 11: Sampling, storage of samples and preparation of test specimens.
10) JIS A 1901 (2003) Determination of the emission of volatile organic compounds and aldehydes for building products – Small chamber method.
11) J Seo, S Kato, and S Nagao (2006) Study on measurement of semi-volatile organic compounds emitted from electrical appliances in large test chamber of laminar flow type. Indoor Environmental Quality – Problems Research and Solution, Air & Waste Management Association, abstract, 44.
12) J Seo, S Kato, N Miura, S Chino, and K Takeuchi (2007) Study of the measuring method of emission rate of SVOCs from electric appliance using large chamber (part 6) – Measurement of SVOCs Emission Rates Released from LCD TV and Examination for PFR Distribution of SVOCs-VOCS in Test Chamber, summaries of technical papers of annual meeting SHASE, pp.529-532.
13) K Hoshino, S Ogawa, S Kato, Q Zhu, and Y Ataka (2003) Measurement of SVOCs Emitted from Building Materials and Electric Appliances Using Thermal Desorption Test Chamber Method. Proceedings of the 7th International Conference – Healthy Buildings 2003, 1, pp.474-479.
14) M. Wensing, E. Uhde, and T. Salhammer (2005) Plastic additives in the indoor environment – Flame retardants and plasticizers, Science of the Total Environment, 339, pp.19-40.
15) N Miura, M Yamaguchi, S Kato, and J Seo (2007) Study of the measuring method of emission rate of SVOCs from electric appliance using large chamber (part 5) – Calculation of purging flow rate around printer and radio cassette player by CFD analysis, summaries of technical papers of annual meeting SHASE, pp.525-528.
16) K. Abe, T. Kondoh, and Y. Nagano (1994) A new turbulence model for predicting fluid flow and heat transfer in separating and reattaching flows. Flow field calculations. Int. J. Heat Mass Transfer, 37(1), pp.139-151.
17) Olaf Wilke, Oliver Jann, and Doris Brödner (2004) VOC- and SVOC-Emission from Adhesives, Floors, Floor Coverings and Complete Floor Structures, Indoor Air, 14(8), pp.98-107.
18) Per Axel Clausen, VivI Hansen, Lars Gunnarsen, Alireza Afshari, and Peder Wolkoff (2004) Emission of Di-2-ethylhexyl Phthalate from PVC Flooring into Air and Uptake in Dust: Emission and Sorption Experiments in FLEC and CLIMPAQ. Environ. Sci. Technol, 38(9), pp.2,531-2,537.
19) Steve M. Hays (1995) Indoor Air Quality, Solutions and Strategies, McGraw-Hill, Inc.
20) T Salhammer, and M Wensing (2002) Flame Retardants in the Indoor Environment Part IV: Classification of experimental data from house dust, indoor air and chamber tests. Proceedings of the 9th International Conference on Indoor Air Quality and Climate – Indoor Air 2002, (2), pp.213-218.
21) WHO. Indoor Air Quality: Organic Pollutants (1987) EURO Reports and Studies 111.
22) WHO. Flame retardants (1998) tris(chloropropyl) phosphate and tris(2-chloroethyl) phosphate, Environmental Health Criteria 209, Geneva.
23) Q Zhu, K Hoshino, S Kato, and Y Ataka (2003) Study on Measurement of SVOCs Emitted from Building Material and Products under Actual Room Temperature Conditions. J.Archit. Plann.Envir. Eng., AIJ, (574), pp.35-41.