A Study of Design for Reduction and Monitoring of Volatile Organic Compounds in Indoor Air: the Case of a Commercial Bank in Japan

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Abstract
The prevention of sick building syndrome necessitates the design and construction of buildings that can maintain low concentrations of Volatile Organic Compounds (VOCs). This study aims to determine whether VOC concentrations in a new commercial bank can be reduced through the selection of building materials and monitoring of construction processes. The building was designed and constructed with close attention to the selection of architectural materials and supervision of construction. Twice during construction, indoor air samples were collected and their chemical compositions determined. The Ministry of Health, Labour, and Welfare of Japan (MHLW) guideline concentrations for VOCs were not exceeded for any of the specified chemicals, including toluene, xylene, ethylbenzene, styrene, p-dichlorobenzene, tetradecane, formaldehyde, and acetaldehyde. After construction, the total VOC concentration was 104 μg/m³. This value is substantially lower than the target value of 400 μg/m³ recommended by the MHLW. Construction of a bank building with low concentrations of indoor chemical substances can be achieved through the proper selection of architectural materials and construction site supervision.

Keywords: indoor air quality; VOC; sick building syndrome; design development; interior design

1. Introduction
Sick building syndrome (SBS) includes a range of health problems such as headaches, pain in the nose and throat and eye irritation caused by exposure to chemicals in the indoor air of newly built or renovated houses, offices, or other buildings (Saijyo et al., 2004; Wang et al., 2007; Takeda et al., 2009; Mori & Todaka, 2011). The Ministry of Health, Labour, and Welfare of Japan (MHLW) defined SBS as symptoms that appear in a specific room, but disappear or improve when leaving the room. Volatile Organic Compounds (VOCs) from building materials and products are suspected to be the major cause of SBS (Hodgson, 2002). Thus, VOC concentrations are considered to be one of the most important factors influencing indoor air quality. However, the occurrence of SBS symptoms largely depend on a person's sensitivity.

In Japan, the Ministry of Land, Infrastructure, Transport, and Tourism (MLIT) set the acceptable concentration for formaldehyde at <0.08 ppm in the revised Building Standard Law of 2003 (MLIT, 2016). The MHLW also set nonbinding guideline values for 13 VOCs and an interim target value for total VOCs (TVOCs) at 400 μg/m³ by 2001 (MHLW, 2016). However, these regulations and guidelines are not sufficient to prevent SBS, as many other chemicals known to cause SBS symptoms have come into use since then (Saito et al., 2011). The problem has become more complicated, and the incidence of SBS has increased (Takigawa et al., 2010).

Most research on SBS, involves the study of residential buildings (Saijyo et al., 2004; Wang et al., 2007; Takeda et al., 2009), as people stay in these structures for long periods of time. Nonresidential buildings studied include schools (Sofuoglu et al., 2010) and offices (Bluyssen et al., 1996). Studies of indoor concentrations of chemicals in commercial retail buildings have also been reported (Eklund et al., 2008). However, studies assessing indoor concentrations of VOCs in commercial buildings in Japan are limited to a small number (Sakai et al., 2009).
Commercial buildings are used by a large number of people, necessitating consideration of users who are highly sensitive to chemicals by creating spaces with low indoor chemical concentrations. Previous reports describe the design of indoor environments with the aim of reducing VOCs starting at the beginning stages of planning the building (Hanazato et al., 2011a; Hanazato et al., 2011b; Tajima et al., 2014 & Nakaoka et al., 2014). However, commercial buildings were not included in these studies.

The present study aims to establish a procedure for designing bank buildings that have reduced concentrations of VOCs, achieved through the selection of materials, and supervision of construction, with monitoring of VOC concentrations.

2. Methods
2.1 Characteristics of the Building
A bank building under construction in Chiba Prefecture was the subject of our study. The structure of the building included a steel frame that was two stories above ground, with a building area of 395.92 m$^2$ and a total floor space of 606.95 m$^2$.

This study was conducted according to the process shown in Fig. 1, which included the selection of architectural materials, supervision of construction, and measurement of VOC concentrations. The final selection of architectural materials took into account both recommendations regarding materials and cost. Table 1. lists the architectural materials and furniture used. Most were selected based on the results of our emission tests (Hanazato et al., 2011a, b). A polyvinyl chloride (PVC) sheet and OA network steel raised floor with PVC tile carpet were used for the flooring. PVC wallpaper with starch adhesives and emulsion paint were used to cover the walls. In addition to our emission tests, we renovated the rooms of our school building using these PVC materials and measured VOC levels. Concentration levels of indoor VOCs in those rooms were low enough and we found that these PVC sheets with starch adhesives and emulsion paint did not produce secondary chemicals (Nakaoka et al. 2009, Hanazato et al. 2011b). The ceiling was made from Rockwool sound absorption paneling.

We maintained communication with the contractor through regular on-site meetings. The following points were made clear during these discussions: the concept of reducing VOCs, strict observance of the types and quantities of specified materials, and strict communication if any changes were made to the materials used at the site. We considered both the selection of construction materials and the construction methods as important to reducing VOCs, as VOC concentrations are affected by the quality and quantity of the emission sources.

![Flow Diagram of Research and Construction](image)

Table 1. Architectural Materials and Furniture for the New Commercial Bank

| Lobby | Office space | Seminar room |
|-------|--------------|--------------|
| Floor | PVC sheet    | OA network steel raised floor with PVC tile carpet | OA network steel raised floor with PVC tile carpet |
| Wall  | PVC wallpaper with starch adhesives and emulsion paint | PVC wallpaper with starch adhesives and emulsion paint | PVC wallpaper with starch adhesives and emulsion paint |
| Ceiling | Rock wool sound absorption panel | Rock wool sound absorption panel | Rock wool sound absorption panel |
| Furniture (Dec. 2013) | Built-in counter | - | - |
| Furniture (Feb. 2014) | Built-in counter and chair | Steel desk, chair and steel cabinet | Steel desk and chair |
2.2 Sampling and Analysis

All VOC concentrations were measured twice: immediately after completion of the construction work (December 20, 2013) and immediately after setup of the signboards, and furniture (February 23, 2014). We conducted the measurements in 4 places: 3 indoors (the lobby, office space inside the reception counter, and seminar room) and 1 outdoors. Since the lobby and office space were not separated by a wall but by a reception counter, the influx of air came from 2 sides. Fig.2. shows the floor plan with the measurement sites.

Before air sampling, the windows and doors were kept open for 30 min for ventilation. All of the windows and doors were then closed for 5 hours, followed by air sampling. Measurements were performed using the standard methods of air sampling and measurement issued by the MHLW (MHLW, 2016b), as follows. An active sampling method was conducted for 1 hour using Tenax TA (Supelco, Sigma Aldrich, St. Louis, MO, USA) to capture VOCs and LpDNPH S10L (Supelco, Sigma Aldrich, St. Louis, Mo, USA) to capture aldehydes. Air was passed through the Tenax TA sampler and DNPH sampler at flow rates of 100 mL/min and 1000 mL/min, respectively. The collected VOCs were extracted by thermal desorption and analyzed by gas chromatography mass spectrometry (GC/MS). Solvent extraction and high-performance liquid chromatography (HPLC) were used to analyze aldehydes. Precise analyses were conducted by the Tokyo Kenbikyo-in Foundation. The limit of quantification for each of the chemicals was 1.0 μg/m$^3$, except for ethanol and acetic acid (4.0 μg/m$^3$). We analyzed 62 VOCs and 15 aldehydes (Table 2.).

The TVOC was calculated as the toluene equivalent of all substances between C6 and C16, as defined by ISO. The total value of identified substances was considered to be the sum of VOCs. During sampling, the indoor air conditions, including temperature, humidity, and atmospheric pressure, were recorded. Facilitated ventilation systems in the rooms were operated during sampling. Table 3. shows the ventilation air volume and air changes per hour (ACH).

| Table 2. VOCs and Aldehydes Analyzed |
|--------------------------------------|
| 62 VOCs analyzed by GC/MS            |
| 1 2-Propanol                         | 32 2-Butoxyethanol                 |
| 2 Pentane                            | 33 Nonane                          |
| 3 Methyl acetate                     | 34 Tricycylene                     |
| 4 Dichloromethane                    | 35 α-Pinene                        |
| 5 1-Propanol                         | 36 3-Ethyltoluene                  |
| 6 Ethyl acetate                      | 37 Camphene                        |
| 7 Hexane                             | 38 4-Ethyltoluene                  |
| 8 Chloroform                         | 39 1, 3, 5-Trimethylbenzene        |
| 9 1, 2-Dichloroethane                | 40 2-Ethyltoluene                  |
| 10 2, 4-Dimethylpentane              | 41 β-Pinene                        |
| 11 1, 1, 1-Trichloroethane           | 42 1, 2, 4-Trimethylbenzene        |
| 12 Butanol                           | 43 D4                              |
| 13 Benzene                           | 44 Decane                          |
| 14 Carbon tetrachloride              | 45 Isododecane                     |
| 15 Cyclohexane                       | 46 p-Dichlorobenzene               |
| 16 1, 2-Dichloropropane              | 47 2-Ethyl-1-hexanol               |
| 17 Bromodichloromethane              | 48 3-Carene                        |
| 18 Trichloroethylene                 | 49 1, 2, 3-Trimethylbenzene        |
| 19 Isooctane                         | 50 p-Cymene                        |
| 20 Heptane                           | 51 Limonene                        |
| 21 4-Methyl-2-pentanone (MIBK)       | 52 4-Ethyl-1, 2-dimethylbenzene    |
| 22 Methylcyclohexane                 | 53 Undecane                        |
| 23 Toluene                           | 54 1, 2, 4, 5-Tetramethylbenzene   |
| 24 Dibromochloromethane              | 55 D5                              |
| 25 Butyl acetate                     | 56 Dodecane                        |
| 26 Octane                            | 57 Tridecane                       |
| 27 Tetrachloroethylene               | 58 D6                              |
| 28 Ethylbenzene                      | 59 Texanol                         |
| 29 m/p-xylene                       | 60 Tetradecane                     |
| 30 Styrene                           | 61 Pentadecane                     |
| 31 o-xylene                          | 62 Hexadecane                      |

| 15 aldehydes analyzed by HPLC       |
|--------------------------------------|
| 1 Formaldehyde                       | 9 Benzylddehyde                    |
| 2 Acetaldehyde                       | 10 Pentanal                        |
| 3 Acetone                            | 11 Hexanal                         |
| 4 2-Furanacrolein                   | 12 Heptanal                        |
| 5 Propionaldehyde                    | 13 Octanol                         |
| 6 2-Butanone                         | 14 Nonanal                         |
| 7 Butanol                            | 15 Decanal                         |
| 8 Cyclohexanone                      |                                     |

| Table 3. Ventilation Air Volume and Air Changes Per Hour at the New Commercial Bank |
|---------------------------------------------|
| Lobby and Office space$^c$                  | Lobby and Office space$^a$          | Seminar room$^a$                 |
| Floor area (m$^2$)                         | 141.34                            | 141.34                            |
| Volume (m$^3$)                             | 671.13                            | 671.13                            |
| Ventilation air volume (m$^3$/h)$^c$       | 600                               | 2580                             |
| ACH (Air changes per hour)$^a$             | 0.89                              | 3.84                             |
| $^c$Exhaust Air Only                       |                                    |                                  |
| $^a$Exhaust Air and Return Air             |                                    |                                  |
3. Results

Table 4. shows the measured concentrations of 62 VOCs and 15 aldehydes, the sum of VOCs, and the TVOC. Fig.3 shows the work in progress, Fig.4 shows the first measurement, and Fig.5 shows the second measurement. In both the first and second measurements, the guideline values were not exceeded for toluene, xylene, ethylbenzene, styrene, tetradecane, p-dichlorobenzene and formaldehyde of acetaldehyde.

In the first measurement, the TVOC in the lobby was 430 μg/m³; those in the office space and seminar room were 476 μg/m³ and 287 μg/m³, respectively. Thus, the TVOC in the lobby and office space exceeded the target value of 400 μg/m³ recommended by the MHLW. In contrast, the TVOC in the second measurement in the lobby was 82 μg/m³; those in the office space and seminar room were 104 μg/m³ and 68 μg/m³, respectively. Thus, unlike the measurements in December, these values were lower than the target value of 400 μg/m³ recommended by the MHLW.

Of the identified substances, the concentration of 2-butanone was somewhat high, with first measurement concentrations for the lobby, office space, and seminar room of 68 μg/m³, 70 μg/m³, and 47 μg/m³, respectively. In the second measurement, the concentrations in the lobby, office space, and seminar room were found to have decreased to 8.0 μg/m³, 8.9 μg/m³, and 5.5 μg/m³, respectively. Ethyl acetate and undecane were the other substances detected in all 3 locations. The concentrations of ethyl acetate in the lobby, office space, and seminar room were 21 μg/m³, 39 μg/m³, and 6.6 μg/m³, respectively, while those of undecane were 12 μg/m³, 12 μg/m³ and 20 μg/m³, respectively.

Regarding the supervision of construction, adherence to the chosen types and quantities of architectural materials was strictly observed. For example, the optimization of the quantity of urethane resin adhesive used in the contact surface of the reinforced concrete underfloor and OA floor legs is shown in Fig.6. After adhesion, the adhesive protruding between the underfloor and the OA floor legs was removed to reduce the VOCs, a process not normally carried out because it is extra work.

4. Discussion

None of the substances measured in this building exceeded the guideline values specified by the MHLW. Current residential buildings are reported to tend toward higher concentrations of nonregulated substances that do not have guideline values provided by the MHLW. The present study also indicated a similar trend.

The sum of VOCs for the lobby in the first measurement was 114 μg/m³, differing significantly from the TVOC of 430 μg/m³. Thus, VOCs other than the 62 substances under consideration contributed substantially to the TVOC. When a peak library search was carried out, diethylene glycol monomethyl ether (DEGME) emerged as a potential candidate. The concentration of DEGME was calculated to be equivalent to that of toluene. As a result, the concentrations of DEGME in the first measurement in the lobby, office space, and seminar room were found to be 104 μg/m³, 102 μg/m³, and 36 μg/m³, respectively. In the second measurement, no DEGME was detected.

The potential sources of DEGME were further investigated. In this building, urethane resin adhesive was used at the contact surface of the reinforced concrete underfloors and OA floor legs. The safety data sheet for this adhesive lists the components as 25–30% urethane prepolymer, 6.6% diphenylmethane di-isocyanate (MDI), 1–5% silica, 50–60% inorganic fillers, and 1–10% diluent. In Chemical Substances Contained in Adhesives, published by the National Institute of Technology and Evaluation, Japan, the following 2 relevant points were made (National Institute of Technology and Evaluation, 2016). The first is that "a diluent is a liquid additive for the purpose of reducing the concentration of solids and viscosity of the adhesive. Chemical substances used for dilution include reactive glycidyl ethers, glycidyl esters, and nonreactive glycol esters and liquid petroleum-based resins." The second point is that "diethylene glycol is used as the raw material for polyurethane-resin based adhesive." From this, it was inferred that one of the sources of DEGME was the urethane resin adhesive used at the contact surface of the reinforced concrete underfloor and the floor legs of the OA floor.

An additional consideration is the glycol ethers reported to be present in cleaning products (Nazaroff and Weschler, 2004 & Onuki et al., 2006) and water-based paints (Wieslander and Norbäck, 2010). However, since we adhered to the 2 guidelines of not using cleaning products and using a water-based paint for smaller areas before the first measurement, the source of DEGME was apparently not cleaning products or water-based paint.

The indoor environments differed between the first and second measurements owing to the addition of furniture such as cabinets and desks. The environmental effects of the VOCs from the furniture were a point of concern. However, the results show that the VOC concentrations were lower in the second measurement than the first. Remarkably, no substances had higher concentrations at the second measurement. Since the temperature and humidity were nearly identical for the first and second measurements, the effects of the furniture items can be said to be small. In addition, the VOCs might have been sufficiently volatilized at the time of the second measurement.
Table 4. Concentrations of Chemicals in the New Commercial Bank

| Room          | First measurement (Dec. 2013) | Second measurement (Feb. 2014) | Guide-line value |
|---------------|-------------------------------|--------------------------------|------------------|
|               | Lobby | Office space | Seminar Room | Outdoor air | Lobby | Office space | Seminar Room | Outdoor air |           |
| Temperature (°C) | 11.8 | 11.9 | 11.3 | 7.2 | 13.9 | 13.5 | 9.8 | 7.1 |           |
| Humidity (%)   | 58.6 | 57   | 61.4 | 81.5 | 26.7 | 26.9 | 32.8 | 34.6 |           |

**VOCs** (µg/m³)

| Chemical                  | First measurement | Second measurement | | |
|---------------------------|-------------------|-------------------| | |
| 2-Propanol                | ND                | ND                | | |
| Ethyl acetate             | 21                | 39                | 6.6 | 4.1 | 0.7 | 5.3 | 2.4 | | |
| Hexane                    | 2.1               | 1.9               | 2.5 | 2.6 | | | | | |
| Butanol                   | 4.0               | 4.2               | 6.1 | ND | ND | ND | ND | | |
| Benzene                   | 1.2               | 1.3               | 1.5 | 1.5 | | | | | |
| 4-Methyl-2-pentanone      | 2.8               | 2.8               | 2.7 | ND | ND | ND | ND | | |
| Methylcyclohexane         | 4.4               | 9.6               | ND | ND | ND | ND | ND | | |
| Toluene                   | 6.2               | 6.4               | 7.0 | 5.9 | 6.1 | 6.6 | 3.4 | 2.1 | 260 |
| Butyl acetate             | 3.2               | 2.8               | 2.3 | ND | ND | ND | ND | ND | |
| Ethylbenzene              | 4.0               | 3.8               | 3.2 | 1.4 | 2.7 | 3.4 | 1.4 | ND | 3800 |
| n-xylene                  | 1.6               | 1.5               | 1.4 | ND | 1.1 | 1.4 | ND | ND | |
| o-xylene                  | 1.0               | 1.0               | ND | ND | ND | ND | ND | ND | |
| 3-Ethyltoluene            | 1.6               | 1.6               | 1.6 | ND | ND | ND | ND | ND | |
| 1, 3, 5-Trimethylbenzene  | 1.1               | 1.1               | ND | ND | ND | ND | ND | ND | |
| D4                        | 2.3               | 2.5               | 2.0 | ND | ND | ND | ND | ND | |
| 1, 2, 4-Trimethylbenzene  | 5.3               | 5.4               | 5.0 | ND | 1.4 | 2.0 | ND | ND | |
| Decane                    | 3.4               | 3.3               | 3.0 | ND | ND | 1.7 | ND | ND | |
| 2-Ethyl-1-hexanol         | ND                | ND                | 7.2 | ND | ND | 3.2 | 16 | ND | |
| 1, 2, 3-Trimethylbenzene  | 1.8               | 1.9               | 1.6 | ND | ND | ND | ND | ND | |
| Limonene                  | ND                | ND                | ND | ND | ND | 1.5 | ND | ND | |
| 4-Ethyl-1, 2-dimethylbenzene | 4.0          | 4.2               | 3.9 | ND | ND | ND | ND | ND | |
| Undecane                  | 12                | 12                | 20  | ND | 2.7 | 3.2 | 2.3 | ND | |
| D5                        | 6.1               | 6.6               | 5.7 | ND | ND | 1.3 | ND | ND | |
| Dodecane                  | 5.0               | 5.0               | 4.9 | ND | ND | 1.4 | ND | ND | |
| Tridecane                 | 5.2               | 5.3               | 4.3 | ND | ND | 1.3 | ND | ND | |
| D6                        | 3.7               | 4.4               | 3.3 | ND | ND | 1.3 | 1.6 | 1.1 | ND | |
| Texanol                   | 3.1               | 3.1               | 2.8 | ND | ND | 2.8 | ND | ND | |
| Tetradecane               | 4.9               | 5.2               | 3.8 | ND | 1.4 | ND | 330 | ND | |
| Pentadecane               | 2.9               | 3.1               | 2.1 | ND | ND | ND | ND | ND | |
| xylene (sum of m/p-xylene, o-xylene) | 2.6 | 2.5 | 1.4 | ND | 1.1 | 1.4 | ND | 870 | |
| Sum of VOC                | 114               | 139               | 105 | 19 | 36 | 50 | 33 | 8.6 | |
| TVOC                      | 430               | 476               | 287 | 50 | 82 | 104 | 68 | 17 | |

**Aldehyde and ketone** (µg/m³)

| Chemical                  | | | | | | | | | |
|---------------------------| | | | | | | | | |
| Formaldehyde              | 2.2 | 2.2 | 2.1 | 1.5 | 2.9 | 3.2 | 2.7 | | 100 |
| Acetaldehyde              | 2.9 | 2.9 | 3.1 | 2.1 | 3.8 | 3.5 | 2.5 | | 48 |
| Acetone                   | 11  | 8.3 | 6.6 | 8.5 | 7.2 | 6.5 | 4.2 | | |
| 2-Butanone                | 68  | 70  | 47  | ND | 8.0 | 8.9 | 5.5 | | 577 |

<sup>a</sup> The following were not detected: Pentane, Methyl acetate, Dichloromethane, 1-Propanol, Chloroform, 1, 2-Dichloroethane, 2, 4-Dimethylpentane, 1, 1, 1-Trichloroethane, Carbon tetrachloride, Cyclohexane, 1, 2-Dichloropropane, Bromodichloromethane, Trichloroethylene, Isocyanate, Heptane, Dibromochloromethane, Octane, Tetrachloroethylene, Styrene, 2-Butoxyethanol, Nonane, Triclylene, α-Pinene, Camphene, 4-Ethyltoluene, 2-Ethyltoluene, β-Pinene, Isodecane, p-Dichlorobenzene, 3-Carene, p-Cymene, 1, 2, 4, 5-Tetramethylbenzene and Hexadecane

<sup>b</sup>The following were not detected: 2-Furanacrolein, Propionaldehyde, Butanal, Benzaldehyde, Cyclohexanone, Pentanal, Hexanal, Heptanal, Octanal, Nonanal and Decanal

<sup>c</sup>Not detected

<sup>d</sup>Missing
5. Conclusion

Because bank buildings are used by a large number of people, we chose a bank as the subject of this study of commercial building design. The selection of materials, supervision of construction, and concentration measurements were carried out at the constructed site. For the substances for which guideline values have been specified by the MHLW, no values were exceeded in the new building. These substances include toluene, xylene, ethylbenzene, styrene, tetradecane, p-dichlorobenzene, formaldehyde, and acetaldehyde. In the measurement taken just after
completion of the construction work, the TVOC was 400 μg/m³, which is higher than the target value set by the MHLW. However, in the second measurement, just before the opening of the bank, the value had fallen to less than 400 μg/m³. Thus, the building of a space with considerably low VOC concentrations can be realized. High levels of DEGME were detected, which we determined to originate from the urethane resin adhesive used between the reinforced concrete underfloor and OA floor legs.

Construction of a bank building with lower concentrations of indoor chemical substances can be achieved through the proper selection of architectural materials and site supervision.

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References
1) Bluyssen, P. M., De Oliveira Fernandes, E., Groes, L., Clausen, G., Fanger, P. O., Valbjørn, O., Bernhard, C. A. and Roulet, C. A. (1996), European Indoor Air Quality Audit Project in 56 Office Buildings. Indoor Air, 6, pp.221-238.
2) Eklund, B. M., Burkes, S., Morris, P., & Mosconi, L. (2008). Spatial and temporal variability in VOC levels within a commercial retail building. Indoor air, 5, pp.365-374.
3) Hanazato, M., Todaka, E., Nakaoka, H., Seto, H., Chemiless Town Project Consortium & Mori, C. (2011b). Designing and developing a laboratory room unit with low volatile organic compounds (in Japanese). Japanese Journal of Clinical Ecology, 20, 2, pp.100-107.
4) Hanazato, M., Todaka, E., Nakaoka, H., Seto, H., Chemiless Town Project Consortium & Mori, C. (2011b). Designing an office with low volatile organic compounds (VOCs) and the analysis of VOCs in its air (in Japanese). Japanese Journal of Clinical Ecology, 20, 2, pp.108-114.
5) Hodgson, M. (2002). Indoor environmental exposures and symptoms. Environmental Health Perspectives, 110 (Supplement 4), pp.663-667.
6) Japanese Ministry of Health, Labor and Welfare. (2016a). Committee on sick house syndrome: indoor air pollution progress report No. 4. 2002 (in Japanese). Retrieved 25 January, 2016, from http://www.mhlw.go.jp/houdou/2002/02/h0208-3.html
7) Japanese Ministry of Health, Labor and Welfare. (2016b). Notice of “The standard methods of air sampling and measurement” (in Japanese). Retrieved 25 January, 2016, from http://www1.mhlw.go.jp/houdou/1206/h0629-2_b_13.html
8) Japanese Ministry of Land, Infrastructure and transport. (2016). Prevention of sick building syndrome based on Building Standard Law (in Japanese). Retrieved 25 January, 2016, from http://www.mlit.go.jp/jutakukentiku/build/jutakukentiku_house_tk_000043.html
9) Mori, C. & Todaka, E. (2011). A new concept for protecting our children environmental preventive medicine. In: Environmental contaminants and children's health. Japan: Maruzen Planet Co, Ltd.
10) Nakaoka, H., Todaka, E., Seto, H., Saito, I., Hanazato, M., Watanabe, M., & Mori, C. (2014). Correlating the symptoms of sick-building syndrome to indoor VOCs concentration levels and odour. Indoor and Built Environment, 23(6), 804-813.
11) Nakaoka, H., Todaka, E., Fukuhara, A., Kondo, Y., Ishikiriyama, M., Hanazato, M., & Mori, C. (2009). Necessity of “Chemiless Lecture Room” for healthy children’s environment. Abstract of 3rd WHO International Conference on Children’s Health and The Environment, 196, Busan, Korea.
12) National Institute of Technology and Evaluation. (2016). Chemical substances contained in adhesive 2012 (in Japanese). Retrieved 25 January, 2016, from http://www.nite.go.jp/data/000010749.pdf
13) Nazaroff, W. W., & Weschler, C. J. (2004). Cleaning products and air fresheners: exposure to primary and secondary air pollutants. Atmospheric Environment, 38(18), pp.2841-2865.
14) Takeda, M., Saio, Y., Yuasa, M., Kanazawa, A., Araki, A., & Kishi, R. (2009). Relationship between sick building syndrome and indoor environmental factors in newly built Japanese dwellings. International archives of occupational and environmental health, 5, pp.583-593.
15) Onuki, A., Saito, I., Seto, H., & Kamimura, H. (2006). VOC concentrations in indoor air after floor polishing. Tokyo-to Kenko Anzen Kenkyu Senta Kenkyu Kenpo, pp.259-263.
16) Saio, Y., Kishi, R., Sato, F., Katakura, Y., Urashima, Y., Hatakeyama, A., Kobayashi, S., Jin, K., Kurahashi, N., Kondo, T., Gong, Y. Y., & Umemura, T. (2004). Symptoms in relation to chemicals and dampness in newly built dwellings. International archives of occupational and environmental health, 7, pp.461-470.
17) Saio, I., Onuki, A., Todaka, E., Nakaoka, H., Mori, C., Hosaka, M., & Ogata, A. (2011). Recent trends in indoor air pollution: health risks from unregulated chemicals (in Japanese). Japanese Journal of Risk Analysis, 21(2), pp.91-100.
18) Sakai, K., Kamijima, M., Shibata, E., Ohno, H., & Nakajima, T. (2009). Annual transition and seasonal variation of indoor air pollution levels of 2-ethyl-1-hexanol in large-scale buildings in Nagoya, Japan. Journal of environmental monitoring: JEM, 11, pp.2068-2076.
19) Sofuoglu, S. C., Aslan, G., Inal, F., & Sofuoglu, A. (2010). An assessment of indoor air concentrations and health risks of volatile organic compounds in three primary schools. International journal of hygiene and environmental health, 1, pp.36-46.
20) Tajima, S., Ono, A., Hanazato, M., Mori, C., Suzuki, H., & Kawase, T. (2014). Development and Construction of Net-Zero-Energy House for Solar Decathlon Europe 2012. AJI Journal of Technology and Design, 20(44), 197-202. http://doi.org/10.3130/ajiit.20.197
21) Takigawa, T., Wang, B. L., Saio, Y., Morimoto, K., Nakayama, K., Tanaka, M., Shibata, E., Yoshimura, T., Chikara, H., Ogino, K., & Kishi, R. (2010). Relationship between indoor chemical concentrations and subjective symptoms associated with sick building syndrome in newly built houses in Japan. International archives of occupational and environmental health, 2, pp.225-235.
22) Wang, B. L., Takigawa, T., Yamasaki, Y., Sakano, N., Wang, D. H., & Ogino, K. (2007). Symptom definitions for SBS (sick building syndrome) in residential dwellings. International journal of hygiene and environmental health, 1-2, pp.114-120.
23) Wieslander, G., & Norbäck, D. (2010). Ocular symptoms, tear film stability, nasal patency, and biomarkers in nasal lavage in indoor painters in relation to emissions from water-based paint. International archives of occupational and environmental health, 83(7), pp.733-741.