Investigation of indoor air quality in a residence using natural materials

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ABSTRACT

Indoor air quality (IAQ) in a house using building materials with low chemical emission was investigated for 8 months. Indoor air concentration, emission rate of aldehydes and VOCs from floor and wall, air change rate, temperature and relative humidity were measured to evaluate the IAQ of the house. Air change rate was measured by two methods. Indoor air concentration and emission rate from building materials were measured at different construction phases (before and after completion) and after being occupied. A questionnaire was used to examine the influence of lifestyle on IAQ. The values of emission rate of foundation materials were larger than that of interior materials. Formaldehyde concentrations were under 100 μg/m^3 (the largest value was 52 μg/m^3), which is below the guideline of WHO and Japanese Ministry, but TVOC concentrations measured after 3 months' occupancy were above 1000 μg/m^3. Major chemical substances in this house were different from those measured in conventional houses.

INDEX TERMS

IAQ assessment; Investigation; Residence; Terpenes; Wood (natural materials)

INTRODUCTION

After the establishment of new standard of energy-saving standard by the Ministry of Construction and International Trade and Industry of Japan in 1992, the number of houses that have high insulation and air tightness performance increased. On the other hand, these houses often have poor indoor air quality (IAQ) due to insufficient ventilation rate. In this study, IAQ of a house with high insulation and air tightness was investigated for 8 months, during construction and after occupancy. The house was built with building materials (mainly natural materials) with low chemical emission rate and equipped with mechanical ventilation. Indoor air concentration, emission rate of formaldehyde and VOCs from floor and wall, air change rate, temperature and relative humidity were measured for evaluation of IAQ. Indoor air concentrations and emission rates from building materials were measured not only under construction, but also after completion and after residential occupancy. A questionnaire was used to examine the influence of lifestyle on IAQ.

METHODS

Building Description

First and second floor plans of the investigated house are shown in Figure 1, and architectural characteristics of the house are summarized in Table 1. The house is well insulated with outer insulation method and carefully designed to increase air tightness to realize high-energy efficiency. Building materials with low chemical emission were selected and mechanical ventilation system was installed. Interior materials of living room were natural chestnut flooring, earthen wall (loess and scrap of straw), and cedar ceiling.

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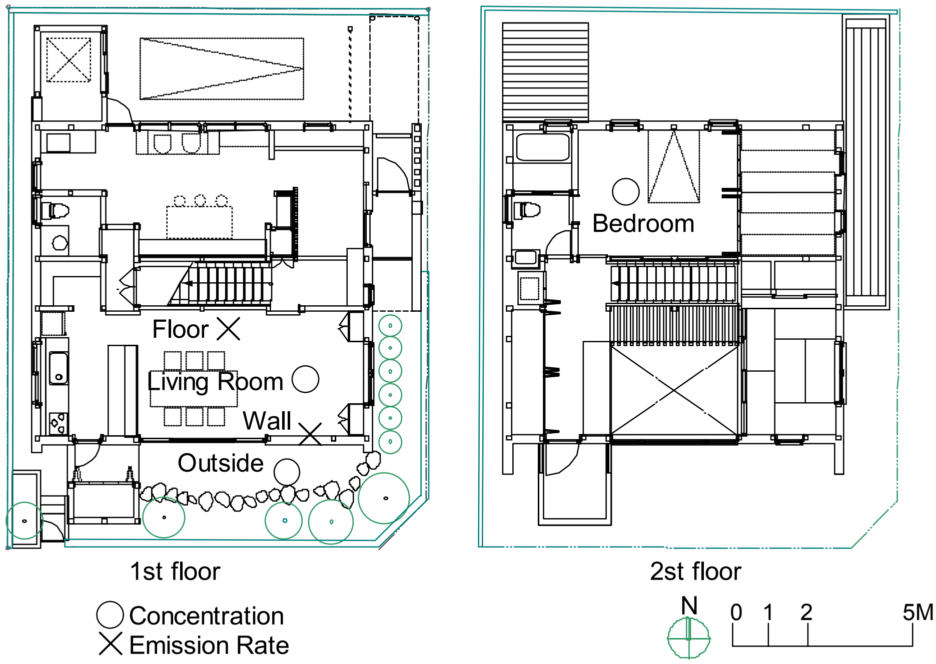

Figure 1 First and second floor plan of investigated house.

Table 1 Summary characteristics of the house

Structure	Japanese wooden house
Performance	Normalized leakage area: 0.3 (cm^2/m^2)
	Heat loss coefficient per floor area: 2.0 ($W/m^2/°C$)
Area (m^2)	Floor area/156.62 (1st floor/87.94; 2nd floor/68.68)
Air exchange rate	0.35 (ACH)

Indoor Air Quality Measurements

Sampling conditions are shown in Table 2. Chemical pollutant concentrations were sampled at three points (living room, bedroom, outside), and emission rates of building materials were sampled by using Field and Laboratory Emission Cell (Wolkoff *et al.*, 1991) at two points (floor, wall of living room) during six different periods (see Table 3); (A) during construction, (B) right after the house was completed and (C–F) periodically after it was occupied.

Environmental Measurements

Air change rate, temperature and relative humidity were measured for evaluation of indoor environment. Temperature and relative humidity were measured at 10 different locations in the house for 8 months. Air change rate of the house was measured by two methods while operating the ventilation system. Active sampling test using SF_6 (tracer gas method) was conducted to measure potential air change rate of the unoccupied house. Mechanical ventilation system was turned off and all windows were closed while spreading out the tracer gas (SF_6). After stirring the air by fan, concentration of SF_6 was measured by multi-gas monitor. To measure the average ventilation rate of 2 weeks under living conditions, passive sampling method, Per Fluorocard Tracer, was used (PentIAQ, 1998).

Table 2 Sampling conditions

	Aldehydes	VOCs
Sampler	Sep-Pak DNPH silica cartridge (short type)	Tenax TA (60/80mesh)
AC air flow rate (ml/min)	400	
Air flow rate (l/min)	0.3	0.1
Sampling time (min)	33	32
Sampling volume (l)	10	3.2
Analysed by	HPLC	GC/MS

Table 3 Date of investigation

Date	Situation of the house	Period
20 May 2001	Under construction	A
July 29	After completion	B
August 9	1 week after occupation	C
September 6	1 month after occupation	D
November 15	3 months after occupation	E
7 February 2002 (concentration) 12 February (emission rate)	6 months after occupation	F

RESULTS

Aldehydes

Concentration. Only minor difference was found between the indoor concentration of living room and that of bedroom (see Figure 2). Concentrations of formaldehyde were lower than 100 μg/m^3, which is below the guideline of WHO and Japanese Ministry. The value dropped greatly after the house was occupied, because measurements were conducted under mechanically ventilated and cooled condition. Results of the questionnaire showed that a lot of wooden furniture was carried into the house between the periods C and D. This was considered to be the reason why the indoor concentration measured during period D was larger than that of period C. Concentration of acetaldehyde at period A was high. It was suspected that foundation materials (e.g. insulator) were the origin.

Emission rate. The result of aldehydes emission rate is shown in Figure 3. The value measured during the period E increased, because floor heating system was used during the measurement. In contrast, the emission rates of wall interior materials were larger than that of foundation materials. After occupancy, walls affect the indoor air quality much more than floors do.

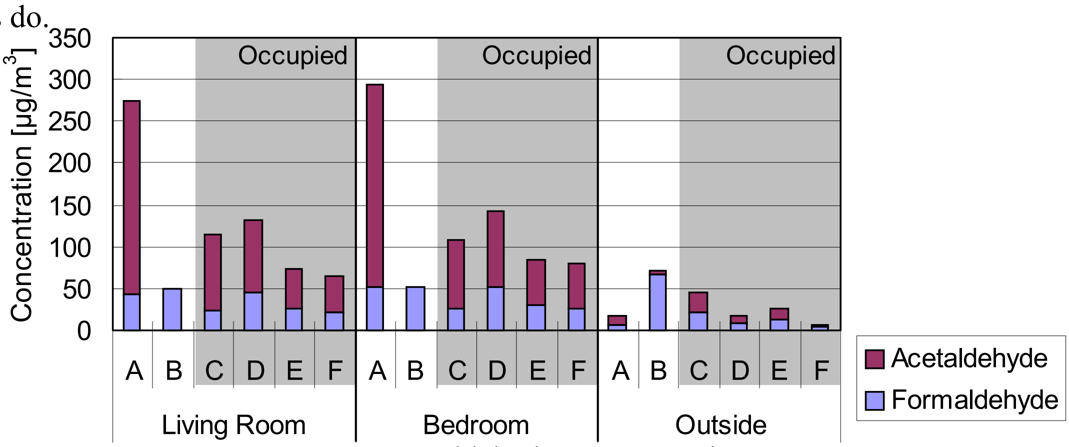

Figure 2 Aldehydes concentration.

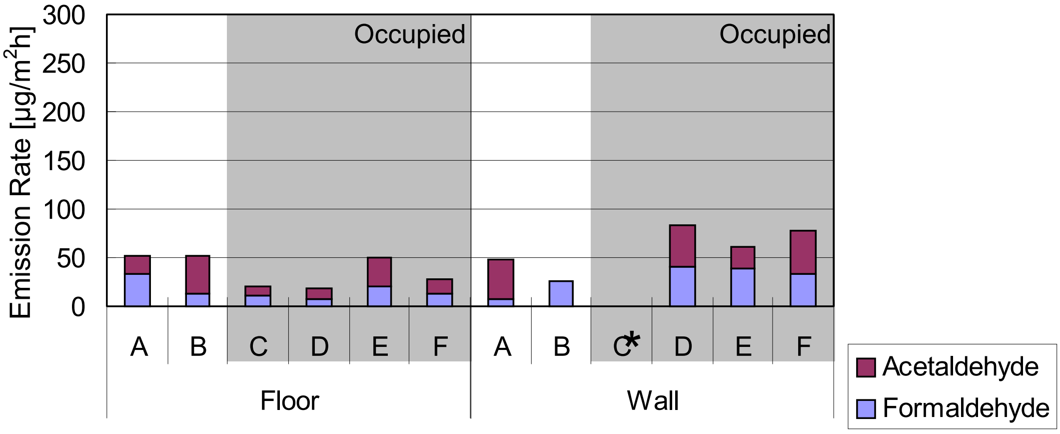

Figure 3 Aldehydes emission rate.

*Not recorded

VOCs

Concentration. The result of VOCs concentration is shown in Figure 4. The values of TVOC measured after three months occupancy were above 1000 µg/m^3. α-Pinene and D-limonene were the main substances.

Emission rate. The result of VOCs emission rate is shown in Figure 5. The emission rates of VOCs from the floor measured during the period E increased as for aldehydes. The emission rates of TVOC from the wall decreased constantly. The main ingredient of VOCs was terpenes.

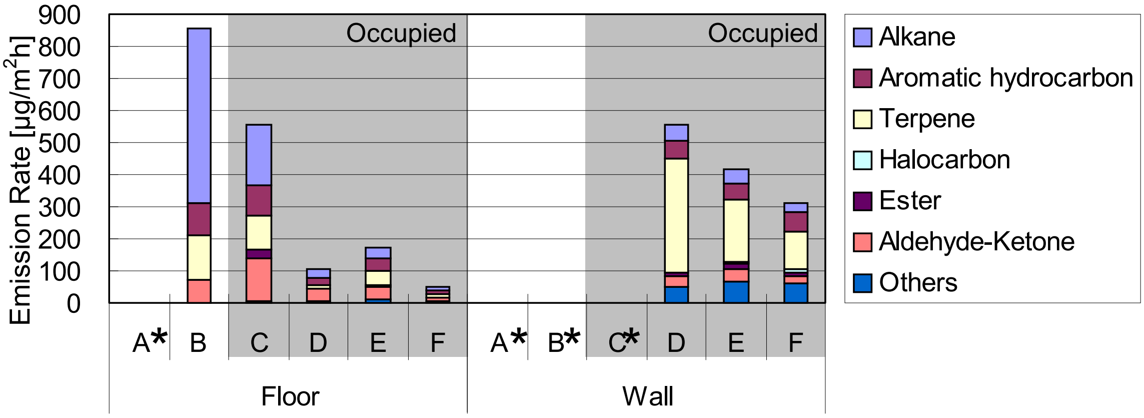

Figure 4 VOCs concentration.

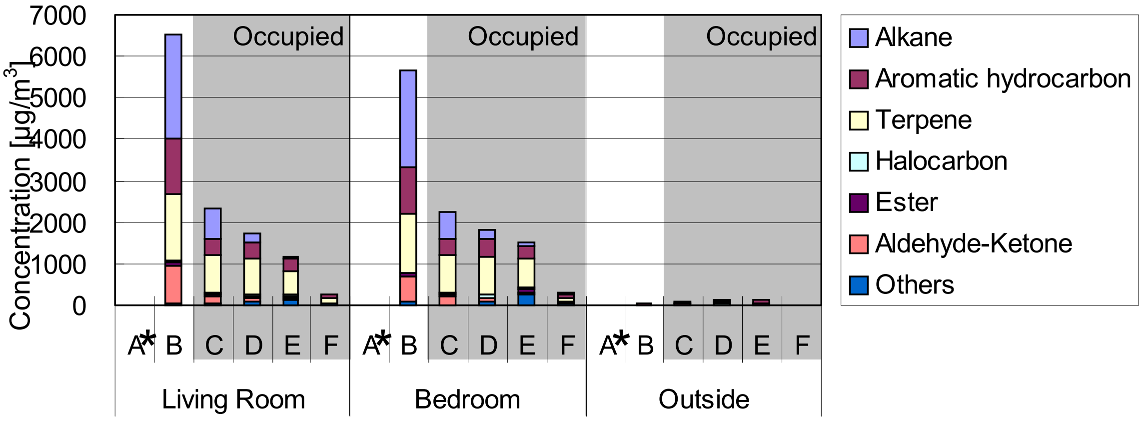

Figure 5 VOCs emission rate.

*Not recorded

Ventilation

The air exchange rate of the house measured by active sampling method was 0.29[ACH], which was slightly smaller than the intended value. The result of passive sampling method using PFT (the average ventilation rate of 2 weeks) was 0.53[ACH] under living conditions. From the result of passive sampling, the two-zone calculation showed a large mixing of air between the first and the second floors. Indoor temperature was uniform after residential occupancy.

DISCUSSION

Indoor concentration of formaldehyde had been kept low. On the other hand, indoor concentration of acetaldehyde was somewhat higher. Government committee published its guideline of 48 $\mu g/m^3$. Some of the natural materials may emit acetaldehyde. So, further discussion is required. High indoor concentration of VOCs was observed. While aromatic hydrocarbon is the main ingredient in a typical house in Japan (Momose and Okada, 1998), terpenes, particularly α-pinene and D-limonene, were the main ingredients in the present house and considered to be emitted from cedar materials and wooden furniture (see Table 4).

Table 4 Details of VOCs concentrations (40 days after completion)

Ingredients	WHO guideline ($\mu g/m^3$)	The house investigated ($\mu g/m^3$)	The house investigated (%)	Typical house in Japan ($\mu g/m^3$)	Typical house in Japan (%)
Alkanes	100	232	13	0	0
Aromatic hydrocarbon	50	357	21	1690	33
Terpenes	30	887	52	120	2
Halocarbons	30	45	3	130	3
Esters	20	24	1	0	0
Aldehyde–ketone	20	76	4	168	3
Others	–	106	6	3020	59
TVOC (ECA, 1997)	–	1669	–	5000	–

The main substances of VOCs are shown in Table 5. α-Pinene is clearly the main substance. Terpenes are VOCs often produced and emitted by wooden products and considered to have a good effect on the human body. The reason why humans feel nice and freshened up when breathing in the woods is considered to be the effect of terpenes (Kamiyama *et al*., 1981).

Naturally generated terpenes are generally not harmful at low concentration. However, air-tight houses built in recent years tend to have high indoor concentration of terpenes compared to the traditional houses.

One study reported that both ozone and terpenes were commonly found indoors, and certain ozone/terpene reactions proceeded fast enough to compete with air exchange rates in buildings. It was proposed that reactions between unsaturated VOCs and oxidants (e.g. terpenes and ozone) might produce products more likely to be responsible for eye and airway irritation than the chemically less reactive VOCs usually measured indoors (Wolkoff *et al*., 1999). When wooden products are used abundantly for building structures and finishings, emission of terpenes increased and thus additional cautions might be necessary if there is a danger of chemical reaction with ozone.

Table 5 Main substances of VOCs concentration (μg/m³)

Substances		B	C	D	E	F
Alkanes	Decane	228	450	15	13	5
	Undecane	1213	126	26	11	4
	Dodecane	960	109	29	11	3
	Total	2505	748	232	58	23
Aromatic hydrocarbons	Toluene	983	266	236	147	34
	Ethyl benzene	104	32	24	23	7
	Xylene	128	41	47	46	13
	Styrene	58	31	22	37	18
	Total	1342	397	357	281	80
Terpenes	A-pinene	1298	722	828	540	104
	β-Pinene	41	21	14	8	3
	D-limonene	247	150	45	24	7
	Total	1586	893	887	572	115
Halocarbons	Total	59	38	45	37	13
Esters	Ethyl acetate	41	24	21	36	10
	Total	67	32	24	37	11
Aldehyde–ketone	Methyl ethylketone	268	61	26	25	4
	Total	900	215	76	54	8
Ohters	Total	57	22	105	133	23
Total		6518	2343	1726	1173	274

CONCLUSIONS

IAQ in a house using natural materials was investigated for 8 months during construction and after occupancy. While formaldehyde concentration had been kept low, high indoor concentration of VOCs was observed. Terpenes were the main ingredients in this house and were considered to be emitted from wooden products.

ACKNOWLEDGEMENTS

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