Effects of Room Specifications and Lifestyles of Residents on Indoor Formaldehyde Concentrations — Formaldehyde Concentrations in Student Dormitories —

Michiyo AZUMA¹⁾, Hiroko KUBO²⁾ and Norio ISODA²⁾

¹⁾ Faculty of Health Science, Kio University,
4-2-2, Umaminaka, Koryo-cho, Kitakatsuragi-gun, Nara, 635-0832, Japan
TEL: +81-745-54-1601; FAX: +81-745-54-1600
E-mail: m.azuma@kio.ac.jp

²⁾ Faculty of Human Life and Environment, Nara Women's University,
Kita-uoyanishimachi, Nara, Nara, 630-8506, Japan

(received on April 14, 2015, accepted on August 20, 2015)

Abstract

The concern with indoor air pollution has been growing as a serious social problem since the 1990s in Japan, the Ministry of Health, Labour, and Welfare has established guidelines for addressing indoor chemical substances, and the amended Building Standards Law has restricted the use of building materials containing formaldehyde and required rooms to have ventilation equipment. The purpose of the present study was to examine the effects of differences in the building material specifications on indoor air quality. Two student dormitories were selected for investigation: a student dormitory remodeled using interior finishing materials containing low- formaldehyde substances; and a dormitory built according to conventional specifications. Indoor formaldehyde concentrations were lower than the guideline established by the Ministry of Health, Labour, and Welfare, even in summer under high-temperature conditions, due to the implementation of the policy to reduce chemical substances in building materials and the effects of the restrictions. However, problems were identified in terms of increases in indoor concentrations after installation of furniture, and mean concentrations during sleeping hours. Ventilation performed by residents effectively reduced mean formaldehyde concentrations. To maintain appropriate indoor air quality, it is important for residents to pay attention to ventilation and room furniture, and their lifestyle, in addition to the selection of building materials.

Keywords: formaldehyde, specification, field measurement, ventilation, lifestyle

1. Introduction

In Japan, a large number of studies on indoor air pollution have been conducted since the 1990s, when this issue started to attract attention as a social problem (e.g., Yoshino et al., 2000; Sick House Syndrome Association, 2001; Azuma et al., 2002, 2003a; Ministry of Land, Infrastructure, Transport, and Tourism, 2006). Since 1997, the Ministry of Health, Labour, and Welfare has established guidelines regarding concentrations of indoor chemical substances. Furthermore, the Building Standard Law was revised and came into effect in 2003 as a measure against so- called “sick house syndrome”. The amended law restricts the use of building materials containing formaldehyde, and requires that all rooms have ventilation equipment, in principle. Some studies

have suggested that formaldehyde concentrations in newly built houses for which the above-mentioned measures have been implemented are lower than those in housing built a few years earlier. (Ministry of Health, Labour, and Welfare, 2013; Osawa et al., 2003, 2004). However, few studies have focused on differences in the specifications of building materials and measurements conducted on a continuing basis. We have previously reported continuous measurements of formaldehyde concentrations in a student dormitory that had been built prior to the establishment of the guidelines (Azuma et al., 2003a). Following the establishment of the guidelines, the dormitory was remodeled, and we had the opportunity to assess indoor air quality. The present study compared different types of dormitories

by focusing on differences in specifications, and discussed factors influencing indoor air quality.

2. Methods

2.1. Object

Summaries of the student dormitories analyzed in this study are shown in Table 1. The dormitories are on the same premises in Nara City. Dormitory 2 was built between 1959 and 1961 as a reinforced concrete house, and was remodeled in 2002. This dormitory was constructed using low-formaldehyde building materials, whereas the interior of Dormitory 1 was finished according to conventional specifications developed before the restrictions had been implemented. Specifically, the following materials were used: non-formaldehyde-based aqueous adhesive; wallpaper meeting the guidelines established by the Japan Wallcoverings Association or wallpaper of a similar level; and F_{C_0} -type plywood. Classification according to formaldehyde emission rate are shown in Table 2. The formaldehyde emission level of F_{C_0} was equivalent to the present $F_{☆☆☆☆}$, representing the lowest level of emission as of 2002.

The areas analyzed comprised one-room, with no inlets of air. Regarding ventilation equipment, a ventilation fan (85 m³/h) was present in the bathroom of both dormitories. Measurement rooms, situations and measurement times are shown in Table 3.

First we obtained a permit to measure the indoor air quality in the dormitories from the administrator of

the dormitory facilities and began taking measurements in 2002. We then conducted two questionnaire surveys in student dormitories in 2003 and 2009, and asked for permission of the residents to measure indoor air quality in their rooms. As a result, residents of 13 rooms (L5-L13 and C1-C4) agreed to participate in the measurement survey. All participating residents were female university students.

2.2. Measurement items

A formaldehyde detector tube (Type710; Kohmyo Rikagaku, Tokyo, Japan) for indoor air was used to make measurements before residents moved into Dormitory 2. Sampling time for the detector tube was 30 min with flow rate of 300 ml/min using an exclusive pump. The accuracy of this method was being confirmed (Azuma et al., 2003b). After ventilation for 15 min, windows of the rooms were closed and the ventilation fan was stopped for at least 5 h before measurements were conducted. Formaldehyde concentration was directly read from the values on the detector tube and corrected using a temperature-correction factor table. Measurement was conducted in the center of the room, 120 cm above the floor. Room temperature and relative humidity (RH) were also measured using a recording device (TR-72; T&D, Nagano, Japan or RS-12; Espec Mic, Aichi, Japan). The DNPH-passive method (Aldehyde Diffusive Sampling Device; Sigma-Aldrich, Tokyo, Japan) was used to measure the mean

Table 1 Profiles of student dormitories

	Dormitory 1	Dormitory 2
Completion	Constructed March 1996, 1997	Remodeled September 2002
Construction method	RC	RC
Floors	5	2
Direction of room	South or north	South
Floor area (excl. a bath and WC)	9 m ²	10 m ²
Interior finishing Wall & Ceiling Floor	Conventional type PVC * wallpaper Vinyl tiles	Low-formaldehyde type PVC wallpaper Wooden floor (plywood)

* PVC: polyvinyl chloride

Table 2 Formaldehyde classification and restrictions in the amended Building Standard Law

Formaldehyde emission rate *1 (mg/m ² ·h)	Formaldehyde-emitting building product		Restrictions on interior finishing materials	Former relevant standard JIS/JAS	Formaldehyde emission rate *2 (mg/L)	
	Type	Relevant standard (JIS, JAS)*			Average	Maximum
Over 0.12	1	Unclassified	Banned	E_2/F_{C_2}	≤5.0	≤7.0
0.02-0.12	2	$F_{☆☆}$	Limited use	E_1/F_{C_1}	≤1.5	≤2.1
0.005-0.02	3	$F_{☆☆☆}$	Limited use	E_0/F_{C_0}	≤0.5	≤0.7
Up to 0.005	-	$F_{☆☆☆☆}$	No restrictions	-	≤0.3	≤0.4

*JIS: Japanese Industrial Standards, JAS: Japanese Agricultural Standards

*1 JIS A1901: Determination of the emission of volatile organic compounds and aldehydes by building products-small chamber method

*2 JIS A1460: Determination of the emission of formaldehyde from building boards-desiccator method

formaldehyde concentration during habitation. Air was collected over a period of 24 h and while the subjects were asleep. Immediately after sampling, the samples were sealed and sent to an institute under low temperature for analysis. Adsorbed constituents were eluted out using acetonitrile, and analyzed using high-performance liquid chromatography. The air change rate was measured by the carbon dioxide concentration (CO₂) attenuation method. Indoor CO₂ concentration was measured 15–20 min after, increasing to approximately 5,000 ppm, and the result was calculated using the Seidel method. A self-completed questionnaire was also conducted to assess ventilation situation and use of air-conditioning by the residents.

3. Results

3.1. Thermal environment and ventilation rate

Table 3 shows the list of measurement times and situations, and measurement results for the thermal environment and indoor air quality. Thermal environment before residents moved into Dormitory 2, mean temperature and humidity at the time of measuring formaldehyde concentrations ranged from 24.7°C to 30.2°C and from 44% to 68%, respectively. Air change

rates ranged from 0.23 times /h to 0.5 times /h (under no ventilation conditions).

Mean temperatures during the habitation were ranging from 26.9°C to 29.6°C in 2003, and were from 24.3°C to 28.0°C in 2009, and those of relative humidity were from 51% to 62% and from 61% to 74%, respectively (Table 3). Those conditions represented high-humidity/high-temperature environments. The situations of ventilation and use of air-conditioning are shown in Table 4. Differences were seen in the habit of opening windows among residents, and duration of windows being open ranged from 1 h to 24 h. A small window for ventilation was opened throughout the day only for [L8]. Achieving ventilation during sleeping seemed difficult, and some residents kept windows closed all night. Air conditioning was used for 2 h by a resident in [L5].

3.2. Formaldehyde concentrations

3.2.1. Measurement in Dormitory 2 (low-formaldehyde type) before residents moved in

Measurements of formaldehyde concentrations just before completion of construction, just after completion of construction (before installation of furniture),

Table 3 List of measurement times and measuring situations, and measurement results for thermal environments and indoor air quality

Measurement time	Situation	Type *1	Room	Floor	Temperature (°C)	Relative humidity (%)	N/h *2	Method *3	Sampling (h)	Number of samples	Formaldehyde (ppm)	Acetaldehyde (ppm)	Figure				
2002.9	Just before completion		L1	1	29.0	68	0.28	A	0.5	2	0.037	-	Fig.1				
			L2	2	30.2	59	0.44				0.026	-					
2002. 9	Just after completion (no furniture)		L1	1	27.3	39	-			2	0.024	-					
			L2	2	28.3	35	-				0.019	-					
2002.10	Just before moving in (with furniture)		L1	1	24.7	59	-			4	0.102	-					
			L2	2	27.0	43	0.23				0.079	-					
			L3	1	25.3	51	0.50		0.102		-						
			L4	2	26.5	44	-		0.095		-						
2003.7	L		L5	1	27.8±1.1	52±3.7	-		P	24h	23.5	6	0.018	0.007	Fig.2		
			L6	1	28.3±0.4	60±3.1	-						24	0.031		0.010	
			L7	1	29.6±0.4	55±5.2	-						24	0.031		0.006	
			L8	2	29.3±0.4	52±3.3	-						24	0.013		0.005	
		L9	2	28.6±0.5	54±2.4	-	24	0.017					0.006				
		L10	2	28.6±1.3	53±3.4	-	24	0.014					0.005				
		L5	1	26.9±1.3	51±5.0	-	Slepi ng	6.3		4	0.018	0.008					
		L6	1	27.9±0.2	62±2.6	-					6.7	0.075	0.023				
		L7	1	29.2±0.1	61±3.8	-					-	0.061	0.014				
		L8	2	29.1±0.2	56±3.0	-					-	-	-				
		L9	2	28.2±0.2	54±1.5	-					7	0.020	0.007				
		L10	2	27.2±1.1	53±3.0	-					-	-	-				
2009.9	Under habitation	L11	1	27.7±0.5	66±2.3	-	P	24h	24	3	0.028	-	Fig.3 Fig.4				
		L12	2	27.7±0.7	61±3.5	-					24	0.013		-			
		L13	2	27.7±0.5	61±2.7	-					24	0.013		-			
		L11	1	28.0±0.3	69±1.2	-					Slepi ng	7		3	0.036	-	
		L12	2	27.2±0.1	62±0.7	-									7	0.014	-
		L13	2	27.4±0.2	62±0.7	-									7.1	0.014	-
		C	C1	4	24.6±0.7	73±4.3		-	24h	24	23.9	4		0.008	-		
			C2	4	27.9±0.5	61±2.7		-						0.061	-		
			C3	3	27.0±0.4	63±2.0		-						24	0.029	-	
			C4	5	25.0±0.9	73±7.1		-						24	0.017	-	
			C1	4	24.3±0.3	74±0.9		-	Slepi ng	7.2	8	3		0.011	-		
			C2	4	28.0±0.0	61±0.6		-						-	-	-	
			C3	3	26.8±0.4	64±1.5		-						-	0.036	-	
			C4	5	24.3±0.3	74±1.6		-						7.5	0.013	-	

* -: no data

*1 L: low formaldehyde type (Dormitory 2), C: conventional type (Dormitory 1)

*2 N/h: air change rate

*3 A: active method (detector tube), P: passive method (DNPH-passive)

and just before residents moved in (after installation of furniture) are shown in Table 3. Concentrations just before and after completion were lower than the guideline ($100\mu\text{g}/\text{m}^3$, 0.08 ppm at 25°C). After wax-coating of the floor following the completion of construction, concentrations remained low (around 0.02 ppm). However, concentrations became significantly higher after furniture had been installed. Previous studies have suggested a significant correlation exists between formaldehyde concentration and temperature (Inoue, 1997), and revised concentrations at 28°C / 50% RH according to Inoue's formula are shown in Figure 1. All results from furnished rooms exceeded guideline value.

3.2.2. Measurement in Dormitory 2 after residents moved in

Measurements were conducted during the first summer season following the completion of construction. Although the temperature was high, mean 24 h formaldehyde concentration was low (range, 0.013 - 0.031 ppm; mean, 0.02 ppm). On the other hand, mean formaldehyde concentration during sleeping hours at night, in which mean temperature was lower than that during 24h measurement, was high (range, 0.018 - 0.075 ppm ; mean, 0.04 ppm). Mean concentrations and

Fig. 1 Formaldehyde concentrations as measured using the detector tube method (revision at 28°C , 50%RH)

Fig. 2 Formaldehyde concentrations as measured using the DNPH-passive method. Values represent means and $\pm$ SD.

standard deviations over 24-h and during sleeping are shown in Figure 2. Simple comparisons could not be performed because residents lived in rooms that were not identical, and concentrations in 2009 (7 years after remodeling) were lower than levels in 2003. Mean concentration during sleep tended to be higher than that over 24 h. Acetaldehyde concentrations were also analyzed as references, and all measurements were lower than 0.03 ppm (the guideline of Ministry of Health, Labour, and Welfare) (Table 3).

3.2.3. Measurements in both student dormitories

Mean formaldehyde concentrations measured in the two dormitories with different specifications of interior finishing are shown in Table 2. [L11], [L12], and [L13] were the rooms in Dormitory 2 remodeled according to low-formaldehyde specifications, and [C1], [C2], [C3], and [C4] were the rooms in Dormitory 1 built according to conventional specifications. Mean concentrations over 24 h and during sleep were both under the guideline level, and when room temperature was over 27°C , concentrations in Dormitory 1 (conventional type) tended to be higher than those in Dormitory 2 (low- formaldehyde type).

4. Discussion

Previous studies have already examined changes in indoor formaldehyde concentrations in Dormitory 1 over time since their establishment. When only a short period of time had passed since establishment, formaldehyde concentrations were significantly higher than the guideline level of 0.08 ppm, and concentrations in summer or under a high-temperature environment were particularly high. Formaldehyde concentrations gradually decreased while also being affected by seasonal temperature changes (Azuma et al., 2003a). The first measurement in Dormitory 2 (low -formaldehyde type) was conducted while exterior work was being finished, immediately prior to the completion of construction. Although room temperature was high (30°C), indoor formaldehyde concentrations were 0.026 and 0.037 ppm, approximately half the level required by the guideline. This confirms the efficacy of establishing guideline values and reduced formaldehyde levels in building materials. According to the results of a survey of concentrations of indoor chemical substances in Hong Kong and East Asia, formaldehyde was detected in 90% of houses in Hong Kong and the mean 24 h concentration was $112.3\mu\text{g}/\text{m}^3$ ($n=100$), compared to $37.5\mu\text{g}/\text{m}^3$ in Japan ($n=97$), as the lowest of the five countries (Guo H. et al., 2009). This survey was conducted around the same period as our own investigation; suggesting that measures to reduce formaldehyde in Japan are proving effective.

The next measurement was conducted 10 days after the second, when the rooms had been furnished,

and some concentrations were significantly higher than the guideline level of 0.08 ppm. When considering the quality of indoor air, the effects of room furniture cannot be ignored. In fact, the formaldehyde concentrations before the installation of furniture were approximately 0.02 ppm, and quadrupled on furniture installation. These effects were particularly significant because the volumes of the rooms selected for investigation in the present study were small.

Regarding formaldehyde concentrations using the DNPH-passive method under habitation, levels did not exceed guideline criteria even in the first summer after completion. The efficacy of measures implemented to improve building materials was thus confirmed. Concentrations differed according to resident lifestyles, including ventilation habits; and concentrations in [L6] and [L7] during sleep were higher than those in others. Mean concentrations for each measurement specification tended to be higher during sleep than the 24-h level (Fig.2). This was attributed to some residents keeping windows closed through the night, especially during the 2003 measurements (Table 4).

A previous study suggested that high indoor formaldehyde concentrations are associated with increased incidence of allergies among children (Garrett et al., 1999). Another study suggested that even short-term exposure to formaldehyde at approximately 0.08 ppm may increase transdermal water loss in patients with atopic dermatitis, damage the barrier function of skin, and aggravate the disorder (Bemadette et al., 1998). Of the six subjects who participated in the 2003 experiment, the residents in [L6] and [L9] had atopic dermatitis. The resident in [L8] was an asthma patient, and residents in [L6], [L7], and [L8] all had allergic rhinitis. The importance of reducing indoor formaldehyde concentrations may increase depending on the constitution of residents. The Japanese formaldehyde concentration

guideline established based on the World Health Organization guideline for stimulant properties, focused on short-term exposure to concentration of $100\mu\text{g}/\text{m}^3$ (0.08 ppm) per 30 min. For example, the Air Quality Guideline of Canada specifies a maximum short-term (one-hour) exposure concentration of $123\mu\text{g}/\text{m}^3$, taking

Fig. 3 Relationship between air temperature and formaldehyde concentration

Notes

- (1) Predicted concentration at minimum value for conventional type by Inoue's formula
- (2) Predicted concentration at maximum value for conventional type by Inoue's formula
- (3) Predicted concentration at minimum value for low- formaldehyde type by Inoue's formula
- (4) Predicted concentration at maximum value for low- formaldehyde type by Inoue's formula
- (5) Approximated line for formaldehyde concentration when using an air conditioner and electric floor heater in identical housing
- (6) Approximated line for formaldehyde concentration with conventional type
- (7) Approximated line for formaldehyde concentrations in apartment buildings constructed in 1995-1996

Table 4 Situation of ventilation and air conditioner use during measurements

Type	Room	24-h				Sleeping			
		Ventilation (h)			Air conditioning (h)	Ventilation (h)			Air conditioning (h)
		Window open	Small window open	Ventilation fan		Window open	Small window open	Ventilation fan	
Low formaldehyde type	L5	8	0	0	2	3.5	0	0	2
	L6	2.75	0	0.25	0	0	0	0	0
	L7	4	0	12.25	0	0	0	0	0
	L8	5	24	0	0	0	7	0	0
	L9	5	0	0	0	0	0	0	0
	L10	5	0	0	0	0	0	0	0
	L11	5.5	0	0.5	0	0	0	0	0
	L12	24	0	0	0	7	0	0	0
Conventional type	C1	24	0	2	0	8.5	0	0	0
	C2	1	0	0	0	0	0	0	0
	C3	24	0	24	0	8	0	8	0
	C4	24	0	8	0	7	0	7	0

into consideration irritation of the eyes, and a long-term (8h) exposure concentration of $50 \mu\text{g}/\text{m}^3$ in terms of the effects on the respiratory condition of children. Consideration about the risks of long-term exposure in living environments in Japan is needed.

Figure 3 shows the relationship between room temperature and formaldehyde concentration based on the specifications of interior finishing using data measured in 2009. When room temperature was high, formaldehyde concentration tended to be high, confirming the temperature dependency of formaldehyde concentration. Years after construction had been finished, when room temperature was high, concentrations in conventional-type rooms tended to be high compared with the low-formaldehyde type. It might be inferred from this result that the adhesive for vinyl floor tiles and large amounts of built-in plywood furniture represented substantial influences. Measurement results were revised for 50%RH using Inoue's formula at maximum and minimum concentrations of each specification to analyze the influence of temperature. Predicted concentrations changed according to temperature change (Fig. 3; (1), (2), (3), (4)). Formaldehyde concentration (Active method) changed with temperature using an electric floor heater and air conditioner measured in identical housing, indicating changing tendencies similar to those predicted (Fig. 3 : (5) ; Azuma 2002). While the approximate line of conventional-type measurement results tended to differ from those predicted ($R^2=0.88$), other factors besides temperature were shown to influence concentrations (Fig. 3; (6)). Regarding the low-formaldehyde type, although the variation in temperature range was small, concentration changes with temperature change were large with conventional-type rooms ; such that increasing the duration of windows being open decreased mean room temperature as no subjects used air conditioning during this measurement. The reason why concentration change increased with temperature change would be the compound influence of temperature and ventilation situation. In another measurement of formaldehyde concentrations (passive method, Ikeda et al., 1997) in apartment buildings constructed during 1995-1996, the relationship between temperature and concentration was unclear because ventilation situations, interior specifications, and kinds of furniture all varied (Fig. 3 ; (7)). Formaldehyde concentrations in living environments are thus influenced by various factors.

According to the results for measuring formaldehyde concentrations emitted from single wooden beds conducted by the National Consumer Affairs Center of Japan, concentrations from three of seven beds at 1 day after installation were higher than the indoor concentration guideline. The concentration from one of these three beds was more than seven-fold higher than the

guideline, and those from the other two were still higher than the guideline at 15 days after the bed had been installed (National Consumer Affairs Center of Japan, 2008). Long-term differences in indoor formaldehyde concentration were presumably attributable to differences in the types of bed installed in the rooms: plywood beds in conventional-type rooms, and beds with pipe frames in low-formaldehyde-type rooms. Some studies have suggested that a large volume of formaldehyde is generated when plywood obtained from buildings constructed several decades ago undergoes hydrolysis, and large volumes of formaldehyde can even be emitted from rooms constructed many years ago if the room temperature and humidity are high (Ohno et al., 2005; Motohashi et al., 2011). A previous survey suggested a correlation between wall temperature and indoor formaldehyde substances identified in a conference room built many years ago (Ohno et al., 2002). A bed is a large piece of furniture often made of plywood, and tends to become humid because people sweat while asleep, and influencing their respiratory activity. Some labeling systems or self-regulatory ratings on products using low-formaldehyde materials have been established in Japan (Azuma et al., 2008). When selecting beds, attention must be paid to these labels to ensure safety.

In principle, the amended Building Standards Law requires all rooms to have ventilation equipment allowing an air change rate of ≥ 0.5 times / h (24-h ventilation system). This is because formaldehyde is emitted from furniture even if building materials containing less formaldehyde are used for interior finishing. The rate of using the 24-h ventilation system suggested in previous studies varies depending on the location and form of the residence, from 30% (Sugimoto et al., 2005; Komatsu et al., 2007 ; Banba et al., 2013) to 70% (Toriumi et al., 2012). In the present study, the rate of using ventilation fans was significantly lower than reported in the above-mentioned studies, with one case showing operation of the ventilation equipment for 24 h. Almost all residents were opening windows for ventilation. According to the records on resident activity, differences existed in the habit of opening windows: fully open ; half - open ; and open only a small amount. Indoor concentrations could be predicted to decrease exponentially with ventilation, depending on the relationship between emission rate and ventilated air volume, because formaldehyde concentrations in outside air are low. The rate of opening windows was thus calculated as an index equivalent to ventilated air volume. Figure 4 shows the relationship between the window-opening correction factor and indoor formaldehyde concentrations, with estimated concentrations for room temperatures of 30°C and 35°C in 2009 (using 100%, 50%, and 30% for windows completely

open, half-open, and slightly open, respectively). Values for percentage of time that windows were open were divided by 24 hours or sleeping hours. During measurement, the ventilator was used in all cases simultaneously with window opening, and no subjects opened a small window, so neither use time was counted in the window opening rate. The window-opening correction factor and indoor formaldehyde concentration were approximated by a negative exponential function ($R^2=0.87$, $R^2=0.82$), and concentrations in the low-formaldehyde type remained sufficiently low when percentage of time window open was $\geq 50\%$. Continuous ventilation must be conducted appropriately in summer or under high-temperature conditions, particularly in conventional-type rooms. These findings are consistent with the results of previous studies involving multiple regression analyses of personal exposure to formaldehyde: opening windows for a short time has negative effects (Matsumura et al., 1985); and due to the characteristics of formaldehyde, concentrations tend to be high when ventilation is poor in airtight houses (Yoshino et al., 2009). Since the materials used for interior finishing and furniture significantly influence the air quality in small rooms, attention must be paid to the indoor thermal environment and to conducting ventilation on a continuing basis, in addition to the appropriate selection of building materials and room furniture. Ventilation is an important measure for addressing sources of air pollution, but windows are sometimes difficult to open for various reasons, including seasons and living environments. Ventilation fans should thus

be actively used to maintain an appropriate level of indoor air quality.

5. Conclusion

The present results suggest that introduction of tighter building materials regulations, indoor formaldehyde concentrations were effectively decreased. However, since formaldehyde concentrations in rooms with furniture were higher, paying attention to room furniture is crucial. The majority of residents opened windows for ventilation, and the rate of using ventilation fans was very low. In general, formaldehyde concentrations were high while residents were asleep because opening windows was considered a security risk. In this case, appropriate use of ventilation fans is important. In the present study, formaldehyde concentrations in conventional rooms were significantly lower than those seen in the initial survey. However, in summer or under high-temperature conditions, indoor concentrations may be above the guideline level when ventilation is poor, even if a number of years have passed since construction. To maintain good indoor air quality, it is essential for residents to ventilate rooms regularly, in addition to the appropriate selection of building materials and furniture.

Acknowledgement

We would like to express our heartfelt gratitude to those who participated in this study as subjects. The present study included parts of graduation research conducted by Natsumi Sako and Maiko Nakatsuji (former students at Kio University), to whom we would also like to express our sincere appreciation.

Note) The ventilation rates with “large windows open” and “small ventilation windows open” were 18.5 times/h and 3.0 times/h, respectively. The area of “slightly open” was determined to be equivalent to approximately twice that of an “open small ventilation window”, and was therefore, set to a value of about 6.0 times/h (30%) as calculated by the area ratio.

Fig.4 Relationship between rate of window being open, formaldehyde concentration, and predicted concentration at room temperature of 30°C and 35°C

Notes

- (1) and (2): Approximated line for formaldehyde concentration with conventional type ($R^2=0.87$)
- (3) and (4): Approximated line for formaldehyde concentration with low-formaldehyde type ($R^2=0.82$)

References

- Azuma K., Uchiyama I., Ikeda K. (2008) The regulations for indoor air pollution in Japan: a public health perspective, *Journal of Risk Research*, 11(3): 301-314 [In Japanese]
- Azuma M., Niiya M., Yagi F., Moriya Y., Hikita Y. (2002) Long term field-measurement survey on formaldehyde and volatile organic compounds in residences, *Journal of Architecture Planning, Transactions of Architectural Institute of Japan*, (552): 29-35 [In Japanese]
- Azuma M., Hikita Y., Isoda N. (2003a) Field study of indoor air quality and the living style in student

- dormitories (Part1) The relationship between formaldehyde concentrations and living style, *Journal of Home Economics of Japan*, 54 (7): 553-560 [In Japanese]
- Azuma M., Endo Y., Miyazaki T., Hikita Y., Ikeda H., Moriya Y., Hara I., Araki S.(2003b) Efficacy of a detector tube method in formaldehyde measurement, *Industrial Health*,41(4): 306-312
- Banba I., Azuma M., Abe H., Ikeda H.(2013) Questionnaire on the use of continuous ventilation system in the Kansai area, *AIJ Journal of Technology and Design*, 19(42): 665-670 [In Japanese]
- Eberlein-König B., Przybilla B., Kühnl P., Pechak J., Gebefügi I., Kleinschmidt J., Ring J.(1998) Influence of airborne nitrogen dioxide or formaldehyde on parameters of skin function and cellular activation in patients with atopic eczema and control subjects, *Journal of Allergy and Clinical Immunology*, 101(1): 141-143
- Garrett M. H., Hooper M. A., Hooper B. M., Rayment P. R., Abramson M. J. (1999) Increased risk of allergy in children due to formaldehyde exposure in homes, *Allergy*, 54(4): 330-337
- Guo H., Kwok N.H., Cheng H.R., Lee S.C, Hung W.T., Li Y.S. (2009), Formaldehyde and volatile organic compounds in Hong Kong homes: concentrations and impact factors, *Indoor Air* 2009, 19: 206-217
- Ikeda K., Matsumura T., Hori M., Kimura H., (1997), Measurement of indoor air quality in apartment buildings (Part 2) Formaldehyde concentrations of indoor air, *Summaries of technical papers of annual meeting Architectural Institute of Japan*: 753-754 [In Japanese]
- Inoue A. (1997), Guideline measure of formaldehyde concentrations in air, *Wood Industry* 52(1): 9-14 [In Japanese]
- Komatsu Y., Sato T., Takahashi A., Masuda S.(2007) Questionnaire study on the use of all day ventilation system toward architects and builders, *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan*: 819-820 [In Japanese]
- Matsumura T., Kametani K., Yoshihara K., Muramatsu S., Furuta Y., Yamada H. (1985), Studies on indoor air pollution (IV) – Personal exposure level of formaldehyde, *Japanese Journal of Public Health* 32(6): 287-295 [In Japanese]
- Ministry of Land, Infrastructure, Transport, and Tourism (2006) Results of the 2005 survey of the indoor concentrations of chemical substances, http://www.mlit.go.jp/kisha/kisha06/07/071130_.html (accessed August 20th 2015)
- Ministry of Health, Labour and Welfare (2013) Summaries of the 2012 national surveys of indoor air pollution and newly built houses, documents for the 17th review conference on sick house (indoor air pollution) -related problems, <http://www.mhlw.go.jp/file.jsp?id=148766&name=0000014475.pdf> (accessed August 20th 2015)
- Ministry of Health, Labour, and Welfare, Manual for the measurement of indoor chemical substances: <http://www.mhlw.go.jp/houdou/0107/h0724-1c.html> (accessed August 20th 2015)
- Motohashi K., Ono Y., Araki T., (2011) Formaldehyde emission from plywood exposed under various conditions for five years, *The Academic Lecture Meeting of the 2011, Conference of the Japan Society for Finishing Technology*: 137-140 [In Japanese]
- National Consumer Affairs Center of Japan (2008) Chemical substances emitted from wooden beds -Focusing on formaldehyde -, http://www.kokusen.go.jp/pdf/n-20081023_1.pdf (accessed August 20th 2015)
- Ohno H., Izumi Y., Sato S., Ito H., Yoshino H., Bogaki K.(2002) Investigation of variations in indoor HCHO concentrations based on experiments in summer and winter, *Journal of Human and Living Environment*, 9(1): 2-9 [In Japanese]
- Ohno Y., Motohashi K., (2005) Formaldehyde emission behavior from wood-based materials in the long term, *Summaries of Technical Papers of Annual Meeting Architectural Institute of Japan*: 937-938 [In Japanese]
- Osawa H., Ikeda K., Hayashi M., Kuwasawa Y., Manabe J., Nakabayashi Y.(2003) Present status of the indoor air chemical pollution in Japanese houses based on the nationwide field survey in 2000, *Journal of Environmental Engineering, Transactions of Architectural Institute of Japan*, (566): 65-71 [In Japanese]
- Osawa H., Ikeda K., Hayashi M., Kojima T., Manabe J., Nakabayashi Y.(2004) Present status of the indoor air VOC pollution in Japanese houses based on the nationwide field survey in 2000, *Journal of Environmental Engineering, Transactions of Architectural Institute of Japan*, (575): 61-66 [In Japanese]
- Sick House Syndrome Association (2001) The 2000 National Survey of Sick House Syndrome and Survey Reports [In Japanese]
- Sugimoto Y., Kurabuchi T., Endo T., Toriumi Y., Kumagai K., Noguchi M., Yanagisawa Y. (2005) Field survey of ventilation condition of houses with regular ventilation equipments, *Technical Papers of Annual, Society of Heating, Air-Conditioning and Sanitary Engineers of Japan*: 1061-1064 [In Japanese]
- Toriumi Y., Kurabuchi T., Kodera S. (2012) Research questionnaire on the usage of housing equipment focusing on ventilation system of apartment houses, *Journal of Environmental Engineering, Transactions of Architectural Institute of Japan*, 77 (674): 293-301 [In Japanese]

Yoshino H., Nakamura A., Ikeda K., Nozaki A., Kakuta K., Hojo S., Amano K., Ishikawa S. (2009) Field survey on IAQ and occupants' health in sick houses, Field survey on 62 houses in Miyagi prefecture, Journal of Environmental Engineering, Transactions of Architectural Institute of Japan, 74 (641): 803-809 [In Japanese]