Long term measurement of molds in the concealed spaces of detached houses in Japan

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ABSTRUCT

Recently, dampness in buildings has been indicated to be associated with occupants' health damages such as allergies. In particular mold in indoor air is considered to be a significant risk factor of health. The indoor concentration of molds becomes higher with mold growth on the surfaces of wall, floor, ceiling and so on. However, mold growth in the concealed spaces: inner wall spaces, beam spaces and crawl spaces, can not be ignored as one of the emission sources. There is a possibility that mold in the crawl spaces should move through the concealed spaces in walls and flow into rooms through the leakages of walls, outlets and so on. Molds in concealed spaces of the walls have been investigated for one year in eighteen detached houses located in the northern cities in Japan. The air of concealed spaces was collected through the leaks of switch panels on the walls and the colonies of molds were counted. This paper describes the measured results of molds and the possibility of molds in the concealed spaces as sources of indoor air pollution.

1. INTRODUCTION

Dampness in buildings has recently been shown to be associated with the health of occupants, causing allergies for example (Bornehag et al., 2001, Fisk et al., 2007). In particular, airborne fungi in indoor air are considered to be a significant health risk factor. In general, mold growth on the surfaces of walls, floors, ceilings and so on increases the indoor concentration of airborne fungi. However, mold growth in concealed spaces such as inner wall spaces, beam spaces and crawl spaces cannot be ignored as sources of airborne fungi (Figure 1). In Japan crawl spaces tend to be damp because of climatic conditions of humid, poor basement insulation, less air change rate in crawl spaces and so on. In the case of detached houses in Japan, many infiltration routes could be found. The equivalent leakage areas of recent houses have become smaller but the infiltration routes are left in the concealed spaces. It has been shown that these routes lead chemical compounds into the indoor air spaces from concealed spaces in a test house with exhaust ventilation in Japan (Hayashi and Osawa, 2008). Its result should show contaminant in concealed spaces could move into indoor spaces. Therefore, airborne fungi in concealed spaces could possibly become a source of indoor air pollution and move through concealed wall spaces and into rooms through wall cracks, power outlets and so on like chemical compounds.

Airborne fungi in concealed spaces of walls and other indoor spaces were studied for one year in eighteen detached houses located in northern Japanese cities to investigate mold in concealed spaces as a possible source of indoor air pollution. The air of concealed spaces was collected through the cracks of switch panels on the walls using an air sampler with PVC duct and the colonies of mold were counted. This paper describes the measured results of airborne fungi and the possibility of mold in the concealed spaces as sources of indoor air pollution thorough correlation analysis.

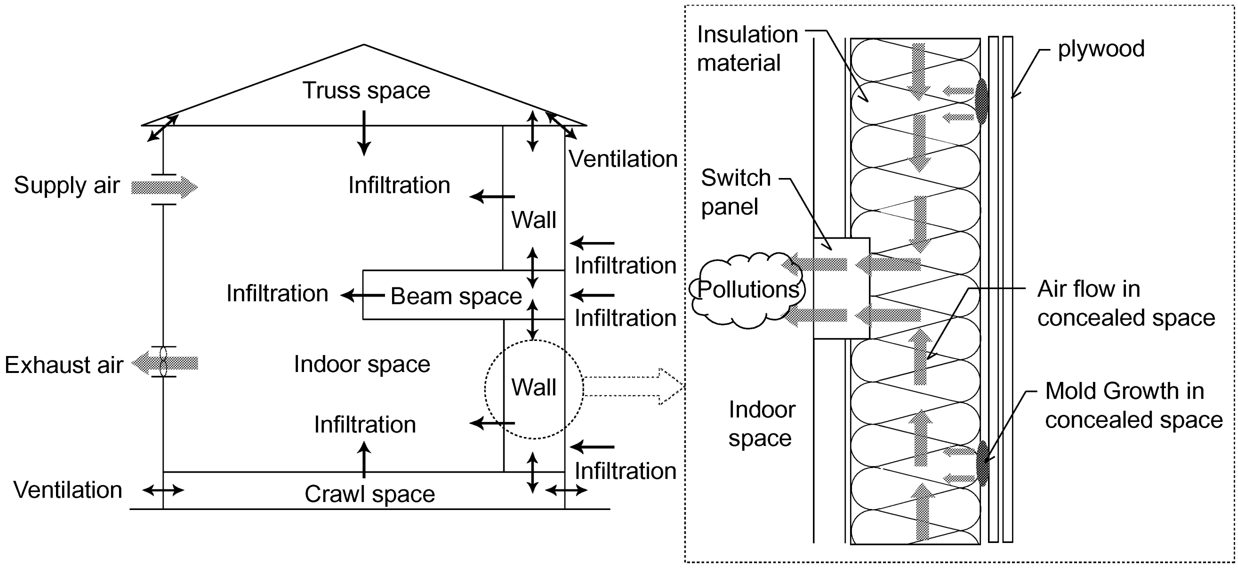

Figure 1: The influence of concealed-pollution sources on indoor air quality (Hayashi and Osawa, 2008)

Table 1: Description of investigated houses

No.	Location	Completion	Floor Area, m^2	Effective Leakage Area, cm^2/m^2	Basement*			Main heating equipment*			Ventilation system*	
					a	b	c	d	e	f	g	h
1	Akita	2003	262	2.8	O			O			Not equipped	
2		2001	146	0.7		O			O		O	
3		1999	124	2.2		O				O		O
4		2005	166	1.8			O	O				O
5		1999	227	0.3			O		O		O	
6		2000	132	1.7	O					O	O	
7		2001	135	2.3	O			O				O
8		2002	129	1.5						O	O	
9		2001	156	2.3		O		O			O	
10		2003	278	5.8	Concrete slab, No insulation					O	Not equipped	
11	Sendai	1980s	112	2.6	O					O		O
12		1990s	137	17.2	O					O		O
13	Morioka	2007	124	0.2			O	Air conditioning			O	
14		2007	161	0.5			O		O		Passive ventilation system	
15		2005	160	0.2			O		O			O
16		2001	154	0.6			O		O			O
17		2006	119	0.2			O		O		O	
18		2005	91	0.4			O	O			O	

* a: Concrete foundation wall, Floor insulation; b: Concrete slab, Floor insulation; c: Concrete slab, Foundation wall insulation; d: Water heating system with panel radiators; e: Electric heater with heat storage; f: Vented kerosene heater; g: Exhaust-supply ventilation system; h: Exhaust ventilation system

2. OUTLINE OF INVESTIGATION

2.1 Houses Investigated

Table 1 shows the description of eighteen investigated houses in Akita Prefecture, Iwate Prefecture and Sendai city, respectively.

Houses in Akita (No.1 to 10) were selected from among those studied previously in a questionnaire survey in 2005 (K. Hasegawa et al., 2007). Except for House No. 7, the houses are of wood-frame construction. All houses were constructed after 1999 and have insulated walls, ceilings and floors. With one exception the houses have a water heating system with panel radiators, an electric heater with heat storage, or a vented kerosene heater. Many of the houses have a mechanical ventilation system serving the entire house. House No. 1 is relatively airtight in order to improve indoor thermal comfort and has no mechanical ventilation system.

Houses in Sendai (No.11 and 12) have floor area in general in Japan. House No.11 is a prefabricated house with wooden panel, and House No.12 is a common wooden structure of Japanese house. The basement of these houses was insulated thermally on floor with concrete foundation.

Houses in Iwate (No.13 to 18) were constructed after 2001 and well-insulated according to recent Japanese building code for energy savings. The houses except House No.14, which has a passive ventilation system, have a mechanical ventilation system. The basement of all houses was insulated on foundation wall with concrete slab.

2.2 Method of Investigation

The investigation in House No.1 to 10 was conducted from August 2006 to July 2007, in House No.11 and 12 form January 2007 to December. The investigation in House No.13 to 18 has been conducted from October 2007 for one year. Temperature and relative humidity in the living room, bedroom and crawl space was measured continuously by small data loggers. Airborne fungal spores in five rooms, including the living room, bedroom and bathroom, were collected by a centrifugal sampler equipped with potato dextrose agar (PDA) medium and M40Y medium. Airborne fungal spores in the concealed spaces of walls were collected using a centrifugal sampler attached to a PVC duct (Figure 2). All samples were incubated at 25^{o}C for five days, and colony-forming units (CFU) were counted.

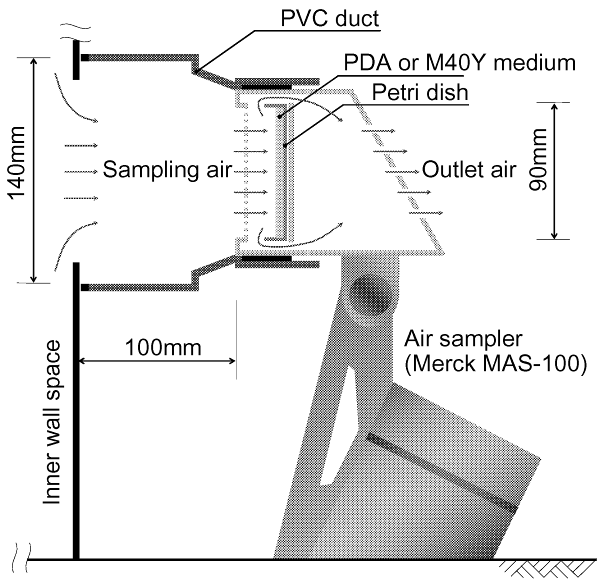

Figure 2: Method for sampling infiltration air from a switch box

3. RESULTS

3.1 Yearly airborne fungi profiles of concealed spaces

Figure 3 shows concentration of airborne fungi (by PDA medium) of indoor rooms and concealed spaces in Houses No. 3 and No. 8. Yearly profiles of airborne fungi in all measured houses were classified into two types. In one type, concentration of airborne fungi of indoor rooms and concealed spaces varied according to concentration of airborne fungi in outdoor air, for example as in House No. 8 (Figure 3(b)). Concentrations of airborne fungi in outdoor air, indoor rooms and concealed spaces were high during rainy and summer seasons and low during winter. In the second type, concentration of airborne fungi in indoor rooms and concealed spaces varied according to mold growth in each space, regardless of concentration of airborne fungi in outdoor air, for example as in House No. 3 (Figure 3(a)). In crawl spaces and living rooms, the concentration of airborne fungi increased to more than 1,000 CFU/m^3 in January and March, when outdoor concentrations were low. The concentration of airborne fungi in wall spaces around corridor in January was more than that in outdoor air, and it indicates that mold should be growing in wall spaces.

3.2 Airborne fungi and relative humidity in crawl space

Figure 4 shows the concentration of airborne fungi (by PDA medium) in the crawl space of each house. The concentrations in Houses No. 1, No. 3, No. 10, No. 11 and No.13 were comparatively high among the measured houses during winter, and they were more than 2,000 CFU/m^3. In general, mold growth is associated with relative humidity. Daily average relative humidity of these houses except for Houses No.13 during winter was higher than 70%. Therefore, humid environment in a crawl space could have caused high concentrations of airborne fungi in these houses. On the other hand, as to Houses No.13 there could be no association between the concentration of airborne fungi and relative humidity. Airborne fungi growing in other concealed spaces and indoor spaces could possibly move into a crawl space.

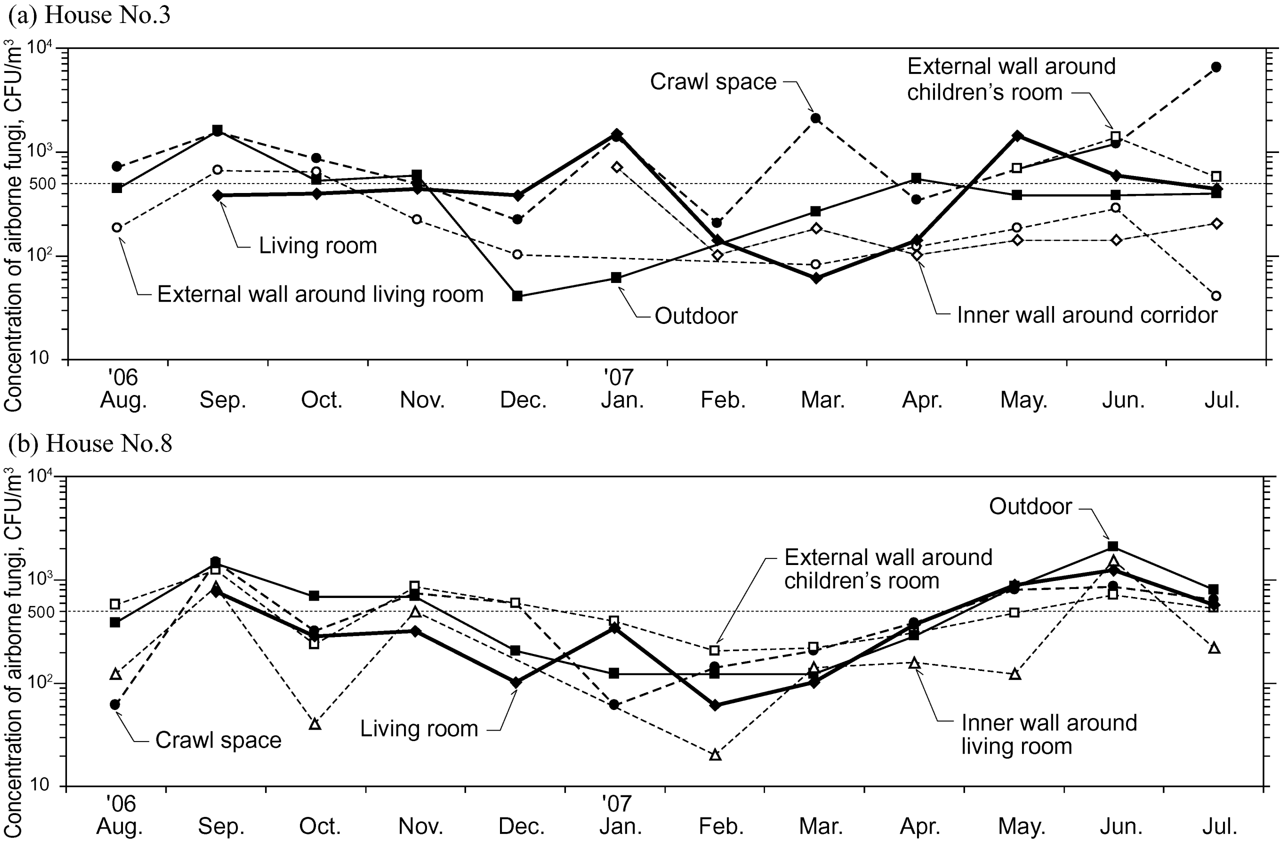

Figure 3: Monthly concentration of airborne fungi in each space in No.3 and No.8 (by PDA medium)

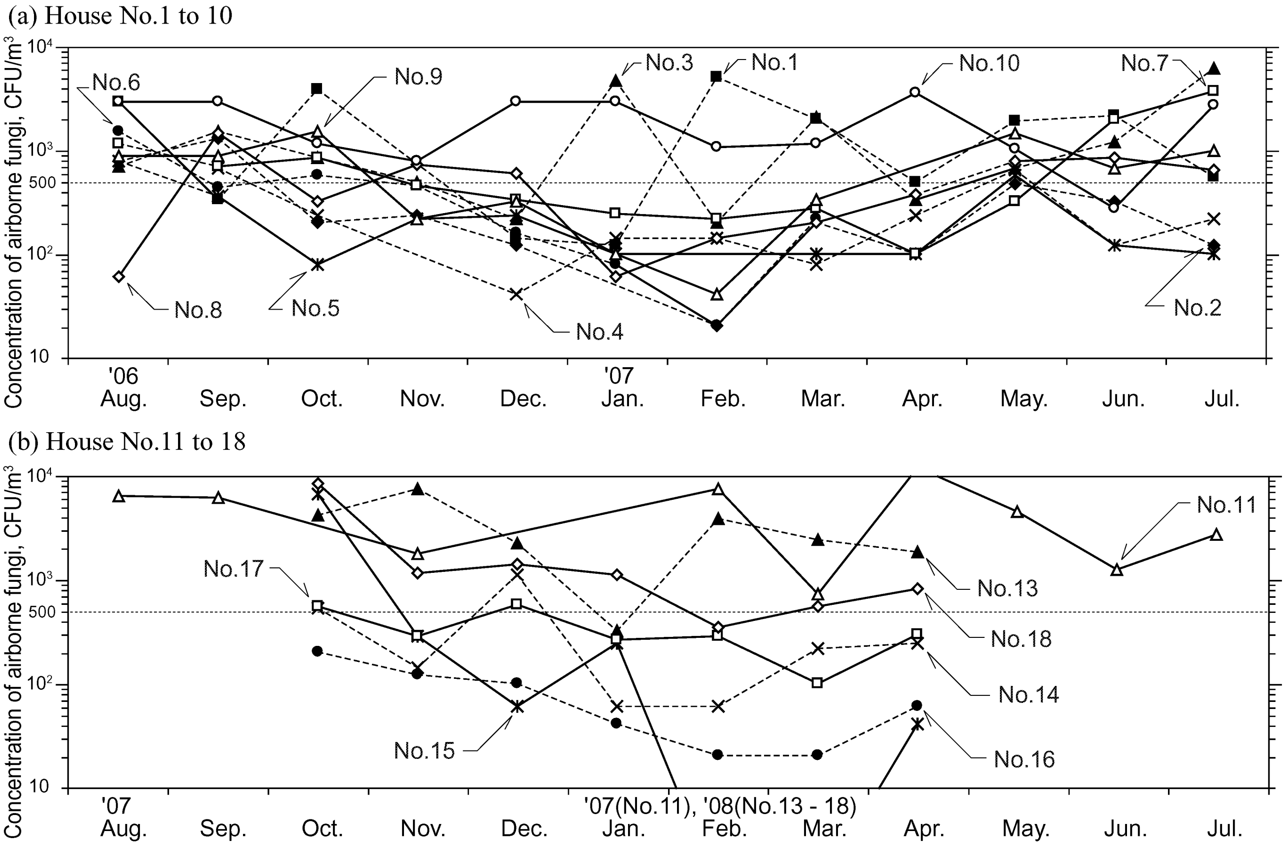

Figure 4: Monthly concentration of airborne fungi in crawl space (by PDA medium)

4. CORRELATION ANALYSIS OF AIRBORNE FUNGI IN CONCEALED SPACES AND INDOOR SPACES

Table 2 shows the results of correlation analysis on airborne fungi among concealed spaces and indoor spaces in Houses No. 2, No. 4 and No. 11. Each table shows results from PDA medium and M40Y medium.

Table 2 (a) shows the results of correlation analysis in House No. 2, which has an exhaust-supply ventilation system, operating continuously. Correlation coefficients between the crawl space and external wall of the children's room were 0.67 ($P<0.05$) in PDA medium and 0.82 ($P<0.01$) in M40Y medium; correlation coefficients between the external wall and the children's room were 0.98 ($P<0.01$) in PDA medium and 0.96 ($P<0.01$) in M40Y medium, respectively. These results indicate that airborne fungi in concealed spaces such as the crawl space and wall space could flow into rooms.

Table 2 (b) shows the results of correlation analysis in House No. 4, which has an exhaust ventilation system operated continuously so that indoor spaces could be kept decompressed. Correlation coefficients between the crawl space and external wall of the living room were high, 0.88 ($P<0.01$) for PDA medium and 0.76 ($P<0.05$) for M40Y medium. Also, concentrations of airborne fungi in the living room and its external wall space were correlated, 0.68 ($P<0.05$) for PDA medium and 0.79 ($P<0.01$) for M40Y medium. There were several high correlation coefficients in House No. 4. That is because the concentration of airborne fungi indoors may similar to that of outdoor air. However, airborne fungi in the crawl space could have moved through the concealed space and into rooms through power outlets on the walls.

Table 2 (c) shows the results of correlation analysis in House No.11, which has an exhaust ventilation system operated continuously. Correlation coefficients between living room (first floor) and children's room (second floor) were high, 0.80 ($P<0.01$) for PDA medium and 0.66 ($P<0.01$) for M40Y medium. It should result from an open floor plan in indoor. Also correlation coefficients between internal wall space around children's room and children's room were high. This result might indicate that airborne fungi in wall spaces could flow into children's room, but there was possibility that collected air by a centrifugal sampler should include indoor air because of much air leakage in internal wall of House No.11.

5. CONCLUSIONS

Yearly profiles of airborne fungi were classified into two types. In one concentration of airborne fungi of indoor rooms and concealed spaces varied according to concentration of outdoor air. In the other, concentration of airborne fungi in indoor rooms and concealed spaces varied according to mold growth in each space. Mold growth should be associated with relative humidity of the air in each space. Correlation analysis indicated that in some houses airborne fungi in the crawl spaces possibly move through concealed spaces and flow into rooms through the power outlets on the walls.

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Table 2: Results of correlation analysis on airborne fungi among concealed spaces and indoor spaces

(a) House No.2

	Crawl space	External Wall space around living room	Internal Wall space around living room	External Wall space around children's	Outdoor	Living room	Children's room
Crawl space		0.68*	0.33	0.82**	0.26	0.79**	0.74**
External Wall space around living room	0.46		0.09	0.41	0.03	0.44	0.48
Internal Wall space around living room	0.16	-0.24	↑ M40Y ↓ PDA	0.79**	0.48	0.51	0.58*
External Wall space around children's room	0.67*	0.4	0.19		0.71*	0.96**	0.96**
Outdoor	0.57	0.17	0.19	0.95**		0.62*	0.65*
Living room	0.62	0.26	0.91**	0.97**	0.99**		0.98**
Children's room	0.66*	0.4	0.17	0.98**	0.96**	0.98**	

*: p<0.05, **: p<0.01

(b) House No.4

	Crawl space	External Wall space around living room	Internal Wall space around living room	Outdoor	Living room	Children's room
Crawl space		0.76*	0.64	0.63	0.70*	0.64
External Wall space around living room	0.88**		0.09	0.87**	0.79*	0.74*
Internal Wall space around living room	0.78*	0.58	↑ M40Y ↓ PDA	0.4	0.82**	0.71*
Outdoor	0.31	0.25	0.53		0.67*	0.69*
Living room	0.68*	0.71*	0.86*	0.67*		0.98*
Children's room	0.64	0.58	0.89**	0.42	0.95*	

*: p<0.05, **: p<0.01

(c) House No.11

	Crawl space	External Wall space around living room	External Wall space around children's room	Internal Wall space around children's	Outdoor	Living room	Children's room
Crawl space		-0.31	0.36	-0.45	-0.26	-0.37	-0.44
External Wall space around living room	-0.19		-0.11	-0.05	0.85**	0.28	-0.44
External Wall space around children's room	0.01	-0.35	↑ M40Y ↓ PDA	-0.42	0.01	0.28	-0.01
Internal Wall space around children's room	-0.28	0.23	-0.17		-0.23	0.45	0.89**
Outdoor	-0.36	0.91**	-0.20	0.09		0.33	-0.15
Living room	-0.47	0.13	-0.19	0.34	0.04		0.66**
Children's room	-0.64	0.29	-0.25	0.56**	0.30	0.80**	

*: p<0.05, **: p<0.01