Simulation on evaluation of Indoor air pollutant diffused in the crawl space of detached house

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ABSTRACT

As the technology in building materials advances, the room air pollution caused by chemical compounds, and also by preservatives and insecticides for termite control, has become a serious problem. With Regard to the air convection in the house to contribute to the movement of the contaminants, there is stack effect, wind presssure, and mechnical ventilation as the driving forces for air movement, that is also much affected by the air tightness and ventilation path of the house. The room air pollution status caused by chemical substances sprinkled in the crawl space are studied by simulation of the temperature ventilation circuitry based on multi-rooms model that assumed non-residential spaces such as crawl space and partition walls as rooms.
As a result of the simulation, it is clarified that the concentrations in the crawl space is affected a lot by the amount of gap and the air tightness of the floor, the concentrations in the residential rooms does not depend on house construction method, keeping approx. 50% of the concentrations in the crawl space, and the pollution status differs according to pressure balance, i.e. ventilation method.

1. INTRODUCTION

The conventional wooden house based on the Japanese traditional wooden axis construction method inevitably has consecutive spaces created in such areas as between the axes, under the floor, behind the ceiling and behind the hut. It has been pointed out that such spaces, while they make useful spaces for such as the filling of the insulation material and facilities/plumbing, there are risks that affect the room air quality through the inflow of diffusing chemical substances from such as plywood and glasswool insulation etc.
In order to control the indoor air quality, it is important to understand precisely what proportion of the chemical substances diffused in the non-residential spaces or the gaps in the non-residential parts, flows in/out of the rooms through those gaps, and the diffusion of which part within the structural gaps affects most.
The ventilation network model that takes into consideration the distribution of gaps in the house based on measurement, and also that assumes each non-residential space such as the crawl space and the partition walls as one room are built in this study. And then ventilation network simulations are executed by using those models, for an analysis of the effects that the occurrence of contaminant in the crawl space had, to the concentrations in the residential room.

2. SIMULATION OF MULTI－ROOMS CONCENTRATIONS IN THE CASE OF CONTAMINANT OCCURRENCE IN THE CRAWL SPACE

2.1 Numerical computation technique

With the heat balance equation under steady state heat transfer for each room and the ventilation network calculation made simultaneously (with room pressures assumed, calculating convergence by the modified Newton-Raphson method until the sum error of the air volume becomes the zero), we make repetitive calculation (convergence condition: temperature norm/number of rooms=0.01-0.05℃ that differs according to opening's condition) until each room temperature converges, to calculate the air quantity. Also we establish a concentrations equilibrium equation for each room to get the temperature of each room by solving the simultaneous equation. The basic equations are as follows;

Heat Balance of the rooms:

$$\sum_{p=1}^{M} S_p \cdot K_p \cdot (T_n - T_p) + \sum_{j=1}^{J} c \cdot G_{ji} (T_i - T_j) - H_n = 0 \qquad (1)$$

Air volume of each openings:

$$G_{mj} = \mathrm{sgn} \cdot \alpha A_{mj} \cdot \sqrt{\frac{2g}{\gamma_i}} \cdot \Delta p^{\frac{1}{n}} \qquad (2)$$

Equation of Continuity:

$$\sum_{j=1}^{n} G_{mj} = 0 \qquad (3)$$

Mass balance of Contaminant:

$$\sum_{m=1}^{n} G_{ji} \cdot (C_i - C_j) - f_i = 0 \qquad (4)$$

where:

S: Surface Area (m^2), K: Thermal Conductance (W/m^2K), c: Heat capacity of air (J/kgK), H: Heat generation (W), G: Amount of air volume (m^3/h), αA: Equivalent Leakage Area (m^2), Δp: Pressure difference (Pa), C: Concentrations of Contaminant (kg/m^3), f: Speed of Contaminant diffusion (kg/h)

2.2 House models for calculation

The house used in the calculation is defined as a whole 2 stories house with the floor area of each story being 66.25 m^2 (9.1m × 7.28 m) and the total floor area being 132.5m^2. There are 3 rooms of a LD (living/dining room), a K (kitchen), one bedroom and a UT (utility room) in the first floor, and 3 bedrooms and a hall with stairs in the second floor, totaling 7 rooms. To this, we added the non-residential spaces of crawl space, beam space between the first and the second floor, attic space, the cavities of 3 partitioning walls, making a model with total 13 rooms. The total number of openings is from 109 to 135.

2.3 Each setting condition of the numerical simulation

The rooms at air exhaust and the quantity of air set for mechanical exhaust ventilation system are LDK:40 m^3/h, UT:20 m^3/h, 2nd floor bedroom (⑥, ⑦, ⑧) : 20 m^3/h each (with total of 2nd floor bedroom being 60m^3/h), making the total quantity of the exhaust air 120 m^3/h.
The heat gain inside the house is 1160 W of combined heat from sun radiation, body and electrical equipment etc. The temperature setting of the bedrooms is 20℃ with heating set as required, but will be left without air-conditioning when the outside temperature is high. Farther, the area of windows is set as 26.4m^2 and the widow area ratio is set as 20% of total floor area.
As this is a steady state calculation, the outside air temperature is given as a setting condition and its temperature is set at 3 levels of 0, 10, 20℃. A temperature can be added after the hyphen of symbol so that it can be identified (see Figure 1).

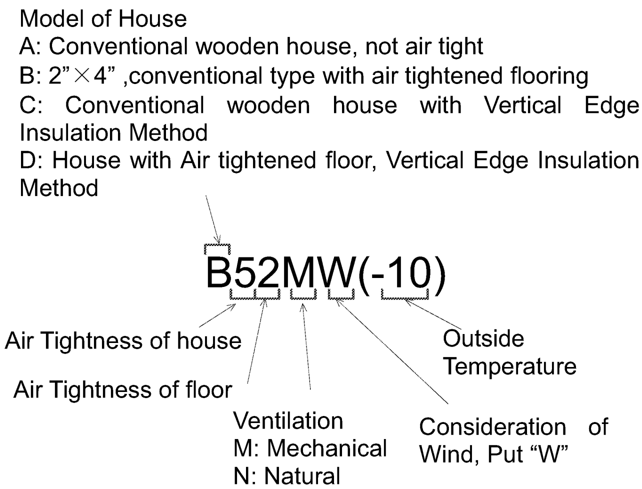

Figure 1: Explanation of symbols in Table.1

Table 1: Calculation Patterns

Model	Symbol	Total ELA *1	Floor ELA *1	Vent Opening on foundation wall	Air Convection in the partition wall	Ventilation System	Thermal Insulation Level
A: Conventional wooden house, not air tight	A75N	7 cm^2/m^2	5 cm^2/m^2	○	○	Natural	JARUE*2 1992 area Ⅳ
	A72N	7 cm^2/m^2	2 cm^2/m^2				
	A95N	9 cm^2/m^2	5 cm^2/m^2				
	A95NW	9 cm^2/m^2	5 cm^2/m^2				
B: 2”×4”,Air tightened floor	B52N	5 cm^2/m^2	2 cm^2/m^2	○	—	Natural	JARUE *2 1992 area Ⅳ
	B55N		5 cm^2/m^2				
	B52M		2 cm^2/m^2			Mechanical	
	B52MW		2 cm^2/m^2				
	B55M		5 cm^2/m^2				
C: Conventional, Vertical Edge Insulation Method	C22N	2 cm^2/m^2	2 cm^2/m^2	—	○	Natural	JARUE*2 1999 area Ⅳ
	C25N		5 cm^2/m^2				
	C22M		2 cm^2/m^2			Mechanical	
	C25M		5 cm^2/m^2				
D: with air tightened floor, Vertical Edge Insulation Method	D22N	2 cm^2/m^2	2 cm^2/m^2	—	—	Natural	JARUE*2 1999 area Ⅳ
	D22M					Mechanical	
	D22MW						

*1 ELA: Equivalent Leakage Area, *2 Japanese Act Concerning the Rational Use of Energy for Houses

2.4 Calculation patterns

The calculation patterns are classified as shown in Table 1. The subject of the A series is the conventional construction method that does not take the airtight structure into consideration, having specification of inside partitioning with spaces under the floor, behind the attic space being connected spatially. The B series is the case where the air tightness is taken into consideration, and is 2” × 4” or the floor insulation method of airtight type conventional construction model. This is a construction method where the partitioning wall parts are made independent spatially by platform floor and ventilation stopper etc.

As described above, the A and C series are the types that have vents openings installed on the foundation wall, and the C and D series that follow are of vertical edge insulation method that does not have the vents on the foundation. The C series is of vertical edge insulation method, however with the floor being airtight like the B series, i.e. the type without convection in the partition walls.

Further, please note that as the vertical edge insulation method can maintain proper material durability without using preservatives and insecticides for termite control, we included it intentionally in this study for the comparison purpose, although there is no precondition set to use chemical substances under the floor.

The way of looking at the symbols in the Table 1, is as shown in the Figure 1. Those with “W” especially are the results of simulation where the effects of outside wind pressure under the weather conditions in Tokyo are taken into consideration.

3. CALCULATION RESULTS

The Figure 3 shows the relation between the concentrations in the crawl space and that in the 1F room, and the Figure 4 shows the relation between the concentrations in the crawl space and that in the 2F room. In the case of natural ventilation, the concentrations in the rooms of the conventional construction method of A and C are approx. 53.7% of the concentrations in the crawl space, and the concentrations in the rooms of B and D of airtight floor are approx. 51.3% of the concentrations in the crawl space, making the conventional construction method higher by approx. 2%. In the 2F rooms, the difference

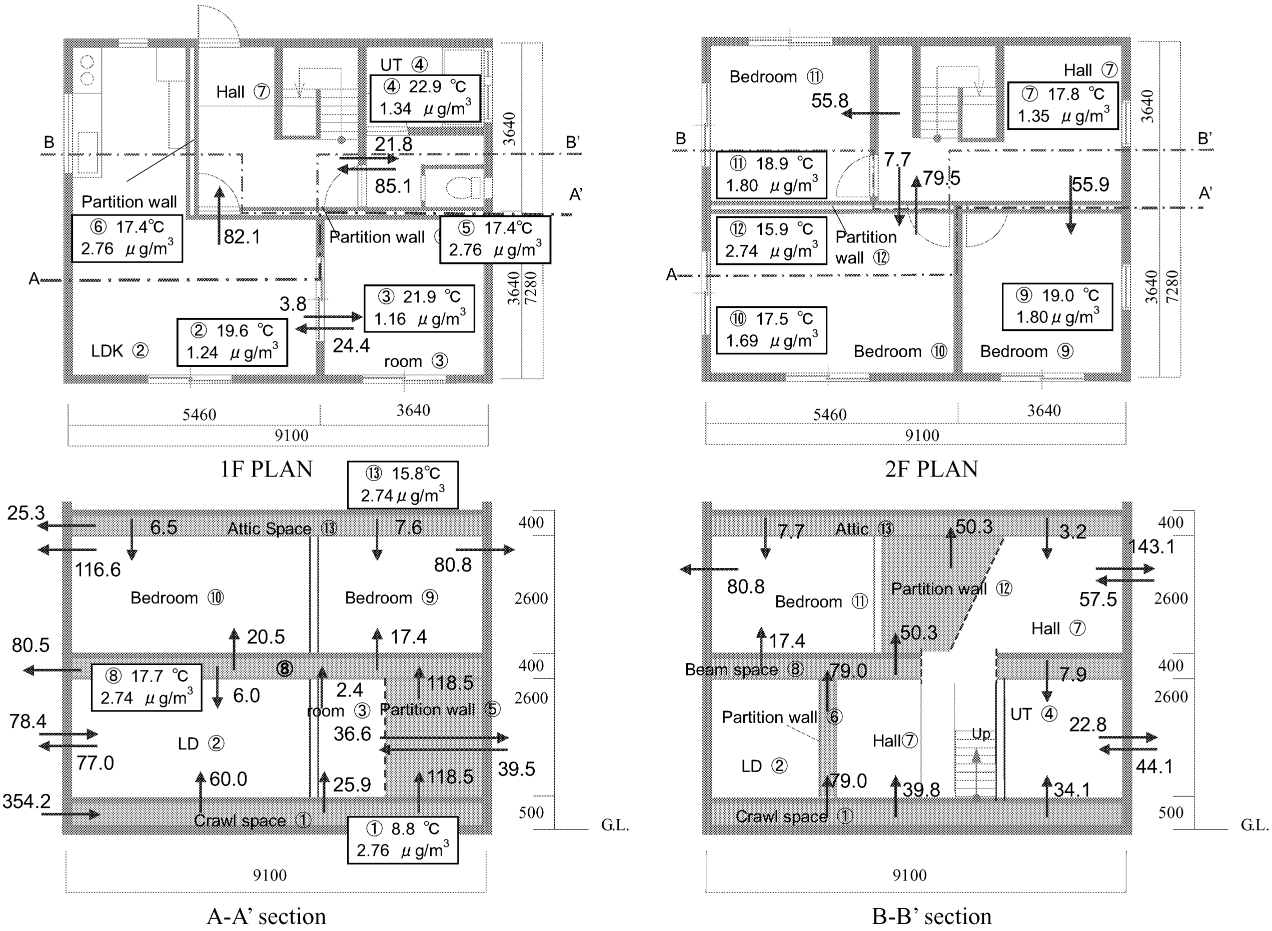

Figure 2: An Example of Calculation Result, A95N-0, at Contamination diffusion Speed is 1mg/h

Numbers beside the Arrow symbol is volume of moving air in unit m^3/h

between different construction methods becomes smaller with almost no difference (approx. 0.5%).

In any way, when there is an occurrence of contaminant under the floor, this means that a half of the contaminant flows into the residential rooms in the case of natural convection only. It would be necessary to study how to reduce the concentrations in the crawl space as a countermeasure in this case. In general, as the vertical edge insulation method makes the volume of outside air intake smaller, the concentrations in the crawl space tends to be higher. Although air tightened floor has an effect to prevent intake contaminant into rooms, it also ends up with making the concentrations in the crawl space higher. Particularly, it would be necessary to caution during the summer time when the stack effect becomes less.

On the other hand, in case of mechanical ventilation, the concentrations of the residential room are reduced compared with natural convection, making the difference between the construction methods smaller. And also when looking at the relation between the inside and outside temperature difference, it is clear that the concentrations is smaller compared with natural convection case.

Base on the above findings, it can be said that more proper ventilation planning is important in case of Vertical Edge Insulation method.

4.SIMULATE THE CONCENTRATIONS IN THE ROOMS IN CASE OF CHLORPYRIFOS BEING THE SUBJECT

The results of the simulation in this study can be used universally regardless of contaminant types as long as there is no absorption/desorption of contaminant to

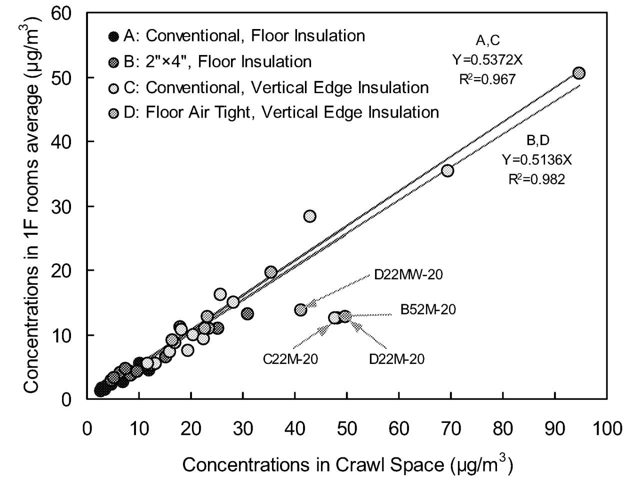

Figure 3: Concentrations in the crawl space and that of 1F rooms average, at Contamination diffusion Speed is 1mg/h

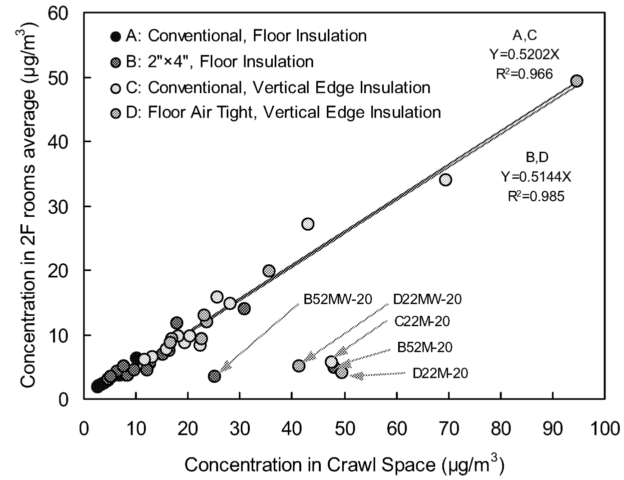

Figure 4: Concentrations in the crawl space and that of 2F rooms average, at Contamination diffusion Speed is 1mg/h

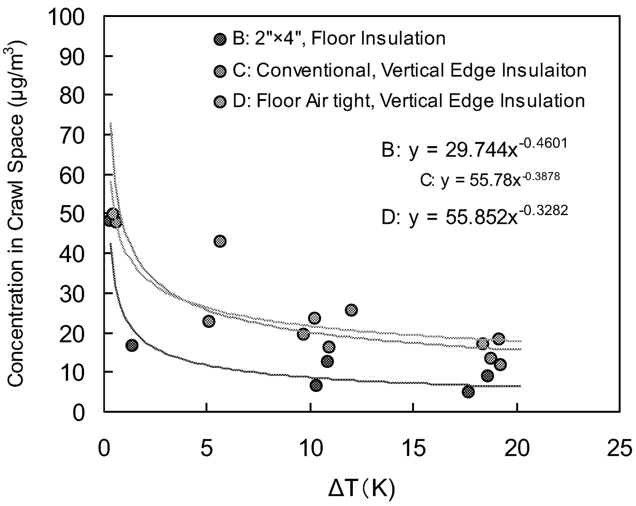

Figure 5: Relation between ΔT and Concentrations in the crawl space, with mechanical ventilation

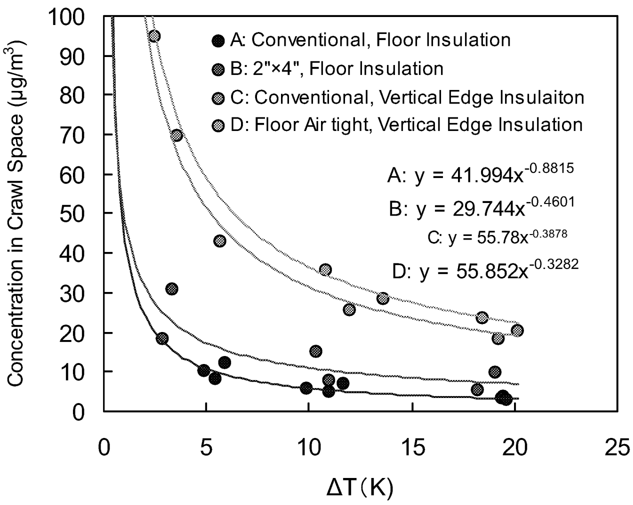

Figure 5: Relation between ΔT and Concentrations in the crawl space, with natural convection only

building materials. While the chlorpyrifos was prohibited for use at the time of revision of the Building Standard Law of Japan in 2003, it had been in use conventionally as an insecticide of termite control.

In the case of an experiment that made the chlorpyrifos a subject, the speed of generating contaminant per unit area was 1.46E-4g/m^2h. When it is applied to the house model used in the simulation with the standard laying area rate being 0.4, the generated quantity becomes 3.9E-3g/h. The Table 2 is the result of the trial calculation for the case study, by using the results of Figure 4 through 6. As long as we see this result, it turned out to be well over the 1.0E-6g/m^3 （0.07ppb） of the concentrations indicator value of Ministry of Health, Labor and Welfare.

5. CONCLUSIONS

The effects of contaminant generated in the crawl space to concentrations in the room by using a ventilation network simulation. As a result, it has been found out that in the case of

Table 2: Simulation results in the case of chlorpyrifos being a subject at diffusion speed 3.6 mg/h

Ventilation	Natural Convection only			Exhaust type Mechanical ventilation		
Diffusion	1.0mg/h		3.6mg/h	1.0mg/h		3.6mg/h
	Crawl Space	Room	Room*	Crawl Space	Room	Room*
A	2.99	1.61	5.79			
B	7.50	3.85	13.86	6.35	1.65	5.94
C	17.46	9.38	33.76	15.66	4.11	14.80
D	20.89	10.73	38.63	17.88	5.95	21.41

* Chlorpyrifos concentrations in the Room to be judged

the house model assumed this time, the concentrations of the residential room has almost no dependency on the house model, keeping approx. 50% of the concentrations in the crawl space, and the concentrations in the crawl space differs a lot according to the air tightness level, and the ventilation in the room affects the concentrations in the residential room a lot.

The subject of under the floor contaminant includes not only chemical substance, but also microbial contamination by such as mold increase caused by high humidity. If we end up with easily taking such a counter measure as directly exhausting from the crawl space by using mechanical ventilation fan, based on the simulation result, there is a risk to have the humidity in the crawl space, moist air inflow through air movement. Fundamentally, the first counter measure is to remove contaminant and after doing that, a measure of exhausting contaminant should be taken. The counter measure of ventilation equipment for non-residential spaces would need to take such a compound situation into full consideration.

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