Prediction of indoor air quality considering the concealed air leaks in the improved houses

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ABSTRACT

There are many infiltration routes in detached houses in Japan. These routs lead chemical compounds into the indoor spaces from the concealed spaces.

In this study, the effects of countermeasures with airtight methods and ventilation methods were cleared using a simulation program. At first, the equivalent leakage areas in the concealed spaces were measured using cut models. Next, the movements of chemical compounds were calculated using the simulation program: "Fresh2006".

The results showed that the concentrations are lower in the improved houses than those in the common houses in some cases. But the methods with exhaust ventilation from crawl spaces or beam spaces were not enough effective to decrease the indoor concentration. Therefore the effects of the methods with ventilation were effective only on the pollutants which generate in these concealed spaces.

1. INTRODUCTION

There are many infiltration routes in detached houses in Japan. The equivalent leakage areas of recent houses have become smaller but the infiltration routes are left in the concealed spaces like the beam spaces, crawl spaces and inside-wall spaces. The authors made it clear that these routes lead chemical compounds into the indoor spaces from the concealed spaces in test houses. Therefore, the consideration of the infiltration from concealed spaces was required in the amendment of building standard law since 2003 in Japan.

The authors have investigated the

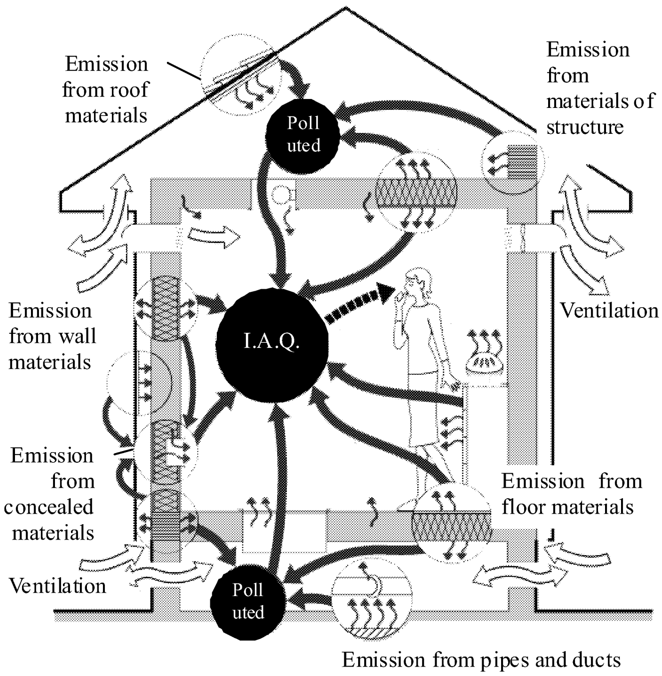


Figure1:I.A.Q. and the concealed pollution sources

Figure 2: A cut model of improved post-and-beam wooden structure.

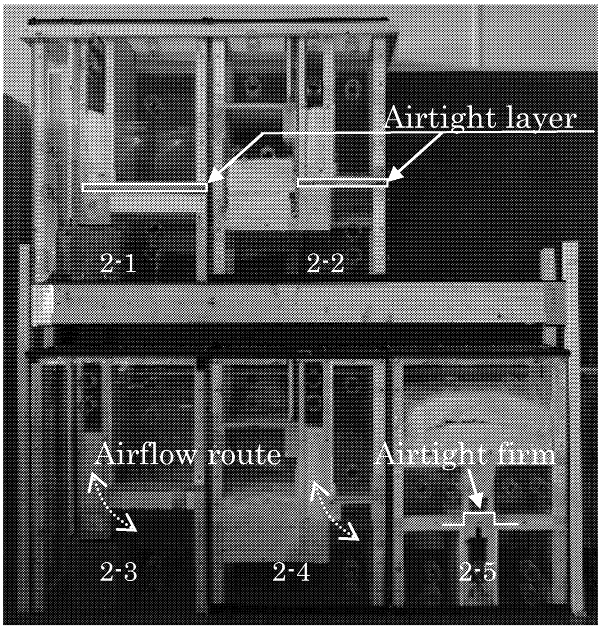
characteristics of the movement of chemical compounds in the concealed spaces and indoor spaces in houses using building cut models and a simulation program named Fresh2006.

These studies showed the infiltration ratios from the concealed spaces to indoor spaces were influenced sensitively by mechanical ventilation. The influence of the infiltration upon the indoor air quality was larger in the house with an exhaust ventilation system than with any other ventilation system. These studies showed that it is necessary to improve the details to make houses more airtight as shown in figure 3 and to improve the ventilation design.

2. METHODS

At first, the equivalent leakage areas in the concealed spaces were measured using cut models. It was difficult to measure the equivalent leakage areas in the concealed spaces of houses. So the cut models of these structures were constructed in a laboratory of Miyagigakuin Women's University. Figure 2 shows a cut model of improved post-and-beam wooden structure which was made according to the building standard law in 2003 for the previous study.

Figure 3 showed the common models according to the building standard law in 2003: 2-3, 2-4 and the more improved models: 2-1, 2-2, 2-5. The sizes of the elements of these cut models are the same as those of elements of real houses. These cut models were built by carpenters in the laboratory. In the case of model 2-1 and model 2-2, the leakage between the space under floor and the space inside wall was made smaller using plywood as shown in figure 5. In the case of model 2-5, the leakage between ceiling space and the space inside the wall was made smaller using airtight firms as shown in figure 3. In the case of cut model 1 shown in figure 2, only the wood was used at the top of partition wall to make this part airtight.



2-1: improved details on the first floor, 2-2: improved details on the second floor, 2-3: common details on the first floor, 2-4: common details on the second floor, 2-5: improved details at the top of partition wall.

Figure 3:Cut models

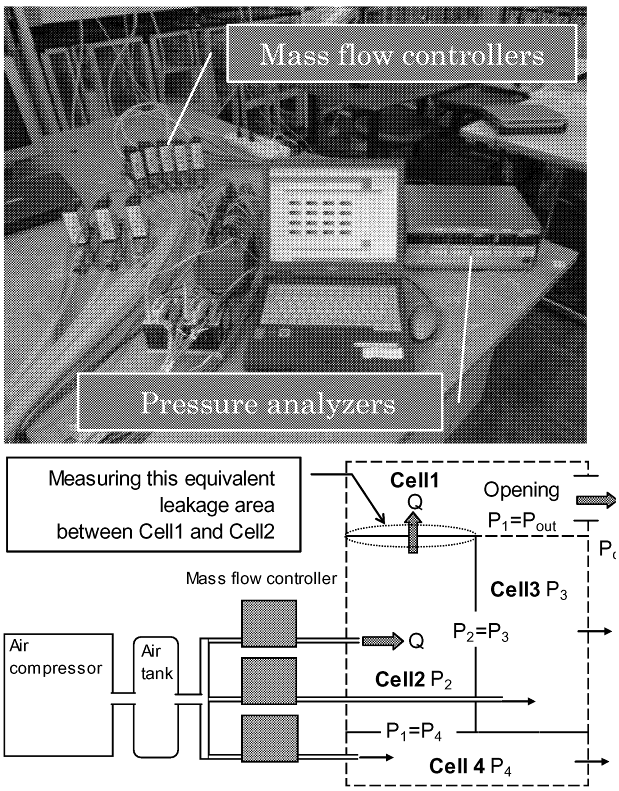


Figure 4:Measurement systems to measure leakage areas between cells

Leakage areas in the concealed spaces and the leakage areas between the concealed spaces and indoor spaces were measured using mass-flow controllers and pressure analyzers shown in figure 4. When the leakage areas between cell1 and cell2 are measured, cell1 must be opened to the outside and the air pressures of cell3 and cell4 have to be controlled to meet the pressure of cell2. On this condition the air of cell2 goes only to cell1. The airflow rate from cell2 to cell1 accords the air flow rate through the mass-flow controller between the air tank and cell2, so the air flow rate can be known. The measured pressure differences and measured air flow rates are known and the equivalent leakage areas were calculated with these measured data. Figure 6 shows the measured equivalent leakage areas. The equivalent leakage areas of the improved models: cut model 2-1, 2-5 were very small.

Next, the movements of chemical compounds were calculated using “Fresh2006”. The program simulates the temperatures, the air flow rates, the concentrations and the generation rates of pollutants like formaldehyde, carbon dioxide: CO_2 using the NHK standard living schedule model and the HASP weather data on Tokyo. The simulation program was written in 1996, and was named ‘Fresh96‘. It was composed of the following three calculation methods.

Dynamic thermal calculation of the temperature, heating and cooling loads: the air-conditioner and the windows are operated to make the indoor climate comfortable considering the daily schedule of a family.

Calculation of air flow rate in the multi-cell system using the equation of the power at the openings: the ventilation rates are calculated considering the stack effect, the wind pressure and the mechanical power using the standard weather data.

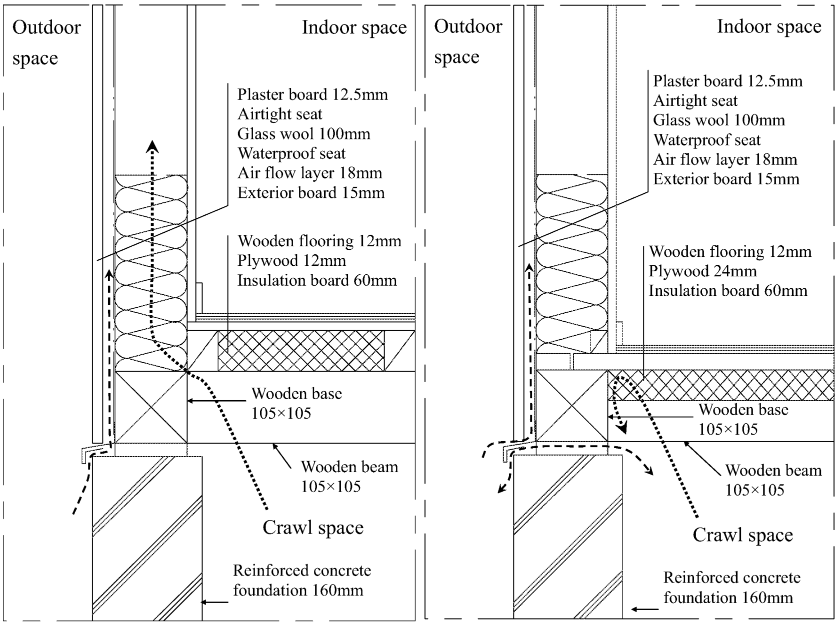


Figure 5: Details of cut models: 2-3, 2-1

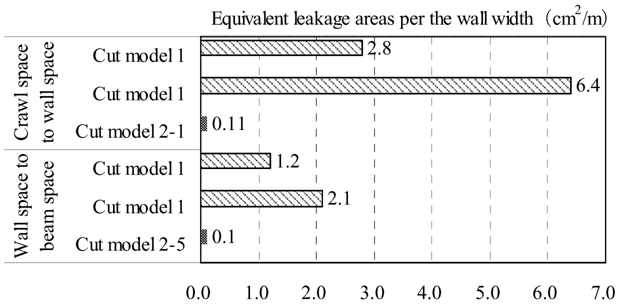


Figure 6: Equivalent leakage areas

Dynamic calculation of concentrations of pollutants using the equation of the amount of pollutants: the emission rates of CO_2 are calculated using the average Japanese daily schedule. The emission rates of formaldehyde were calculated considering the influences of temperature and sink.

In these studies, in order to make clear the influence of the infiltration of chemical compounds from beam spaces and a crawl space to indoor space upon the indoor air quality, SF6 was released at the beam spaces and R22 was released at the crawl space in the simulation models. Formaldehyde emission rates in the concealed spaces are set to be 100μg/hm^2 considering the surface area of emission sources like plywood and the emission rates.

This model was designed considering the shape of a low house with two stories. The emission rates of SF6 and R22 were 300ml/h. The movement and the concentrations of each gas were calculated. The outdoor concentrations were set as follows. The concentration of carbon dioxide: CO_2 is 400ppm, that of formaldehyde 0μg /m^3, that of SF6 0ppm and that of R22 0ppm. Figure 7 shows the equivalent leakage areas of a model with standard airtight details. The truss space is opened to the outdoor and the crawl space is also opened. Table 1 shows the simulation models with various improvement methods.

3. RESULTS

At first, the equivalent leakage area of the structure was measured using this simulation program. A large fan was set and the inside air was exhausted. The airflow rates are controlled to meet five ranks of airflow rate and the pressure differences were calculated. The equivalent leakage areas were calculated. The equivalent leakage area was 2.8cm^2/m^2. It meets the standard of equivalent leakage area: 2.0-5.0 cm^2/m^2 in Tokyo.

Figure 8 shows the annual change of the air supply rates and the formaldehyde concentrations in a house with standard airtight details and with an exhaust ventilation system. Most of the supplied air was led from concealed spaces to the indoor spaces in most seasons. The total air supply rate became high with the window opening in summer. Therefore the concentration of formaldehyde became higher in summer with the temperature.

Figure 9 shows the calculated temperatures and airflow routes in January in the case of a model with standard airtight details and with the improved ventilation system. There are many airflow routes and the air infiltrate from the concealed spaces to the indoor spaces. In the

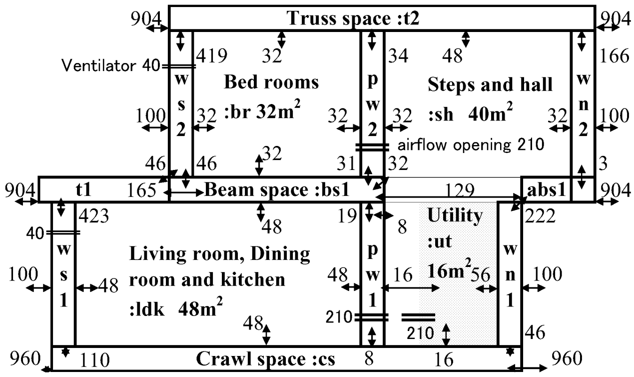


Figure 7: Leakage network of the post-and-beam structure (cm^2)

Table 1: Simulation models

Model	Airtightness	Ventilation	Air flow rate from utility	Air flow rate from concealed spaces	Total air flow rate
			m^3/h	m^3/h	m^3/h
S_S 128/0	Standard	Standard	128	0	128
1-S 128/0	Improved 1	Standard	128	0	128
2-S 128/0	Improved 2	Standard	128	0	128
S-C 128/32	Standard	Crawl space	128	32	160
S-C 128/42	Standard	Crawl space	128	42	170
S-C 128/64	Standard	Crawl space	128	64	192
S-B 96/32	Standard	Beam space	96	32	128
S-B 86/42	Standard	Beam space	86	42	128
S-B 64/64	Standard	Beam space	64	64	128
1-B 96/32	Improved 1	Beam space	96	32	128
1-B 86/42	Improved 1	Beam space	86	42	128
1-B 64/64	Improved 1	Beam space	64	64	128
2-B 96/32	Improved 2	Beam space	96	32	128
2-B 86/42	Improved 2	Beam space	86	42	128
2-B 64/64	Improved 2	Beam space	64	64	128
S-B* 96/32	Standard	Beam space *	96	32	128
S-B* 86/42	Standard	Beam space *	86	42	128
S-B* 64/64	Standard	Beam space *	64	64	128
1-B* 96/32	Improved 1	Beam space *	96	32	128
1-B* 86/42	Improved 1	Beam space *	86	42	128
1-B* 64/64	Improved 1	Beam space *	64	64	128
2-B* 96/32	Improved 2	Beam space *	96	32	128
2-B* 86/42	Improved 2	Beam space *	86	42	128
2-B* 64/64	Improved 2	Beam space *	64	64	128

Airtight/Standard：method according to the building law in 2003 in Japan, Improved 1：cut model 2-1、Improved 2：cut model 2-1,2-2,2-5.
Ventilation/Standard: exhaust ventilation system. Beam space* ：an opening :200cm^2 is set between beam space and utility.
Total air volume of the house is 326m^3,The required ventilation rate is 128m^3/h meets 0.5 time of the total air flow rate of rooms.

case of “S-C 128/32”, the air of the crawl space: cs is exhausted using a fan. The air flow does not influence the other airflows at all because the crawl space is opened to the outside. When the air is exhausted from the crawl space, the air-exhausting rates from indoor the spaces have to meet the required ventilation rate: 128m^3/h in the case of the models. In the case of S-B 96/32, the air is exhausted from the beam space: bs1. The air infiltrates from the crawl space: cs to the beam space: bs1 through the wall spaces: ws1. The air flow does not effect directly upon the indoor air quality. When the opening is set between the utility and the beam space, the rates of the air flow through the concealed spaces decrease and the airflow rates through the indoor spaces increase. So, the indoor concentrations are expected to be lower. This is the condition of “B*” as shown in table 1.

Figure 10 shows the yearly average of the concentrations. The effect of the improvement of airtight method can be found the results of S-S 128/0, 1-S 128/0 and S-2 128/0. These effects were not high on the concentration of most pollutants. In the case of R22 which was generated in crawl space, the effect of improved airtight details at the floor: ”improved 1” was found. The effect of exhausting from crawl space: S-C 128/32, 128/42, 128/64 was found only in the concentrations of R22 which was generated in the crawl space. The effect of beam space ventilation was not found on the concentration of formaldehyde and carbon dioxide. These concentrations became higher than those in the model without beam space ventilation. The concentrations of carbon dioxide were lower in the model with the beam space ventilation and the opening in the utility: S-B*, 1-B*, 2-B*. These reasons had been already mentioned using figure 9. Therefore the concentrations of SF6 which was generated in the beam space became lower in the case of the beam space ventilation without opening in the utility: S-B, 1-B, 2-B than those with the opening: S-B*, 1-B*, 2-B*.

4. CONCLUSIONS

The effects of the improvement of airtight

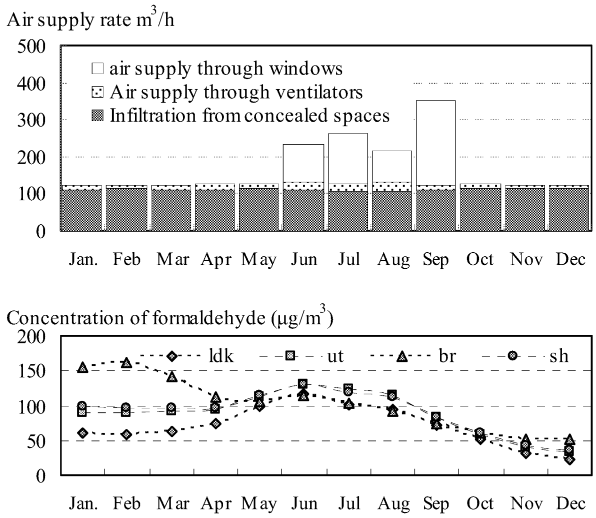


Figure 8: Results of S-S 128/0

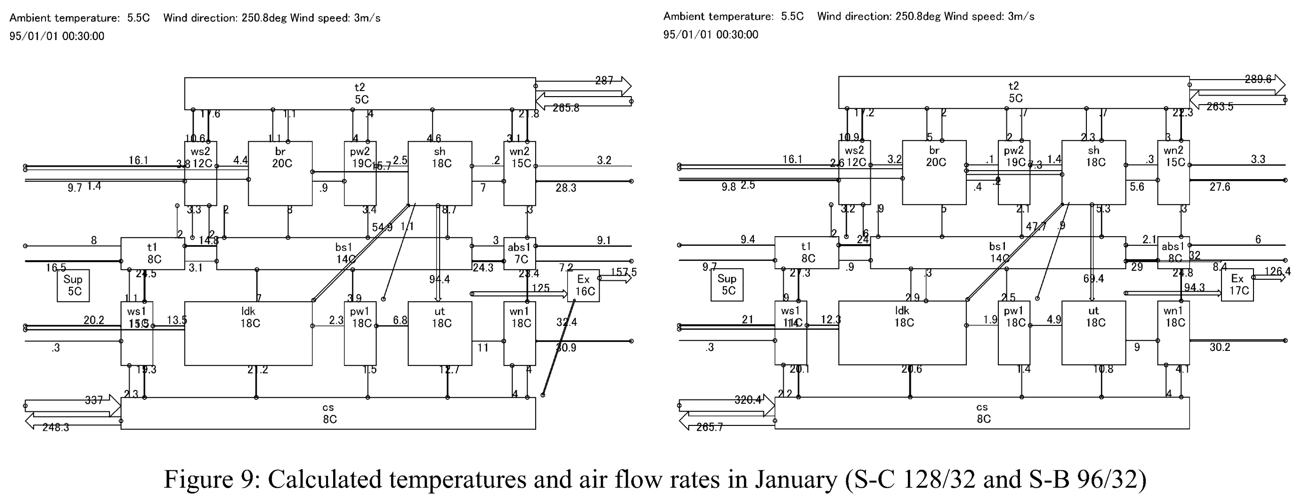


Figure 9: Calculated temperatures and air flow rates in January (S-C 128/32 and S-B 96/32)

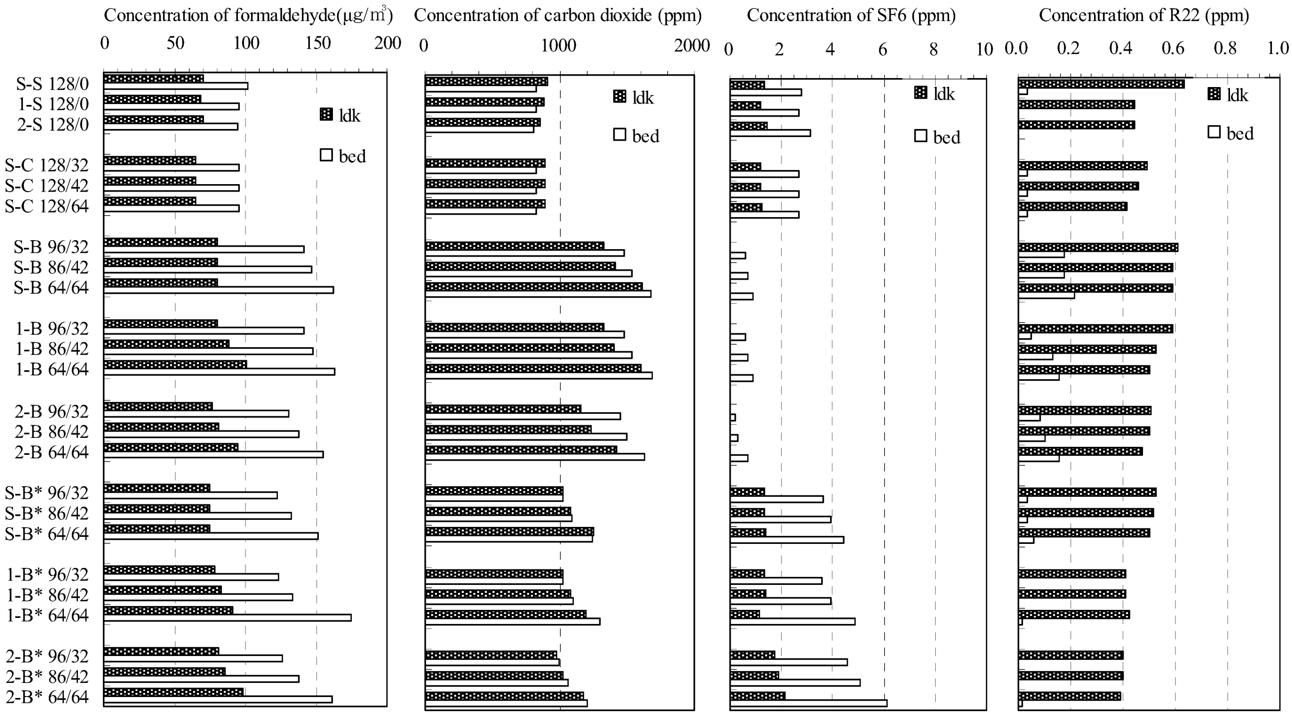


Figure 10: Calculated indoor concentrations of each case study

details and ventilation design upon the indoor air quality with the consideration of concealed infiltration routes were shown. It was known in the previous studies, that the influence of this infiltration upon the indoor air quality was larger in the house with an exhaust ventilation system than with any other ventilation system. This study showed that the effects of the improvement of airtight details were not large and those of the improvement of ventilation is found only in the concentration of pollutant which volatize in the concealed spaces. So, the total ventilation rate has to be higher with the ventilation of the concealed spaces. These results suggested that it is the most important to consider the materials in the concealed spaces for a countermeasure against sick house syndrome in the case of exhaust ventilation.

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