原　著

Improvement of Traditional Japanese Houses and Indoor Air Quality
—Measurements on Infiltration and VOCs in Three Test Houses.

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Three types of structure; a traditional house with soil wall, a new house with insulation and a hybrid house were designed and built in Kyoto city. The hybrid house was built by traditional carpenters using traditional building materials and modern materials. Soil wall of the house, was covered with insulation board outside. The new house was built according to the latest building code for energy saving. Exhaust ventilation systems were installed in the three houses.

The airtight levels, ventilation rates, infiltration ratios of pollutants from crawl space, concentrations of volatile organic compounds were measured in these three test houses in winter. The results show the followings. The equivalent leakage area of the traditional house was three times of that of the new house. However the indoor air quality of the traditional house is not so high. Because, chemical compounds infiltrated from the crawl space, these characteristics were shown in the hybrid structure.

INTRODUCTION

The traditional Japanese houses have been made with natural materials; woods, soils and grasses. Therefore these materials don't emit chemical compounds and the indoor concentrations of chemical compounds are very low. These houses were not insulated and not airtight. Therefore the indoor temperature becomes very low in winter. Since 1970's the houses have been improved in order to save energy and to make better indoor climate. The airtight level became higher and ventilation equipment was used in new houses. However, the indoor air quality became low and sick house problem was closed up in 1990's. One of the factor of sick house was the dependence on new materials using chemical compound. Chemical compounds were useful to produce industrial building materials and to prevent biological pollution.

Under these background, we made studies on the improvement of traditional Japanese houses considering indoor air quality and energy saving. This report shows measurement results in three test houses. Three types of structure; a traditional house, a new house and a hybrid house were designed and built in Kyoto prefecture. The airtight levels, ventilation rates, infiltration rates of pollutants from crawl space, concentrations of volatile organic compounds were measured in winter.

Figure 1.　Model A: traditional house

Figure 2.　Model B: hybrid house

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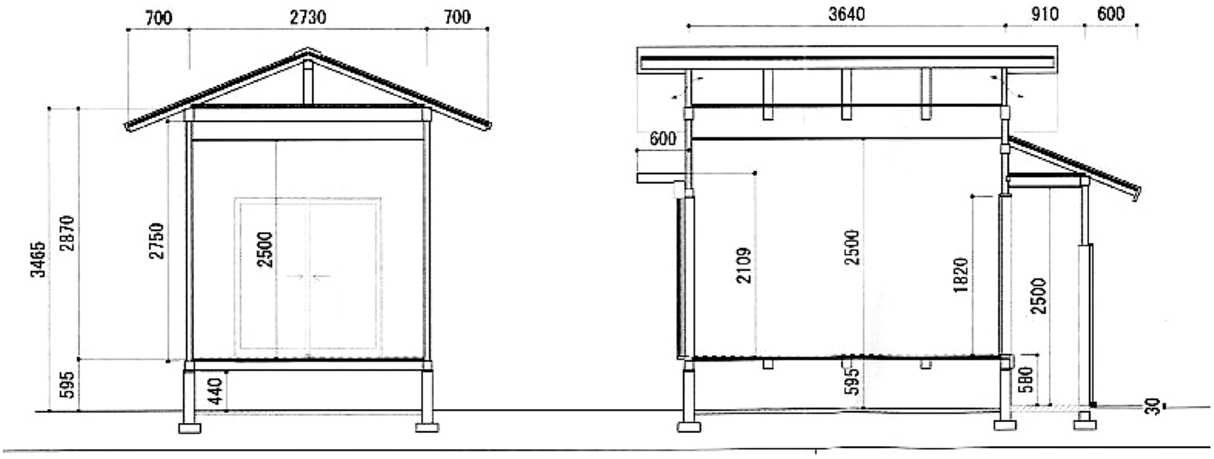

Figure 3.　Scale of a test house: Model A

Table 1: Materials of three houses

	Model A	Model B	Model C
Exterior wall	・ Soil wall: 75mm	・Soil wall (Clay wall and interior finishing with soil): 60mm	・Vinyl wall paper
	・Plastered wall	・Thermal insulating material 64K: 30mm	・Vapor proof seat
		・ Vapor waterproofing seat	・High glass wool 16K: 100mm
		・Venting layer: 18mm	・Structural plywood: 9mm
		・ Ceramic　siding: 16mm	・Vapor waterproofing seat
			・Venting layer: 18mm
			・Ceramic　siding: 16mm
Ceiling	・Layer with Japanese cedar on girders: 30mm	・Layer with Japanese cedar on girders: 31mm	・ Vapor proof seat
	・Interior finishing　with Japanese cedar: 45.5mm	・Plaster board: 12.5mm	・Glass wool 16K: 160mm
		・ Vinyl wall paper	・Plaster board: 12.5mm
			・ Vinyl wall paper
Floor	・Reinforced　concrete foundation w120	・Reinforced　concrete foundation w120	・Reinforced concrete foundation w120
	・ Spacer on the foundation: 20mm	・ Spacer on the foundation: 20mm	・ Spacer on the foundation: 20mm
	・Sill(105×105)	・Sill (105×105)	・Sill (105×105)
	・Sleeper(105×105)	・Sleeper (105×105)	・Sleeper (105×105)
	・Japanese cedar board: 30mm	・Japanese cedar board: 15mm	・Glass wool with moisture prevention seat 32K: 80mm
	・Japanese cedar decorate board: 24mm	・Flooring: 15mm	・Structural plywood: 24mm
			・Flooring: 15mm

METHODS

The houses were built in a field surrounded by rice field and bamboo forest in Kyoto city as shown in figure 1 and figure 2. Table 1 shows the materials and the structure. These structures consist of wooden post and wooden beam. In these houses, windows consist of double glazing with air space and aluminum frame and a reinforced concrete was used at the basement. General chemical compound was applied to the wooden foundation in order to prevent decomposition and to prevent termites. The space under the floor opens to outside space using slit ventilators between the wooden foundation and the basement.

The traditional house: model A was built by carpenters who built traditional architecture with soil wall in Kyoto. The hybrid house: model B was built using traditional technologies and new technologies. The soil wall was covered with insulation boards outside. The new house: model C was built according to the latest building code for energy saving. Exhaust ventilation systems were installed in the three houses. The measurements were made for thirty days in winter. The rooms are heated by electric heaters for five days and not heated for five days in a cycle. This cycle was repeated.

Figure 4. Measurement system of equivalent leakage area

Figure 6. Sealing with Tape and sheet

Figure 5. Taping on the end of floor

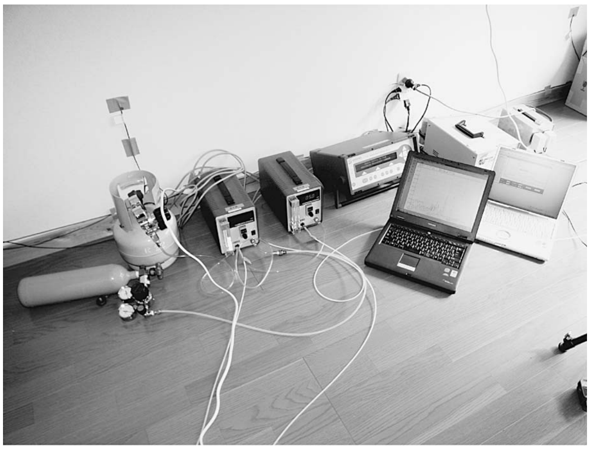

Figure 7. Measurement system to measure ventilation rates, infiltration ratios from crawl space and concentrations of VOC

① Measurement on the equivalent leakage area

The equivalent leakage area of each part was measured with a fan and a pressure analyzer. The air flow rate and the pressure difference between inside and outside was measured as shown in figure 4. The equivalent leakage area was calculated using these measurement results by five pressure differences by least square method. The equivalent leakage area of each part was calculated using the measurement results before sealing and that after sealing as shown in figure 5 and figure 6.

② Measurement on the ventilation rates

Tracer gas: R22 was injected in a room space. And the concentration of the tracer gas was measured at the exhaust fan using a multi-gas monitor. The ventilation rate was calculated using the injection rate and the measured concentration.

③ Infiltration ratio of pollutants from crawl space

Tracer gas: SF6 was injected in the crawl space. And the concentration of the tracer gas was measured at the exhaust fan using a multi-gas monitor as shown in figure 7. The infiltration ratio: κ is calculated from the concentration of R22 and SF6.

$$\kappa = Q \cdot C_{SF6}/m = C_{SF6}/C_{R22} \quad \cdots\cdots (1)$$

Q: Ventilation rate
C_{SF6}: Concentration of SF6 at exhaust fan
C_{R22}: Concentration of R22 at exhaust fan
m: Injection rate of SF6 in crawl space

The ratio: κ means a ratio of the infiltration rate of pollutant from crawl space to the indoor space toward the generation rate of the pollutant in the crawl space. Therefore, it is desirable that the ratio: κ is enough low.

④　Concentrations of volatile organic compounds

Concentrations of toluene, xylene, ethyl benzene and styrene were measured in rooms using a VOC-monitor with gas chromatograph: GX-100V-UK by NEW COSMOS ELECTRNIC LTD.

RESULTS

①　Measurement on the equivalent leakage area

Equivalent leakage areas of test houses were 267.5 cm^2 in the case of model A, 145.3 cm^2 in model B and 35.5 cm^2 in model C as shown in figure 8.

Equivalent leakage areas per it's floor area: C were calcurated considering the ratio of the length of envelope in a common house which floor area is 132 m^2, toward that in the test house. Equivalent leakage areas per it's floor area: C were 10.4 cm^2/m^2 in the case of model A, 5.6 cm^2/m^2 in model B and 1.4 cm^2/m^2 in model C. Equivalent leakage areas per it's floor area: C in model C was lower than 5.0 cm^2/m^2: the latest guideline for airtightness in Japan. Because, the test house was built in accordance with the guideline on the airtight methods. The airtight level of the hybrid type was expected to be higher than the guidelines. But the equivalent leakage area of model B was larger than the standard: 5.0 cm^2/m^2.

In the case of model B, the air leakages were detected at

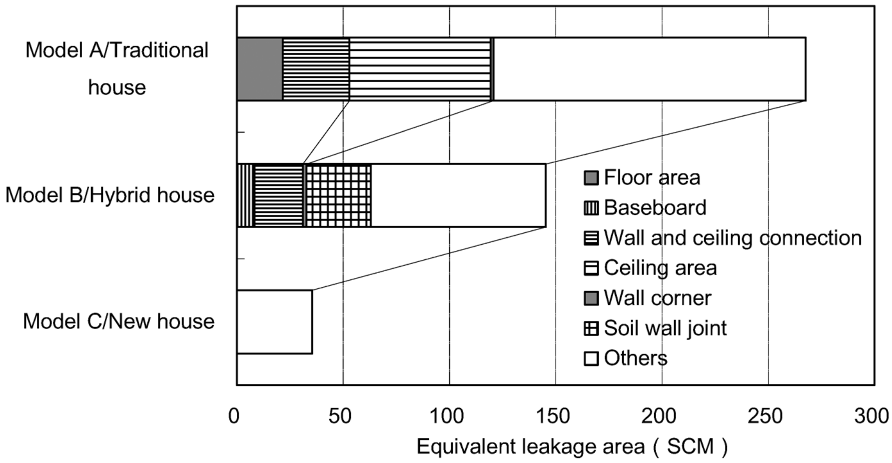

Figure 8.　Measured equivalent leakage areas with sealing

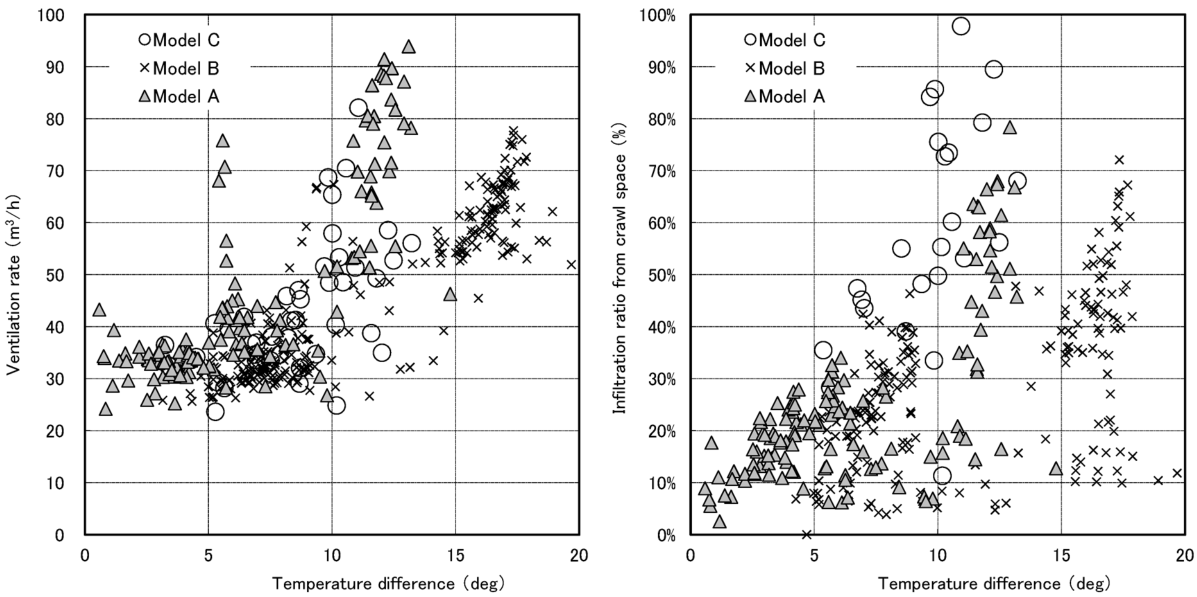

Figure 9.　Ventilation rate and infiltration ratio from crawl space

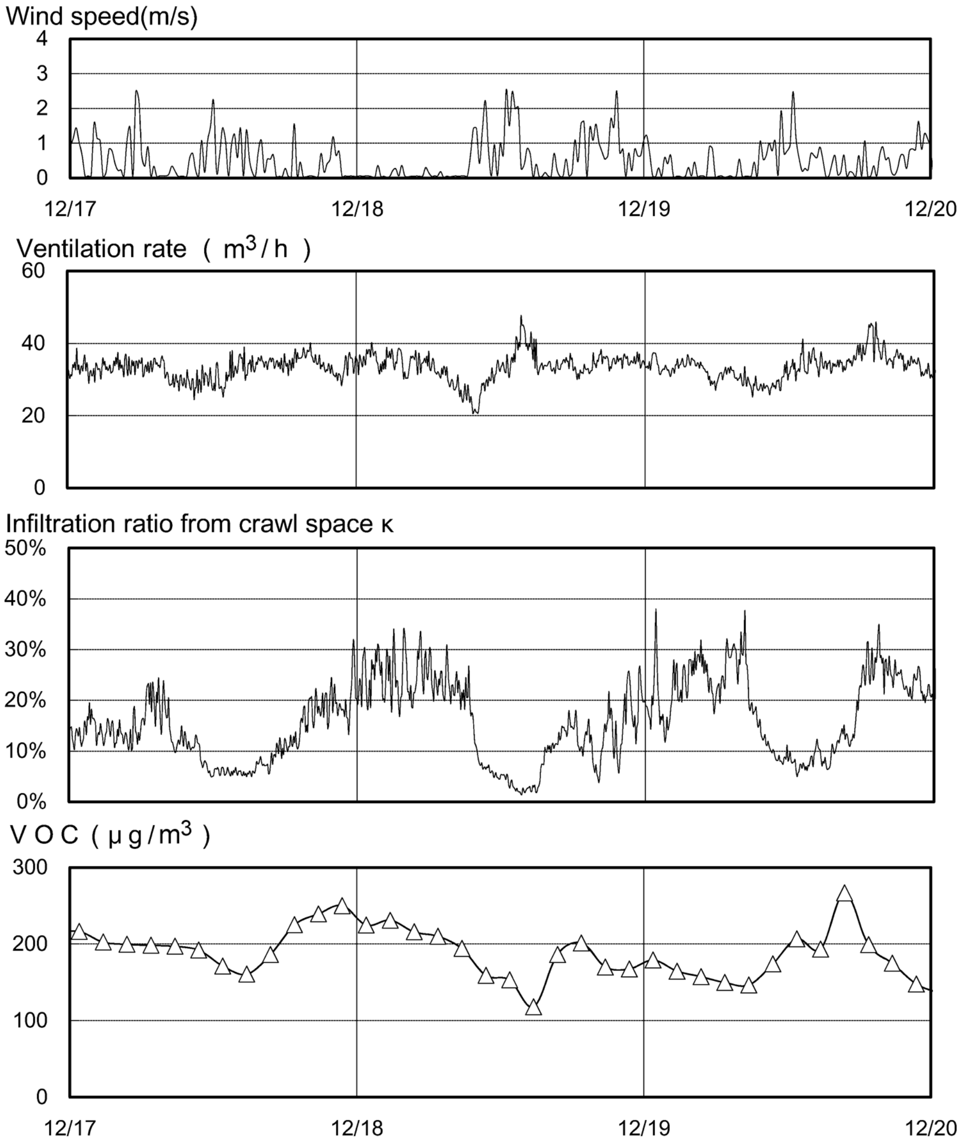

Figure 10. Wind speed, ventilation ratios, infiltration ratio of pollutants from crawl space, concentrations of VOC in Model A

the joint of wall and cieling and the joint of soil wall and wooden pillar. The reason was thought to be that leakages become wider when the material dries in winter.

② Measurement on the ventilation rate

An exhaust fan and a ventilator were installed in the houses. The air flow rate was kept to meet 30 m^3/h by the fan. The ventilation rate increased with the temperature difference between inside and outside as shown in figure 9. And the measured ventilation rate became higher when the house was heated and when the wind speed was high. This increase was shown clearly in the case of model A: traditional house.

③ Infiltration ratio: κ of pollutants from crawl space

The Infiltration ratio from crawl space increased with temperature difference as shown in figure 9. The air infiltrates from the space under the floor to the indoor space by the pressure difference of temperature difference between inside and outside.

Figure 10 shows wind speed, ventilation rate and the ratio in the case of Model A. The ratio increases with the ventilation rate when the wind speed is low. When the wind speed is high, the ratio did not increase. Because, the ratio is influenced by not only the infiltration rate from the crawl space to the indoor space, but also the ventilation rate of the crawl space. When the wind speed is high, the ventilation rate of crawl space is high and its concentration is low.

④　Concentrations of volatile organic compounds

Figure 10 shows change of VOC in the case of model A. ''VOC'' in figure 10 is a total of the measured concentrations of VOCs. The concentration of VOC changed with the infirtration ratio from crawl space in genaral.

The concentrations of volatile organic compounds were varied in the houses. Styrene and ethyl benzene were detected in model B and model C. Xylene was detected in model A. The generation rates of volatile organic compounds were calculated using the ventilation rate and the concentration. In the case of model A and model B, the generation rates increased with the infiltration ratios from crawl space. Therefore we thought that volatile organic compounds infiltrated from the crawl space to the indoor space.

CONCLUSIONS

The insulation level of the hybrid house Model B was improved from that of the traditional house. Therefore the airtight revel was not improved enough. And the indoor air quality was improved in a sense. But the infiltration of pollutant from crawl space made the indoor air quality worse. In the crawl space, chemical compounds are used to prevent mites and fungus. Therefore the airtight performance at the floor is one of the important factors for the better indoor air quality.

In order to expand comfortable houses and to save energy, it is necessary to improve the traditional houses using soil. Because most carpenters to build detached houses in the mild regions in Japan are not used to build with new materials to airtight. The traditional technologies have various values. It gives Japanese a suitable indoor climate for their living style. The result of this study shows the feasibility of the hybrid house.

ACKNOWLEDGEMENT

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