Evaluation of Domestic Passive Ventilation Systems in Mild Climate Region and Hot Humid Region in Japan

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Abstract

Purpose / Context –The purpose of this study is to investigate indoor environment and energy saving performance of houses, which employ passive ventilation systems, built in mild climate region and hot humid region in Japan.

Methodology / Approach – In this study, investigation of passive ventilation systems, such as passive stack ventilation systems and solar heating panels, have been conducted by two steps. The first step is real measurement of indoor environment and heating energy in houses employing passive ventilation systems. The second is analysis of total primary energy consumption of heating, cooling and ventilation by using a computational program based on *the extended heating degree method.*

Results – From the measurement results, a passive ventilation system can be used in the regions from the viewpoint of the indoor environment. From the calculations results, a passive stack ventilation system with a self regulating damper yields less energy than typical mechanical ventilation systems. It is confirmed that a solar heating panel have a positive effect on heating energy reduction even in hot humid region.

Key Findings / Implications – In mild climate region, indoor environment of the house employing a passive stack ventilation system have almost met the reference values of the Act on Maintenance of Sanitation in Buildings in Japan. A solar heating panel works well as an assistant heating system on houses even in hot humid region. In mild climate region and hot humid region, a passive stack ventilation system which is generally adopted in cold climate regions can be used with less energy by employing a self regulating damper than typical mechanical ventilation systems.

Originality - In mild climate region and in hot humid region, where passive ventilation systems are generally not employed in housing, primary energy consumption and indoor environment of houses employing passive ventilation systems are evaluated by real measurement and computational calculations.
Keywords - Passive Ventilation, Domestic Ventilation, Mild Climates, Hot Humid Climate, Primary Energy Consumption

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1. Introduction

The Energy Saving Standard for houses in Japan was amended in 2013. The amended standard requires applying to the standard values, such as insulation performance and primary energy consumption, for each of 8 zones in Japan as shown in Table 1. Additionally, using the official program “Program for calculating primary energy consumption in house” and selecting a type of equipment employed in house, primary energy consumption in house can be estimated.
Within the program, passive ventilation systems cannot be selected as a ventilation system but only typical mechanical ventilation systems can be selected. The passive ventilation, which is just adopted in cold climate region in Japan, is considered to reduce the operating energy of ventilation in mild climate region and in hot humid region, if it works in heating season.
Therefore, this study aims at investigation about the indoor environment and the energy performance of houses employing passive ventilation systems in mild climate region and hot humid region in Japan.

Table 1: Zone classification of the Energy-Saving Standard in Japan and climate classification

Zone	1	2	3	4	5	6	7	8
Climate	Cold climate				Mild climate		Hot humid climate	
Typical City	Kushiro	Sapporo	Morioka	Sendai	Nigata	Tokyo	Kochi	Naha

2. Methodology

In this study, investigations of passive ventilation systems have been conducted by real measurement and calculations using computational program.

2.1 Measurement

Real measurement has been conducted in 2 houses employing passive ventilation systems and the reference house. Measuring items and measuring instruments employed are shown in Table 2 and the outlines of subject houses are shown in Table 3. The House A which is the reference house employs a mechanical exhaust only ventilation system (MEO) and a central heat pump air-conditioner under the basement floor. The House B employs a passive stack ventilation system with a self regulating dumper by sensing humidity and a central heat pump air-conditioner on the basement floor. Moreover, The House B is measured during heating period with the aim of evaluating its performance. The House C employs a wall-mounted solar heating panel warming up supply air by using solar radiation as a passive ventilation system, a heat pump air-conditioner and a mechanical exhaust only ventilation system.

Table 2: Measuring items and instruments

measuring item	instrument
Temperature & Relative Humidity	Thermometer RTR-53, RVR-52
CO_2 concentration	KNS-CO2S
Power consumption	KNS-WP-WL

Table 3: Subject houses

	House A (reference house)	House B	House C
Location	Tokyo	Tokyo	Kochi
Zone	Mild climate(zone 6)	Mild climate (zone 6)	Hot humid(zone 7)
Completion date	December 2013	March 2014	March 2013
Family member	husband and wife	husband and wife and two children	husband and wife and a child
Floor area	93.8m^2	90.2 m^2	98.0 m^2
Q value	2.08 W/ m2･K	1.91W/ m^2･K	2.51W/ m^2･K
n50	6.42	2.81	3.61
Ventilation system	Mechanical Exhaust Only Ventilation System	Passive Stack Ventilation System	Mechanical Exhaust Only Ventilation System*
Heating & cooling system	Underfloor air conditioner (heating) Air conditioner (cooling)	Floor type air conditioner (heating) Air conditioner (cooling)	air conditioner (heating &cooling) Solar heating panel (heating)
Measurement period	28th.Dec.2013-11th.Mar.2014	10th.Mar.2014-25th.Mar.2014	15th.Dec.2013-7th.Feb.2014

*including air supply by solar heating panel

2.2 Estimation of primary energy consumption related to ventilation

Estimation of primary energy consumption of each whole-house ventilation system including a solar heating panel has been carried out. The primary energy consumption related to ventilation must be considered energy of heating and cooling as well as power input of operation, because ventilation load affect energy consumption of heating and cooling. Therefore total energy consumption of heating, cooling and ventilation operation is calculated by using program based on the *extended heating degree method*. The conditions for computational calculation are shown in Table 4 and the model house for calculation is shown in Figure 1.

Table 4: Calculation conditions of model house

Setting items	Level
City	Tokyo, Kochi, Naha
Floor area	120.8m^2
Insulation Performance	2013 energy-saving standard for houses in Japan
n50	4.02
Whole-house Ventilation System	[a]Mechanical Exhaust Only ventilation system(MEO) [b]Balanced ventilation with heat recovery (MEO during cooling and in-between season) [c]Balanced ventilation with heat recovery [d]Passive stack or hybrid ventilation
Heating and Cooling method	Central air-conditioning System, continuous use
Air Conditioning rate	0.92
Ventilation rate	160m^3/h ([e]with self regulating dumper: 173m^3/h)
Net Air Volume rate	0.95 ([b] (heating season)and[c])
COP of air-conditioner	3.0
Heat Exchange Efficiency	Sensible heat exchange efficiency: 0.65 latent heat exchange efficency: 0.40
Specific Fan Power [W/(m^3/h)]	[a]0.144, [b]0.315(heating season) 0.159(in-between and cooling season), [c]0.315, [d]0.14(SFP of MEO)

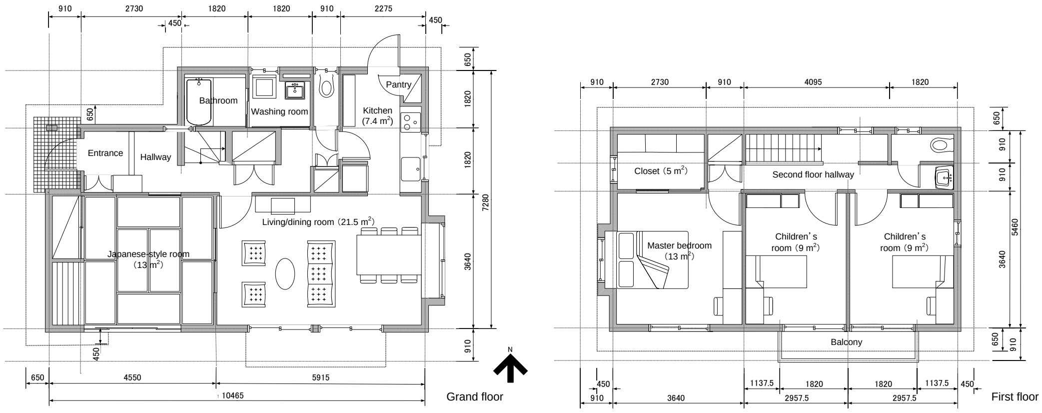


Figure 1 The model house for calculation

3. Results and Discussion

3.1 Measurement

3.1.1 Indoor Environment

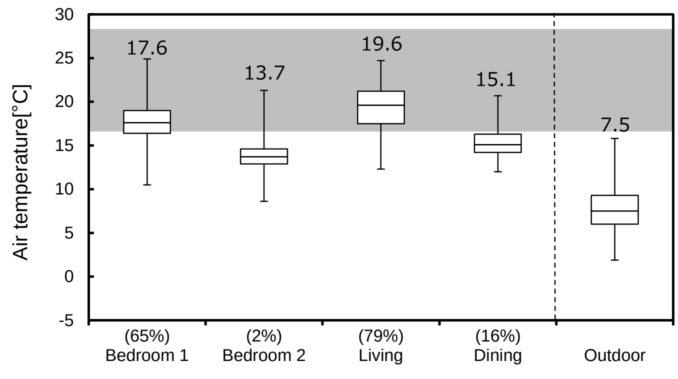
Indoor air temperature, relative humidity and CO_2 concentration were measured. These measurement values are compared with the reference values of the Act on Maintenance of Sanitation in Buildings in Japan (shown in Table 5) since the standard for residential building indoor environment in Japan is not established.

Table 5: Measuring items of the Act on Maintenance of Sanitation in Buildings in Japan

measuring item	reference value
CO_2 concentration	1000 ppm
Temperature	17°C-28°C
Relative Humidity	40 %RH-70%RH

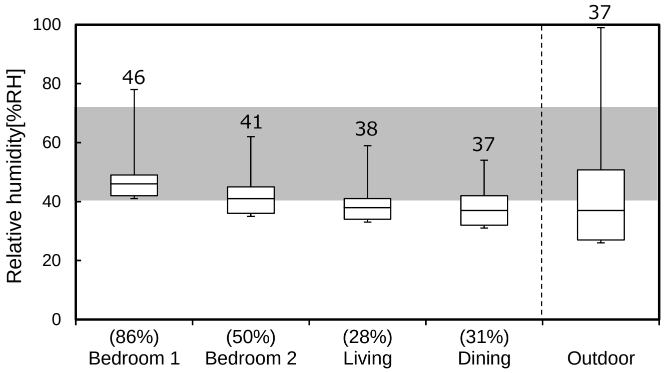
(1) House A (reference house)

The measuring results of air temperature and relative humidity of each room are shown in Figure 2 and 3. The grey areas in the diagrams indicate the range of the reference value of the ACT. Air temperature of the living is within the reference value at a rate of 79%. In the Bedroom1, the air temperature is within the reference value at a rate of 65 % and the rate of relative humidity within the reference value is 86%, larger than one of other rooms because a humidifier was employed there.



Value above box plots indicates mean value, () indicates rate of meeting within the reference value

Figure 2 Air temperature of each room in the House A



Value above box plots indicates mean value, () indicates rate of meeting within the reference value

Figure 3 Relative humidity of each room in the House A

(2) House B

The measuring results of air temperature, relative humidity and CO_2 concentration of each room are shown in Figure 4, 5 and 6. The air temperature of the loft, the living and the bedroom1 meet almost the reference value. Although the real measurement is conducted without occupants, the relative humidity of the house is approximately 40%RH in each room. This is believed to be due to using self regulating dumper by sensing humidity. The CO_2 concentration of both rooms is within the reference value in most of the measurement period. This result shows that passive stack ventilation system can be used as a whole house ventilation system during heating season even in mild climate region.

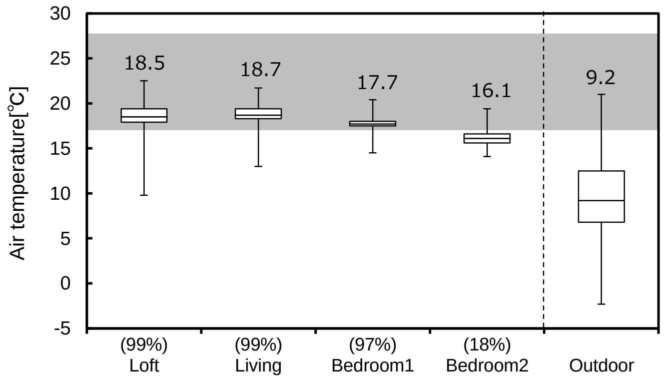


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Figure 4 Air temperature of each room in the House B

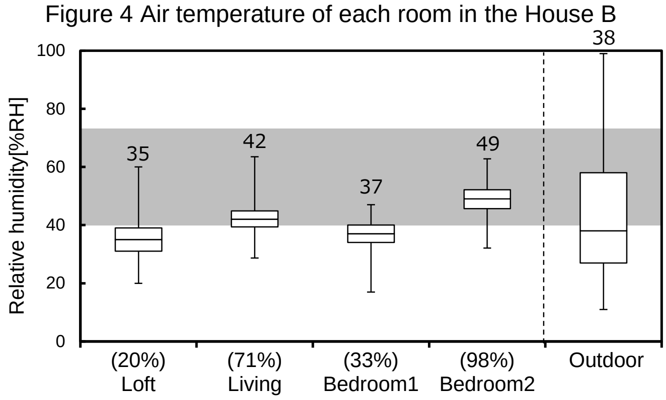

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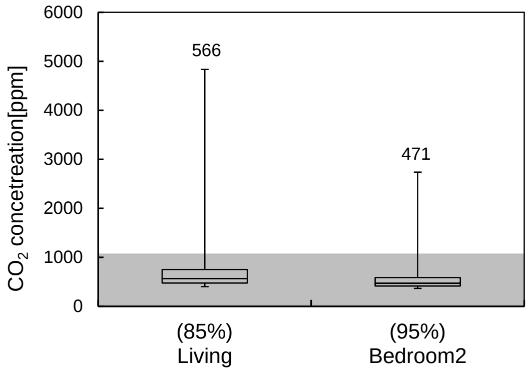
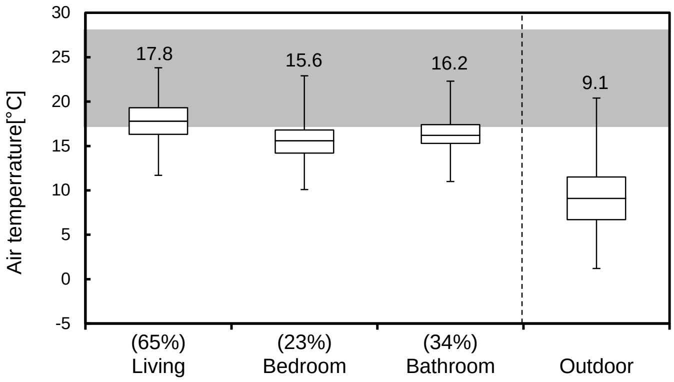
Figure 5 Relative humidity of each room in the House B



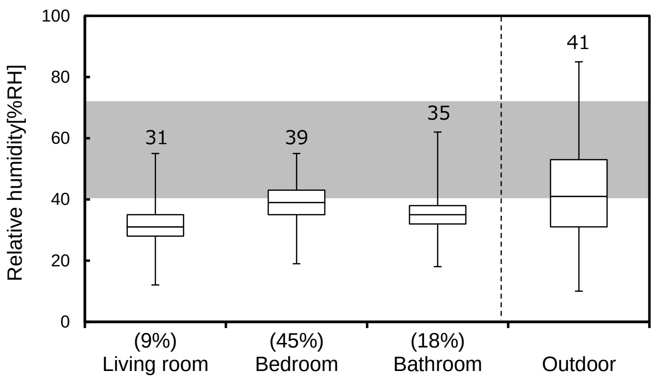
Value above box plots indicates mean value, () indicates rate of meeting within the reference value
Figure 6 CO_2 concentration of each room in the House B

(2) House C

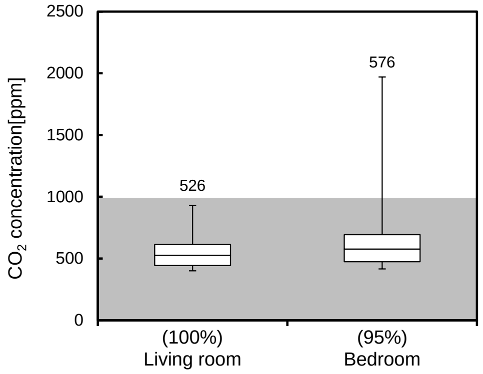
The measuring results of air temperature, relative humidity and CO_2 concentration of each room are shown in Figure 7, 8 and 9. The air temperature of living is the highest in house C and meets the reference value at a rate of 65%. The CO_2 concentration of both rooms is within the reference value in most of the measurement period. It is comparatively low relative humidity and very low CO_2 concentration in the living because of supply air to living by solar heat panel during the working.



Value above box plots indicates mean value, () indicates rate of meeting within the reference value
Figure 7 Air temperature of each room in the House C



Value above box plots indicates mean value, () indicates rate of meeting within the reference value
Figure 8 Relative humidity of each room in the House C



Value above box plots indicates mean value, () indicates rate of meeting within the reference value

Figure 9 CO_2 concentration of each room in the House C

3.1.2 Heating energy

Measuring results of the heating energy consumption and day average outdoor air temperature are shown in Figure 7. The House B uses more energy for heating than the House A under same daily average outdoor air temperature. One of the reasons is considered that House B has no internal heat generation including occupants. House C uses less energy for heating than House A when daily average outdoor air temperature is below 9°C. Therefore solar heating panel is recognized a positive effect as assistant heating system. However when it is over 9°C, House C uses more energy for heating than the House A. This reason is believed the occupants opened the window by habit.

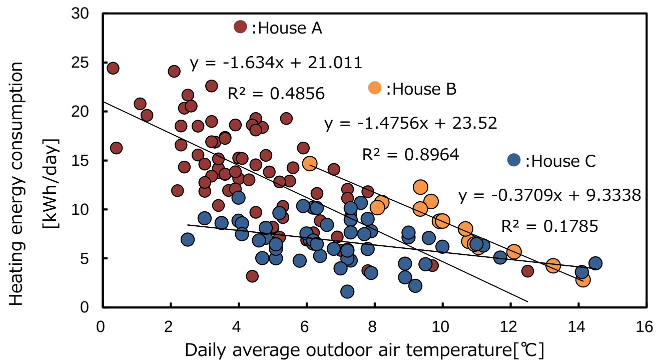
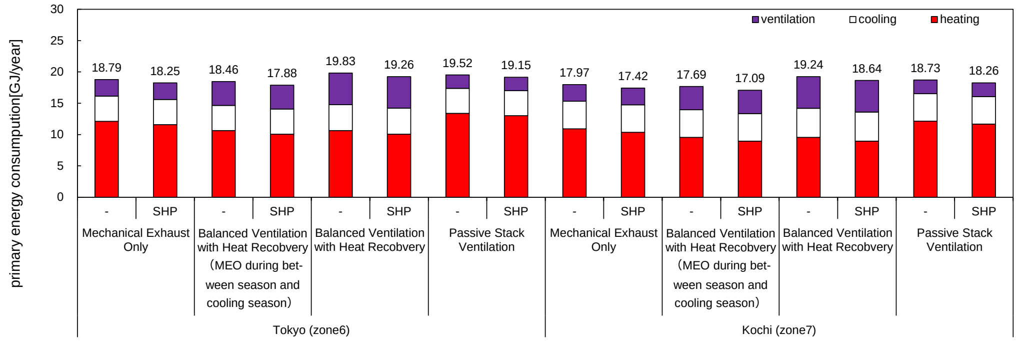


Figure 10 Heating energy consumption and daily average outdoor air temperature

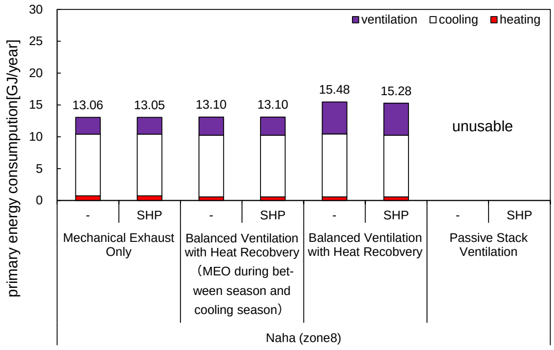
3.2 Estimation of primary energy consumption related to ventilation

Primary energy consumption of heating, cooling and ventilation calculated by using the computational program is shown in Figure 11 and 12. In Tokyo and Kochi, the balanced ventilation system with heat recovery which is switching MEO during in-between season and cooling season yields less total energy than other ventilation systems. In Naha, the mechanical exhaust only ventilation system uses less than other ventilation systems. The passive stack ventilation system yields more total primary energy consumption than typical mechanical systems in all zones. It is thought to be affected by heating load of excess ventilation whose rate is larger than 160m^3/h when the outside temperature is low condition. Therefore, the primary energy consumption of passive stack ventilation has been additionally calculated under the condition of adopting the self regulating damper. As a result of the additional calculation, the primary energy consumption calculated has been reduced as shown in figure 13. Notice that in warm climate region and in hot humid region such as Tokyo (zone 6) and Kochi (zone 7), the passive stack ventilation system which is generally used in cold climate region is available with less primary energy consumption than typical mechanical ventilation systems by adopting self regulating damper. In addition if a house employs a solar heating panel, it has been confirmed that the primary energy consumption was decreased approximately 0.6 GJ, expect in Naha where the heating load is less than 1.0 GJ.



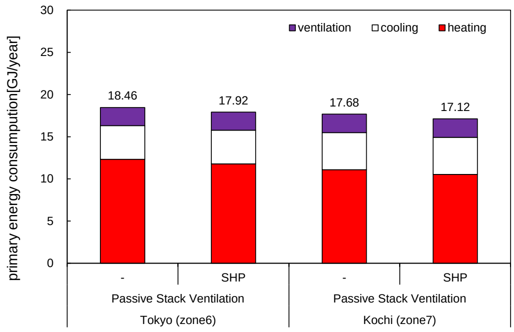
* SHP: employing solar heating panel

Figure 11 Primary energy in Tokyo and Kochi calculated by using the program



* SHP indicates with solar heating panel

Figure 12 Primary energy consumption in Naha calculated by using the program



* SHP indicates with solar heating panel

Figure 13 Primary energy consumption of passive stack ventilation system with a self regulating damper calculated by using the program

4. Conclusion

In this study, investigation the indoor environment and primary energy consumption of houses employing passive ventilation systems in mild climate region and hot humid region has been conducted. The real measuring results have shown that indoor environment in house employing a passive stack ventilation have fulfilled almost the reference values of the Act on Maintenance of Sanitation in Buildings in Japan. Measuring results of heating energy consumption have indicated that a solar heating panel works well as an assistant heating system on houses in hot humid region. In addition, the calculation results of the computational program also have suggested that a solar heating panel reduces heating energy consumption. A passive stack ventilation system without self regulation dumper has consumed more energy than other ventilation systems. However, in case of a passive stack ventilation system adopting self regulating damper, the primary energy consumption has been reduced. Notice that a passive stack ventilation system which is generally used in cold climate region can be used with less primary energy consumption than typical systems by adopting self regulating damper in mild climate region and hot humid region such as Tokyo (zone 6) and Kochi (zone 7). From results, this study has shown the availability of passive ventilation systems in mild climate region and hot humid region.

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