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EXPERIMENTAL ANALYSIS OF A HYBRID VENTILATION SYSTEM

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ABSTRACT

There are many ventilation and air conditioning systems, having their own set of advantages, disadvantages and applications. Inadequate control on ventilation rate for the case of natural ventilation system can lead to indoor air quality problems or excessive energy loss, while mechanical system is often expensive for the installation, operational and maintenance costs. The purpose of this study is to develop a new kind of hybrid ventilation system which can be described as a two-mode system to provide a comfortable internal environment using different features of both natural passive ventilation and mechanical systems at different times of the day or season of the year, and then to evaluate the performance of this kind of system by experiments in a full-scale test house which is located in the Tohoku University, Japan.

KEYWORDS

Hybrid ventilation systems, constant concentration tracer measurement, airflow in houses

FULL-SCALE TEST HOUSE WITH HYBRID VENTILAION SYSTEM

Full-scale Test House

The full-scale test house (Photo 1) is located in Tohoku University, Japan. That had been a one-story house used in a previous solar study but was reformed to a two-story house with a crawl space. The house plan and sections are shown in Figures 1 and 2, respectively. The floor area is 78.9m^2 and volume is 166.7m^3. Except for the staircase outside, the two floors are connected by open ceiling in the south side. For heat insulation, except the exterior wall on the gable side (20cm), other exterior walls, ceilings and floors are made by 10cm polystyrene foam board. The windows are double-glazed (the

Photo 1: The Full-scale Test

windows in the first floor are 5+A6+5, while in the second floor are 3+A12+3). Two electric movable windows aimed for air exchange are installed in the north roof of hall on the second floor. Each vent has an equivalent leakage area of about 13cm^2, which is located at 2.1m above the floor. In addition, room air conditioners are installed in the north walls of habitable rooms. The tubes (PE ducts, 20cm in diameter) from outside to the first floor are installed inside the earth, which can be used as air supply ducts. The total leakage area of the building is about 2.6cm^2/m^2 when all the vents were closed, the supply and exhaust openings of ducts, sashes in the first floor were sealed.

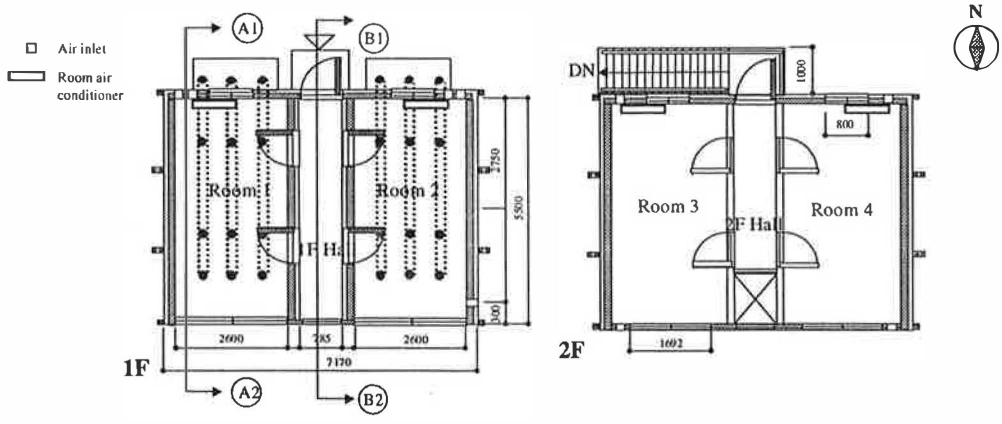

Figure 1: Floor plan of the full-scale test house

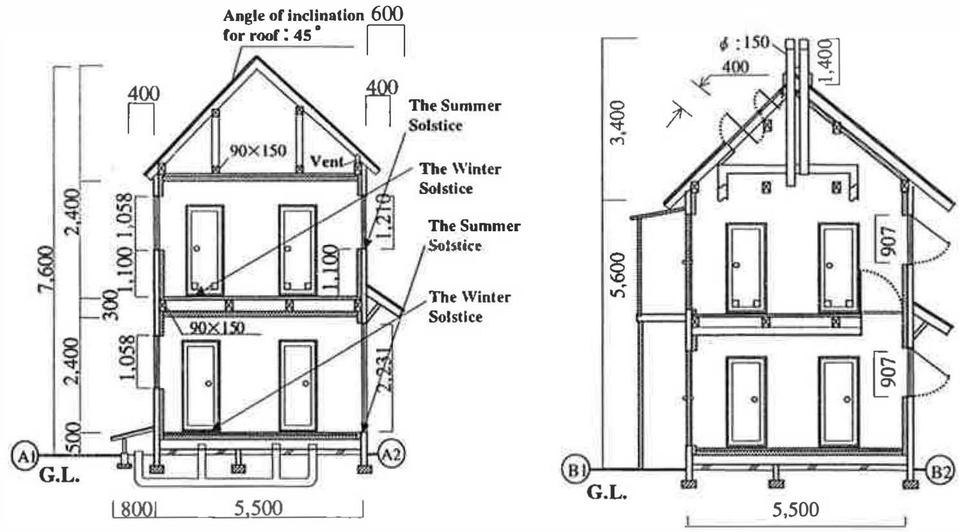

Figure 2: Elevations of the full-scale test house

Hybrid Ventilation System

The schematic of hybrid ventilation system is shown in Figure 3. The hybrid system consists of two passive ducts, a chamber and ducts connected with the chamber and each room. There is a small fan located on one of the passive ducts, with a capacity of 170/173m^3/h (50/60Hz) at a pressure of 1.9/1.9mmAq. The electric fan of power 5/6W (50/60Hz) will run when the airflow is insufficient.

The passive duct diameters are 20cm and the height of the top is 9m above the ground.

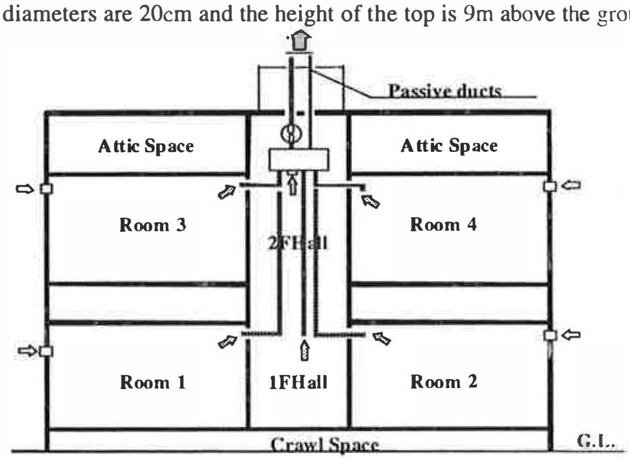

Figure 3: Schematic of Hybrid Ventilation System in the Full-scale Test House

EXPERIMENTS ON THE HYBRID VENTILATION SYSTEM PERFORMANCE

Experiments

The airflow characteristics of the hybrid ventilation system was measured and analyzed by the constant concentration method in the full-scale test house. The measurement system comprised of a multi-gas monitor and two multi-point sampler and doser was used to measure the fresh airflow rates per room. The measurement conditions are summarized in Table 1. Each case was carried out for about two days. Except for the fresh airflow rate entering each room, the airflow rate through passive ducts were determined by measuring the SF_6 concentration variation in the duct work which is dosed continuously. All the interior doors were closed and sealed during the measurements with the exception of two small openings (each has an equivalent area of 100cm^2)at the bottom of the doors.
The following three cases can be described as:

Case 1: passive system with exhaust air from all the rooms. The indoor air is extracted and connected in the chamber at the top of the hall at the second floor and exhausted through the two passive ducts to the top of the building and at last removed to the outdoor.

Case 2: hybrid system with exhaust air from the rooms on the second floor. The additional fan installed at the bottom of the passive ducts operates if the indoor-outdoor temperature difference is below 10℃. When the fan is off, it is a passive system like case. The schematic of the control system for additional fan is shown in Figure 4.

TABLE 1

MEASUREMENT CONDITIONS OF THE THREE CASES

	Case 1	Case 2	Case 3
Ventilation system	passive	hybrid	hybrid + damper control
Exhaust strategy	all the rooms	the rooms on the 2nd floor	hall (1st and 2nd floor)
Air inlets	open	open at only 2nd floor	open
Indoor temperature [℃]	20	16	26
Measurement date	12/06 17:00 - 12/09 0:00 (1999)	01/05/14:00 - 01/07/16:00 (2000)	01/06 21:00 - 01/10 0:00 (2000)
Measurement method	the constant concentration method		
Tracer gas	CO_2		
Fan mixing	no		
Target value	1000ppm	1500ppm	1500ppm

Case 3: hybrid system with damper control with exhaust air from hall. On the base of Case 2, when the indoor-outdoor temperature is above 20℃, one of the two passive ducts will be closed by an electrical damper to avoid over-ventilation. The principle of damper control is similar with case 2 shown in Figure 4. When the additional fan and electrical damper are not operated, it is a passive system like case 1.

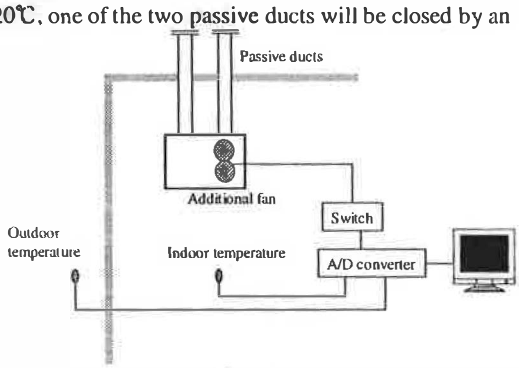

Figure 4: Schematic of the Control System for Additional Fan

Results

(1) Total airflow variation

Figure 5(1) shows the variation of total fresh airflow rates of each room and the exhaust airflow rate through passive ducts. It is evident to see that the airflow rates depend on the indoor-outdoor temperature difference. At temperature difference of 20℃, the airflow rate through passive ducts is about $180m^3/h$, which is a very high air change rate of $1.1h^{-1}$. With the higher temperature difference, the total fresh airflow rate from each room is larger than the airflow rate through passive ducts. It means that some of indoor air is not extracted from the passive ducts but goes out from the leakages or vents in the second floor directly.

Figure 5(2) shows the variation of total fresh airflow rates of each room and the exhaust airflow rate through passive ducts. When the additional fan is off, it cab be seen that the relationship between the airflow rate and the indoor-outdoor temperature difference is similar to Case 1. Because of the lower temperature difference and the closed air inlets on the first floor, the airflow rate through passive ducts is very low compared with Case 1. At temperature difference of 10℃, the airflow rate through passive ducts is only about $55m^3/h$ ($0.33h^{-1}$). For solving this problem of under-ventilation, the additional fan should be operated when temperature difference is too low. During the period of fan on, the airflow rate through passive ducts assured a stable level of about $130m^3/h$ ($0.78h^{-1}$).

Figure 5(3) shows the variation of total fresh airflow rates of each room and the exhaust airflow rate through passive ducts. Without the damper control, similar relationship of the airflow rates vs. the indoor-outdoor temperature difference can be seen. Because the indoor air is only extracted from the hall, the airflow rate through passive ducts is very low compared with Case 1. At high temperature difference of 20℃, the airflow rate through passive ducts is only about $62m^3/h$ ($0.38h^{-1}$). If two passive ducts are used together, the airflow rate through passive ducts could reach $90m^3/h$ ($0.55h^{-1}$). Therefore, even at high temperature difference, damper control is not necessary for this ventilation strategy.

(2) Fresh airflow rate per room

Figure 6 shows the content of average fresh airflow rate during the measurement period per room for the three cases. A key aspect of airflow characteristic for Case 1 is that the outdoor airflow rate to the first floor is very high while very little enter the second floor. For example, for Case 1, the average air change rate of hall on the first floor is about $52m^3/h$ ($4.5h^{-1}$), while that of Room 3 is only $2.9m^3/h$ ($0.07h^{-1}$). This can be attributed to two causes. One is the feature of driving force due to temperature difference and the other is the airtightness distribution. Although all the exterior walls in each room have been carefully sealed, due to the degradation of the construction of the first floor before refurbishment, the airtightness of the second floor is much tighter than that of the first floor which results into very low air leakage to the second floor. To overcome this problem, in Case 2, air is only extracted from the rooms in the second floor through ducts and the air inlets in the first floor were all closed. As a result, the fresh airflow through the first floor decreases and raises the neutral pressure level a little. For example, without fan operation, the average air change rate of hall on the first floor is about 15.9m^3/h (1.0h^{-1}), while that of Room 3 on the second floor is 4.5m^3/h (0.15h^{-1}). But when the additional fan is operated, the fresh airflow rates to each room increase, especially the rooms on the second floor. The air change rate of the east room on the second floor reaches 0.5h^{-1}, corresponding to mechanical ventilation.

(3) Comparative analysis of the airflow characteristic for the three cases

Figure 7 is a plot of the airflow rates through passive ducts versus the indoor-outdoor temperature difference. All the data of the three cases lie above a certain level which is determined by the ventilation strategy and installation of air inlets. For Case 1, there is a predominance of airflow rates in the 160 to 200m^3/h range within the temperature difference of 15 to 22℃, which is the highest level among the three cases. The somewhat expected dependence of the airflow rates through passive ducts on temperature difference could be shown. The scatter in the points is due to wind effect. The data for Case 2 fall into two main groups, with the upper group associated with the operation of additional fan, with a mean airflow rate of about 130m^3/h regardless of temperature difference. The variation in the lower group of points corresponds to no fans running and airflow is due to temperature difference only. There are some points between these two major groups. This is due to the measuring interval of the fan control sensor is about 10 seconds, while the measuring interval of multi-gas monitor for airflow measurement is about 8 minutes. Therefore, during the 8 minutes, the temperature difference may

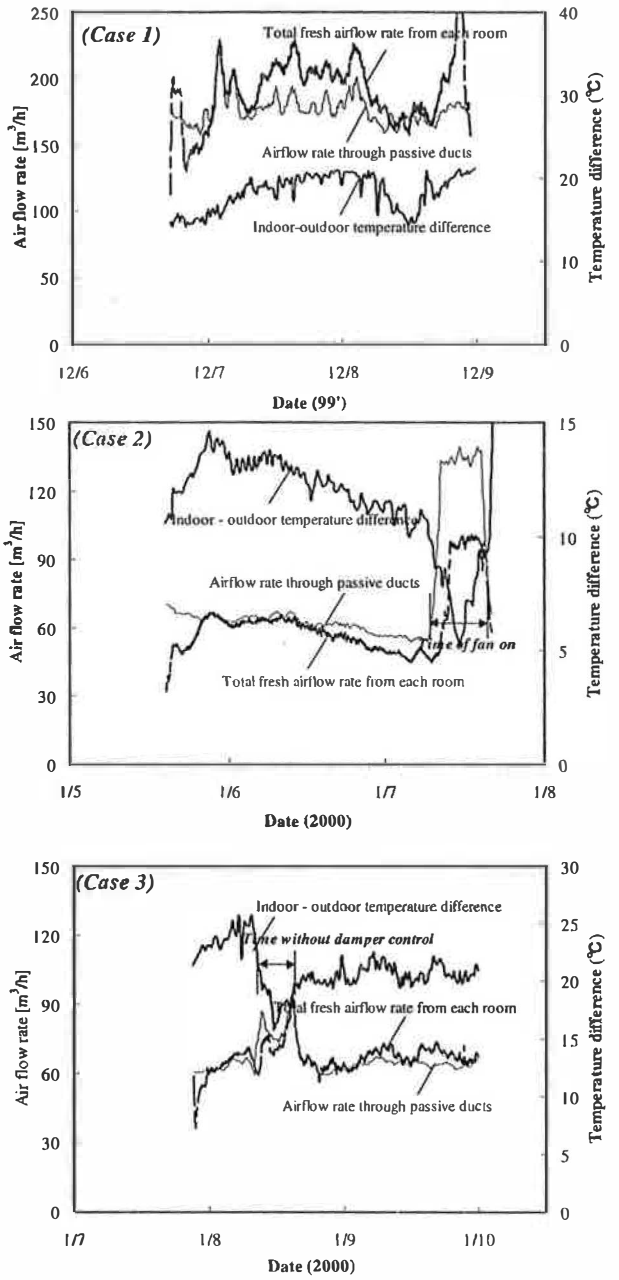

Figure 5: Airflow Variation of the Three Cases

vary by around 10℃ causing the fan to switch on and off frequently. The data for Case 3 can also be divided into two groups. The lower group corresponds to the duration of damper control. The airflow through the passive ducts is very low, in the range 60 to 70m^3/h for 20 to 25℃ temperature difference, while the upper group of points corresponds to two passive ducts open.

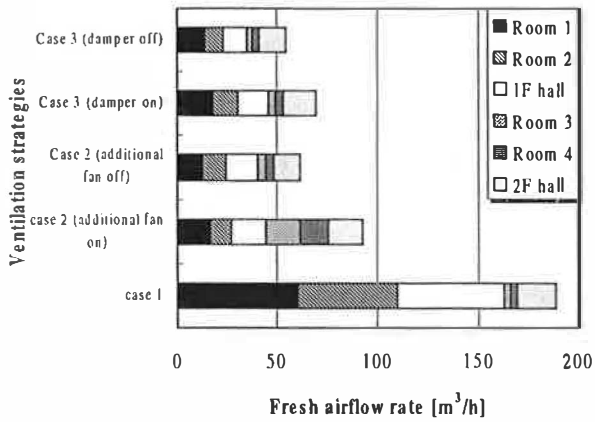

Figure 6: Fresh Airflow Rate in Three Cases

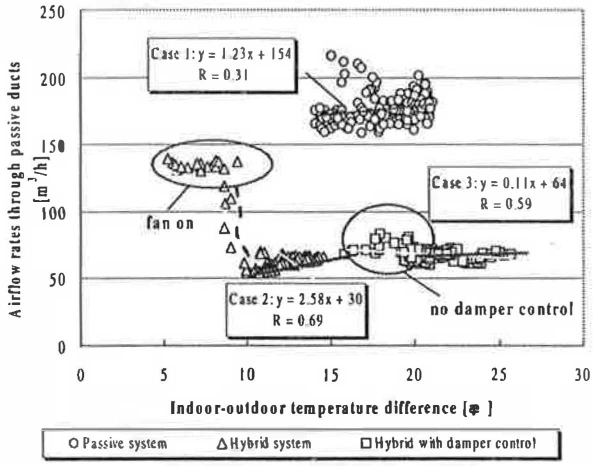

Figure 7: Airflow Rates through Passive Ducts versus Temperature Difference

CONCLUSION

In order to evaluate the performance of a new kind of ventilation system – hybrid ventilation system, airflow experiments were carried out in a full-scale test house in the Tohoku University, Japan. The main results can be summarized by:

(1) With passive system, because the fresh airflow rates for the whole building and for each room mainly depend on the indoor-outdoor temperature difference, the air change rate is often not enough to satisfy the requirement for fresh air during milder weather. Even if the total airflow rate can satisfy the necessary airflow rate, because of the upward airflow pattern and air leakage distribution, the fresh air entering the second floor is still very low.

(2) Compared with passive system, for the case of hybrid system, due to the operation of additional fan, even under the milder weather condition, the under-ventilation can be supplemented and the airflow rate can be fixed at a certain high level. The fresh air to the rooms at the second floor is increased, too. In addition, due to the damper control, under the very cold weather conditions, the over-ventilation can be restrained.

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