INNOVATIONS IN VENTILATION TECHNOLOGY

21ST ANNUAL AIVC CONFERENCE
THE HAGUE, NETHERLANDS, 26-29 SEPTEMBER 2000

PERFORMANCE EVALUATION OF HYBRID VENTILATION SYSTEM IN A FULL-SCALE TEST HOUSE

Jing Liu[1], Hiroshi Yoshino[2]

[1] Tokyo Gas Co., Ltd.
[2] Department of Architecture and Building Science, Graduate School of Engineering, Tohoku University, Sendai 980, Japan

Synopsis
Hybrid ventilation system is a two-mode system that can automatically switch between passive and mechanical mode at different times of the day or season of the year. Some ventilation systems including hybrid system have been set up in a full-scale test house constructed in Tohoku University, Japan to assess their performance. In this paper, the performance of each system is described by some measurement results.

1 Introduction
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. Hybrid energy saving ventilation and air conditioning system is a developing system that has a large potential for future application. It 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. The basic philosophy is to maintain a satisfactory indoor environment by alternating between and combining these two modes to avoid the cost, the energy penalty and the consequential environmental effects of year-around air conditioning. However, despite that a large number of research has been carried out on natural and mechanical ventilation systems, hybrid ventilation and air conditioning system is still to be thoroughly investigated, and there is even hard to seek published information specifically aimed at this kind of ventilation strategy.

2 Full-Sale Test House with Hybrid Ventilation System

2.1 Full-Scale Test House

The full-scale test house (Photo 1) is situated at the Tohoku University, Japan. The house plan is shown in Figure 1. The floor area is 78.9m^2 and volume is 166.7m^3. That had been a one-story house used for a passive solar study but was reformed to a two-story house with a crawl space. Except for the staircase outside, the two floors are connected by an opening in the south side. For thermal 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 made by double glazing. Each air inlet 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 each room. The airtightness of the total building is about 2.6cm^2/m^2 (about 3.3h^{-1} at a pressure difference of 50Pa) when all the vents were closed, and the openings of ducts and sashes were sealed.

Photo 1 A full-scale test house

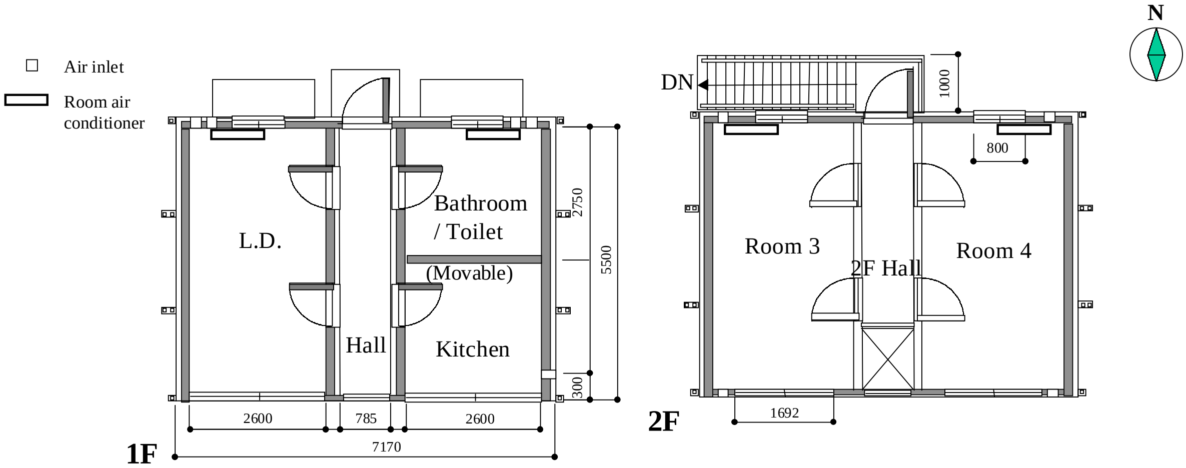

Figure 1 Floor plan of the full-scale test house

2.2 Hybrid Ventilation System

The schematic of hybrid ventilation system within the test house is shown in Figure 2. This system consists of two passive ducts, a chamber and ducts connected with each room. At the end of one of the passive ducts, there is an additional fan, with a capacity of $170m^3/h$ at a pressure of 1.9mmAq, and the electric power is 5W. This fan will be run when exhaust airflow rate is not enough. In addition, an electric damper was installed to restrict the airflow through passive ducts. The diameters of passive ducts are 20cm and the height of top is 9m above the ground.

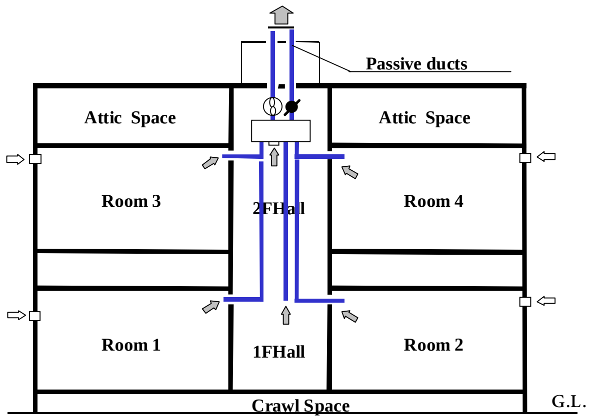

Figure 2 Schematic of Hybrid Ventilation System

3 Experiments On Hybrid Ventilation System Performance

3.1 Experiments

The outdoor airflow rates of various ventilation systems were measured and analyzed using the constant concentration method in the full-scale test house. The measurement system comprised of a multi-gas monitor and two sets of multi-point sampler and doser. The measurement conditions are summarized in Table 1. In addition, the airflow rates through passive ducts were determined by measuring the gas concentration variation in the ducts using massflow controller. All the interior doors were closed and sealed with the exception of two small openings (each has a size of 10cm×10cm) at the bottom of the interior doors. The following ventilation systems were tested:

Passive system (Case 1): this system is served as a baseline for comparing with the hybrid system. The indoor air is extracted to the chamber at the top of the hall, exhausted through the two passive ducts to the top of the building and at last removed to the outdoor. The effect of three exhaust strategies, in which indoor air

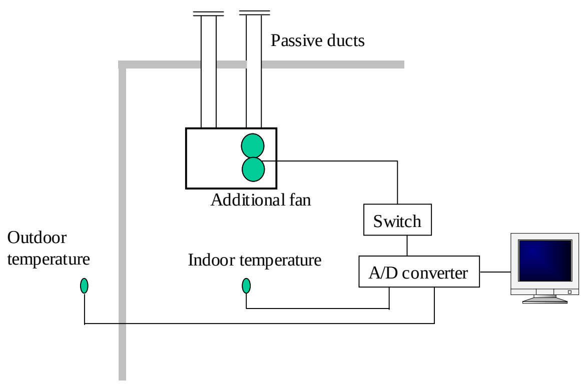

Figure 3 Schematic of the Control System for Additional Fan

exhausted from all the rooms (Case 1-1), 2nd floor (Case 1-2), or hall (Case 1-3), was analyzed.

Hybrid system (Case 2): the additional fan installed at the bottom of the passive ducts operates when the indoor-outdoor temperature difference is below 10• . If the additional fan is off, it is a passive system like Case 1. In this case, the indoor air is exhausted from the rooms at the second floor. The schematic of the control system for the additional fan is shown in Figure 3.

Hybrid system with damper control (Case 3): on the base of Case 2, when the indoor-outdoor temperature difference is above 20• , one of the two passive ducts will be closed by the electrical damper to avoid over-ventilation. If the additional fan and electrical damper are not operated, it is a passive system like Case 1. Two exhaust strategies, in which indoor air exhausted from hall (Case 3-1) or all the rooms (Case 3-2), were discussed.

Mechanical supply to the second floor (Case 4): in this case, and shown in Figure 4, an another fan operates to supply outdoor air to rooms 3 and 4 on the second floor, with the indoor air exhausted through passive ducts from the first floor.

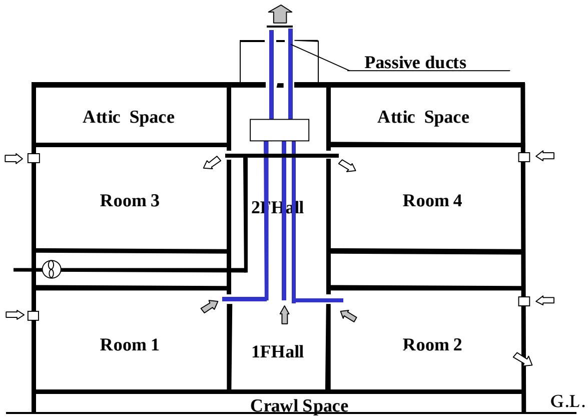

Figure 4 Schematic of Case 4 – Mechanical Supply to the 2nd Floor

Table 1 Measurement Conditions of the Three Cases

	Case 1			**Case 2**	**Case 3**		**Case 4**
	Case 1-1	**Case 1-2**	**Case 1-3**		**Case 3-1**	**Case 3-2**	
Ventilation system	Passive			Hybrid	Hybrid with damper control		Mechanical supply to 2nd floor
Exhaust strategies	all the rooms	2nd floor	hall	2nd floor	hall	all the rooms	1st floor
Air inlets	open	open (2nd floor)	open	open (2nd floor)	open (2nd floor)	open	open
Indoor air temperature [•]	20	20	20	16	26	26	20
Measurement period	12/6 17:00 - 12/9 0:00	1/24 17:00 - 1/31 11:00	2/1 0:00 - 2/7 10:00	1/5 14:00 - 1/7 16:00	1/7 21:00 - 1/10 0:00	2/8 14:00 - 2/14 10:00	2/20 0:00 - 2/22 19:00
Tracer gas	CO_2	SF_6	SF_6	CO_2	CO_2	SF_6	SF_6
Mixing	no	yes	yes	no	no	yes	yes
Target value [ppm]	1000	10	10	1500	1500	10	10

3.2 Experimental Results

(1) Total airflow variation

Figure 5 shows the variation of total outdoor airflow rate and the airflow rate exhausted through passive ducts for some cases.

Passive system (Case 1-1): it is evident to see that the airflow rates depend on the indoor-outdoor temperature difference. The total airflow rate from each room is larger than the airflow rate through passive ducts at higher temperature difference. It means that some of indoor air is not exacted from the passive ducts but goes out from the leakages or vents in the second floor directly.

Hybrid system (Case 2): when the additional fan is off, the similar relationship of the airflow rates and the indoor-outdoor temperature difference like Case 1 can be seen. Because of the lower temperature difference and the close of 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 $130m^3/h$ ($0.78h^{-1}$).

Hybrid with damper control system (Case 3-1): without the damper control, the similar relationship of the airflow rates vs. the indoor-outdoor temperature difference can be seen. 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 $90m^3/h$ ($0.55h^{-1}$).

Mechanical supply to the 2nd floor (Case 4): due to the supply fan, no significant dependence of outdoor airflow rate on the temperature difference can be seen. In addition, the airflow rates through passive ducts are very small compared with the total outdoor airflow rate. The reason is maybe that, due to the supply fan, the building is pressurized, reducing the stack impact. There are some periods where airflow rate through passive ducts shows an extreme level. The reason for this maybe due to the occurrence of reverse flow.

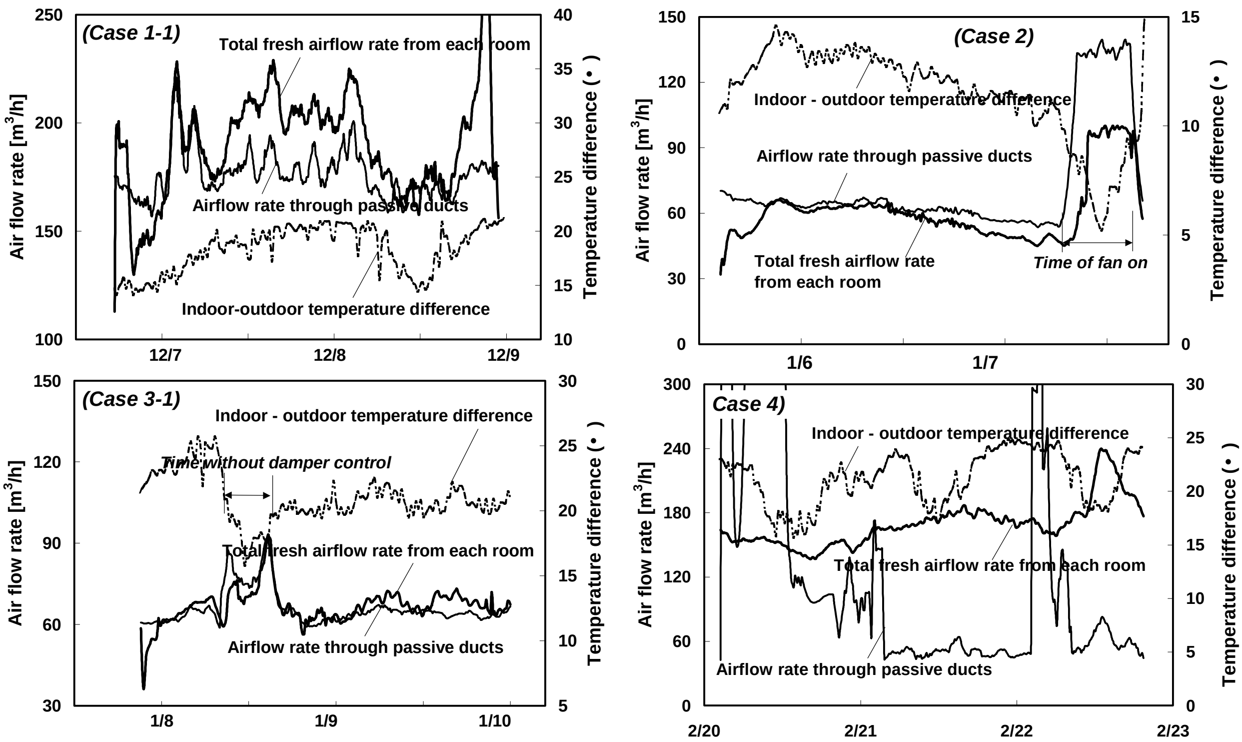

Figure 5 Variations of Airflow Rates

(2) Comparative Analysis of the Airflow Rates

In order to compare the various ventilation strategies, a plot of the total outdoor airflow rates versus the indoor-outdoor temperature difference for all the cases is shown in Figure 6. Except Case 4 and Case 2 (additional fan on), the somewhat dependence of the airflow rates through passive ducts on temperature difference is shown. For Cases 1-1 and 3-2 (damper off), 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 all the cases because indoor air is exhausted from all the rooms. For Cases 1-2 and 2 (additional fan off), with the first floor inlets closed, and air is exhausted only from the second floor, the measured airflow rate is reduced to 50m^3/h (about 0.3h^{-1}) when temperature difference is 10• . However, associated with the operation of additional fan, the outdoor airflow rate increases considerably to about 100m^3/h. For Cases 1-3 and 3-1 (damper off), with the air exhausted from the hall at the first and second floor, the airflow rates is in the range of 90 to 120m^3/h, corresponding to the temperature difference of 12 to 24• . The effect of damper control is shown from the results of Cases 3-1 and 3-2 when damper is closed. For example, for Case 3-1, at the same temperature difference of 20• , the airflow rate is about 130m^3/h with damper on, while that is 200m^3/h with damper off. For Case 4, due to the operation of an another mechanical supply fan, the temperature difference appeared to have little impact on the airflow rate, which always exceeds 150m^3/h. There is a significant scatter of the results because of the influence of wind speed.

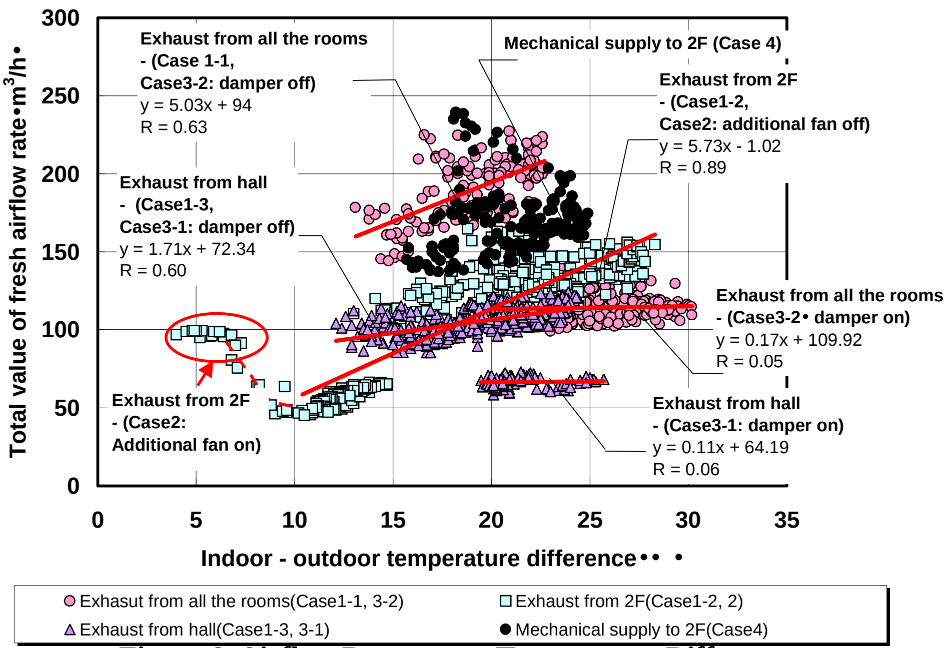

Figure 6 Airflow Rate versus Temperature Difference

(3) Outdoor Airflow Rate per Room

Figure 7 shows the ratio of average outdoor airflow rate to each room, and the total airflow rate of each case on the right side. A key aspect of airflow characteristic for passive ventilation strategies (except Case 2 with additional fan on and Case 4) is that the outdoor airflow rate to the first floor is large while that entering to the second floor is very small. For example, the total airflow rate for Case 1-1 is about $180m^3/h$, but the ratio of that to the second floor is only 14%. This is due to the feature of driven force, caused by the temperature difference, and the airtightness distribution is probably another reason. By the airtightness measurement, although all the exterior walls in each room have been sealed carefully, due to the degradation of the construction of the first floor before refurbishment, the airtightness at the second floor is much tighter (about $1.2cm^2/m^2$) than that at the first floor (about $4.2cm^2/m^2$), and leads to the low airflow via the leakages at the second floor. To solve this problem, in Case 1-2 and Case 2, the indoor air is only extracted from the rooms at the second floor through ducts and the air inlets at the first floor are all closed. But as the results, no significant effect can be seen. On the other hand, due to the operation of additional fan (Case 2) and mechanical supply to the second floor (Case 4), the ratio of outdoor airflow rates to rooms 3 and 4 on the second floor increases to 35% and 45%, respectively.

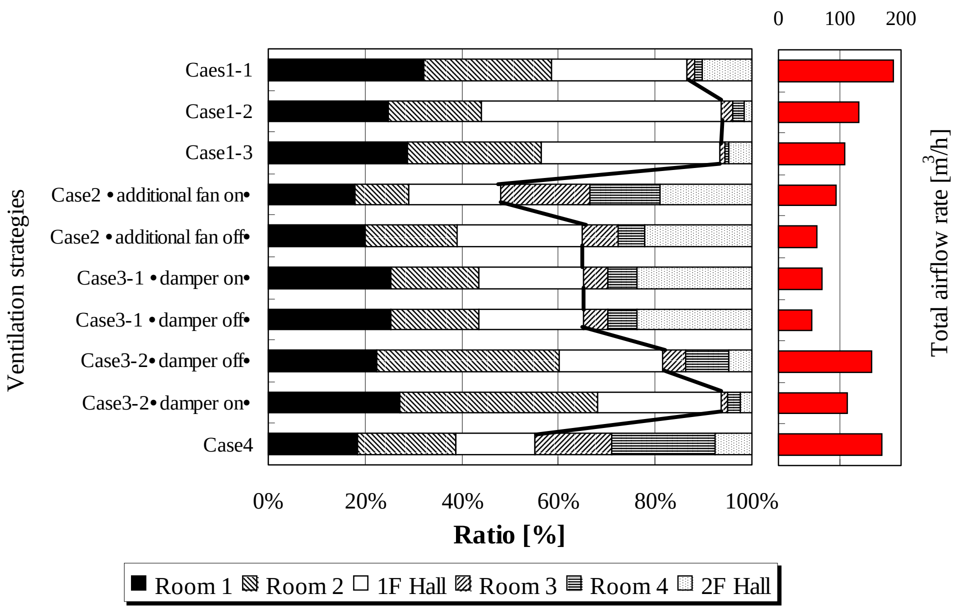

Figure 7 Ratio of Outdoor Airflow Rate to Each Room

4 Conclusions

The performance of a new kind of ventilation system – hybrid ventilation system and other several strategies was discussed experimentally in a full-scale test house. As the results,

(1) Compared with passive system, by 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. In addition, by the damper control, under the cold weather conditions, the over-ventilation can be restrained.

(2) With passive system, even if the total airflow rate can satisfy the requirement of necessary airflow rate, because of the upward airflow pattern due to stack effect, the outdoor air entering the second floor is still too small. This problem can be solved by supplying outdoor air to the second floor directly by a mechanical fan.

5 Acknowledgement

This research is one subtask of "Indoor Air Chemical Pollution Research for Healthy Living Environment" (chairman: Prof. Murakami, Institute of Industrial Science, the University of Tokyo), which is supported by the Special Coordination Funds for Promoting Science and Technology of the Science and Technology Agency of the Japanese Government.

5 References

[1] Yoshino, H., Liu, J. "Experimental Analysis on Hybrid Ventilation System", 7th International Conference on Air Distribution in Rooms, 2000

[2] Feustel, H.E., et al. Fundamentals of the Multizone Airflow Model – COMIS, AIVCTN29, 1990

[3] Liddament, M. W. Air Infiltration Calculation Techniques. AIVC, 1986