Measurement of natural ventilation rate in Japanese residential building

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ABSTRACT

It is difficult to design indoor environment under natural ventilation because there is insufficient knowledge to evaluate the effect of the natural ventilation space quantitatively. Especially, natural ventilation rate is not yet fully understood. In this paper, the properties of the natural ventilation with large openings are examined mainly from the measurement result of ventilation rate. As a result of the measurement, the resistance of the interior doors is large and the ventilation rate is almost caused by air exchange in one opening when the interior doors are closed (single-sided ventilation). In contrast, high ventilation rate is caused when the interior doors are opened (cross ventilation). And it is confirmed that what factors influence the ventilation rate through the large openings.

1. INTRODUCTION

In Japan, natural ventilation with large openings is one of the most important techniques for maintaining a comfortable indoor environment and reducing the cooling energy consumption in hot and mild seasons. But, at present, it is difficult to design indoor environment under natural ventilation because there is insufficient knowledge to evaluate the effect quantitatively. Especially, natural ventilation rate is not yet fully understood. The lack of knowledge is one of the problems in popularizing the technology.

•Location: on the premises of Building Research Institute, Tsukuba
•Construction method: Reinforced Concrete
•Number of stories: 3 stories above ground
•Building height: 9.6 m
•Number of units: 9 units (approximately 73 m^2 per unit)
Figure 1: Southeast side of the experimental building

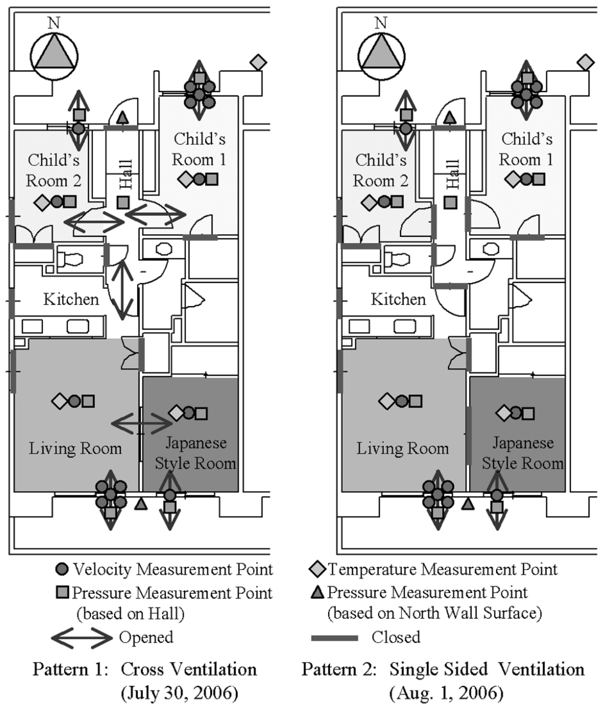

Figure 2: Plan of the unit and measurement point

In this paper, the result of the measurement of ventilation rate and indoor velocity under cross ventilation and single-sided ventilation in a unit of a multi-family dwelling is reported, and the property of natural ventilation with large openings is examined.

2. MEASUREMENT METHOD

The multifamily building has been built for experiment on an open site, and surrounding buildings have little influence to block the wind (Figure 1). The west unit on the third floor used for the measurement has four rooms; Living room, Japanese-style room, Child's room 1 and 2. Each room has one horizontal sliding window with screen (Figure 2) and actual opening areas are shown in Table 1. In this measurement, some patterns are tested

to examine the property of cross-ventilated space by opening or closing the windows and interior openings. In this paper, two patterns are reported. One pattern is cross ventilation case (CV): Four windows and interior doors and a partition are open (Pattern 1, left of Figure 2). Another pattern is single-sided ventilation case (SV): Four windows are open but all interior openings are closed (Pattern 2, right of Figure 2).
Airflow velocity is measured by using sixteen three-dimensional ultrasonic anemometers, (Kaijo Sonic WA-390, DA-600). Outside on the window of Living room and Child's room 1, five anemometers set to measure the ventilation rate through the opening (Figure 3). And the ultrasonic anemometers are also set to measure the velocity in the rooms and other openings. And the pressure on exterior wall surface around the openings, pressure on interior surface of ceiling is measured by the differential manometers (MKS Baratoron 220). And the temperature and the relative humidity is also measured. All data is measured every 0.1 second, except for the temperature and the relative humidity.

3. RESULTS

Measurement results are shown in the ten-minute average value and standard deviation.

3.1 Wind Synopsis

Figure 4 and 5 show the wind synopsis of two days; July 30 (Pattern 1, CV) and Aug. 1 (Pattern 2, SV). In figures, gray area shows that the 10 minute averaged pressure of the north side is higher than that of the south side of the measurement unit. Wind velocity is measured at 15 meters high from the ground. At both days, wind direction is mainly from South to East, which is typical wind direction in summer season in Tsukuba and is not advantageous for the unit with south and north openings. The frequency of appearance of main three wind directions (prevailing wind direction and adjacent direction) also shows that wind direction is relatively stable at both days. Mean wind velocity is 1 – 2 m/s in the morning, and 4 m/s in the afternoon on July 30. And it is 1 – 3 m/s on Aug. 1.

Table 1: Parameter of Rooms

	Volume of Room[m^3]	Opening Size (W[m] x H[m])
Living Room	54.0 (including Kitchen)	0.65 x 1.86
Japanese Style Room	22.3	0.64 x 1.86
Child's Room 1	23.2	0.52 x 1.07
Child's Room 2	18.0	0.42 x 1.07

*Opening size is the actual projected size of opening.

Figure 3: Five Anemometers Setting on Opening

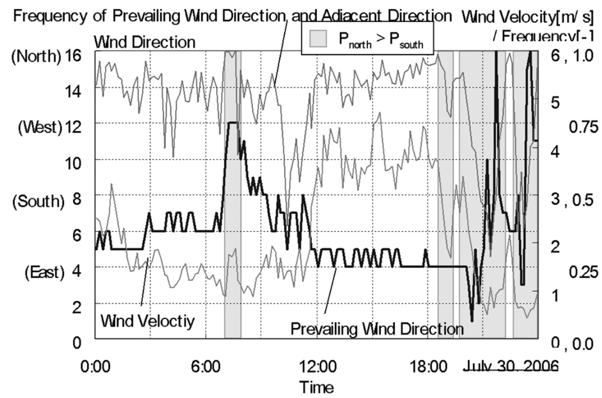

Figure 4: Wind Synopsis on July 30 (Pattern 1)

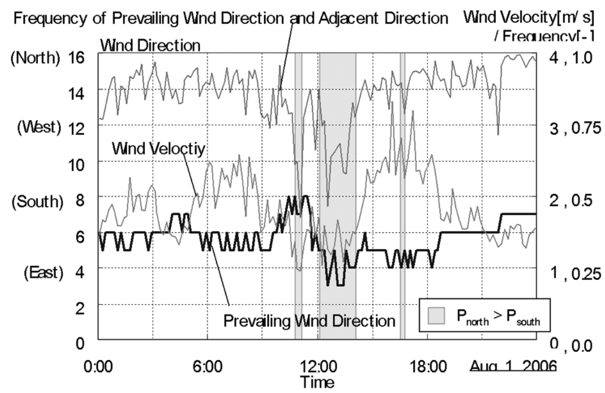

Figure 5: Wind Synopsis on Aug. 1 (Pattern 2)

3.2 Airflow Distribution

Figure 6 shows the indoor airflow patterns when wind direction is east-southeast (ESE). In Pattern 1 (CV), there is diagonal inflow on the south windows and outflow on the north windows. At the center of each room, the mean velocity is about 0.1 m/s, and the maximum velocity is 0.3 - 1.0 m/s.
In Pattern 2 (SV), there is bidirectional flow in one window. And the mean velocity is under 0.05 m/s, and the maximum velocity is under 0.2 m/s at the center of each room. Indoor velocity is very slow in the case of the

single-sided ventilation.

3.3 Pressure Difference

Figure 7 and 8 show the change of pressure on both days. South side shows higher pressure basically as is shown by the wind synopsis (Figure 4 and 5). In Pattern 1, there are large pressure differences between the exterior wall surface and the inside of Child's room 1 and 2. In contrast, pressure differences between inside and outside of Living room and Japanese style room show smaller value. This is because the openings of Child's room 1 and 2 have half size of the opening area of Living room and Japanese style room, and north openings have larger resistance.

In Pattern 2 (SV), there are little pressure differences between inside and outside (Figure 8 and 9) and the interior doors cause large pressure differences. The interior doors make up total resistance of the unit, in the case that the interior doors are closed, even though the interior doors have the door undercut of a few cm (Figure 9).

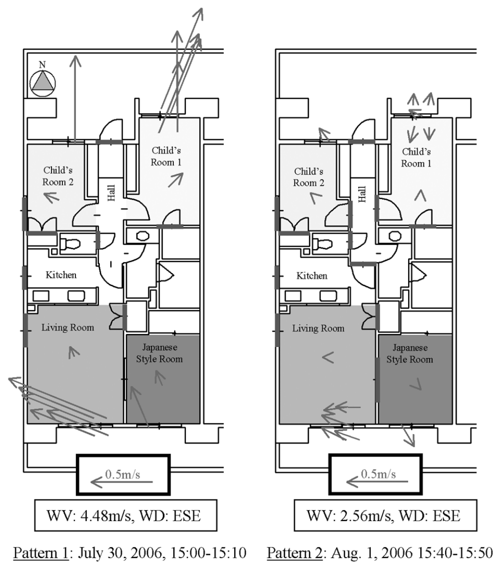

Figure 6: Airflow Pattern

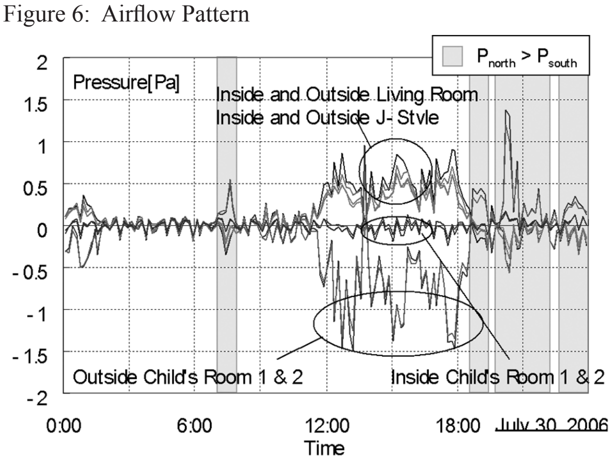

Figure 7: Change of Pressure on July 30 (Pattern 1)

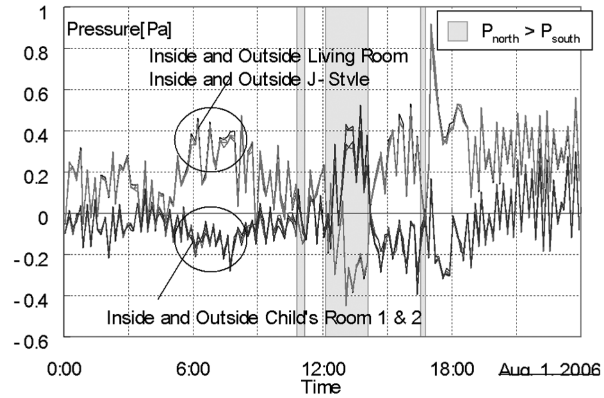

Figure 8: Change of Pressure on Aug. 1 (Pattern 2)

3.4 Ventilation Rate and Airflow through the Opening

Ventilation rate is calculated from the normal velocity measured at five measurement points on opening of two rooms; Living room and Child's room 1. Inflow rate Q_{in}(>0), outflow rate Q_{out}(<0), total rate Q and the exchange flow rate Q_{ex} is calculated from the equations in Figure 10. Q_{ex} means the exchange flow rate driven by buoyancy, diagonal flow, unsteady flow, and other factors. Figure 11 and 12 show the change of ventilation rate through the opening of Child' room 1 on both days. Figure 13 and 14 show the frequency of inflow through the window of Child's Room 1. And Figure 15 – 18 show the relation about the determinants of Q and Q_{ex}.

In Pattern 1, the outflow (Q_{out}) dominates in Child's room 1 throughout the day, except for a few hours when the pressure on north side prevails (gray area in Figure 11). And the air volume of 1,000 m^3/h (about 50 ACH) flows out when strong winds blow. In CV (Pattern 1), it is confirmed that the ventilation rate is high because there is the airflow path through the corridor.

In Pattern 2, Q shows very small value throughout the day, and the inflow (Q_{in}) and the outflow (Q_{out}) coexist in one opening (Figure 12). Exchange flow rate Q_{ex} is about 3 ACH throughout the day. There is outflow at the top measurement points, and inflow at the bottom points (Figure 14). In SV, ventilation rate through an undercut of a door is not so much, and exchange flow rate is driven by temperature difference, diagonal flow, change of flow and pressure, and so on.

In contrast, it has a feature for the airflow to pass through the opening synchronously in Pattern 1 (Figure 13). There is little bidirectional flow on one opening in CV. But, even under relatively stable wind synopsis that Child's room 1 is located on the leeward side, inflow accounts for 20 - 40% at the window of child's room 1 because there is the pressure pulsation caused by east wind.

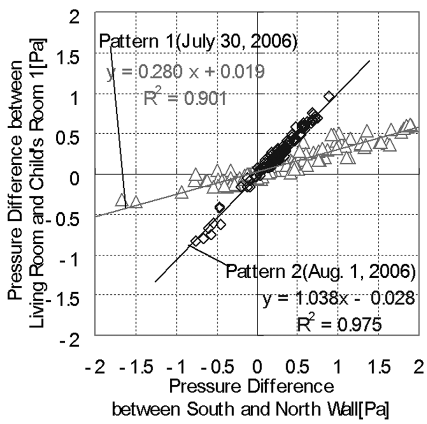

Figure 9: Relation of Pressure Difference

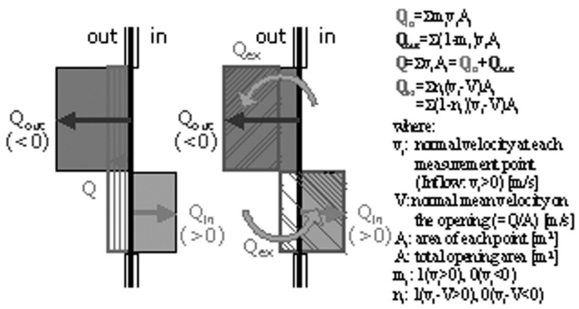

Figure 10: Definition of Ventilation Rate

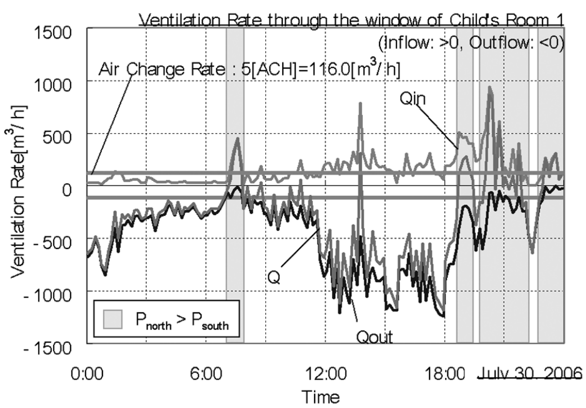

Figure 11: Ventilation Rate through the opening of Child's Room 1 on July 30 (Pattern 1)

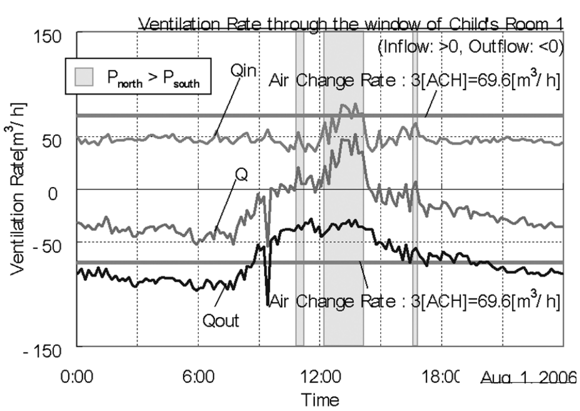

Figure 12: Ventilation Rate through the opening of Child's Room 1 on Aug. 1 (Pattern 2)

3.5 Determining Factors in Ventilation Rate

In Pattern 1, it is confirmed that the ventilation rate Q is relevant to the pressure difference (Figure 15). The discharge coefficient C_d is 0.2 to 0.3 when calculating from the orifice equation. 0.2 is small value as the commonly used C_d of an opening, because the opening has lace curtain and screen, and there are diagonal flows in the inflow openings. But in pattern 2, the relation between the pressure difference and Q is not clear in SV, because the pressure difference shows very small values.

The exchange flow rate Q_{ex} also has clear relation with the fluctuation of pressure difference between inside and outside in pattern 1 (Figure 16). In contrast, Q_{ex} correlates weakly with the indoor-outdoor temperature difference. This is because the fluctuation of pressure difference dominates and the indoor-outdoor temperature difference has little influence on Q_{ex} in the case of cross ventilation with large openings.

In contrast, in Pattern 2 (SV), the temperature difference has a stronger influence on Q_{ex} than the fluctuation of pressure difference (Figure 17, 18). It is confirmed that there are more than one change factor of Q_{ex}, and the ventilation pattern and the climate condition change the influence of each factor.

3.6 Change of Indoor Temperature

Figure 19 and 20 shows the change of temperature. At both days, the indoor temperature in the south rooms (Living room and Japanese style room), which is often located on the windward side, is basically lower than the north rooms. On July 30 (Pattern 1), the temperature in south rooms is about 1 degree lower than the north rooms in the morning. But when the pressure of the north side is higher, it is confirmed that the direct inflow from outside reduces the temperature in the north rooms. On August 1 (Pattern 2) with low ventilation rate, there is a gradual change of indoor temperature. The temperature of the south rooms is lower than north side all day, but when the pressure of the north side is higher, the temperature in the north rooms decreases slowly.

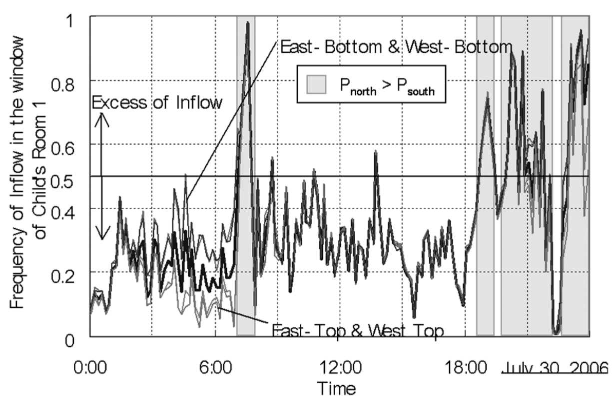

Figure 13: Frequency of Inflow of Child's Room 1 on July 30 (Pattern 1)

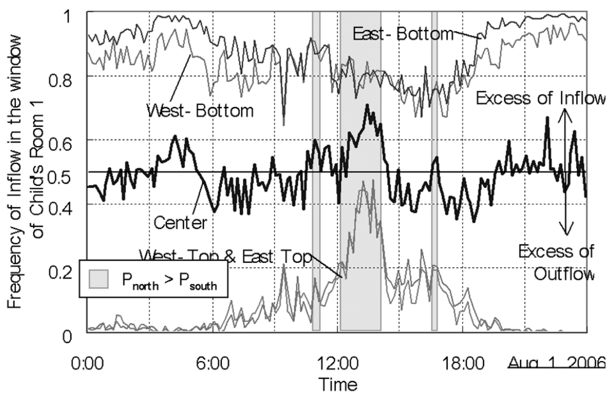

Figure 14: Frequency of Inflow of Child's Room 1 on Aug. 1 (Pattern 2)

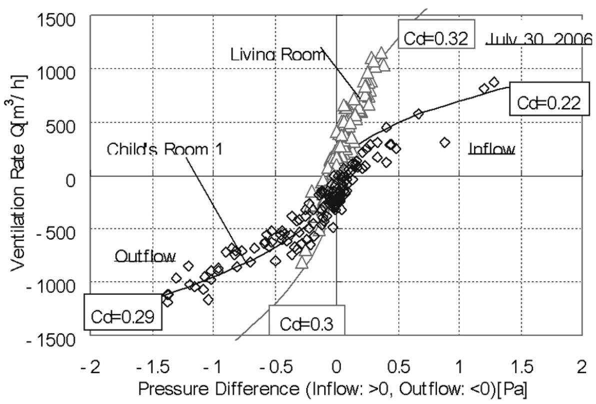

Figure 15: Relation between Pressure Differences and Ventilation Rate Q (Pattern 1)

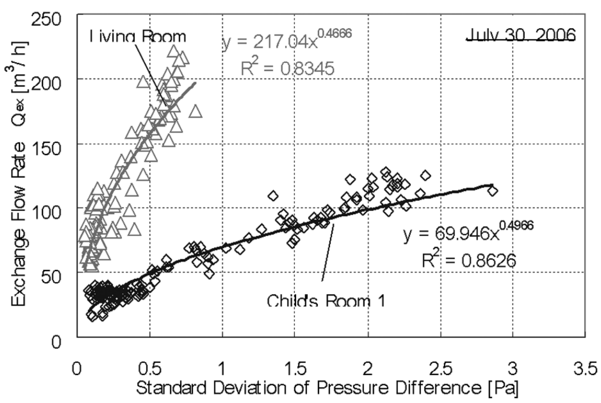

Figure 16: Relation between Standard Deviation of Pressure Differences and Exchange Flow Rate Qex (Pattern 1)

4. CONCLUSIONS

In this paper, the properties of the natural ventilation with large openings are examined mainly from the measurement result of ventilation rate. The conclusion is as follows;

− On July 30 (Pattern 1, cross ventilation (CV)) and Aug. 1 (Pattern 2, single-sided ventilation (SV)), wind direction is mainly from South to East, which is not advantageous for the experimental unit with south and north openings.

− In CV, there is larger pressure difference across the narrower window. In SV, there is little pressure difference between inside and outside.

− In CV, air change rate is 20-50 ACH under wind velocity of 2 - 4 m/s. In SV, it is 3 ACH through the day almost caused by air exchange in one opening. Higher ventilation rate is caused in CV.

− Ventilation rate Q depends on the pressure difference in CV. And the fluctuation of pressure difference mainly influences the exchange flow rate Q_{ex} in CV.

− In contrast, the temperature difference has a stronger influence on Q_{ex} than the fluctuation of pressure difference in SV.

− Indoor temperature in the south rooms that is often located on the windward side is basically lower than the north rooms. When the direction of indoor airflow turns over, the temperature in the windward room quickly change to be lower than the leeward room in CV. And change of the temperature in the windward room is slower than CV.

As a next step, we plan the experiment in the units with the mechanical life-style simulation, including the operation of air-conditioners and windows, to evaluate how the natural ventilation reduces the cooling energy consumption.

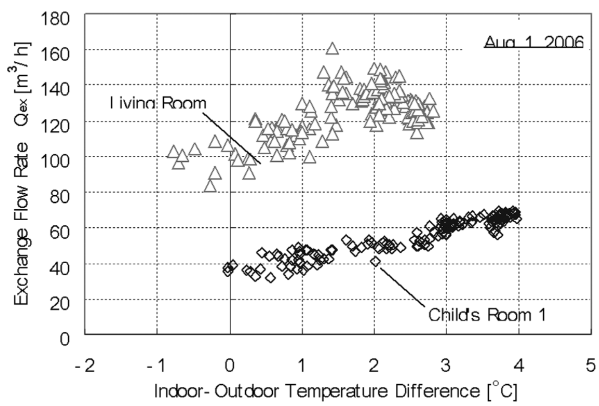

Figure 17: Relation between Temperature Differences and Exchange Flow Rate Qex (Pattern 2)

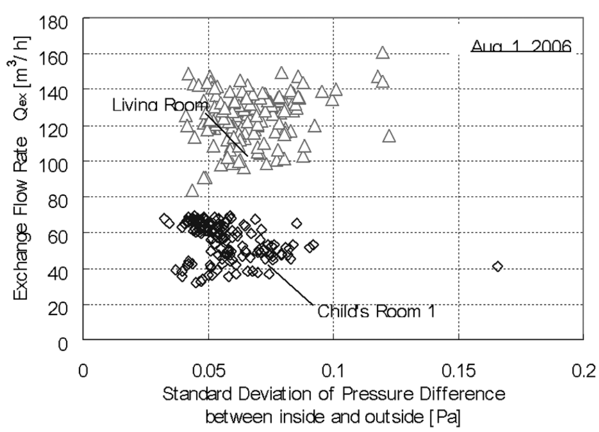

Figure 18: Relation between Standard Deviation of Pressure Differences and Exchange Flow Rate Qex (Pattern 2)

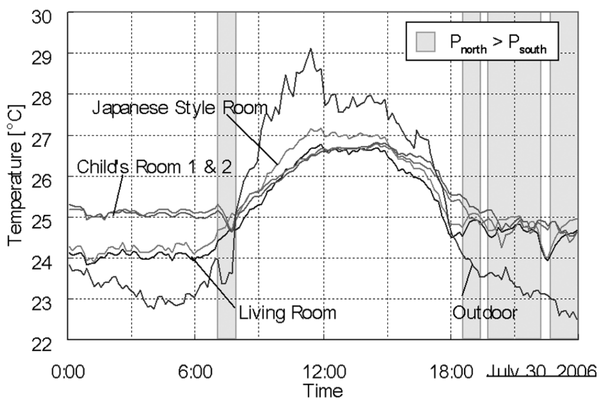

Figure 19: Change of Temperature (Pattern 1)

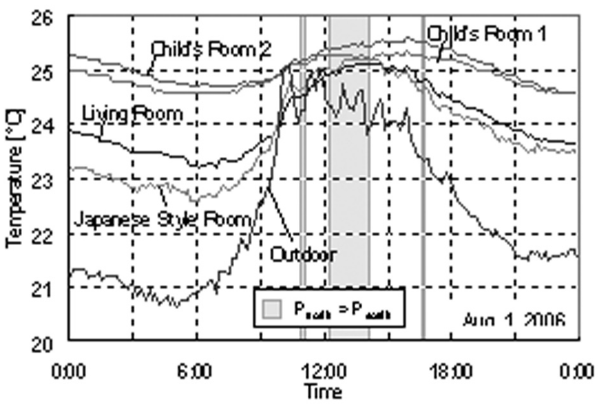

Figure 20: Change of Temperature (Pattern 2)

REFERENCES

Habara, Hiromi et al. (2007). Reduction of Cooling Energy Consumption by Utilizing Cross Ventilation: Experimental result by using simulated occupancy. Proceeding of Roomvent 2007: 1066.