Thermal comfort and ventilation performance of retrofitted apartment houses

Y. Toriumi
Polytechnic University
T. Kurabuchi, T. Nagai and K. Fukada
Tokyo University of Science
T. Endo
Kanto Gakuin University
S. Kodera and J. Asami
Urban Renaissance Agency

ABSTRACT

The primary purpose of the present study was to evaluate the effects of retrofitting of window sashes by measuring air tightness performance and thermal environment of apartment houses built during the period 1965 - 1974 before and after the retrofitting of window sashes. Also, ventilation rate in each zone and air tightness on room fittings were determined in multi-zone type dwelling units, and evaluation was made on ventilating simulation between multi-zone dwelling units. From the results of actual measurement, it was found that room fittings made of aluminum had relatively high air tightness performance even before the retrofitting, and that ELA (Effective Leakage Area) decreased in all dwelling units by about 30% in these dwelling units. Before retrofitting under natural ventilation, the influence of outdoor wind was observed in ventilation rate of each zone, depending on the arrangement of zones. After retrofitting, almost no expectation can be put on ventilation rate of each zone, but it was confirmed that a constant ventilation rate could be maintained by introducing mechanical ventilation equipments. By the retrofitting of window sashes, variations in depth direction of floor surface temperature could be improved.

1. INTRODUCTOIN

In the so-called "high economic growth period" in Japan some 40 years ago, a great number of apartment houses were built in Japanese urban areas. At present, these apartment houses are getting older and timeworn year by year. It is now an important task to perform adequate retrofitting to these old apartment houses from viewpoints of structure, plan of house, facilities, etc., and to give them over to the next generation. The most conspicuous differences between these old houses and the houses currently built are air tightness and the ventilation equipments. In the houses with lower air tightness, IAQ problems due to insufficient ventilation rate such as sick house syndrome do not likely occur, while there are negative influences on thermal comfort due to the infiltration. In this respect, the project of retrofitting is now going on primarily on ventilation equipments and room fittings.

In the previous study[1)], air tightness performance, natural ventilation rate, thermal environment, etc. were determined before and after retrofitting by regarding the object under study as a single zone. Simulation study was performed according to the actual measurement data, and the effects of retrofitting were assessed. In the present study, the single zone was extended to multi-zone type dwelling unit, and evaluation was made on the effects of retrofitting on thermal and air environment by the retrofitting of the existing apartment houses.

2. METHODS

Air tightness performance and ventilation rate were measured before and after retrofitting, and prediction accuracy of ventilating simulation was confirmed by using the results of measurement. Also, at the same time as the measurement of ventilation rate, measurement was made on outdoor air temperature, room temperature, power consumption of electric heaters and vertical temperature difference, and the influence of building air tightness improvement on thermal environment were confirmed.

3. MEASUREMENT

The study was performed on 6 cases in 4 dwelling units of staircase type apartment house (apartment house C) built in Yokohama in 1970: C-1 and C-2 (before and after retrofitting); C-3 (only after retrofitting) and C-4 (only before retrofitting). The general features of the dwelling units under study are shown in Table 1, Fig. 1 and Fig. 2. Window sashes were made of aluminum from the time before retrofitting except bathrooms, and window sashes were renewed except bathroom windows. The doors of entrance halls were made of steel, and these were not included in the objects of retrofitting. No ventilating opening was installed before and after retrofitting.

Table 1: Specification of the measurement dwelling unit.

Total floor area[m^2]	43.6(C-1), 44.0(C-2), 43.3(C-3), 43.3(C-4)
Construction	Reinforced concrete
Component member [mm] North wall (3.9 m^2)	Plasterboard 9 Polystyrene foam 15 Concrete 115 Mortar and others
Component member [mm] South wall (10.2 m^2)	Mortar 18, Concrete 115 Mortar and others

3.1 Air Tightness

ELA of each dwelling unit was determined by the pressurization method and the depressurization method, and ELA at each measuring point was determined by the pressurization method. Also, after confirming that the measured values of ELA of indoor fittings determined by pressure compensated method and sealing method corresponded well to each other, the measurement was made by the sealing method.

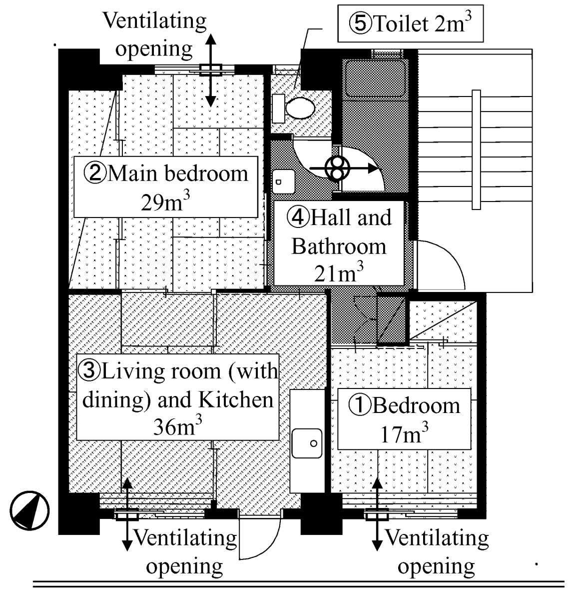
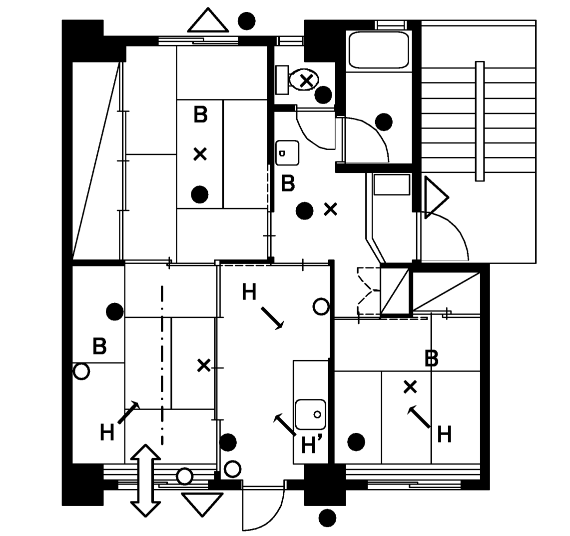


Figure 1: Plan and zoning of the measurement dwelling unit C-1.



× : Tracer gas concentration
△ : Pressure
⇔ : Air tight measuring instrument
● : Temperature
○ : Surface temperature + Heat flow meter
H : Electric heater
H' : Infrared heater
B : Light bulb
—·—·—·— : Temperature distribution of a cross section

Figure 2: Measurement Points.

3.2 Ventilation Performance

On the C-1 dwelling unit, ventilation rate of each zone was measured by tracer gas constant concentration method on 3 cases, i.e. a case where natural ventilation rate was measured before retrofitting, a case where it was measured after retrofitting, and a case where mechanical ventilation equipment was installed after retrofitting (all-time mechanical ventilation was estimated by an exhaust-only system. By giving due consideration on living conditions, inner space of each dwelling unit was divided to five zones (Fig. 1). In the case where mechanical ventilation equipment was installed, a ventilating opening with ELA = about 12 cm^2 was provided in each habitable room. In mechanical ventilation equipment, exhaust fan was installed in bathroom so that the air change rate in the whole dwelling units would be about 0.8 air changes per hour (ACH). Wind direction and wind velocity were determined at a point, which is at 2 m from the roof of the apartment house (i.e. 30 m from ground surface), and wind pressure was measured on three wall surfaces of north, east (entrance hall), and south, by taking the wind pressure on the southern wall surface as reference.

To evaluate prediction accuracy of ventilation simulation, ventilation simulation code named "VentSim[2)]" was used. "VentSim" is an airflow network simulation program which National Institute for Land and Infrastructure and Building Research Institute of Japan has developed. Based on measurement of air tightness, it was assumed that ELA of fittings was distributed around the sash frame. For the setting of ELA of outer wall, ELA value of fittings was subtracted from ELA of the whole building, and the remaining ELA was proportionally distributed by area of outer wall. Measured outdoor and room temperature, and wind pressure were given as boundary conditions, and ventilation rate was calculated and compared with measurement.

3.3 Thermal Comfort

At the same time as the measurement of ventilation rate (table 2), thermal environment measurement was performed on the items shown in Fig. 2. A pole was erected in each zone, and air temperature was measured at a height of 1,100 mm above floor surface. In living room (with dining) and kitchen, air temperature at a height of 50 mm above floor surface, globe temperature and wall surface temperature were measured. Electric heaters were installed in living room and kitchen, and the heating temperature was controlled to 22.5 deg C to match the living schedule. By providing electric bulbs in the zones and by adequately controlling them, indoor heat generation was simulated (Fig. 3). Also, vertical profile of temperature (distribution of temperature on vertical cross-sections measured by shifting the measuring points every four minutes in south-to-north direction) was determined at family circle time (family gathering time) (19:00 – 21:00) in living room before and after retrofitting.

Table 2: Measurement schedule.

Date	Window sash Retrofit	Ventilation
Dec. 6	Before	Natural ventilation
Dec. 7		
Dec. 8		
Dec. 9		
Dec. 13	After	Natural ventilation
Dec. 14		Mechanical ventilation from 19:10 on Dec. 14
Dec. 15		
Dec. 16		

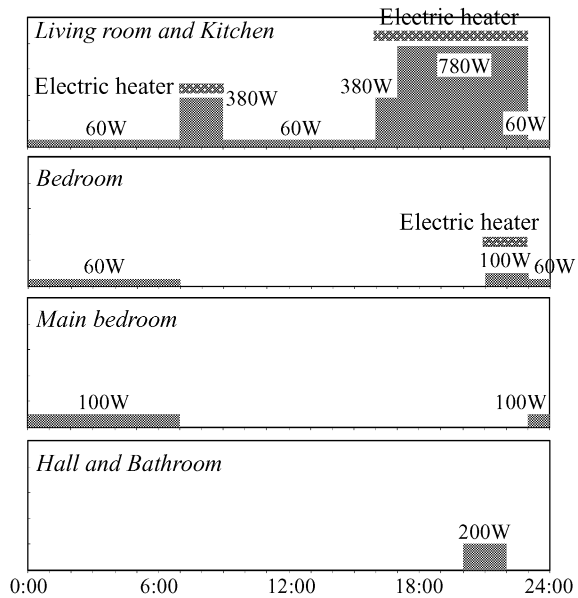


Figure 3: Inside heat generation schedule and heating schedule.

4. RESULT OF MEASUREMENT

4.1 Air Tightness

The results of measurement are summarized in Table 3, Fig.4, and Fig.5. In Fig.4, the values of ELA at the openings with the same shape as that of the openings with air tightness measuring instrument were included in all dwelling units, and the measured values were compensated. The values of ELA per floor surface (measured by the pressurization method) (i.e. the values converted to 9.8 Pa; hereinafter referred as C-value) were 4.6 cm^2/m^2 and 4.6 cm^2/m^2 before retrofitting, and the values after retrofitting were 2.8 cm^2/m^2 and 3.3 cm^2/m^2. That is, the C-values showed the decrease of more than 1 cm^2/m^2 after retrofitting. There were some variations depending on the situations, and it was confirmed again that air tightness performance of aluminum sashes was relatively high even before retrofitting. When the values of ELA per site of indoor fittings were compared for each category, differences were found, which may

Table 3: ELA of the whole dwelling unit. (The values of ELA do not include the value for the air tightness measuring instrument.)

Dwelling unit	C-1		C-2		C-3	C-4
Retrofitting	Before	After	Before	After	After	Before
ELA of dwelling unit[cm^2]	151 (142)	117 (138)	167 (-)	131 (113)	97 (94)	150 (148)
C-value [cm^2/m^2]	3.5 (3.3)	2.7 (3.2)	3.8 (-)	3.0 (2.6)	2.3 (2.2)	3.5 (3.4)
Gap characteristic value: n [-]	1.62 (1.83)	1.60 (1.87)	1.30 (-)	1.57 (1.54)	1.72 (1.66)	1.48 (1.50)

(   ): The value of depressurization method

Figure 4: Distribution of ELA of the skin in retrofitting before and after. (Living room, bedroom and Main bedroom: Double sliding window, Toilet: Projected window, Bathroom: Double-hung window.)

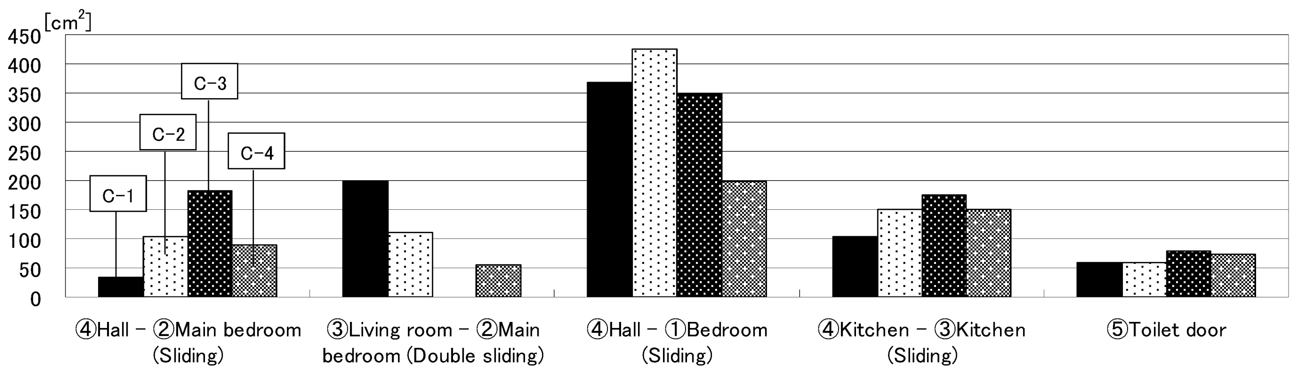


Figure 5: ELA of indoor fittings. (The bedroom of dwelling unit C-3 does not have the same shape sliding door.)

have been caused by the strains on the fittings in each dwelling unit. In particular, the strains on sliding screens were big.

4.2 Ventilation Performance

Fig. 6 shows the results of the comparison of the measured values with the calculated values. In wind direction and wind velocity during the whole measurement period, winds of north-northwest, north and north-northeast accounted for 50% or more of all winds and average wind velocity was 2.3 m/s. The measured value of natural ventilation rate before retrofitting was about 40 m^3/h (air exchange rate: 2.0 ACH) in entrance hall and bathroom, less than 10 – 20 m^3/h (air exchange rate for all habitable rooms was 0.1 – 0.3 ACH) in average during the measurement period, showing strong influence of outdoor wind. On the other hand, the measured values of natural ventilation rate after retrofitting were about 20 m^3/h (1.0 ACH) in average throughout the measurement period in hall and bedroom, less than 10 m^3/h (0.5 ACH) in bedroom, and about 0 m^3/h in other zones. When mechanical ventilation equipment was installed after retrofitting, ventilation rate of about 20 m^3/h was obtained in each habitable room at all times. In the comparison of the measured values with the calculated values, the calculated values were lower than the measured values in all cases. This shows general trend as a whole. Ventilation rate showed higher fluctuations in the measured values. One of the reasons for this may be that air volume in each zone was minimized because the dwelling unit was divided to multi-zones and the dosage of tracer

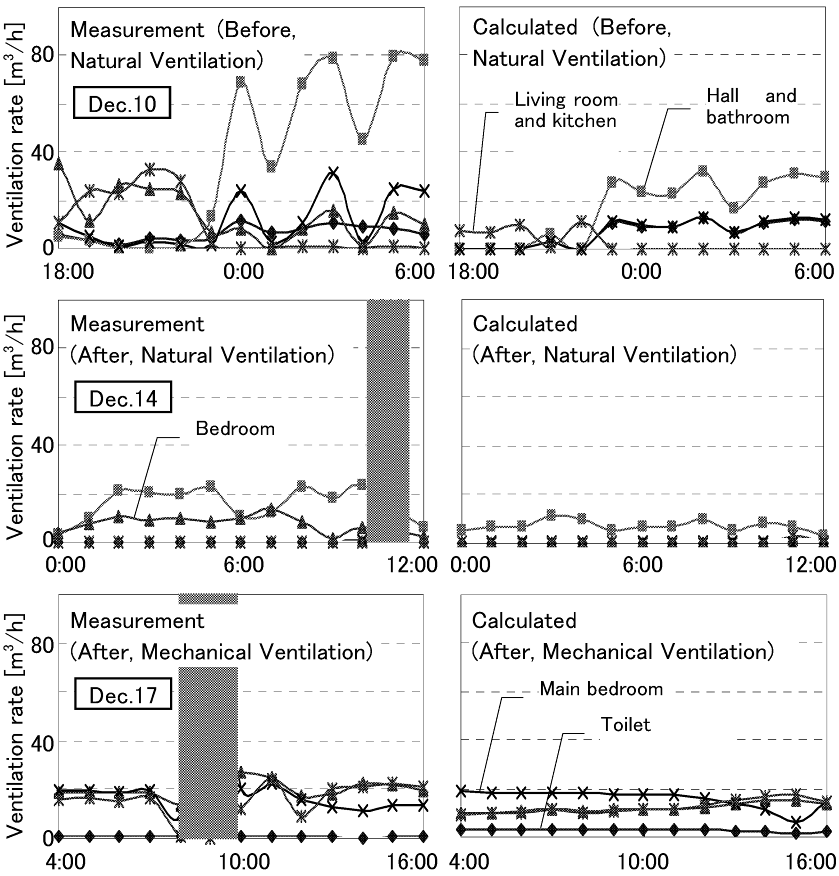


Figure 6: Comparison of ventilation rate. (The shading part indicates a deficit. Before: before retrofitting, After: after retrofitting.)

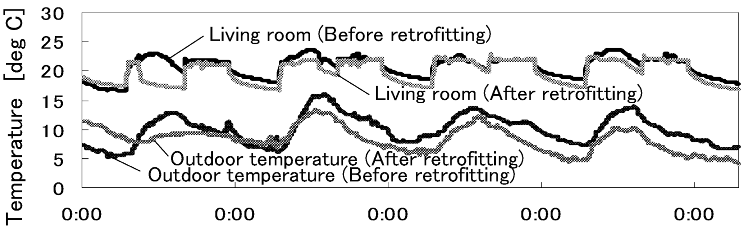


Figure 7: Living room temperature and outdoor temperature.

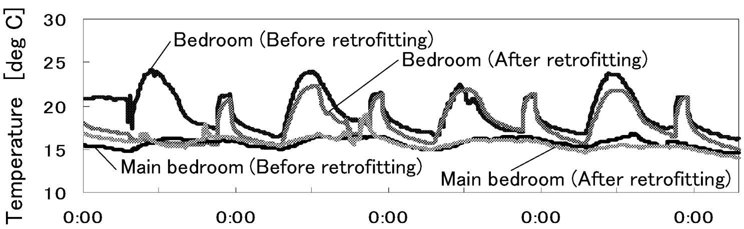


Figure 8: Bedroom temperature and Main bedroom temperature.

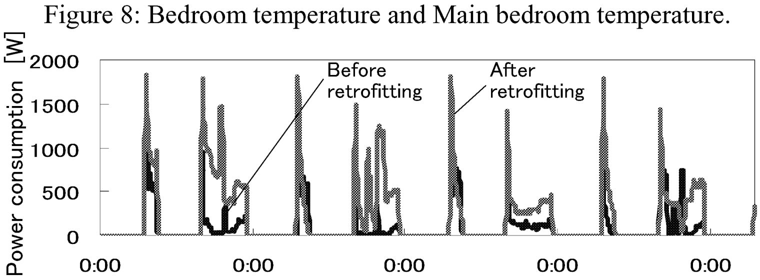


Figure 9: Power consumption of the electric heater of living room.

gas with respect to the target concentration was extremely high when ventilation rate was measured by constant concentration method. In the calculation, the values of ELA are uniformly distributed on outer wall, while these values may actually be deviated from each other.

4.3 Thermal Comfort

Fig. 7 to Fig. 9 shows the fluctuations of room temperature and electric power of heaters during the measurement period. As a whole, room temperature was lower after retrofitting. This may be attributed to the fact that outdoor air temperature after retrofitting was by 4.2 deg C lower in maximum, and by 1.7 deg C lower in average than the values before retrofitting. Power consumption by electric heaters was also higher after retrofitting, and this may have been caused by lower outdoor air temperature after retrofitting. It depends for a room temperature or a heater demand on outdoor temperature rather than window retrofitting. Fig. 10 shows vertical temperature distribution during family circle time in living room before and after retrofitting. The values of temperature shown in the figure indicate relative temperature values by taking the temperature at a point 1,500 mm from window and 1,200 mm above floor surface as reference. Because the measurement was made not in mid-winter season with the coldest weather conditions, temperature difference between the point at 200 mm in height and the point at 1,200 mm in height was about 1.5 deg C in maximum, and this was not the vertical temperature difference, which may cause problem in thermal environment. Also, it was revealed that a variation of floor surface temperature in depth direction was improved by the repair of window frames. However, except floor surface and ceiling surface, vertical temperature difference was partially higher after retrofitting. This may have been caused by heat mass storage of building due to weather conditions and by influence from the neighboring dwelling units.

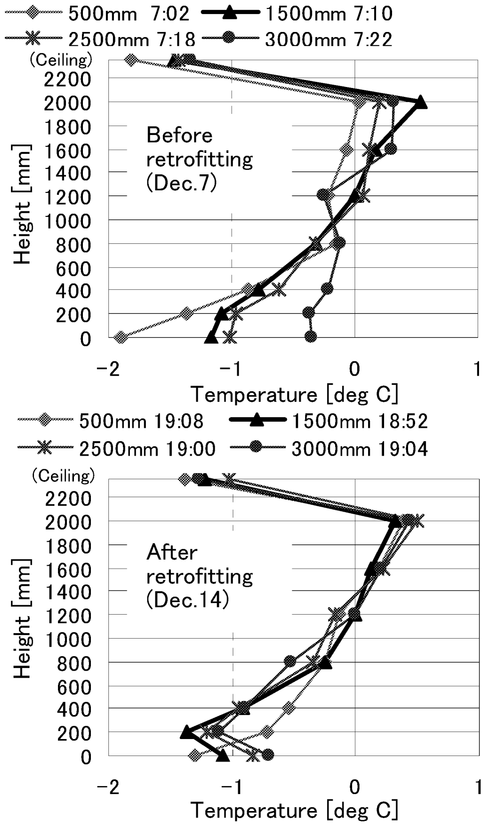


Figure 10: Vertical profile of temperature during family circle time in living room.

5. CONCLUSIONS

The results of the study revealed that room fittings made of aluminum showed relative higher air tightness performance even before retrofitting and the values of ELA of all dwelling units decreased by about 30% after retrofitting. In the multi-zone dwelling units under natural ventilation, there are many small openings and gaps around windows. As a result, the ventilation rate in each zone is under influence of outdoor wind due to the arrangement of rooms before retrofitting. After retrofitting, not much expectation can be placed on fresh outdoor air volume in each zone, while a constant ventilation rate can be maintained by introducing the mechanical ventilation equipments. By the retrofitting of window sashes, variations in depth direction of floor surface temperature could be improved.

REFERENCES

[1] Kurabuchi, T et al. (2008). Measurement and simulation of thermal and ventilation performance of retrofitted apartment houses. Indoor Air 2008 Proceedings

[2] YAMAUCHI PLANNING INC: http://www.yp-i.co.jp/download/