A Case Study of Energy Consumption and Indoor Environment in a Wood Constructed Office Building

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ABSTRACT

In this study, field measurements and investigations have been carried out to understand the energy consumption and indoor environment of a sustainable designed office building. The office building is located in the north of Sendai City, northeast area of Honshu Island, Japan. It was completed in June 2006 and covers an area of 4090 m^2. The building is constructed in wood so as to reduce the generation of CO_2. In order to improve the indoor thermal environment while reducing the energy consumption used in heating, the whole building is well insulated: high performance insulators are fitted in the exterior walls (180 mm thick) and on the roof (200 mm thick); windows are fourfold-glazing with high insulated sash. Besides, sunshade technology is well utilized in this building to reduce the energy consumed by cooling. For the HVAC system, high quality air-conditioners with COP value over 5.0 are installed for heating and cooling, while mechanical ventilation system is used for ventilating. Measurements which included indoor/outdoor air temperatures, inside wall temperatures and energy consumption for different end-uses has been carried out since June 2006.
Measurement results indicated that indoor air temperature was found much more stable comparing to the outdoor temperature. It is due to the use of the high performance insulators and well utilization of sunshade. Temperature difference between the height at 1.1 m and 0.1 m was lower than 3 ℃ which meets with ASHRAE standard 55. On the other hand, energy consumption measured in this office showed much lower, referred to the statistical data, than other existing office buildings.

1. INTRODUCTION

CO_2 emission from office buildings accounts for 25% of all the sectors and it increased by 30% during the last ten years. GHG mitigation options in office buildings and equipments should be taken in account seriously.
In this study, field measurements and investigations of the energy consumption and indoor environment have been carried out in a sustainable designed office building (Figure 1). Table 1 shows the description of this building.

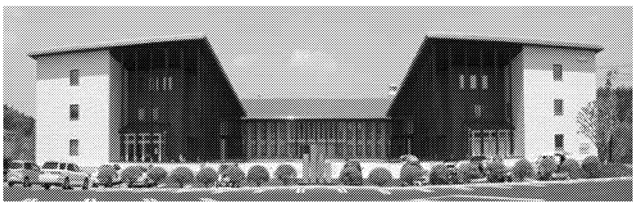

Figure 1: Feature of the Office Building

Table.1 Description of the investigated office building

Completed	Jun. 2006	
Floor Area	4090m^2	
Occupancy Density	0.025Person/m^2	
Construction	Wood	
Insulation	λ	0.042W/(m・K)
	Thickness	184mm (Exterior wall)
		200mm (Roof)
Heating and Cooling	Ari-conditioners	
Ventilation	Mechanical ventilation	
Energy Source	Electricity	

2. MEASUREMENTS

2.1 Outline of the measurements

Measurement items include indoor/outdoor air temperature and humidity, temperatures inside the exterior walls, and electricity consumption for different end-uses. Measurements from Jun. 2006 to Dec. 2007 in Offices A, B and C (as shown in Figure 2) will be reported in this paper.

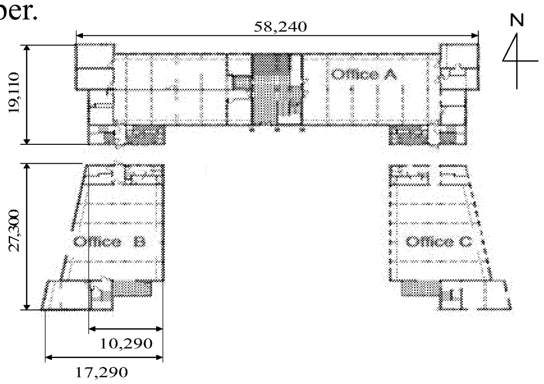

Figure 2: Plan of the investigated offices

2.2 Indoor/outdoor air temperature and relative humidity

Small data loggers with temperature and humidity sensors record the data every 15minutes. Measured points were set in the center of each office. In order to clarify the vertical temperature difference in the measured Office A, the main office of the company, except the central measured point, three points at different heights (10 cm, 110 cm, and 200 cm respectively) were measured. Data logger which was used to measure the outdoor temperature and humidity was put in a small aluminum tube so that the data sensor would not be influenced by the direct solar radiation.

2.3 Temperature inside the exterior wall

Figure 3 shows the measured points on both sides of the insulator (MPO and MPI respectively) inside the exterior wall. Data loggers with temperature and humidity sensors were used to record the data every 15 minutes.

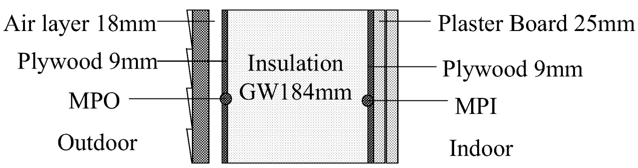

Figure 3: Measured points inside exterior wall

2.4 Electricity consumption

Electricity consumption for different end-uses in Office A in every ten minutes was recorded by data loggers. Data recorded by data loggers was transferred to the computer automatically so that electricity consumption could be known at any moment.

3. RESULTS AND ANALISYS

3.1 Indoor/outdoor air temperature & relative humidities

3.1.1 Long-term fluctuation

Figure 4 shows the long-term fluctuation of the indoor/outdoor temperature and relative humidities during the period from June 2006 to December 2007. Temperature of each room stays stable around 20 ℃～25 ℃ throughout a whole year. In winter season, temperature in Office B was about 4 ℃ higher than that in the other two offices because of the high occupancy and office appliances densities. On the other hand, relative humidity was lower than 30% in winter and higher than 70% in summer which resulted in dryness and humidity condition, respectively, in each office. Especially in Office B, sometimes relative humidity fell lower than 20% in winter.

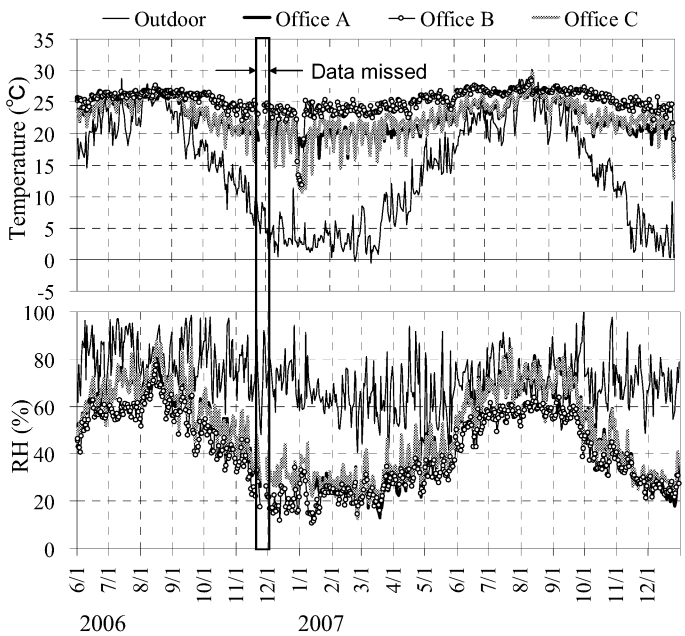

Figure 4: Long-term fluctuation of Indoor/outdoor temperature and humidity

3.1.2 The coldest days

Upper side of Figure 5 shows the temperature and relative humidity changes in three days including the coldest day (Feb 25th). It was a weekend from Feb 24th to 25th, there were no people working in Office A or C, and thus, temperatures in these two offices during the weekend were much lower than during the weekdays. However, in contrast, workers in Office B came to the office even during the weekends. As a result, temperature in Office B did not change much between weekends and weekdays. During weekends, temperatures in Office A and C changed with the solar radiation. On the other hand, during the weekdays, temperatures in each office start to increase when the air-conditioners were turned on around 8:00am ~ 9:00am for heating and stayed around 22 to 26 ℃ during the business hours; Temperatures started to decrease around 6:00 pm when the air-conditioners were turned off. Temperature in Office B was about 3 to 4 ℃ higher than in the other two offices, as mentioned above. In addition, relative humidity in each office was lower than 25%, which resulted in extreme dryness.

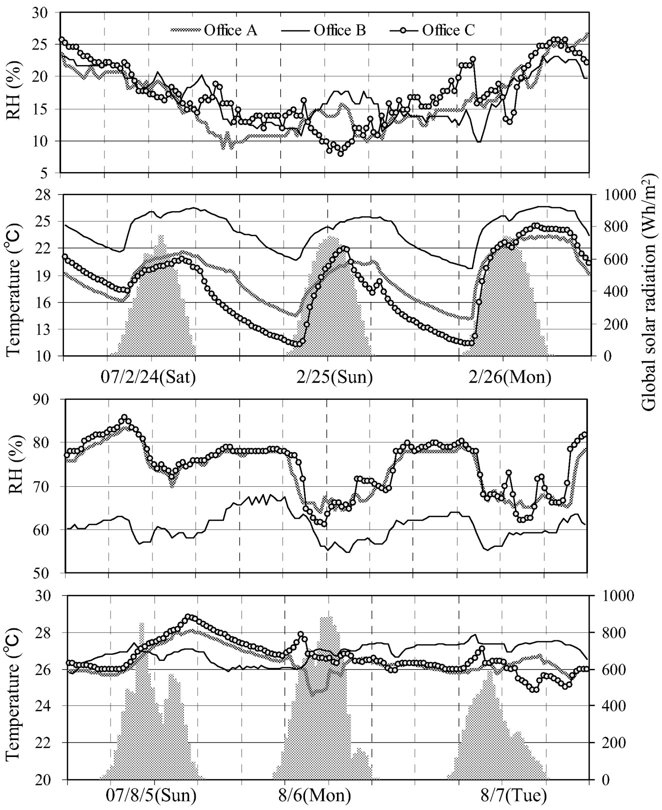

Figure 5: Temperature and humidity
(Upper side: the coldest days; lower side: the hottest days)

3.1.3 The hottest days

Lower side of Figure 5 shows the temperature and relative humidity changes in three days including the hottest day (Aug 6th). It was Sunday on Aug 5th, as mentioned above, workers in Office B were working even during the weekends, and therefore temperature in Office B did not change much between weekends and weekdays. However, temperatures in Offices A and C was about 2 to 3 ℃ higher during weekends than that during weekdays. During the weekdays, Temperatures in Offices A and C started to decrease around 8:00 ~ 9:00 am when the air-conditioners were turned on for cooling and stayed around 25 to 27 ℃ during the business hours. Temperature in Office B was about 1~2 ℃ higher than the other two offices because of relatively higher densities of occupants and office appliances. On the other hand, relative humidity in Office B was around 55% to 65%. However, it was higher than 70% in Offices A and C most of the time; it was higher than 60% even when the air-conditioners were working.

3.2 Vertical temperature difference

Figure 6 shows the vertical temperature difference and the relationship with the electricity consumption of the air-conditioners during the one week including the coldest day (Feb 25th). It shows that vertical temperature differences changed with the electricity consumption for air-conditioners. Temperature difference between the height of 1.1 m and 0.1 m (between the head and the ankles while sitting) was lower than 3 ℃, which meets the ASHREA standard 55. However, it was higher than 3 ℃ between the height of 2.0 m and 0.1 m when the air-conditioners were just turned on around 8:00 am ~ 9:00 am.

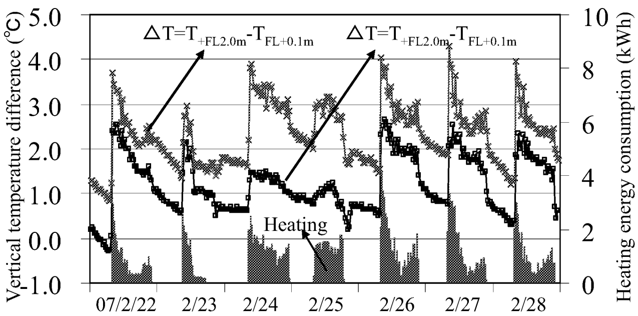

Figure 6: Vertical temperature difference

3.3 Temperature inside the exterior wall

Figures 7 show the temperature changes inside the exterior wall during four days include the coldest day (Feb 25th) and four days include the hottest day (Aug 6th).

During the coldest four days, temperature at MPI stayed almost the same as the indoor air temperature. However, temperature at MPO changed with the outdoor ambient temperature and affected by the solar radiation. Temperature of MPO reached 25.6 ℃ on Feb 26th, when the solar radiation was very strong. In contrast, temperature did not change much on Feb 23rd, when the solar radiation was weak.

On the other hand, during the hottest four days, indoor air temperature and temperature at MPI stayed at about 26 ℃, which was constant compared to the outdoor ambient temperature. High performance of the sun-shading shelters can be considered as one of the reasons that the temperature at MPI was much lower (maximum 9 ℃) than the outdoor ambient temperature. Temperature at MPO changed with the outdoor ambient temperature and also affected by the solar radiation. However, the influence of solar radiation was not so obvious comparing to the winter time.

3.4 Energy consumption

Electricity consumptions in Office A for different end-uses were recorded by data loggers. As shown in Figure 8, electricity consumption increased during the heating (from November till the end of April next year) and cooling period (August and September). Lighting, the largest energy user, accounted for about 43% of the total electricity consumption and it was followed by OA (Office Appliance) machines which accounted for 25%. Annual heating and cooling electricity consumption accounted for 12% and 2% of the total electricity consumption, respectively. The statistical data for energy consumption of the office buildings in Japan was divided into four types of end-uses, namely Lighting, Ventilation, Heating & Cooling and Others. Energy consumption for OA machines was put under the catalogue of "Others", while energy consumption for heating and cooling were calculated together. Figure 9 show that annual energy consumption of the measured office building (921 MJ/m^2・year) was 47% lower than the statistical data (1739 MJ/m^2・year). Energy consumption for heating and cooling of the measured office building accounted for only

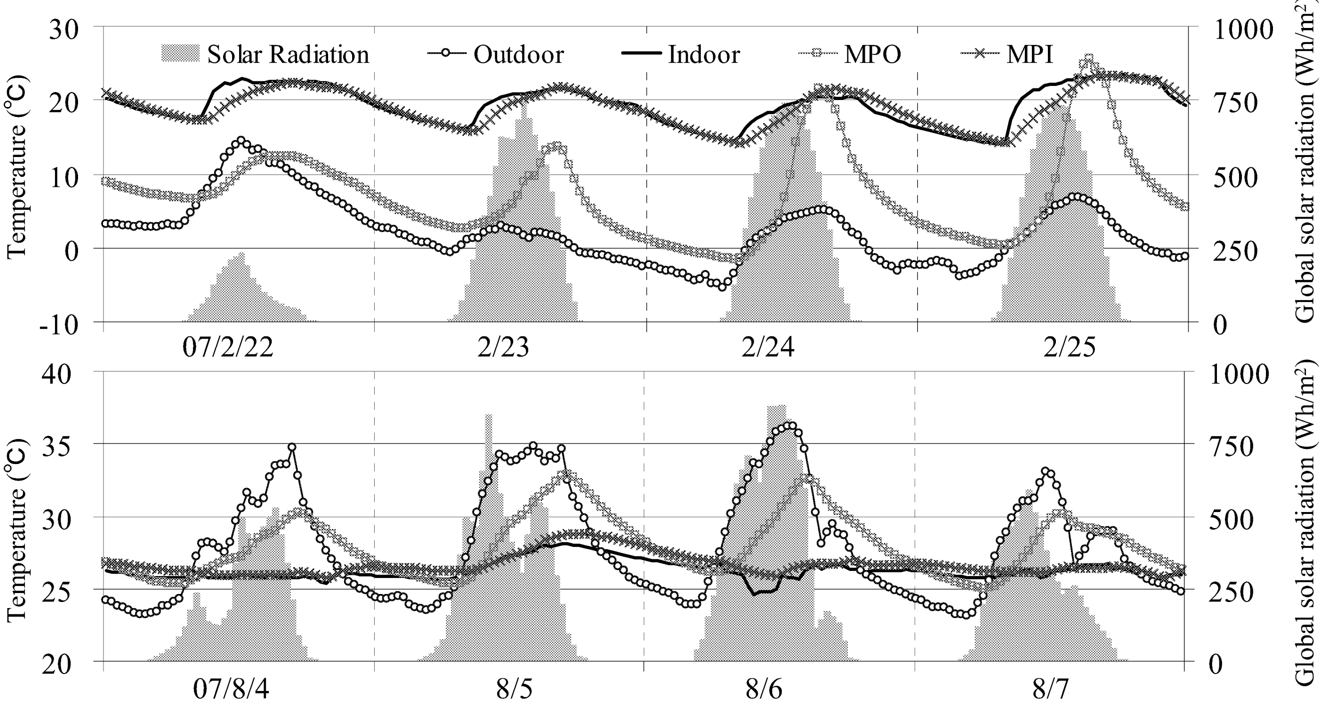

Figure 7: temperature inside the exterior wall
(Upper side: the coldest days; Lower side: the hottest days

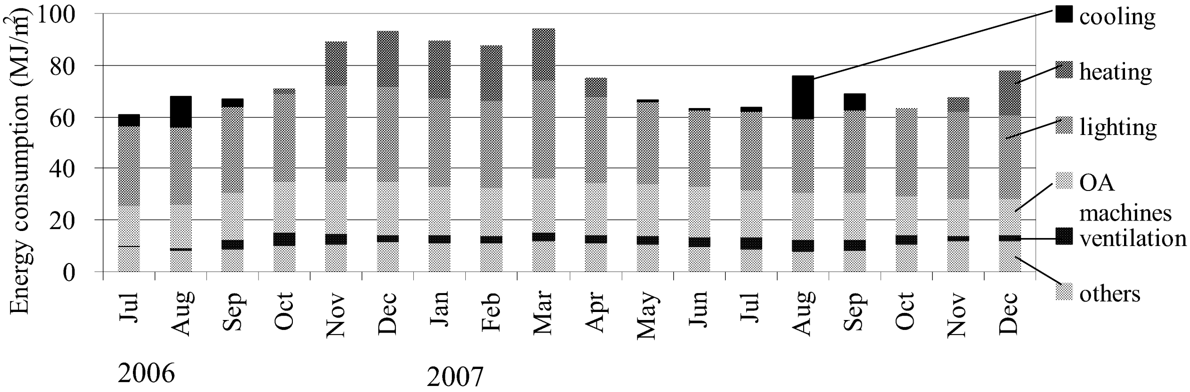

Figure 8: Monthly energy consumption

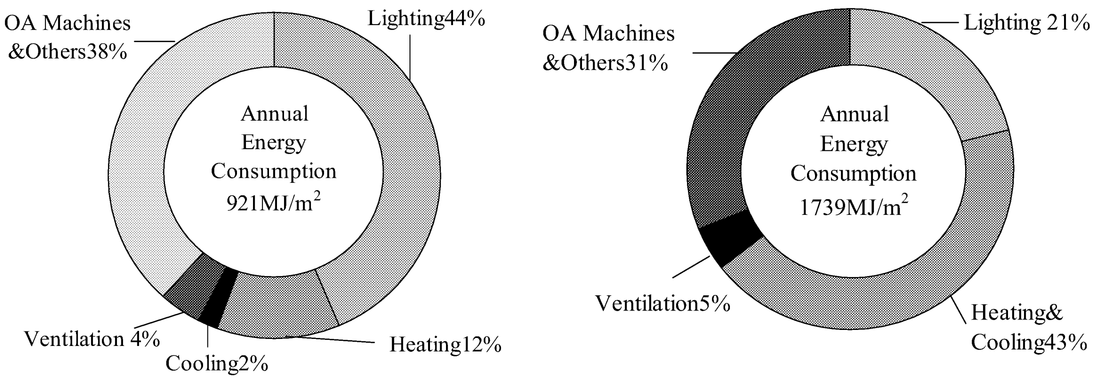

Figure 9: Annual energy consumption (Left: Measured office building; Right: Statistical data)

14% of the annual energy consumption, while in the statistical data it accounted for 43%, which indicated the significant benefits in utilizing high performance insulations and sun-shading constructions.

3.5 Trial Assessment with Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)

CASBEE is an environmental assessment tool based on the concept of BEE (Building Environmental Efficiency), which is defined by

$$\text{BEE} = \frac{\text{Q (Building environmental quality \& performance)}}{\text{L (Building environmental loadings)}}$$

$$= \frac{25 \times (\text{SQ-1})}{25 \times (5\text{-SLR})}$$

In CASBEE, sub-items are classified into two assessment categories: Q and LR (reduction of building environmental loadings). Table 2 shows the contents of all sub-items.

A five-level scoring system is used; SQ and SLR in the above-mentioned definition represent the scores of Q and LR respectively.

Table 2: Contents of the sub-items

Item	Sub-item	Content
Q	Q-1	Indoor Environment
	Q-2	Quality of Service
	Q-3	Outdoor Environment on Site
LR	LR-1	Energy
	LR-2	Resources & Materials
	LR-3	Off-site Environment

Figure 10 shows the final assessment results of the investigated office building (Left hand side: scores of sub-items; right hand side: BEE value). In CASBEE, buildings are labeled into five classes, which are Class C (poor), B^{-}, B^{+}, A and S (excellent), determined by the BEE value. The calculated BEE value of the investigated building was 2.8 and it fell in Class A (buildings with BEE value over 3.0 fall in Class S). Among all the sub-items, due to the great efforts to concern/adapt the surroundings more amenity (e.g. cultural conscious, communication with local people, etc.), sub-item of Q-3 which was scored to evaluate the outdoor environment on site, got the highest score (S_{Q-3}=4.5). In addition, sub-item of LR-1 which was scored to evaluate building energy efficiency got the second highest score (S_{LR-1}=4.3). The results of the field measurements also showed that with the benefits of utilizing high performance insulations and sun-shading constructions, energy consumption in this building was significantly less than statistical data in Japan.

On the other hand, since back-up space for facilities or equipments has not been taken into account during the architectural design process, sub-item of Q-2 which was scored to evaluate the quality of service got the lowest score (S_{Q-2}=3.0). In addition, the control strategies of humidity and air-flow were not adequate, sub-item of Q-1 which was scored to evaluate indoor environment did not get a high score either (S_{Q-1}=3.3).

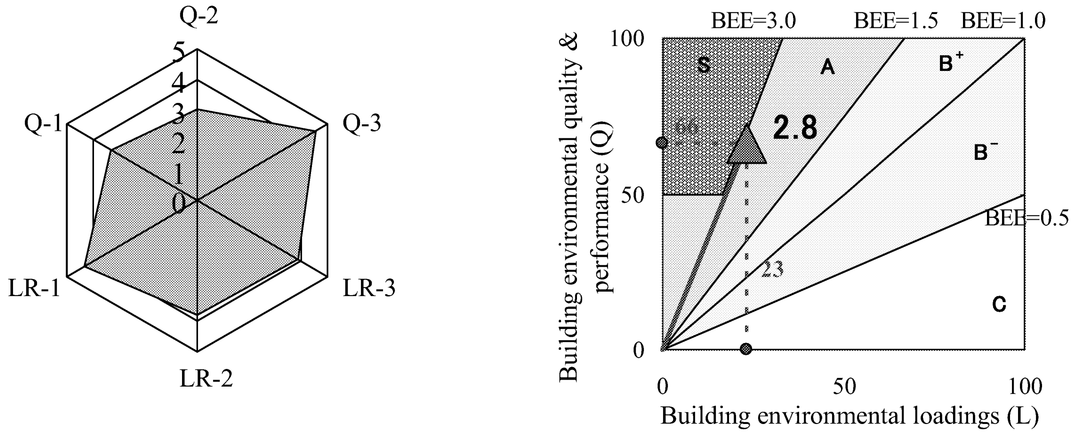

Figure 10: Assessment results by CASBEE (Left: Scores of sub-items; Right: calculated BEE value)

4. CONCLUSIONS

Various field measurements were carried out in a sustainable designed office building. The results show that temperatures in each office stayed much more constant compared to the fluctuation of outdoor ambient temperature. Indoor air temperature stayed stable around 20 ~ 25 ℃ throughout a whole year, due to the utilization of high performance insulation and sun-shading constructions.

On the other hand, annual energy consumption for heating and cooling in this sustainable designed office building accounted for 12% and 2% respectively, which is significantly less than in a building with conventional construction and operation.

With the benefits of well insulated building envelop and sun-shading constructions, the investigated building provides a high level thermal environment while consumes less energy simultaneously. This also indicated that in the northeast area of Japan, where the investigated office building is located, utilization of high performance insulation and high air-tightness constructions is one of the most effective design strategies for energy conservation.

A trial assessment with CASBEE was carried out to evaluate the environmental efficiency of the investigated office building. BEE value of this office building was 2.8 and it was labeled to Class A in CASBEE.

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