Impact of the Change of Gross Building-to-Land Ratio upon the Residential Ventilation Usage and Energy Consumption for Air-Conditioning and Lighting

- Development of a Method to Estimate Indoor Climate and Air Conditioning Energy Consumption in Residential House Considering the Influence of Cross Ventilation -

D.Narumi, A.Taketa and Y.Shimoda

Osaka University

ABSTRACT

In this paper, using the "SCIENCE vent" method for estimating the energy consumption for air conditioning in residential buildings, we evaluated the wind environment and the radiative conditions with respect to the target buildings in the case where the gross building-to-land ratio was taken into consideration by altering the distance between individual buildings. In addition, we examined the influence exerted by these parameters on the use of air conditioning and the annual energy consumption for air conditioning and illumination. As a result, based on the fact that a decrease in the gross building-to-land ratio entailed an increase in the energy consumption for air conditioning and a decrease in the energy consumption for illumination, it is necessary to take into account the energy consumption for both air conditioning and illumination when evaluating the potential for using natural energy in residential buildings.

1. INTRODUCTION

At present, the strong pursuance of energy efficiency in the context of global warming requires that measures are taken to reduce energy consumption in the residential sector. In this regard, research related to the reduction of energy consumption in residential buildings through the use of renewable energy sources is advancing, and natural wind ventilation, which has been used since ancient times for cooling in summer, is currently being reconsidered. It is thought that the potential for using the effects of natural wind ventilation is greatly influenced by the block-style design of cities with high building-to-land ratios, where groups of buildings are crowded together. However, as yet there has been no sufficient study of the influence of wind environment and radiative conditions on annual room temperature adjustment tendencies and energy consumption for air conditioning and illumination. Based on the above, the authors used the "SCIENCE vent" method for estimating the energy consumption for air conditioning in residential buildings, and present here the results of a study designed to explore the effects of altering the gross building-to-land ratio with respect to the usage of natural wind ventilation and the energy consumption for air conditioning and illumination in residential buildings.

2. COMPUTATION METHOD

Using the "SCIENCE" software (Ohnishi et al., 1995) for analyzing indoor thermal current environments, authors built a numerical model for estimating the energy consumption for air conditioning in dynamical indoor thermal environments on the basis of models of the stationary airflow around buildings, indoor airflow analysis and thermal load computations, as well as ventilation network models (Habara et al., 2003). An overview of the numerical model is provided in Fig. 1.

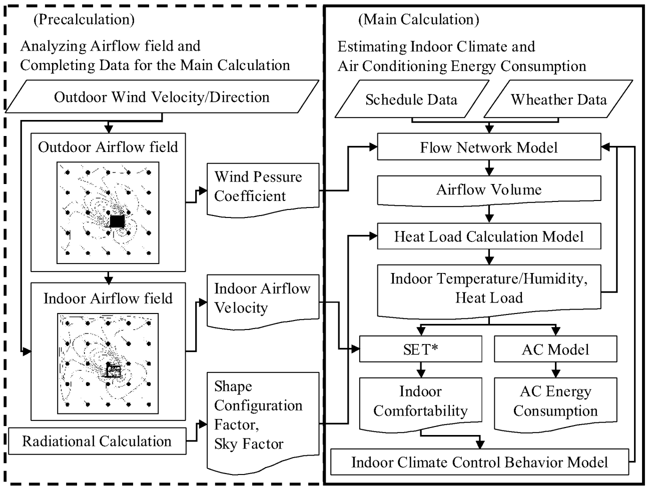
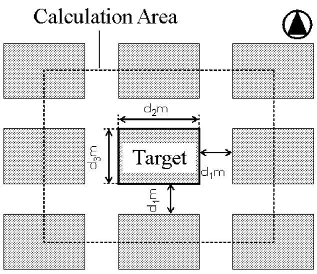


Fig.1: Overview of the numerical model



BtLR	d1	d2	d3
33%	6m	8.8m	7.4m
16%	12m	8.8m	7.4m
11%	18m	8.8m	7.4m
6%	24m	8.8m	7.4m
0%	INF	8.8m	7.4m

BtLR:Building to Land Ratio

Fig.2 : City block layout

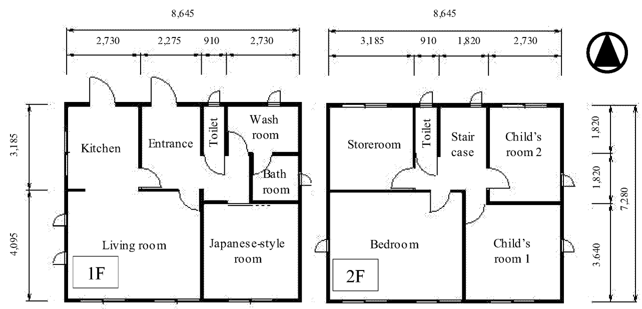


Fig.3 Plan of the standard wooden residential house

3. COMPUTATIONAL CONDITIONS

The details regarding the outdoor conditions, the building specifications and the living conditions adopted in the computations are presented below.

3.1 Outdoor Conditions

Regarding the weather conditions, we used data estimated for the summer period between July 1 and September 30, as well as data for the winter period between December 1 and February 28, based on the standard annual Expanded AMeDAS Weather Data (Osaka).

A city block was assumed to be a regular lattice of evenly distributed buildings, where the gross building-to-land ratio was varied by altering the distance between the individual buildings. The city block layout is presented in Fig. 2.

3.2 Building Specifications

We used standard wooden houses (Fig. 3) as defined by the Architectural Institute of Japan (Udagawa, 1985). The thermal isolation specifications included the equivalent of the Japanese old energy conservation standard, the isolation construction method was based on internal isolation, the windows comprised ordinary single-layer glass, and an eave with a protrusion of 0.65m was placed 0.20m above the upper edge of each window.

3.3 Living Conditions

The cooling temperature and the humidity were set at 27°C and 60%, respectively, and the heating temperature was set to 21°C. Furthermore, it was assumed that all doors were shut, and only windows in rooms with occupants were assumed to be opened. An electrically powered heat pump air conditioner was used during the heating period, and heating was not used in the winter during sleeping times. Schedules regarding the presence of people and heat generation were selected with the aid of the automatic lifestyle schedule generation program "SCHEDULE (Ishida, 1996)". As for the thermal control behavior of the occupant, it was decided by the occupant indoor thermal environmental control behavior model (Habara et al., 2005).

4. RESULTS OF THE ANALYSIS OF WIND ENVIRONMENT AND RADIATIVE CONDITIONS

The results of the wind environment analysis comprised the amount of indoor ventilation, while the results of the radiative condition analysis comprised the daily amount of sunlight absorbed by the inner walls of the rooms, and their respective comparisons with each value of the gross building-to-land ratio are presented.

4.1 Comparison Results for the Amount of Natural Ventilation

We compared the amount of natural ventilation for 16 different directions of the gross building-to-land ratio. Fig. 4 presents the results for living room. It is clear from the figure that the amount of ventilation increased as the gross building-to-land ratio decreased. In particular, since the distance between the buildings was large for gross building-to-land ratios of 11% or less, the velocity of the outside wind close to the building increased due to the generation of air currents sinking into the space between the buildings, and the amount of ventilation was relatively large in comparison to building-to-land ratios of 33% and 16%.

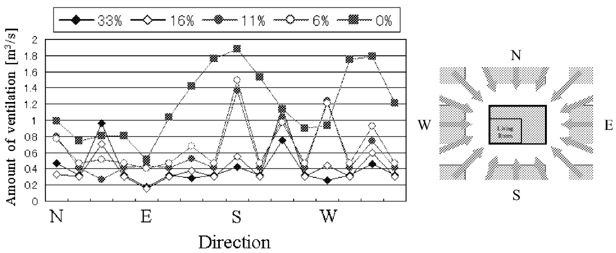


Fig.4 : Amount of natural ventilation for 16 different directions (living room)

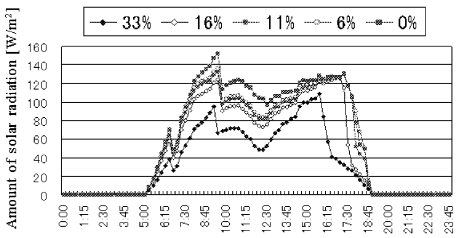


Fig.5 : Amount of sunlight absorbed by the walls for a representative day in the summer period (living room)

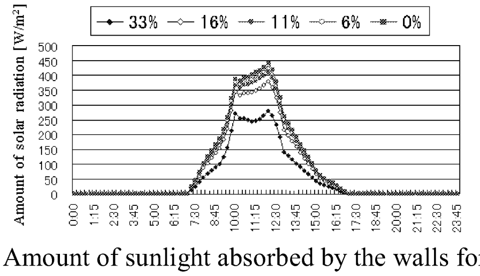


Fig.6 : Amount of sunlight absorbed by the walls for a representative day in the winter period (living room)

4.2 Comparison Results for Absorbed Sunlight

Fig. 5. presents the results of the comparison of the amount of sunlight absorbed by the walls in living room for a representative day in the summer period (August 3), while Fig. 6 presents the results for the winter period (January 3). It can be seen that for both the summer and the winter period, the amount of absorbed sunlight was greater for lower gross building-to-land ratios. The differences between the gross building-to-land ratios with respect to the reduction of the amount of sunlight in the evening due to the influence of the neighboring buildings were successfully reproduced.

5. INFLUENCE ON ENERGY CONSUMPTION, AND USE OF NATURAL WIND VENTILATION

5.1 Influence on Energy Consumption for Air Conditioning and Illumination, and Use of Natural Wind Ventilation in Summer

The respective rates of use of air conditioning in living room and bedrooms for this period are shown in Fig. 7. The rates were calculated by dividing the total hours of air conditioning by the total hours of presence of people in the room. Moreover, the overall energy consumption for air conditioning and illumination for living room and bedrooms with respect to this period is presented in Fig. 8, where the rate of use of air conditioning decreased as the gross building-to-land ratio decreased. The energy consumption for air conditioning in bedrooms decreased as a result of the lower rate of using air conditioning, while it remained constant for living room. The hourly rates of using air conditioning in living room for this period are presented in Fig. 9. From this figure, it is clear that while the rate of using air conditioning decreased for the morning period due to the decreased gross building-to-land ratio, it increased in the evening. It is considered that this effect is connected with the fact that it is possible to use natural wind ventilation in the morning, when the outside air temperature is low, and the time interval during which natural wind ventilation is usable is prolonged for low building-to-land ratios due to the increased wind velocity in the city block, which results in lower

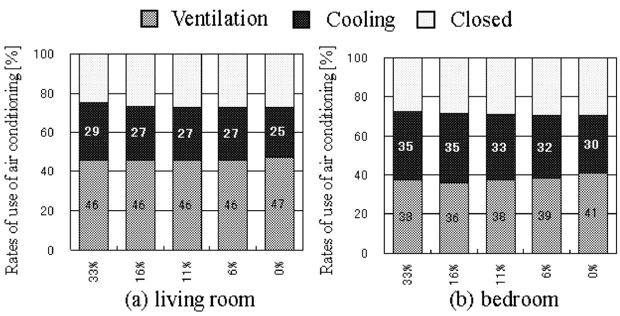


Fig.7 : The respective rates of use of air conditioning in living room and bedrooms (Summer)

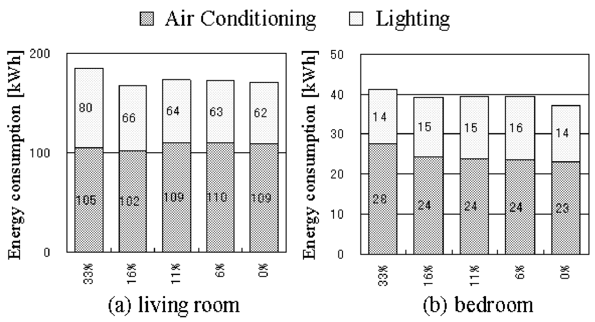


Fig.8 : Energy consumption for air conditioning and illumination for living room and bedrooms (Summer)

energy consumption for air conditioning. In the evening and during the night, using natural wind ventilation is not feasible since the outside air temperature is high, and as a result of the absorbed sunlight, the energy consumption for air conditioning increased as the gross building-to-land ratio decreased. In this regard, due to the outdoor air load (caused by air leakage) in the evening, the energy consumption for air conditioning increased as the gross building-to-land ratio decreased. In addition, since the amount of sunlight increased as the gross building-to-land ratio decreased, we observed a tendency for energy consumption for illumination to decrease.

5.2 Influence on Energy Consumption for Air Conditioning and Illumination, and Use of Natural Wind Ventilation in Winter

The respective rates of use of air conditioning in living room and bedrooms for this period are shown in Fig. 10. Moreover, the overall energy consumption for air conditioning and illumination for living room and bedrooms for this period is presented in Fig. 11. From these two figures, it is clear that the rate of use of heating methods increased as the gross building-to-land ratio decreased, which resulted in increased energy consumption for air conditioning. Furthermore, as described in 4.2, it was found that the amount of sunlight entering the rooms increased as the gross building-to-land ratio decreased, and as a result the energy consumption for illumination in the evening decreased. It was shown that the lower amount of sunlight in winter exerts strong influence on the rate of use of air conditioning as well as on the energy consumption for air conditioning and illumination.

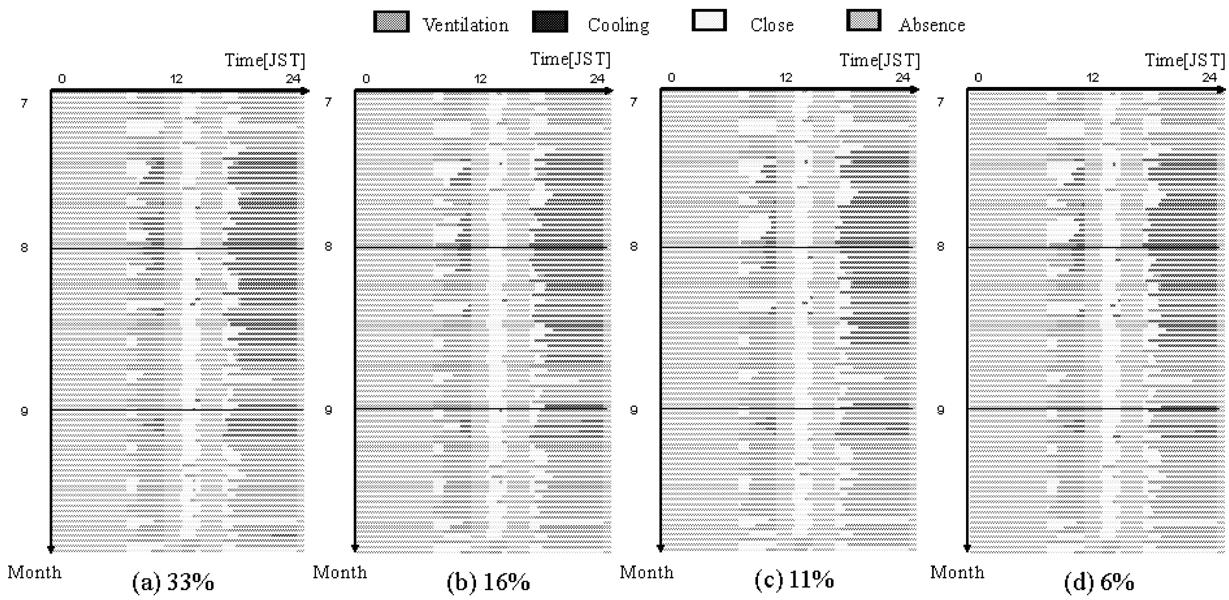


Fig.9 : Hourly rates of using air conditioning in living room

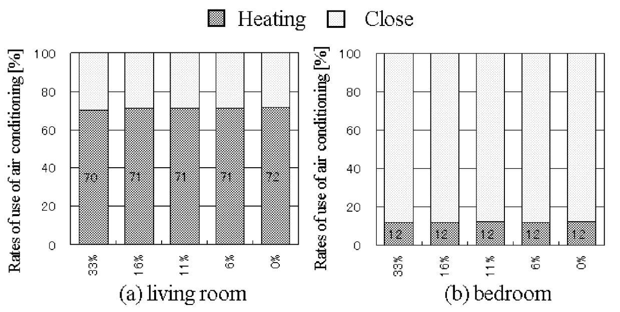


Fig.10 : The respective rates of use of air conditioning in living room and bedrooms (Winter)

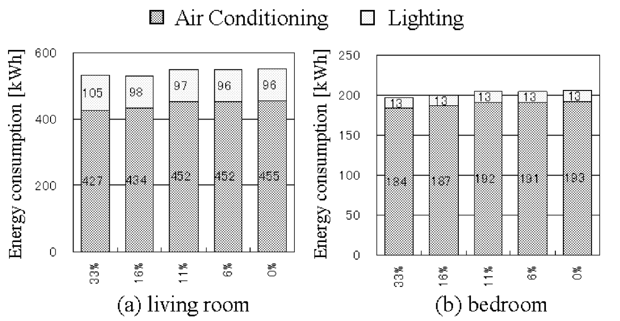


Fig.11 : Energy consumption for air conditioning and illumination for living room and bedrooms (Winter)

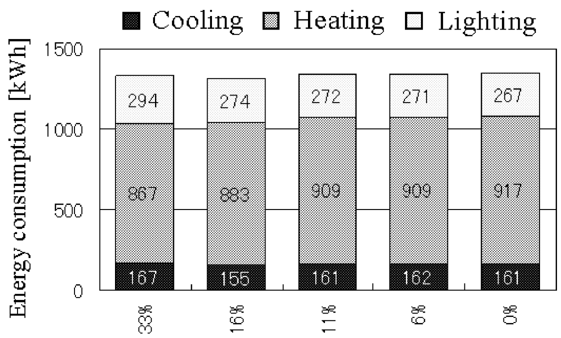


Fig.12 : Overall energy consumption for air conditioning and illumination with respect to the entire residence

5.3 Influence on Annual Energy Consumption for Air Conditioning and Illumination

The overall energy consumption for air conditioning and illumination with respect to the entire residence is shown in Fig. 12. The figure clearly shows that as the gross building-to-land ratio decreased, the energy consumption for air conditioning increased, while that for illumination decreased. As a result, gross building-to-land ratio of 16% yielded the lowest overall energy consumption. Therefore, it was demonstrated that it is necessary to consider the energy consumption for both air conditioning and illumination when evaluating the potential for using natural energy in residential buildings.

6. CONCLUSIONS

In this paper, using the "SCIENCE vent" method for estimating the energy consumption for air conditioning in residential buildings, we elucidated the wind environment and the radiative conditions with respect to the target buildings in the case where the gross building-to-land ratio was taken into consideration by altering the distance between individual buildings. In addition, we examined the influence exerted by these parameters on the use of air conditioning and the annual energy consumption for air conditioning and illumination. As a result, based on the fact that a decrease in the gross building-to-land ratio entailed an increase in the energy consumption for air conditioning and a decrease in the energy consumption for illumination, it is necessary to take into account the energy consumption for both air conditioning and illumination when evaluating the potential for using natural energy in residential buildings.

REFERENCES

Habara et al. (2003). Development of a method to estimate indoor thermal condition and air conditioning energy consumption in residential house using natural ventilation. J. Environ. Eng., AIJ, No. 582: 107-114.

Habara et al. (2005). An Occupant Indoor Thermal Environment Control behavior Model to Estimate Residential Cooling Energy Consumption. Proceedings of The 10th International Conference on Indoor Air Quality and Climate: 1179-1183.

Ishida (1996). Program for scheduling of indoor heat generation rate due to livelihood. Proceedings of the SHASE Symposium.

Ohnishi et al. (1995). Study on Numerical Prediction Methods for Indoor Air-flow and Thermal Environments Part 1 - Calculation Procedure Used in the Simulation Code SCIENCE -. Transactions of the Society of Heating, Air-conditioning and Sanitary Engineering of Japan, No.58: 22-33.

Udagawa (1985). Proposal of a standard calculational condition for a residential house. The 15th Heat Transfer Symposium, AIJ: 22-33.