EFFECT OF TELECOMMUTING ON ENERGY CONSUMPTION IN RESIDENTIAL AND NON-RESIDENTIAL SECTORS

Yoshiyuki Shimoda[1], Yohei Yamaguchi[2], Kaoru Kawamoto[3], Jun Ueshige[4], Yoshimasa Iwai[1], Minoru Mizuno[1]

[1]Division of Sustainable Energy and Environmental Engineering, Osaka University, 2-1, Yamadaoka, Suita 565-0871, Japan
[2]Research Institute for Sustainability Science, Osaka University, Japan
[3]Osaka Gas Co., Ltd., 4-1-2 Hirano, Osaka 541-0046, Japan
[4]Toshiba Carrier Corporation, 336 Tadewara, Fuji, Shizuoka 416-8521, Japan

ABSTRACT

In this paper, the change of energy use by telecommuting (working at home) is simulated for residential and office buildings by modeling the differences in the occupants' behavior. By summing up these results, the change in annual energy use in Osaka City caused by the saturation of telecommuting is evaluated in three dissemination scenarios for the transformation of office buildings. The results indicate that telecommuting tends to increase energy consumption in the residential sector and to decrease it in the non-residential sector, and that it is possible to increase energy consumption if the floor area of office buildings is not decreased by sharing the space among telecommuters. If the floor area of an office building decreases with the increase of telecommuters, energy consumption will decrease by 0.6% of the total energy consumption of the residential and non-residential sectors in Osaka City at a 60% saturation level of telecommuting.

KEYWORDS

Telecommuting, Occupants' behavior, Residential building, Office building

INTRODUCTION

Due to the advance of Internet technology, the work styles of white-collar workers are expected to change drastically in the future. The most typical style is "telecommuting", which means that a worker works in his or her home instead of commuting to the office for several days of a week.

Telecommuting can have a considerable effect on the activities in both residential buildings and office buildings. In residential buildings, where people stay home in the daytime, energy consumption will be relatively increased. On the other hand, the number of occupants in office buildings will decrease. Since energy consumption for office equipment and cooling load will decrease, energy consumption in the office building is also expected to decrease.

Han and Ojima (2005) investigated the energy consumption of a home office and an office building and calculated the total energy saving on the condition that the office building is no longer used after the spread of telecommuting. However, it is unrealistic to presume that all office buildings will be diminished. To evaluate the change in energy consumption in buildings due to telecommuting, a simulation model which considers the occupants' behavior is necessary. The authors have developed an end-use energy simulation model in residential and non-residential sectors of a city or region based on each occupant's activity (Shimoda et al. 2004, Shimoda et al. 2007, Yamaguchi et al. 2003, Yamaguchi et al. 2007).

In this paper, the change in energy use by telecommuting is simulated for residential and office buildings. By summarizing the results, the change in annual energy use in Osaka City caused by the saturation of telecommuting is evaluated.

SIMULATION MODELS

City-level end-use energy simulation models for the residential sector and non-residential sector are used in this study. In these models, the annual energy consumption in various types of residential buildings or office buildings in the objective area are simulated, given the thermal load characteristics, occupants' behavior schedule, weather data, and energy efficiencies of appliances. By summing up the simulation results with weights based on the number of each household type or the total floor area of each non-residential building class, the total energy consumption in the residential sector or non-residential sector in the objective region can be estimated.

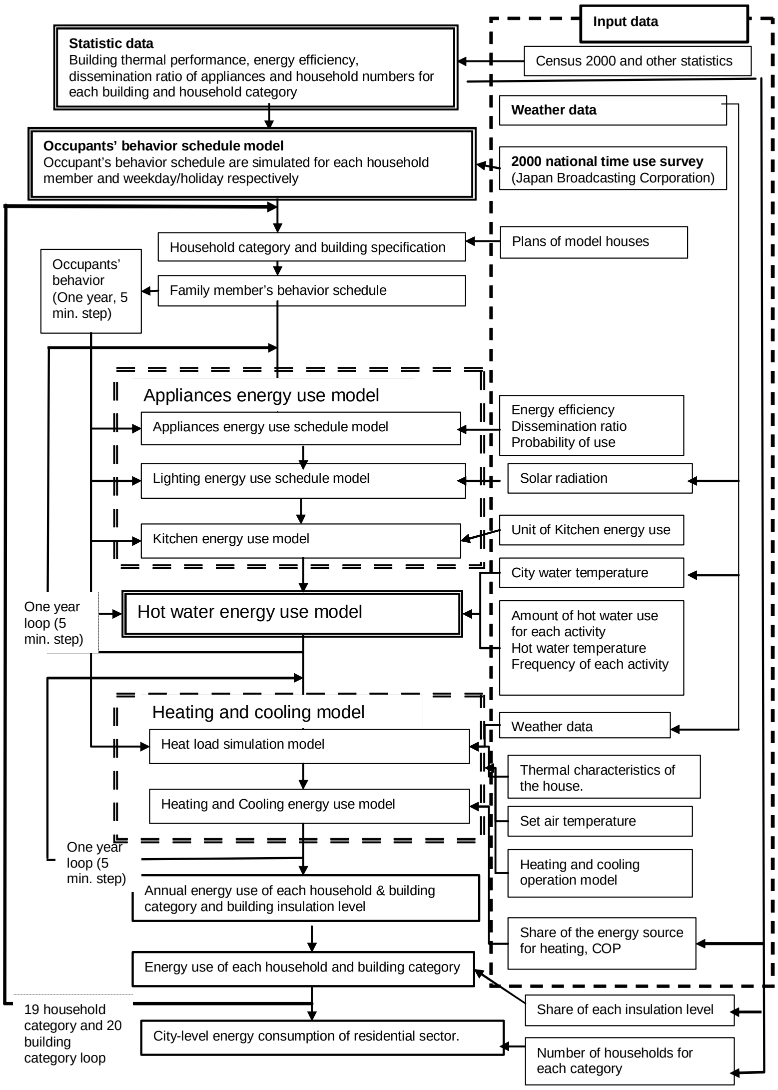


Figure 1. Flowchart of the residential sector model

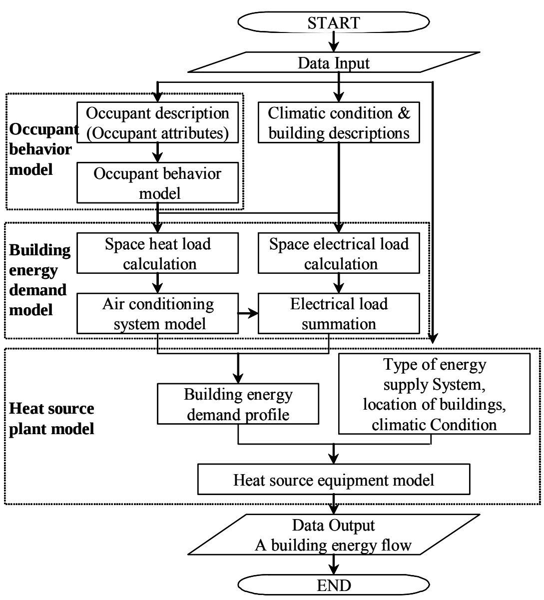


Figure 2. Flowchart of the non-residential sector model

In the residential sector, all the households in Osaka City are classified into 380 categories based on the household type, building type and building size. Each occupant's time allocation for living activities and the energy efficiency properties of appliances are provided as input data. The simulation of the heat load and energy use is conducted in time steps of 5 min. The flowchart of the model is shown in Figure 1 (Shimoda et al. 2007).

The non-residential sector model consists of three basic components: occupant behavior model, building energy demand model and heat source plant model. Figure 2 shows the flowchart of this model (Yamaguchi et al. 2003).

MODELING OF TELECOMMUTING

Classification of residential and office buildings

Among the 2,598,000 people in Osaka City, the number of white-collar workers who live and work in Osaka City is estimated at 337,000. Therefore, the "dissemination ratio of telecommuting" is defined as the ratio of the number of telecommuters to 337,000.

Household types which telecommuters belong to and their ratios are estimated from the survey results (Japan Industrial Policy Research Institute 2001, Japan Teleworking Association 2001), as shown in Table 1.

In the non-residential sector, only office buildings are considered in this paper. Office buildings in Osaka City are classified by their floor areas, as shown in Table 2.

Table 1. Classification of telecommuter households

Household type	Building type	Floor area [m^2]	Household type	Ratio
1	Apartment house	30~39	Single	20%
2		50~59	Working couple	11%
3		50~59	Couple (One worker)	10%
4		60~69	Couple and two children (One worker)	24%
5	Detached house	50~59	Single	11%
6		90~99	Working couple	6%
7		90~99	Couple (One worker)	5%
8		100~ 119	Couple and two children (One worker)	13%

Table 2. Classification of the office buildings in Osaka City

Office class	1	2	3	4	5
Range of floor area	~3,051 [m^2]	~ 8,188	~ 19,651	~ 65,536	65,536~
Ratio of building stock in Osaka City	9.6%	19.9%	17.1%	28.0%	25.4%
Floor area of typical floor	279 [m^2]	633	1,194	2,736	4,509
No. of stories	6	7	10	10	23
Floor area of model building	1,671 [m^2]	4,432	11,944	27,537	103,716

Scheduling model of telecommuters

In the residential sector model, the occupants' schedules of living activities are calculated based on the results of a time allocation survey of living activities, which was conducted by the Broadcasting Culture Research Institute of Japan Broadcasting Corporation (Broadcasting Culture Research Institute 2001), as shown in Figure 3. In this paper, the time allocation data of office workers is replaced with that of telecommuters.

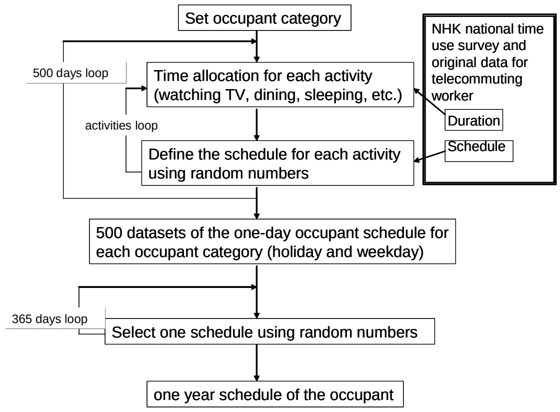
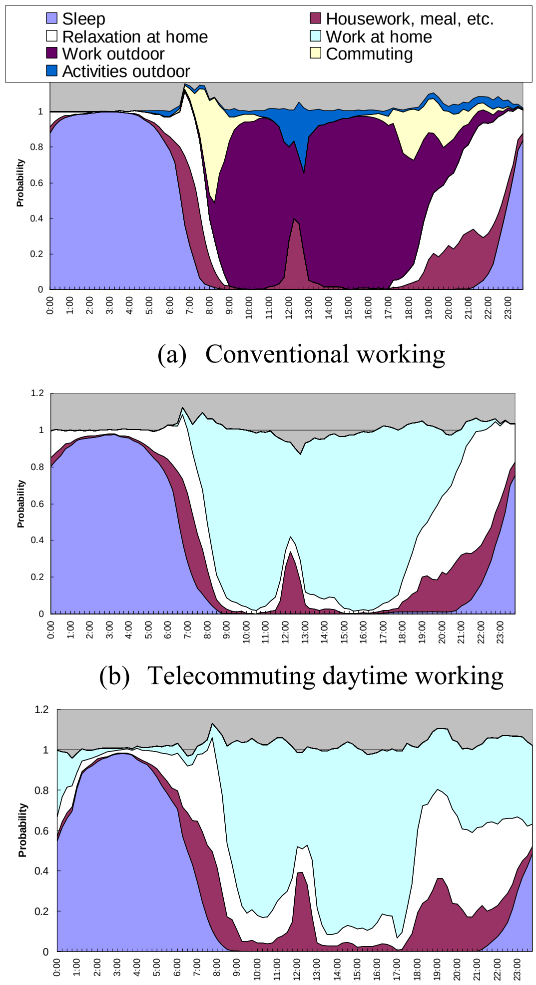


Figure 3. Flowchart of occupant schedule model in a residential building



(a) Conventional working

(b) Telecommuting daytime working

(c) Telecommuting nighttime-shift working

Figure 4. Activity schedule of a male worker

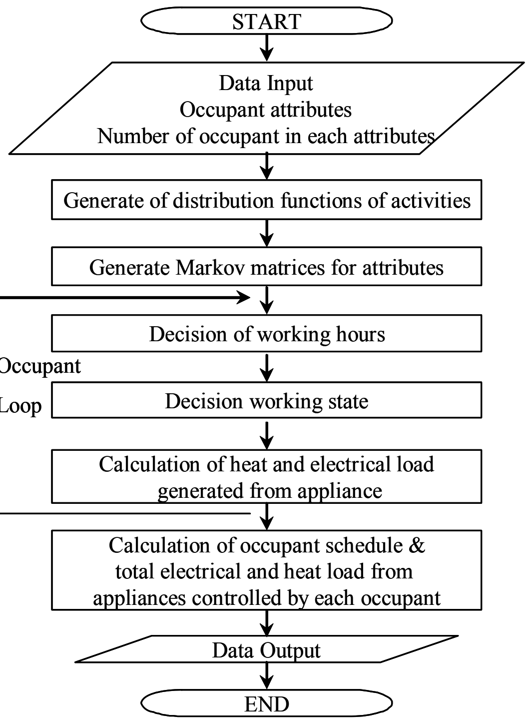


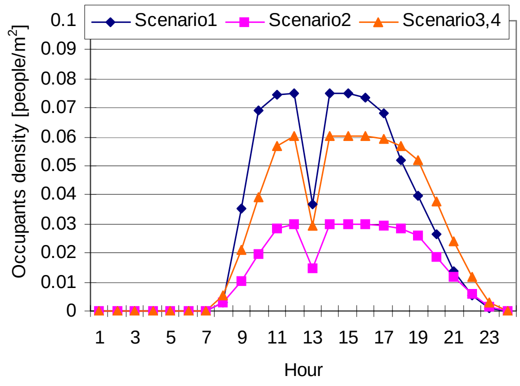
Figure 5 Flowchart of occupant behavior model in an office.

The living activities of telecommuters are modeled as two types: "daytime workers" who work in the daytime as same as office workers; and "nighttime-shift workers" who work flexible hours, sometimes in the midle of the night. Figure 4 shows the activity schedule of a male worker during a weekday in the case of "conventional working," "telecommuting daytime working" and "telecommuting nighttime-shift working."

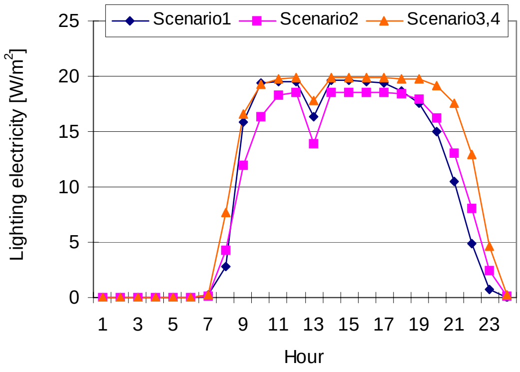
Figure 5 shows the flowchart of the occupant behavior model in an office building. In the scenario where telecommuting is considered, flextime in an office is assumed. The area of lighting is assumed to be 50 m^2. When at least one occupant is in the area, the lighting is switched on. The electricity demand of PCs, copiers and elevators are calculated from the occupants' behavior schedule. The electricity consumption of network servers, fans and pumps are considered as independent items from the occupants' schedule. Air-conditioning hours are defined as 9:00-20:00 in the base case and 9:00-21:00 in the flextime case.

Telecommuting scenarios for an office building

In this paper, four senarios for the spread of telecommuting in office buildings are examined, as shown in Table 3.



(a) Occupant density



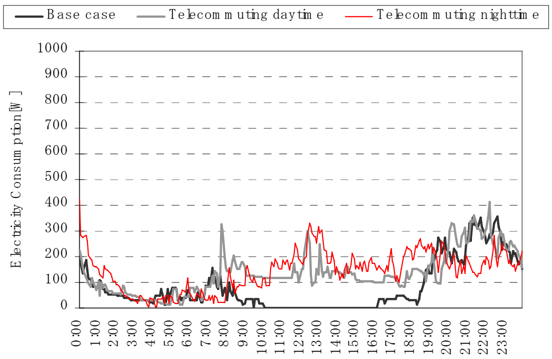
(b) Lighting electricity

Figure 6. Schedules in an office building

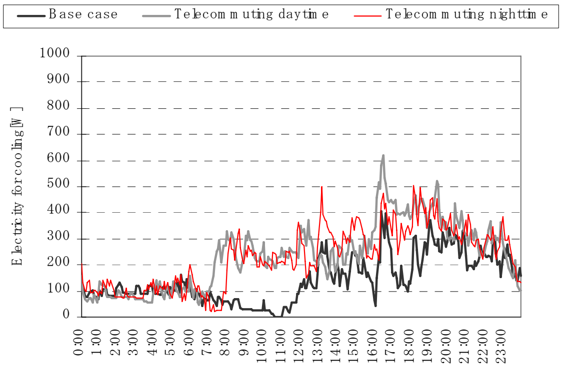
Table 3 Telecommuting scenarios

Scenario	Description	Telecommuting	Office building stock
Scenario 1	Business as usual	Not spread	Same as present
Scenario 2	Telecommuting only	Spread	Same as present
Scenario 3	Telecommuting and decrease in building stock	Spread	Building floor area is decreased by free address system
Scenario 4	Telecommuting, decrease in building stock and building replacement	Spread	Scenario 3 + reduction in only small size building.

In Scenario 2, since the total floor area is set to be the same as the base case, the occupant density decreases as the dissemination ratio of telecommuting increases. In Scenarios 3 and 4, by sharing the floor area among telecommuters (free address system), the total floor area of office building decreases with increasing the dissemination ratio of the telecommuting. In this paper, it is assumed that the number of employees in the unit floor area is doubled from Scenarios 1 and 2. In Scenario 3, the floor area of the office buildings decreases from all classes of buildings shown in Table 2. On the other hand, the floor area decreases



(a) Household type 1 (Apartment house, single)



(b) Household type 2 (Apartment house, couple with two children)

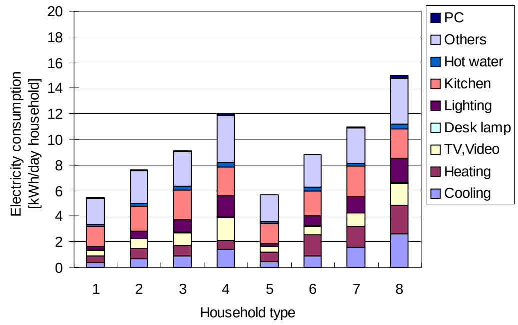
Figure 7. Simulated electricity consumption profiles of room air- conditioner in residential buildings

from the smaller office classes in Table 1 (class 1 → class 2→ …) in Scenario 4. Since the energy efficiency of office buildings becomes higher with the increases of total floor area of a building (Yamaguchi et al. 2007), the total energy consumption in Osaka City is expected to become lower than that of Scenario 3. A schedule of the occupants' density and lighting electricity in the respective scenarios is shown in Figure 6.

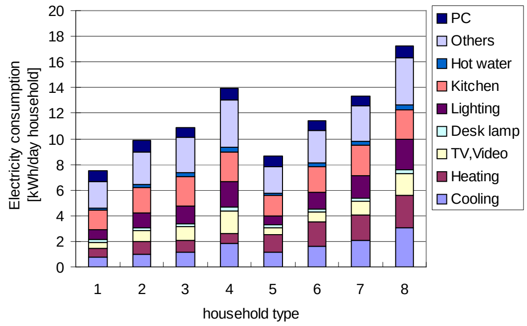
RESULTS

Residential building

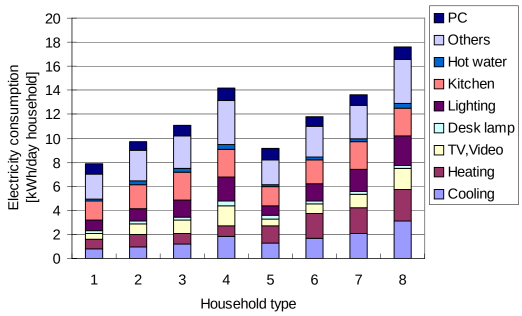
Figure 7 shows examples of the simulated electricity consumption profile of a room air-conditioner for the base case and telecommuting case. In all cases, the electricity consumption of the room air-conditioner is increased by telecommuting, especially in the daytime. Figure 8 shows the simulated daily electricity consumption during a weekday for the base case and telecommuting work case. The electricity consumption in the case of telecommuting increases by 15-61% from the base case. The difference is larger in small households. These increases mainly occur due to the use of heating, cooling, PCs, desk lamps and lighting. The difference in energy consumption between the daytime worker and nighttime-shift worker is small.



(a) Conventional working



(b) Telecommuting daytime working



(c) Telecommuting nighttime-shift working

Figure 8. Simulated daily electricity consumption in a residential building on a weekday (household type number corresponds to the 'household type' in Table 2).

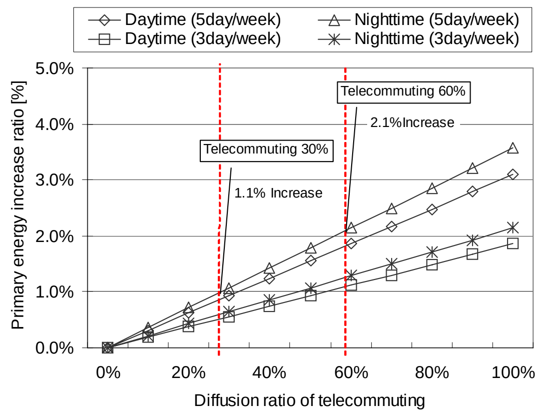
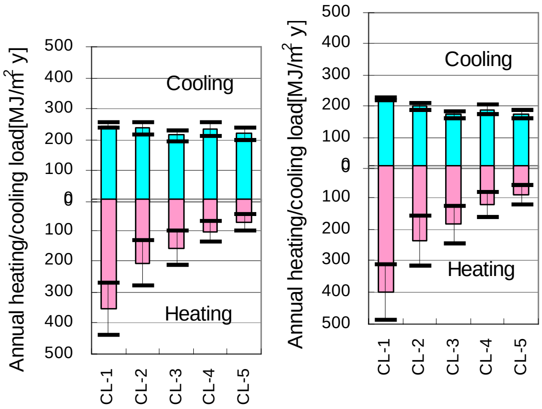


Figure 9. Relationships between diffusion ratio and primary energy consumption in a residential sector of Osaka City

Figure 9 shows the relationship between the increase of the diffusion ratio of telecommuting working and the changes in the primary energy consumption in Osaka City. If the diffusion ratio of telecommuting (5 days/week) reaches 60%, the primary energy consumption in the residential sector of Osaka City increases by about 2%.

Office building

Figure 10 shows the simulated annual cooling and heating loads per unit floor area in each office class for Scenario 1 and Scenario 2. Since the occupants' density becomes lower in Scenario 2, the cooling load becomes smaller and the heating load becomes larger than that in Scenario 1. The heating load per unit floor area increases with the decreasing total floor area since the ratio of the perimeter length to floor area is larger. Figure 11 shows the simulated annual electricity demand per unit floor area (heat source equipment is not included). The electricity demand per unit floor area also decreases with the increase of total floor area, because the difference in applied energy-saving measures as well as the difference in the heating and cooling loads are considered in this simulation model. The simulated annual primary energy consumption, including the heat source equipment per unit floor area, is shown in Figure 12 for each office class, for each kind of heat source equipment and for each telecommuting scenario. The primary energy consumption per unit floor area varies with the telecommuting scenario and type of heat source equipment. However, the difference due to the scale of the building is the largest. Figure 13 shows the total primary energy consumption of office buildings in the Osaka City area. The difference between Scenarios 1 and 2



(a) Scenario1 (b) Scenario 2

Figure 10. Simulated annual cooling and heating loads per unit floor area (CL-1~5 indicates office class 1~5 shown in Table 2)

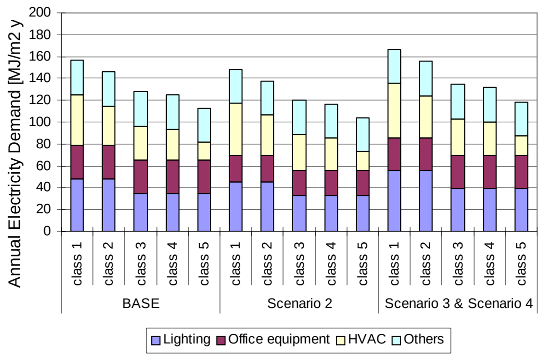


Figure 11. Simulated annual electricity demand per unit floor area of an office building ('class' indicates office class 1~5 shown in Table 2)

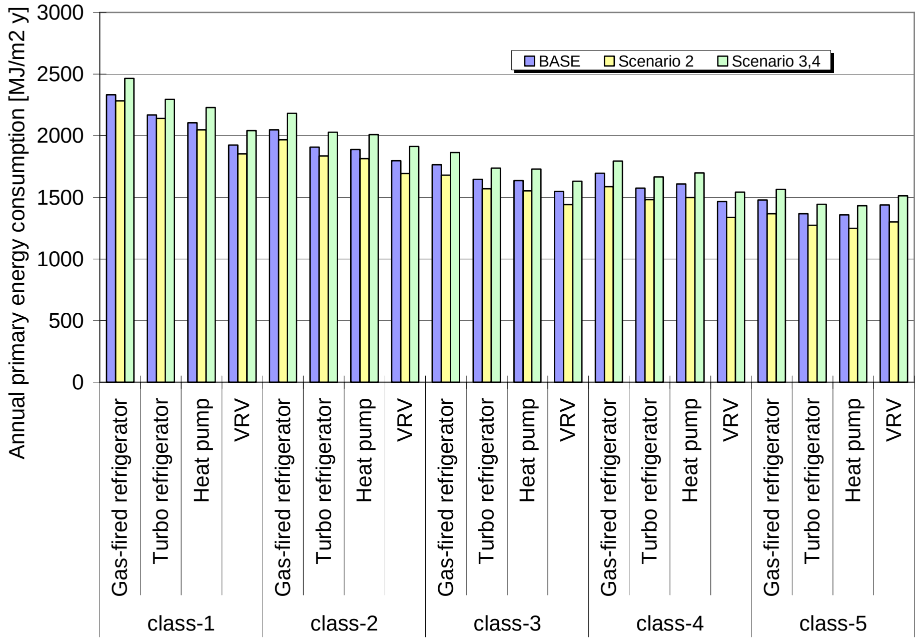


Figure 12. Simulated annual primary energy consumption per unit floor area of an office building

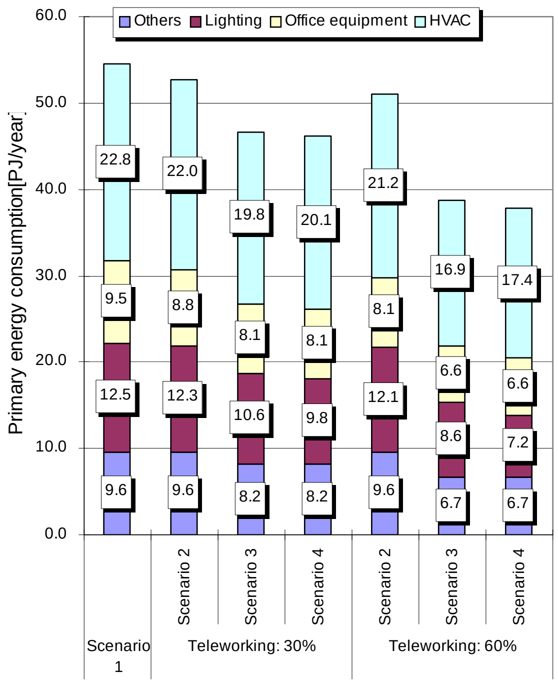


Figure 13 Total primary energy consumption of office buildings in the Osaka City area.

indicate that the reduction in energy consumption by the decreasing number of occupants is only 2-3%. On the other hand, the difference between Scenarios 1 and 3 indicate that the reduction of total floor area by sharing floor area among telecommuting workers becomes 28% when the dissemination ratio reaches 60%. In addition, the primary energy consumption in Scenario 4 is reduced by 2-3% from Scenario 3, because more kinds of energy-saving measures such as high efficiency lighting are assumed in larger buildings.

Total evaluation of the city scale

By combining these results, the influence of telecommuting on the total energy consumption of residential and non-residential sectors in the city is evaluated. Since the difference of annual energy consumption between "daytime working" and "nighttime-shift working" in residential buildings is small, as shown in Figure 9, only the result of "nighttime-shift working" is considered in the following evaluation. In addition, the frequency of telecommuting is assumed to be 3 days/week.

From the results of residential sector and office buildings, the change in the primary energy consumption in Osaka City is estimated. Figure 14 shows the change in the primary energy consumption due to the diffusion of telecommuting. The energy consumption of the base case is the total primary energy consumption of the residential and non-residential sectors in Osaka City, estimated from statistical data. In Scenario 2, which assumes that the floor area of the office buildings is not reduced, the total primary energy consumption increases by the diffusion of telecommuting due to the increase in energy consumption in residential buildings. However, in Scenarios 3 and 4, which reduce the total floor area of office buildings by sharing the floor area among telecommuters, the primary energy consumption decreases. When the diffusion ratio of telecommuting reaches 60%, primary energy is reduced by 0.6% of the total primary energy consuption of residential and non-residential sectors

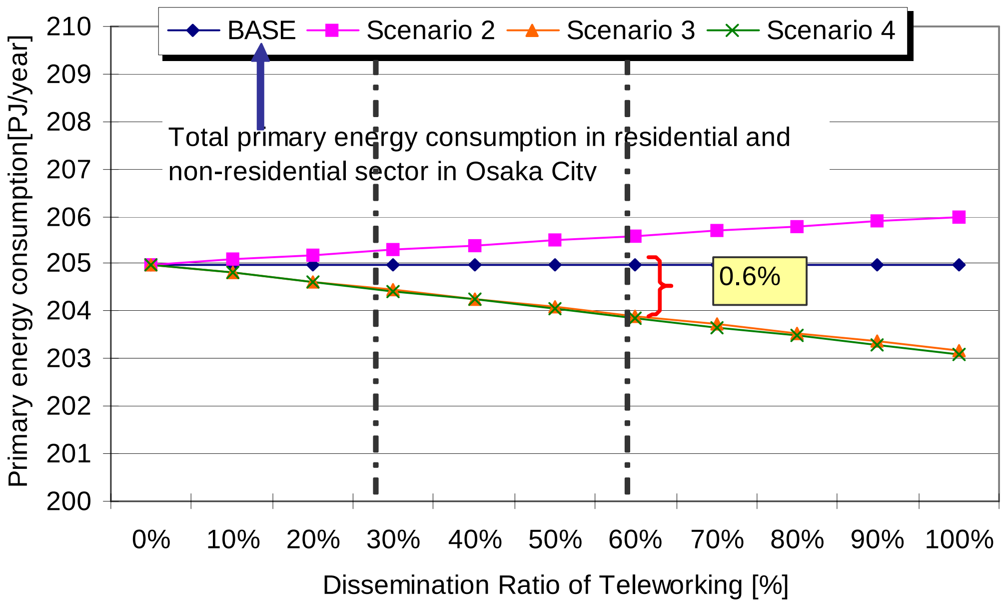


Figure 14. Change in primary energy consumption in residential and non-residential sectors in Osaka City by the diffusion of telecommuting

in Osaka City. The difference between Scenarios 3 and 4, which indicates the difference in the distribution of the building scale, is much smaller than the difference between the base case and Scenario 3.

CONCLUSION

In this paper, the change in energy consumption in the residential and non-residential sectors in Osaka City due to the diffusion of telecommuting from home is predicted by detailed end-use energy simulation models based on the occupants' behavior.

In the residential sector, energy consumption increases with the increasing number of occupants in a residence. However, energy consumption in office buildings is reduced by the decrease of occupant density in these buildings.

The reduction of floor area of office buildings by sharing the space among telecommuters is indispensable for energy saving in the total residential and non-residential sectors of Osaka City.

To evaluate the influence of telecommuting working on energy consumption, the evaluation of the change of transportation energy is essential. From the results of rough estimates, the reduction of transport energy by telecommuting is about one-third of the increase of energy consumption in the residential sector for commuting inside Osaka City.

In future work, a detailed evaluation on transportation energy and a field survey on the schedule of living activities and energy use of telecommuting workers are planned.

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