EVALUATION OF GLOBAL WARMING MITIGATION MEASURES IN THE RESIDENTIAL AND NON-RESIDENTIAL SECTORS OF A SUBURBAN CITY IN JAPAN

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Summary

In Japan, CO_2 emissions from the residential and non-residential sectors have increased significantly. This paper focuses on reducing CO_2 emissions in suburban areas, where little attention has been paid to the management of CO_2 emissions even though the building stock in suburban areas accounts for a large percentage of the country's total. In this paper, we conduct a case study to estimate potential reductions in CO_2 emissions from the residential and non-residential sectors of Toyonaka city, Japan, considering technological advancements and dissemination of energy-saving technologies as well as the management of building stocks. This study on Toyonaka city, a typical suburban city, is relevant to addressing future challenges in finding ways for shifting Japanese suburban areas toward a low-carbon society. The results of the case study show that a CO_2 emission reduction by more than 50% of the current levels is achievable by combining these measures for the residential and non-residential building sectors and managing building stocks, along with an expected population decrease in Toyonaka city, which account for one-fifth of the reduction.

1. Introduction

Reducing CO_2 emissions has become an urgent challenge. The management of energy demand in the residential and non-residential sectors is imperative in Japan, as these sectors have been the main contributors to the current increase in national CO_2 emissions. The total floor area in the non-residential sector in major cities (23 wards in Tokyo, Osaka, and Nagoya) occupies 15% of the total floor area in Japan, while households in major cities account for 12.5% of households in Japan (Statistics Bureau. 2000). This means that the majority of buildings in the residential and non-residential sectors are built in suburban cities. Thus, it is important to find a vision for a future low-carbon society in Japanese suburban areas and pathways to realize the vision.

When we imagine the future of a suburban city in Japan, we cannot ignore the trends in decreasing and aging population and decreasing number of households. These changes might result in a decrease in the demand for housing and changes in the demand for businesses and services. In addition, due to the decades-long lifetime of buildings in the residential and non-residential sectors, buildings that are constructed in the next few decades are likely to still exist in 2050. While adapting to these trends, we have to manage our building stocks and infrastructure to reduce CO_2 emissions to a large extent. It is important to find development pathways with synergy between the management of carbon emissions and building stocks. For example, we can avoid declines in the quality and efficiency of administrative services that can be expected due to a decrease in the density of residents per land area by managing housing locations and density appropriately.

The purpose of this paper is to quantitatively evaluate various energy-saving measures and implementation strategies for building stock management, with the objective of creating future visions of a low-carbon society with CO_2 emissions reduced by more than 70% from the current level. For this purpose, we developed a simulation model that estimates energy use in the residential and non-residential sectors of Toyonaka city. We estimate CO_2 emissions in 2050 based on assumptions regarding technological advancements, dissemination of energy-saving technologies, and management of building stocks, with the purpose of quantifying potential reductions in CO_2 emissions by pursuing different pathways in the next decades. In this paper, we first introduce Toyonaka city and the current situation of its building stocks. We then describe the methodology of this study, including simulation models and cases designed in this study. We finally derive some implications based on the results of the case study.

2. Case study area: Toyonaka city

Toyonaka city has an area of 36.6 square kilometers with a population of 390,000 in 159,000 households. This city has prospered as a bedroom suburb of the Osaka urban area. The population size is decreasing, while the number of households has increased, especially those housing families with few members. The residential and non-residential sectors account for 58% of the current emissions from the city. The authority of Toyonaka city has currently explored the feasibility of reducing CO_2 emissions by more than 70% compared with 1990 levels by 2050 (Toyonaka city. 2007).

Figure 1 shows the regional partition of Toyonaka city. The city is divided into seven regions according to the Master Plan of the Toyonaka City (Toyonaka city. 2000). Table 1 shows the total floor area of buildings in the residential and non-residential sectors for each region. The North-central, Central, and East regions of Toyonaka city can be characterized by their high proportion of building stock in the residential sector. The Northeast and Western regions have a business district, while approximately 70% of the building stock is occupied by residential sector buildings.

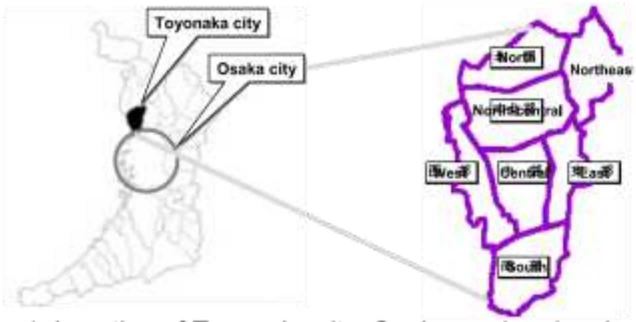

Figure 1 Location of Toyonaka city, Osaka, and regional partitions

Table 1 Seven regions of Toyonaka city

Regional Partition	Ratio of total floor area			Total floor area [1000 m^2]	area [km^2]
	Detached houses	Apartments	Non-residential sector		
North	38%	42%	19%	2,091	5.0
Northeast	15%	54%	31%	2,562	4.8
North-central	52%	35%	12%	3,930	7.0
Central	43%	42%	15%	3,414	5.2
West	31%	32%	37%	1,052	5.0
East	22%	67%	11%	1,605	3.9
South	46%	30%	24%	2,724	5.7

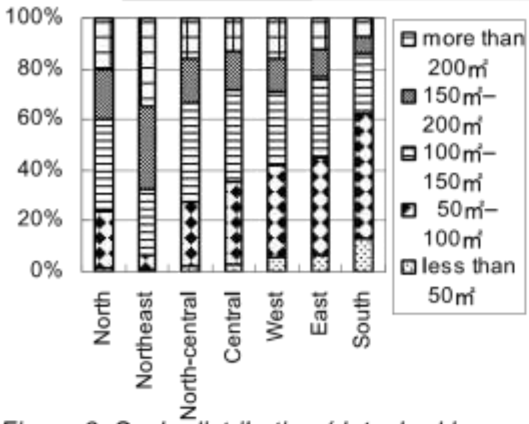

Figure 2 Scale distribution (detached houses)

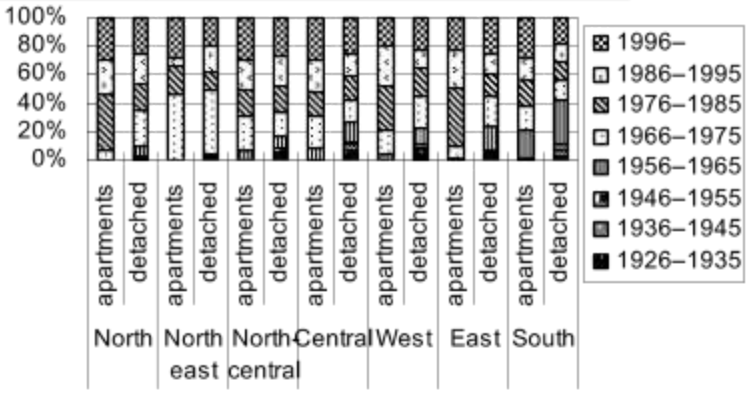

Figure 3 Distribution of the construction date houses in the residential sector

The existing building stock in each region has distinctive characteristics in terms of scale and age, as shown in Figures 2 and 3. Figure 2 shows the scale distribution of detached houses. Figure 3 shows the distribution of the construction date for houses. Differences have arisen as a result of the way these regions have been developed. In the North region, the building stock constructed after 1976 occupies approximately 80% of the total, as the region has been developed since 1976. The Northeast region is characterized by Senri New Town, which has many large apartment buildings constructed in the 1960s and 70s. This region has a business area consisting of high-rise office and commercial buildings, where the first Japanese district heating and cooling (DHC) system was introduced. The percentage of large buildings here is the highest in the city. The North-central and Central regions have the longest history in Toyonaka city. Approximately 40%

of the building stocks have accumulated in these regions, and they have been renovated at fixed intervals. In the West, there is less building stock because there is an airport in this region (Itami Osaka Airport). The East region, like the North region, has been developing since 1976. In this region, however, apartment buildings have dominated regional development, while relatively large detached houses were provided in the North region. The South region is characterized by a high proportion of small and old buildings, as the region rapidly developed from 1930 to 1960 and has been slowly renovated.

3. Methodology

In this study, we estimate CO_2 emissions from the residential and non-residential sectors of Toyonaka city in 2050. We develop five simulation cases in order to quantify the potential reduction due to stepwise improvements in home appliances and insulation performance as well as the incorporation of more radical actions for CO_2 reduction, or the implementation of building stock management that would lead to the development of a different landscape from that existing. We first explain the business-as-usual (BAU) case of this study in Section 3.1. We then explain the simulation cases in Section 3.2. We finally introduce the simulation model developed for this study in Section 3.3.

3.1 BAU case

Figures 4 and 5 show the population and household estimates of the National Institute of Population and Social Security Research (National Institute of Population and Social Security Research. 2004, 2005). For all cases, we assumed that population and the number of households will follow Figures 4 and 5 until 2050.

Table 2 lists the total floor area in the non-residential sector assumed in the BAU case. We assumed that the total floor area in all the principal usages except hospitals and schools will remain at 2000 levels until 2050. We assumed that the total floor area of the hospital building stock will increase according to increases in patient beds. Similarly, we assumed that the total floor area of schools will decrease according to the estimated decrease in the number of children. We also assumed that the geographical distribution of the residential building stock will remain as it is in 2000 until 2050.

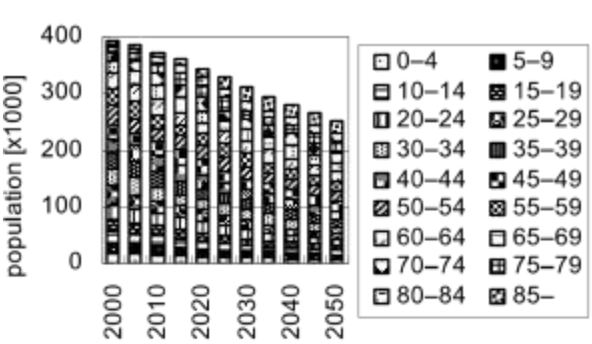

Figure 4 Estimated population

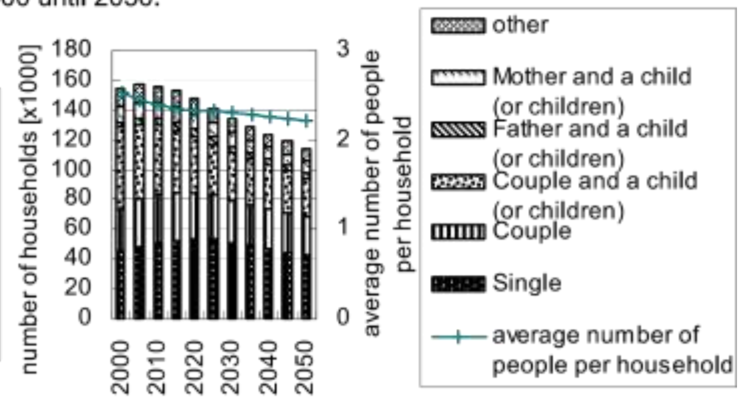

Figure 5 Estimated number of households

Table 2 Method of estimation

Item		Method of estimation
Population*		Followed the estimation of national Institute of Population and Social Security Research
Households*		Same as above
Area distribution of households		Constant
Total floor area in the non-residential sector	Offices	Constant
	Commerce	Constant
	Hotels*	Constant
	Hospitals	Estimated based on the capacity of a hospital bed
	Schools	Decrease due to the number of children in each region

*suppose that it stays constant in this city in 2050

3.2 Simulation cases

Table 3 lists the simulation cases. In Step 1, we assumed stepwise improvements in the energy efficiency of home appliances for the residential sector, and of lighting, office equipment, and heat source machinery for the non-residential sector (explained in Subsection 3.2.1). In Step 2, we assumed improvements in the insulation performance of building envelopes for both the residential and non-residential sectors (explained in Subsection 3.2.2). In Step 3, we assumed the incorporation of the building stock management such that the accumulation pattern of the building stock in each region will vary until 2050 (explained in Subsection 3.2.3). We designed three cases in Step 3 in order to examine the effect of different building stock management strategies on CO_2 emissions.

Table 3 Simulation cases

			Res dent a sector	Non-res dent a sector
Step1		Technical advance-ments	Improvements in the efficiencies of air conditioners, televisions, refrigerators	nergy-saving measures are introduced to all buildings when rebuild
Step2			Insulation performance gain (all buildings after 2010)	Insulation performance gain (less than 2,000 m^2)
Step3	Case 1	Manage-ment of building stock	Housing stock locating in South and West regions will be replaced with new stock in the other regions with the same shape and scale when they are disposed	In South and West regions, the total floor area of offices, commerce, and schools will be reduced according to the decrease in the number of households
	Case 2		Housing stock locating in South and West regions will be replaced with apartment buildings in other regions when they are disposed	Same as above
	Case 3		In addition to the changes assumed in Case 1, all the detached houses will be replaced with apartment buildings	Buildings for offices and commerce with a total floor area less than 2,000 m^2 will be replaced with a building larger than 2,000 m^2 while the total amount of the building stock rema n constant as that n Case 2

3.2.1 Efficiency of available technologies (examined in Step 1)

Table 4 shows the efficiencies of air conditioners. The future efficiencies of TVs, personal computers, refrigerators, VTR/DVDs, and air conditioners were estimated by taking their lifetime function and volume of sales into account, and those of other appliances were kept constant.
Table 5 shows efficiencies of appliances in the non-residential sector.

Table 4 Efficiency of air conditioners

	COP of air conditioners									
	Cooling					Heating				
	2.2 kW	2.5 kW	2.8 kW	3.6 kW	4.0 kW	2.2 kW	2.5 kW	2.8 kW	3.6 kW	4.0 kW
2000	3.65	3.73	3.78	3.40	3.16	3.96	4.10	4.08	3.93	3.47
2050	6.22	6.10	6.21	4.89	4.99	6.71	6.53	6.52	5.70	5.58
2050Step1	6.47	6.25	6.36	5.26	5.19	6.76	6.51	6.60	5.68	5.65

Table 5 Available technologies in the non-residential sector

System alternative	Heat source					
	Cooling	Cooling COP		Heating	Heating COP	
		2000	2050		2000	2050
Absorption	Direct gas-fired absorption chiller	1.00	1.65	Same as cooling	0.83	0.83
Turbo/boiler	Water-source turbo refrigerator	4.50	8.00	Boiler	0.83	0.83
AHP	Air-source heat pump driven by electricity	2.89	5.00	Same as cooling	3.12	5.4
Individual	Individual air-conditioning system	2.60	4.00	Same as cooling	3.12	5.4
GHP	Heat pump driven by gas engine	0.95	1.60	Same as cooling	1.19	2.00
		Annual system COP				
DHC (Senri chuo area)		0.57	0.80			

3.2.2 Thermal insulation performance (examined in Step 2)

We distinguished four levels for thermal resistance of exterior walls in the residential sector, as listed in Table 6, based on Japanese government standards first established in 1980 and upgraded two times. Figure 6 shows the current proportions of the four insulation levels, as well as those assumed in the simulation cases that were estimated based on trends of newly constructed houses. For the estimation, we distinguished house types, insulation levels, and the date of construction, since the share of the four insulation levels depends on these elements. In the non-residential sector, we assumed two levels of thermal insulation of external walls, "No insulation" and "Insulated." Current statistical data shows that approximately 15% of newly constructed buildings with more than 2,000 m^2 of total floor area are insulated. We assumed that all the newly constructed buildings after 2000 more than 2,000 m^2 will be insulated.

Table 6 Thermal resistance of exterior wall insulation

	Thermal resistance [m^2 K/W]	
	Detached houses	Apartments
Below 1980	-	-
1980 Standard	0.60	0.50
1992 Standard	0.86	0.77
1999 Standard	2.20	1.10

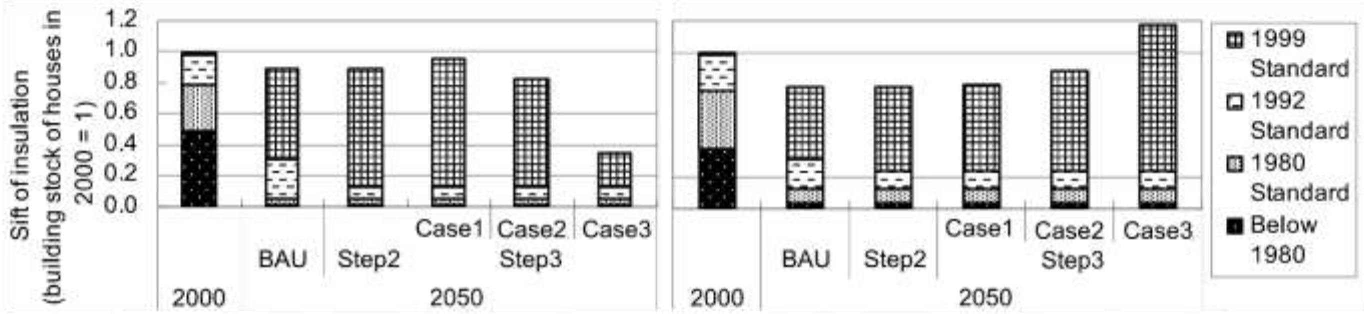

Figure 6 Shift in heat insulation of houses (Left: detached house, Right: apartment)

3.2.3 Shift in total floor area

As shown in Figures 4 and 5, the population and number of households in Toyonaka city will decrease in the next decades. If people continue to live where they currently live, the density of residents per land area will decrease considerably, possibly resulting in declining quality and efficiency of administrative services. We thus propose to implement the management of urban areas in the city so as to limit the space for new buildings. We assumed that the housing stock in the South region, where there are many old houses highly likely to be destroyed in the near future, and in the West region, where there is little housing stock (as explained in Section 2), will be replaced by construction in other regions.

In this study, we identified the following three directions that possibly contribute to reducing CO_2 emissions:

- Increasing multifamily housing in the residential sector
- Replacing detached houses with apartment buildings, due to a higher energy efficiency of apartment buildings than detached houses
- Replacing small buildings with large buildings in the non-residential sector (larger buildings have higher energy efficiency)

We designed three cases in Step 3, each considering one of these directions in order to quantify the potential benefit of the management of the building stock in Toyonaka city. Figures 7 and 8 show the estimated total floor area in the residential and non-residential sectors, respectively.

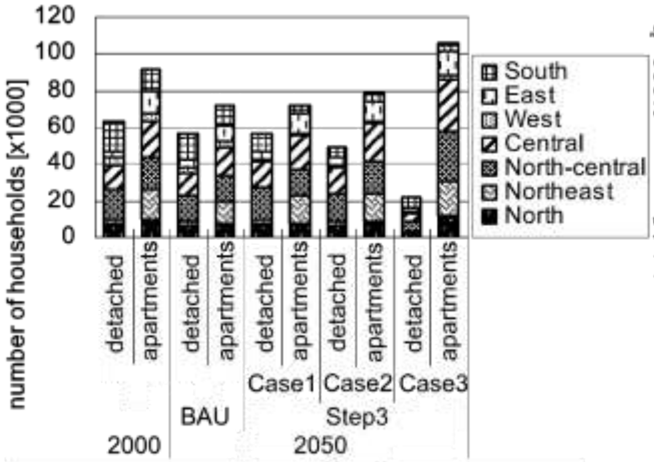

Figure 7 Estimated total floor area of buildings in the residential sector

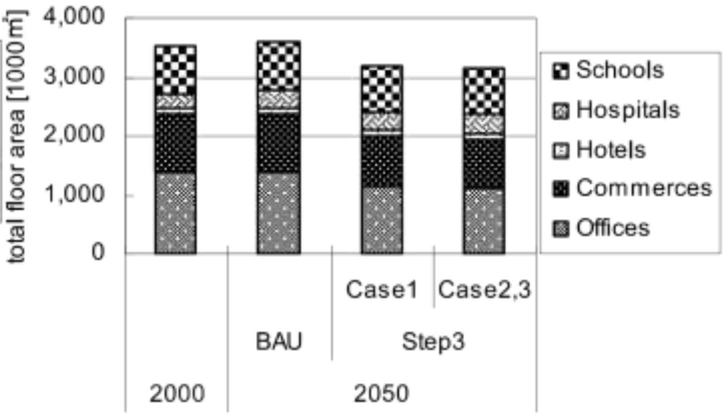

Figure 8 Estimated total floor area of buildings in the non-residential sector

In BAU scenarios, we assume that people continue to live where they do now. The total floor area of hospitals will increase by 36% from 2000. The total floor area of schools will decrease by 4% from 2000, because 5 elementary schools (from 41 in 2000 to 36 in 2050) are closed due to a decrease in the number of children.

In Case 1 of Step 3, we assume that the housing stock located in the South and West regions will be replaced in other areas. In the non-residential sector, the total floor area of office buildings, commercial buildings, and schools decreases according to the decrease in the number of households. The total floor area of office and commercial buildings will decrease by 17%. The total floor area of schools will decrease by 6% from 2000, because 7 elementary schools (from 41 in 2000 to 34 in Case 1 of Step 3) are closed.

In Case 2 of Step 3, we assume that the housing stock in South and West regions will be replaced by apartment buildings in other areas. In addition, office and commercial buildings with a total floor area less than 2,000 m^2 will be replaced by buildings with more than 2,000 m^2. The total floor area of both office and commercial buildings will be constant, as in Case 3 of Step 3.

3.3 Simulation model

We developed a simulation model for estimating the energy consumption and CO_2 emissions of the residential and non-residential sectors of Toyonaka city. The models for both sectors are developed based on the building clustering modeling approach (Yamaguchi et al. 2007). This methodology can be summarized as follows:

- Designing building prototypes, each representing a building stock category with particular characteristics in terms of energy use
- Performing simulations using these prototypical building models as input in order to predict the energy use in each building stock category
- Aggregating the total energy use by summing up the predicted energy use of all the building stock categories

Subsections 3.3.1 and 3.3.2 explain how this methodology is applied to the residential and non-residential sectors in this study.

3.3.1 Simulation model for the residential sector

The residential building stock is divided into 912 categories that are arranged under 19 household categories and 12 building categories—six for detached houses and six for apartment buildings—as well as four levels of insulation performance of building envelopes. For each building stock category, a prototypical building model was designed as input for the simulations. We then performed simulations to quantify end-use energy consumption, or electricity, city gas and kerosene, for each category, considering occupants' behavior, operation and performance of energy-consuming appliances, and requirements for air conditioning and ventilation. A detailed explanation of this model is given elsewhere (Shimoda et al. 2007).

3.3.2 Simulation model for the non-residential sector

The building stock in the non-residential sector was divided into 864 categories considering the principal usage (offices, retail, hotels, hospitals), size (4 categories for each principal usage), zoning of floor plan (9 categories), and heating systems used in buildings (6 categories). For each building category, a prototypical building model was developed as input for a simulation model that predicts the end-use energy consumption, or electricity and city gas. In the simulation model, the cooling, heating, hot water, and electricity demand profiles are simulated on an hourly basis. The end-use energy consumption is then quantified by simulating the operation of heat-source systems. A detailed explanation of this model is given elsewhere (Yamaguchi et al. 2007).

3.3.3 Validation

Figures 9 and 10 show the simulation result of the total end-use energy consumption of the residential and non-residential sectors of Toyonaka city, respectively. The simulation results show good agreement with the statistic score in both the residential and non-residential sectors.

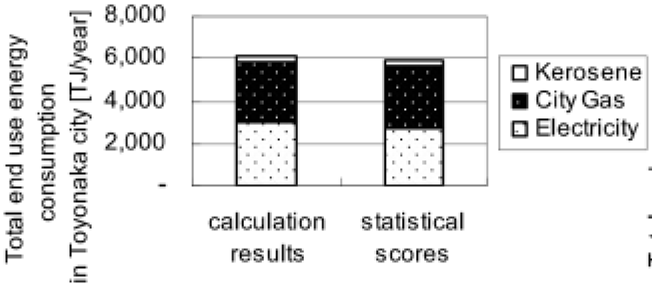

Figure 9 Comparison of calculation results with statistical scores in the residential sector

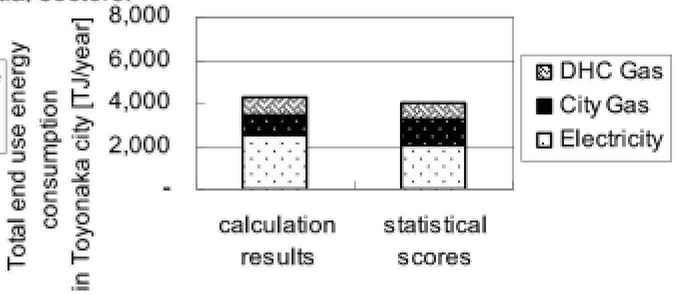

Figure 10 Comparison of calculation results with statistical scores in the non-residential sector

4. Results

4.1 BAU case

In the residential sector, the annual primary energy consumption in 2050 is estimated to decrease by approximately 40% from 2000. Figure 11 shows the decomposition of this decrease. The decrease results from decreases in both the population and number of the households, as well as improved energy efficiency in energy-consuming appliances and improved performance of insulation in building envelopes. The improvement in appliances and insulation performance is likely to be realized, as national standards have been established. This implies that these standards will contribute significantly to reducing CO_2 emissions. Regarding the number of households, although it decreases by 26%, the annual primary energy consumption will decrease by only 13%. This can be attributed to an increase in the proportion of elderly people and households with a small number of family members that have a higher energy demand than average.

In the non-residential sector in 2050, the annual primary energy consumption decreases by approximately 13% due to improved efficiency in energy-consuming appliances and heat source machinery as well as increases in DHC energy performance. Figure 12 shows the decomposition of the decrease.

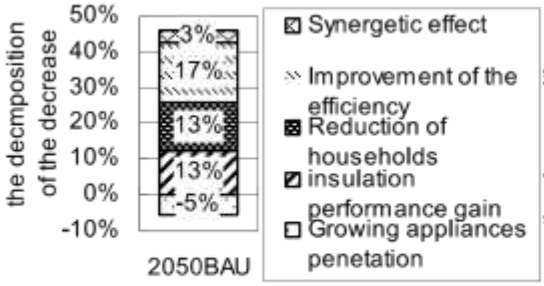

Figure 11 Results of factor analysis in the residential sector

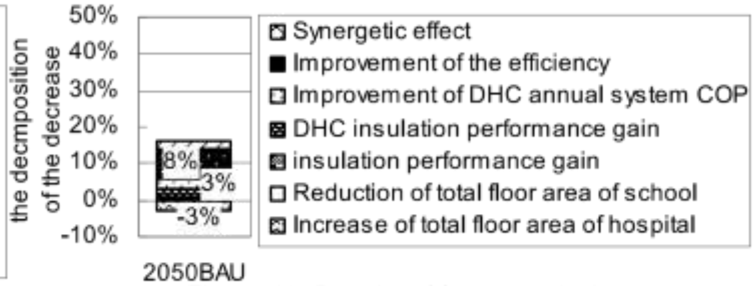

Figure 12 Results of factor analysis in the non-residential sector

4.2 Results of case study

Figures 13 and 14 show the annual primary energy consumption of the case study in the residential and non-residential sectors, respectively.

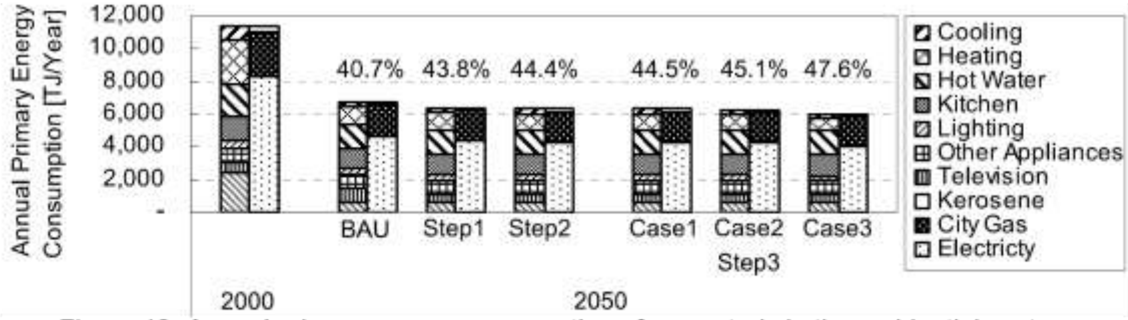

Figure 13 Annual primary energy consumption of case study in the residential sector

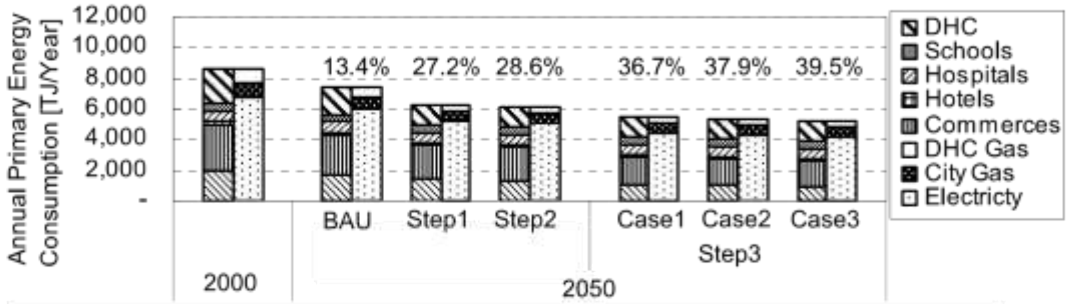

Figure 14 Annual primary energy consumption of case study in the non-residential sector

In Step 1, the additional reduction from the BAU case in the residential sector is 3.1%, based on the consumption in 2000. The gain is small because the improvement in the efficiency assumed in Step 1 is much smaller than that assumed between the BAU case and the baseline. In the non-residential sector, the improvement in the efficiency of energy-consuming appliances assumed in the BAU case results in an approximately 13% reduction in primary energy consumption. An additional 14% is gained by dissemination of energy-saving measures assumed in Step 1.

In Step 2, we assumed the accelerated adoption of the highest-level insulation standard in newly constructed buildings in addition to the BAU case following the current trend in the adoption of building insulation standards. The gain in saved energy is small. In the non-residential sector, as the improvement in the insulation performance is assumed to occur in all buildings, the increase in the saving ratio is not so large.

In Case 1 of Step 3, where we assumed a reduction in the total floor area of office and commercial buildings for the non-residential sector, the energy reduction ratio increased by 7.9%. In Case 2 of Step 3, in the non-residential sector, primary energy consumption decreased by 1.2% due to the decrease in the total floor area of office and commercial buildings. In Case 3 of Step 3, where we assumed that all the houses that are destroyed will be replaced by apartments for the residential sector, the annual primary energy consumption decreases by 2.5%. We assumed the replacement of small buildings with large buildings with more than 2,000 m^2 of total floor area in the non-residential sector, and the annual primary energy consumption decreased by 1.6%.

Figure 15 shows CO_2 emissions in 2050 for each simulation case, where the CO_2 emission rates of city gas and kerosene are 51.3 t-CO_2/TJ and 68.5 t-CO_2/TJ, respectively. The horizontal axis shows the CO_2 emission rate of grid electricity. While it is currently 0.358 kg-CO_2/kWh (Kansai area in Japan), the value in coming decades is uncertain. As shown in the result for Case 3 of Step 3, CO_2 emission can be reduced by approximately 44%, if the CO_2 emission rate of grid electricity remains at the current value until 2050. To achieve a 50% reduction in the total CO_2 emission, the CO_2 emission rate of grid electricity must be lower than 0.299 kg-CO_2/kWh even in Case 3 of Step 3. This value is not unrealistic because the local electricity company has provided electricity with an emission rate of 0.277 kg-CO_2/kWh, although great effort will be required to achieve this value.

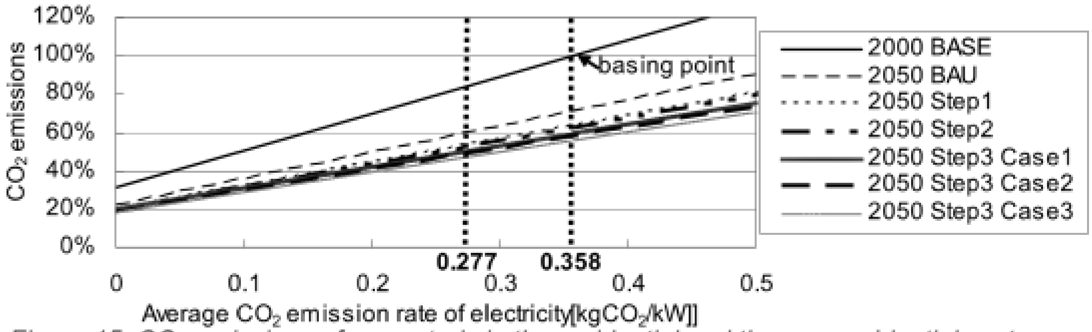

Figure 15 CO_2 emissions of case study in the residential and the non-residential sectors

5. Implications

We show that a 50% reduction in total CO_2 emissions in the residential and non-residential sectors is achievable by combining available options including implementing technological advances, improving insulation performance, disseminating energy-saving technologies, managing building stock, and improving the CO_2 emission rate of grid electricity. At least the first three options have a substantial direct potential for reducing carbon emissions. While policy instruments have been applied and are expected to be effective, it is important to enhance and widen the effort. The management of the building stock is less effective than the technical measures. However, it is must be implemented in order to achieve a 70% reduction in total CO_2 emissions. To achieve such a substantial reduction, we must consider more radical changes in buildings and infrastructure, e.g., further dissemination of photovoltaic and fuel cells. Although we did not consider these technologies in this study, it can be expected that there is a synergy between dissemination of these technologies and management of the building stock.

Conclusion

In this paper, we quantified the potential reduction in CO_2 emissions from the residential and non-residential sectors of Toyonaka city, a typical suburban city in Japan. The result of this study showed that in the residential sector, a substantial reduction in CO_2 emissions is feasible by implementing technological advances in home appliances and improving insulation performance, in addition to the smooth decrease in the number of households expected in the next decades due to the population decrease. For the non-residential sector, technological advancement, and dissemination of energy-saving technologies could lead to a substantial reduction in CO_2 emissions. This study also showed that a CO_2 emission reduction by more than 50% of current emissions is achievable by combining these measures for the residential and non-residential building sectors and managing the building stock. The management of the building stock would play a more important role, together with dissemination of emerging technologies (e.g., photovoltaic and fuel cells), if the city sets a higher target than a 50% reduction in CO_2 emissions. This study addressed key challenges for suburban cities in Japan that account for a large portion of the building stock.

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