

# What kinds of HVAC technology could improve energy efficiency in Japan? Gas CHP or advanced heat pump system?

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**Abstract:** Technological innovation would lead to a structural change in future energy market. For example, gas combined heat and power systems and advanced heat pump systems are recognized as key technologies to reduce carbon emission. We have developed a bottom-up energy demand model based on customer's preference to assess the impact of penetration of innovative energy technologies. As a case study, we focused on HVAC demand in Japanese commercial sector and estimated the potential reduction of carbon emission in 2010.

## 1. INTRODUCTION

Technological innovation is a key factor of structural change of future energy market. The gas combined heat and power systems (CHP) and advanced electric heat pump systems (EHP) are recognized as key HVAC technologies in demand side to reduce carbon emissions and have been supported by public financial measures such like low-interest loan and subsidy programs, and public and private R&D programs in Japan.

While, until now, the gas CHP systems such as gas turbine and engine with waste heat recovery systems, have been used mainly by industrial and large commercial customers with a great deal of steam or hot water demand, reaching a cumulative installed capacity of 6500MW in Japan until FY2002[1], CHP systems for small commercial and residential customers such as micro gas turbine, gas engine and fuel cell systems are currently under development or have been just commercialized. Market penetration of CHP systems might lead to structural change of energy system, meaning a shift from grid power system to on-site energy system.

On the other hand, the advanced EHP systems for air conditioning or hot-water supply have been just commercialized and promoted by government and electric utilities. The EHP systems are also expected to reduce carbon emission because of high-energy efficiency than conventional system and low carbon emission factor of grid electricity (non-fossil generation dominant).

Ongoing retail liberalization of electricity and city gas market is another factor of changing energy market structure. Although the present liberalization regime, which was introduced from 2000, is limited in a part of the retail electricity and city gas market for large industrial and commercial customers with a contract capacity of over 2000kW, or with a yearly contract gas consumption of one million cubic meters or higher, having about 30-40% of total electricity and city gas demand in Japan, further deregulation of both of the markets is now planned within next a couple of years beyond the current regime. Under the next regime, most of industrial and commercial customers with a contract capacity of over 50kW, or with a yearly contract gas consumption of one hundred thousand cubic meters or higher, having about 50-70% of total electricity and gas demand in Japan, can switch electricity and city gas suppliers from the franchise utility. The electric utility and gas company now faces increasing competitive circumstances under the coming reforms of electricity and city gas industry. The CHP and EHP systems are regarded as competitive technologies with each other to take market share of electricity and city gas demand.

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The aim of this paper is to analyze the impacts of market penetration of CHP and EHP systems on carbon emission and carbon emission reduction cost toward FY2010 in order to see which are more effective in carbon emission reduction in Japan.

In a case study, we focused on only four major segments of commercial and public sector, that is, office building, retail store, hotel and hospital, which account for about 62% of total energy consumption in commercial sector. In addition to that, Tokyo Metropolitan (TYO) area is taken as a case study objective, which almost covers the franchise area of Tokyo Electric Power Company (TEPCO)[2], accounting for a third of total of Japanese electricity sales, and this area includes the business area of Tokyo Gas (TG)[3], accounting for about 35% of total of Japanese city gas sales. The reason why this area is chosen is that, it is expected to be most competitive market under the coming reform of energy industry and, in addition to that, such new commercial end-use technologies as CHP systems and advanced EHP systems are likely to make the energy market structure change in the future.

To analyze the impacts, we developed an end-use energy demand model[4] for the TYO area, which is a bottom-up model to forecast energy demand based on micro data such as energy efficiency of demand-side technology, electricity and city gas rates, energy demand needs of segmented customers. One of advantageous points of bottom-up demand model is to make possible to see directly the impact of market details such as technological parameters or energy pricing on overall energy market structure. Our model has a unique feature that, technology choice among energy systems is determined by end users with various choice criteria.

Change in carbon emission induced by technology switch in demand side, is projected by the combination of end-use demand model and power generation resource expansion model for TEPCO. The power generation expansion model is used for load dispatch analysis of the forecasted grid electricity to estimate change in carbon emission from the power sector.

The method of model analysis by use of end-use demand model and power generation model is outlined in Section 2. The data and conditions on market details used in the model analysis are explained in Section 3. Section 4 describes the results of BAU case and Section 5 does the results of scenario-based model simulation to assess the impact of HVAC system switch in carbon emission level. Section 6 makes a conclusion of this paper.

## 2. MODEL ANALYSIS OF END-USE TECHNOLOGICAL CHANGE

### 2.1 End-use energy demand model for commercial sector

Figure 1 shows the process of model analysis by use of end-use energy demand model and power generation mix model.

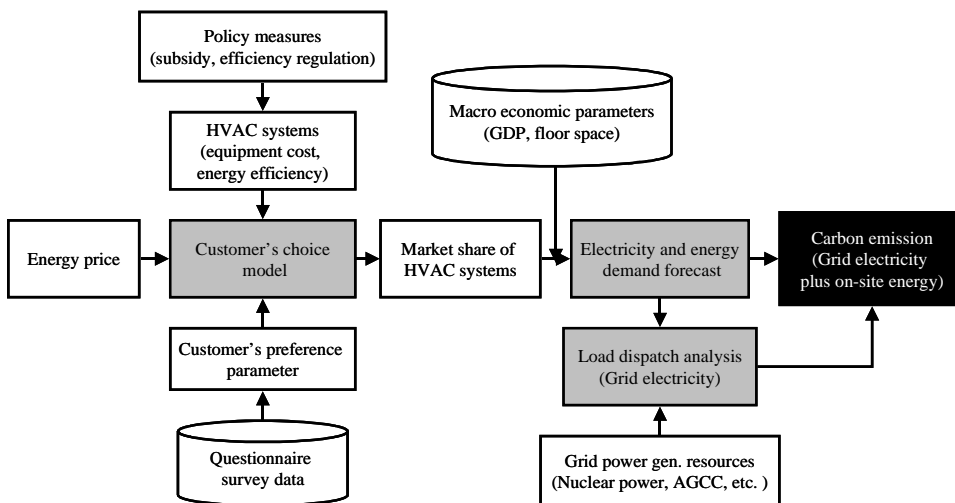


Figure 1 Method of model analysis

First, the end-use energy demand model performs long-term energy and electricity forecasting by a bottom-up approach. The energy demand level depends on customer's business type, floor space and location of building, and customer's end-use energy system. The unit energy consumption of segmented

customers is estimated for each end-use energy system, e.g. gas CHP system and EHP system. The estimated unit energy consumption is aggregated to project future electricity and energy demand of target sector using Equation (1).

$$E^f(t) = \sum_{S,K} UEC_{S,K}^f(t) \times SHARE_{S,K}(t) \times FLOOR_S(t) \quad (1)$$

where  $S$  and  $K$  are indices of segmented customers and end-use energy systems in demand side, respectively.  $E^f(t)$  is the future electricity and energy demand in a year  $t$ .  $UEC_{S,K}^f$  is the unit energy consumption of the  $k$ -th end-use energy system, measured in units of Mcal per square meters.  $SHARE_{S,K}$  is a percent of the stock share of  $k$ -th end-use energy system in  $s$ -th market segment.  $FLOOR_S$  is a total of floor space of a market segment  $S$ , measured in a unit of square meters.

The dynamical change of stock share of end-use energy system is calculated using Equations (2), the first term of the right hand corresponds to increasing share by end-use system switch and the second term corresponds to decreasing share. The transition rate from  $k'$ -th system to  $k$ -th system in a year  $t$ ,  $F_{S,K' \rightarrow K}(t)$ , is estimated as a replacement rate of  $k'$ -th system,  $D_{S,K'}(t)$ , times a probability of  $s$ -th segmented customers choosing a  $k$ -th system,  $Pr_{S,K}(t)$  as seen in (3). Note that, when a new installation of the end-use system considered, the replacement rate is set to be 1.

The choice probability of  $k$ -th system is estimated as a probability of the customer's utility of  $k$ -th system having a maximum value among choices, where the utility function is determined based on market details such like energy price, energy efficiency, customer's preference parameters as seen in equation (4). That is, the customer's choice of end-use energy systems drives a dynamical change in stock share of end-use system and energy market structure.

The end-use energy model is able to perform detailed analysis of energy pricing, economic change, technological development and policy issues on future market penetration of end-use systems and long-term electricity and energy forecast.

$$SHARE_{S,K}(t) - SHARE_{S,K}(t-1) = \sum_{K'} (F_{S,K' \rightarrow K}(t) - F_{S,K \rightarrow K'}(t)) \quad (2)$$

$$F_{S,K' \rightarrow K}(t) = D_{S,K'}(t) \times Pr_{S,K} [U_{S,K}(w_S) - \max] \quad (3)$$

$$U_{S,K} = U_{S,K}(w_S, P_K^f(t), \eta_K(t)) \quad (4)$$

where  $P_K^f$  and  $\eta_K$  are the price of electricity, city gas and other fossil fuel and the coefficient of energy efficiency for  $k$ -th end-use system, respectively.  $U_{S,K}$  and  $w_S$  are the customer's total utility function related with choice of end-use system and the customer's preference parameters, respectively.

## 2.2 Customer's choice model of end-use energy system

Our model has a unique feature that technology choice among end-use energy systems is made by individual customers with various choice criteria. The individual choice criteria are estimated using our questionnaire survey results on choice of energy efficient equipment and investment in the commercial and public sector.

A fundamental assumption of our survey is that, the individual's total utility for a given energy system can be decomposed into a set of numerical value associated with each attribute of the end-use system. Suppose that a customer, labeled  $i$ , faces choice situation among end-use energy systems, labeled  $k$ . The

total utility is assumed to be in a Cobb-Douglas form below. The customer is supposed to choose an end-use system that maximizes the individual total utility compared to other systems.

$$U_k^i = \sum_j w_j^i \times \log Z_{j,k} \quad (5)$$

where  $U_k^i$  is i-th customer's total utility of k-th end-use system,  $Z_{j,k}$  is j-th attribute level of k-th end-use system and  $w_j^i$  is i-th customer's part-worth coefficient of j-th attribute level corresponding to customer's preference parameter.

The part-worth coefficient varies over customers, reflecting the fact that the customers have different preferences for energy facilities each other. Not only the price effect but also the non-price effect can be taken into consideration in this model by adding non-price attribute terms to equation (5). In our survey study, the part worth coefficient is estimated by the use of conjoint analysis[5,6], which is a customer survey technique for valuing services and products developed in marketing science. The information on population distribution of customer's preference gives a choice probability of end-use system.

### 2.3 Load dispatch analysis by power generation mix model

Environmental impact of future grid electricity is analyzed by a power generation mix model of TEPCO we developed[7], which is called load dispatch analysis (LDA)[8]. Though the average carbon emission factor is generally used to assess the impact and is so rational if the change of generation mix is marginal, it is necessary to adopt a system analysis approach like LDA in a case that the generation mix of grid electricity might be significantly changed by considerable market penetration of small-scale generators and efficiency improvement systems.

In the LDA method, a load curve that the grid power system needs to meet is firstly estimated in consideration of incremental or reduced demand by end-use energy system changes, where the yearly load curve is represented by seven types of daily load curves in our model simulation and the seven representative days are the peak load day in summer, weekday in summer, weekday in winter and week day in other seasons, weekend in summer, weekend in winter and weekend in other seasons.

After the load demand estimation, generation mix of grid electricity is estimated by use of a cost-minimizing dispatch of grid power generation resources to meet the load demand under several constraints and conditions of power generation system operation such like seasonal availability of generation resource and load-following capability of generation technologies and so on.

Throughout the dispatch process, not only the existing power plants but also new power plants in the development plan are taken into consideration. The growth of peak load demand is an essential parameter to determine whether investment in new generation capacity is needed or not. The carbon emission level of a given power generation mix is the sum of carbon emission from generated electricity of dispatched existing and new power generation resources. The overall change in carbon emission by end-use energy system switch consists of the LDA estimate of carbon emission change of grid electricity and that of customer's fossil fuel use in the demand-side energy systems such as CHP systems and gas absorption refrigerating systems.

## 3. DATA SETTING

As a case study, we focused on the Tokyo Metropolitan area, which almost covers Tokyo Electric Power Company and includes Tokyo Gas Company, having a third of total of electricity sales and about 35% of total of city gas sales in Japan, respectively. The future electricity and energy demand of four commercial segments in this area was projected by the end-use energy demand model. The data and conditions for model simulation were explained below.

### 3.1 Estimation of floor space of commercial buildings for HVAC system penetration

Figure 2 shows estimated floor space of eight segmented commercial buildings for HVAC system penetration in TYO area. As well as business type, building floor space is taken as another segment

boundary. Large building has a floor space of over ten thousand square meters and small building has that of less than ten thousand square meters. The estimation was based on several public data sources. The floor space of new buildings for retail store, hotel and hospital is supposed to grow at an annual rate of 1% through FY2000-FY2010, reflecting continuing recession of Japanese economy with a low real GDP growth rate of less than 1%, while the growth rate of new office building's floor space is set to be 2% a year because the rush to office building development can be seen in this area through FY2000-2010. We estimated the floor space of existing buildings that needs a renewal of HVAC systems, assuming that the lifetime of HVAC system is 15 years on average, though the actual lifetime might become longer than 15 years if recent inactive business investment is considered.

As seen in Figure 2, it is characteristic that office buildings and retail stores are the dominant market segments in TYO commercial sector, reflecting that TYO is the center of Japanese business activities and a quarter of total population is concentrated in this area.

Figure 3 is energy demand needs of the eight-segmented commercial customers by end-use; light and motor, space cooling, space heating and hot water supply, which are estimated based on questionnaire and measurement survey data. The energy demand needs of hotel and hospital is more than those of office building and retail stores mainly because of hot water demand.

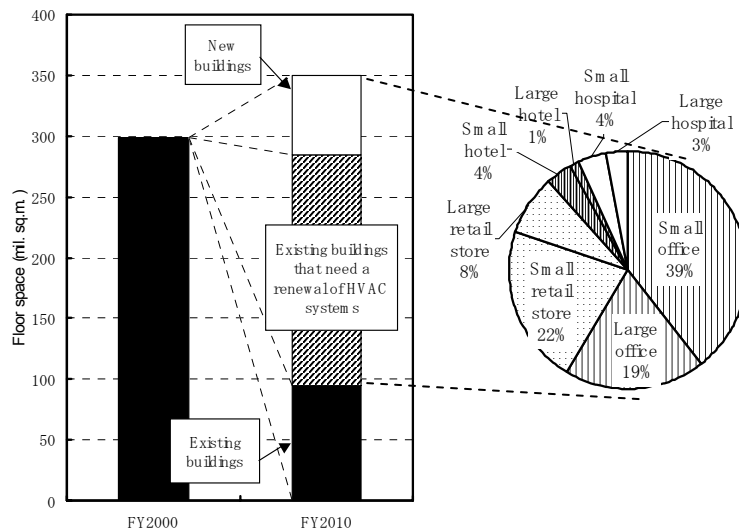


Figure 2 Estimate of floor stock of commercial buildings in TYO

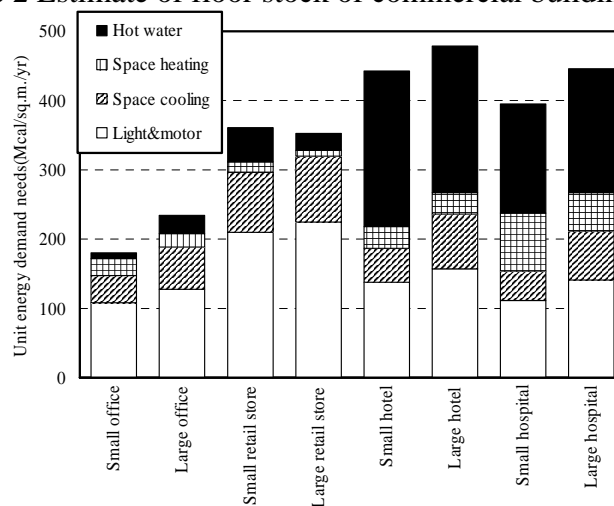


Figure 3 Energy demand needs by business type and floor space

### 3.2 Commercial HVAC systems in Japan

Table 1 shows ten types of commercial HVAC system assumed to be customer's choices in this model analysis. The district heating and cooling (DHC) system is excepted because DHC occupies a small share.

The decentralized system is a multiple air-conditioner system that is commonly adopted for

small-to-medium size buildings in Japan. The examples are electric heat pump air conditioner and gas-engine driven air conditioner. The centralized system is a single heat resource system that is used for large buildings and massive heat users in Japan. Fossil fuel-fired boiler, electric heat pump chiller, absorption liquid chilling system and CHP system are the examples. Thermal storage air-conditioning system is peak-shift typed DSM technology developed and promoted by government and electric utilities, which stores off-peak power as ice or hot water for air-conditioning demand in daytime.

Table 1 Commercial HVAC systems

	Energy resource for space cooling	
	electricity	city gas and fuel oil
<b>Decentralized system</b>	Electric heat pump air conditioner	Gas engine-driven air conditioner
	Thermal storage air conditioner	
<b>Centralized system</b>	Electric chiller and gas boiler	Gas absorption liquid chiller
	Electric chiller and oil boiler	Oil absorption liquid chiller
	Thermal storage system	Gas combined heat and power system
		Oil combined heat and power system

Tables 2 and 3 show energy prices for HVAC demand, equipment cost and average energy efficiency of HVAC systems. The recent rates of TEPCO and TG are taken as electricity and gas prices in this model analysis. The equipment cost and energy efficiency of HVAC technology is based on recent catalogues of HVAC system manufactures and market surveys.

To project future energy demand in BAU case, we suppose that, during FY2000-2010, the growth rate of real energy price is set to be zero and the market-based improvement rate in energy efficiency of all HVAC systems is set to 1% annually, called autonomous energy efficiency improvement (AEEI).

The initial and running cost are estimated by HVAC system for each of segmented customers based on the above cost parameters. Figure 4 shows examples of the estimated costs of HVAC systems over an operation period for large office building and large hotel. For simplicity, fuel oil equipments and decentralized systems are excepted from the figure. The figure indicates that, the gas absorption liquid chiller is a system with the lowest initial cost for both of the segments, however, the gas CHP system for large hotel and thermal storage system for large office building, are the most economical system in the long term, reflecting the difference between their energy demand structure shown in Figure 3.

Table 2 Energy prices in Tokyo metropolitan area, used in model analysis

Electricity	Energy charge (yen/kWh )		Demand charge (yen/kW/month )		Type of HVAC system
	Summer	Other seasons	Summer	Other seasons	
Commercial power service	12.02	10.93	1560		Electricity demand
Thermal storage load adjustment	3.25	3.25	-	-	Night electricity demand for thermal storage
Peak time adjustment	-	-	-905	-	Peakcut by thermal storage system
Back up power service	-	-	1716		On-site generator
City gas					
	Energy charge(yen/m3)		Demand charge (yen/m3/hr/month)		Type of HVAC system
	Other seasons	Winter	Other seasons	Winter	
General gas supply service	90	90	-	-	Gas boiler
Gas supply service with TOU rates	40.26	40.26	410	410	Gas boiler with constant seasonal demand
Gas supply service to gas air-conditioning	39.66	42.46	1140	2350	Gas absorption liquid chiller, Gas engine-driven air conditioner
Gas supply service to gas CHP system	38	38	1000	1000	Gas CHP system
Fuel oil					
	Averaged fuel price (yen/l)				Type of HVAC system
Fuel oil A	30				Oil boiler, Oil absorption liquid chiller, Oil CHP system

Table 3 Equipment cost and average energy efficiency of HVAC technology

	equipment	Coefficient of performance and generating efficiency	Unit capacity cost* (1000yen/kW )
Electricity	Heat pump air conditioner	3.0	55.6
	Centrifugal liquid chiller	4.5	27.0
	Thermal storage air conditioner(decentralized)	3.0 (storage efficiency 0.72)	127.5
	Thermal storage system(centralized)	3.6 (storage efficiency 0.72)	85.0
City gas and fuel oil	Boiler	0.8	6.0
	Steam-driven absorption refrigerator	1.2	24.4
	Gas/oil absorption refrigerator	0.85	35.7
	Gas engine-driven air conditioner(decentralized)	0.90	98.1
CHP	Gas turbine	0.25 (heat recovery rate =2.0)	193.2
	Gas engine	0.3 (heat recovery rate =1.3)	190.0
	Diesel engine	0.4 (heat recovery rate =1.0)	193.8

\*The capacity(kW) means a generating capacity of self generator, a heating capacity of boiler and a refrigerating capacity of other HVAC equipments

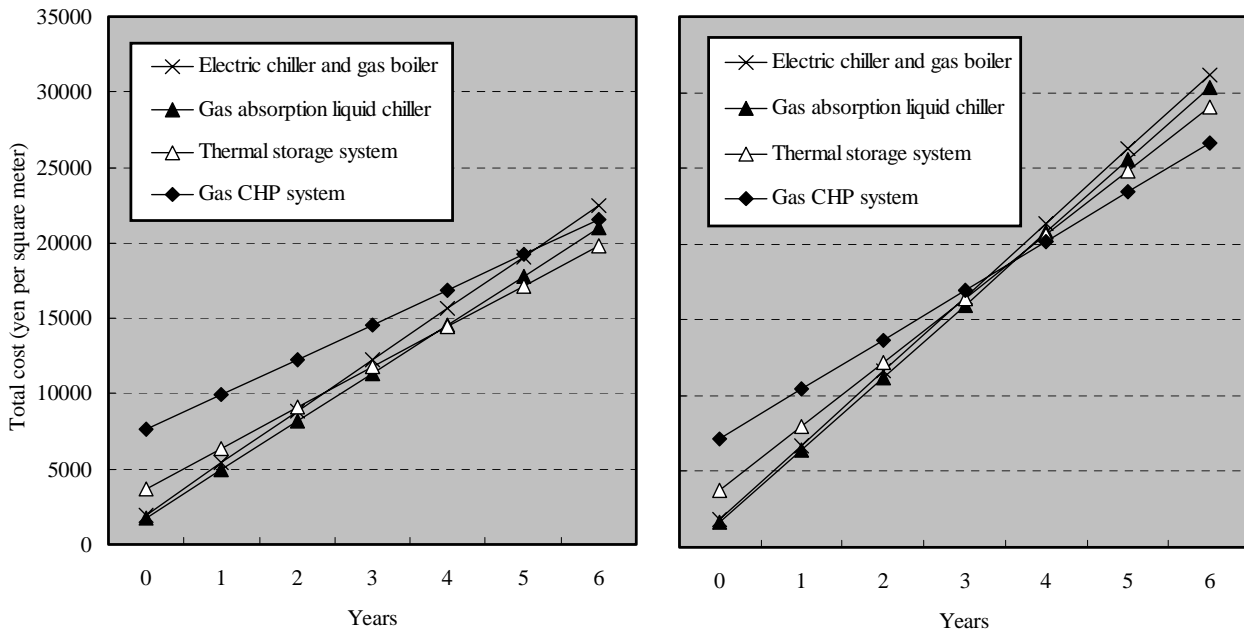


Figure 4 Comparison of total cost of HVAC systems (left: Large office, right: Large hotel)

### 3.3 Parameter estimation of customer's choice model by conjoint analysis

As noted in Section 2, the customer's choice model of HVAC system is developed based on the results of our questionnaire survey, conducted in early 2001, of 837 business and public-sector commercial customers in the TYO area on their choice criteria of end-use energy systems with conjoint type choice experiment.

In the choice experiment, eight hypothetical HVAC systems were offered to respondents, each system differed with level of four attributes, that is, initial cost, running cost, environmental impact and required space, which are involved in the experiment as a results of our preliminary analysis. The survey data is analyzed by a multi regression model to estimate the distribution of part-worth coefficients. In this paper, we developed the choice model in consideration of two price attributes only, that is, initial cost and running cost, because they were the dominant factors of choice behavior of business customers, though the non-price attributes are important. The non-price effect is a remaining issue to be studied.

Figure 5 shows average and coefficient of variation of part-worth coefficient of initial cost as an example. The figure indicates that the preference differs by business type of customers, which might result in different choices of end-use energy system.

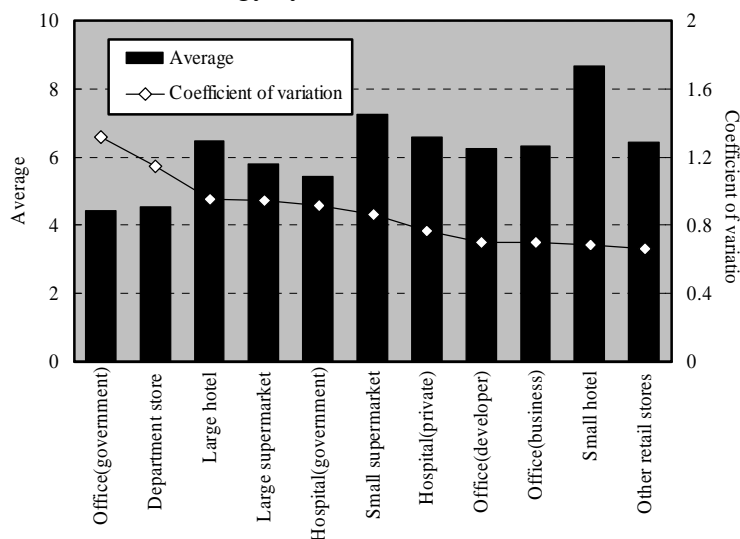


Figure 5 Average and coefficient of variation of part-worth coefficient of initial cost

## 4. ENERGY DEMAND FORECASTING IN BAU CASE

### 4.1 Estimation of stock share of HVAC system

Firstly, the stock share of HVAC system in FY2000 and FY2010 is estimated by use of the choice model explained in the above. The estimated share by business type and floor space is shown in Figure 6. The left bar corresponds to the FY2000 share and the right bar the FY2010 share. As a whole, it can be seen an increase in market share of gas or fuel oil fired absorption liquid chilling system because of the lowest initial cost mentioned above, which is consistent with actual market trend.

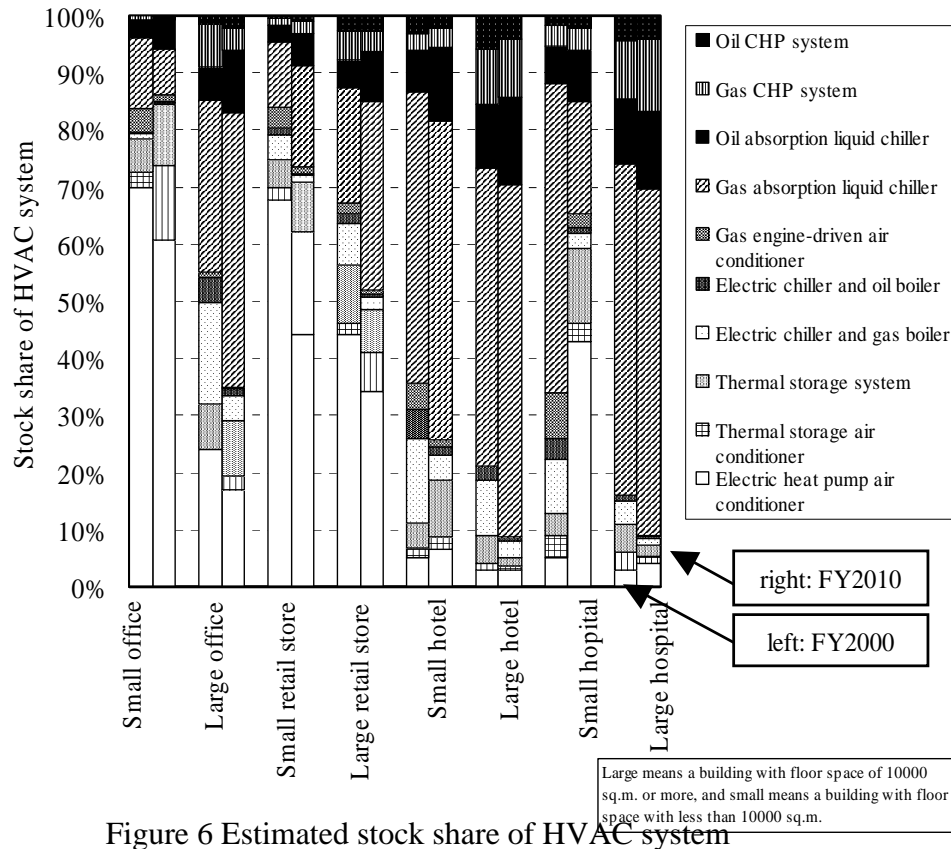


Figure 6 Estimated stock share of HVAC system

### 4.2 Energy demand forecasting in BAU case

The electricity and energy demand in the FY2000 and FY2010 is estimated by aggregating energy demand of individual HVAC systems of the eight-segmented commercial customers using the equation (1). The estimated energy demand is shown in Table 4, compared with actual energy consumption of commercial sector in the TYO area, FY2000. In the FY2000 results, the estimated electricity demand accounts for about 70% of the actual total demand in the commercial sector and the city gas demand accounts for about 92% of the actual value. The former is consistent with data, though the latter needs some elaboration, because the percent of objective segmented customers' energy use in that of the whole commercial sector is about 62% on a nationwide average.

Table 4 Electricity and energy demand forecast in BAU case

	Estimated demand (four commercial segments only)			Actual demand (commercial sector)	Ratio of estimated value to actual data in FY2000
	FY2000	FY2010	Annual growth rate	FY2000	
Electricity (GWh)	61,218	70,111	1.4%	86,825	70.5%
City gas (TJ)	116,465	124,344	0.7%	126,000	92.4%
Fuel oil (ML)	524	776	4.0%	n.a.	-

## 5. RESULTS: IMPACT OF END-USE ENERGY SYSTEM SWITCH ON CARBON EMISSION

### 5.1 Simulated cases

To assess the impact of end-use energy system change on carbon emission, we set additional four cases in Table 5, that is, CHP case, CHP+ case, EHP case and EHP2 case. In CHP case, 30%<sup>2</sup> of the initial cost of gas CHP system installation is subsidized to promote market penetration of CHP system. Similarly, in CHP+ case, 50 % of the initial cost is subsidized to promote more. In EHP case, 30% of the initial cost of EHP system is subsidized to support for the promotion of EHP system on behalf of gas or oil cooling and heating system. In EHP2 case, in addition to the subsidy for EHP system penetration, the improvement in energy efficiency of EHP system is accelerated from autonomous energy efficiency improvement of 1% annually to double, that is, 2% annually, which might be achieved by a couple of policy measures such as additional funding to R&D programs and enhanced regulation of energy efficiency standards of electric appliances.

Table 5 Cases for model simulation

	BAU	CHP	CHP+	EHP	EHP2
Subsidy for gas CHP system	No	30% of initial cost	50% of initial cost	No	No
Subsidy for EHP system	No	No	No	30% of initial cost	30% of initial cost
Energy efficiency improvement of EHP system	1%p.a.	1%p.a.	1%p.a.	1%p.a.	2%p.a.

### 5.2 Change in future electricity and energy demand by HVAC system switch

Figure 7 shows estimated change in stock share of HVAC system in CHP+ case and EHP case as examples. In CHP+ case, large building customers are likely to switch from thermal storage system and gas/oil absorption chilling systems to gas CHP system, because the larger building the more economical CHP system is. On the other hand, in EHP case, gas/oil absorption chilling system shifts to EHP system as a whole.

Table 6 is the resulting electricity and energy demand in FY2010 from the HVAC share switch. In the former two cases of CHP system promotion, the annual growth rate of grid electricity decreases by 1.3% in CHP case and 1.1% in CHP+ case, respectively, because of bypassed electricity demand from CHP users, though the BAU electricity growth rate is 1.4% a year. The city gas demand growth rate increases from 0.7% in BAU case to 0.9% in CHP case and 1.7% in CHP+ case.

In the latter two cases of switching to EHP system, on the other hand, the annual growth rate of grid electricity increases from 1.4% in BAU case to 1.6% in EHP case and 1.5% in EHP2 case. The city gas demand decreases by less than zero in both two cases, because of the switch from gas absorption chilling system to EHP system.

The electricity load curves are also changed by the HVAC system switch. As an example, changes of daily load curve on peak load day in summer are shown in Figure 8. The shift in peak demand is an essential factor for timing of start in operation of new power generation plant and choice of power generation mix.

<sup>2</sup> The government subsidizes on third of initial costs of gas CHPs.

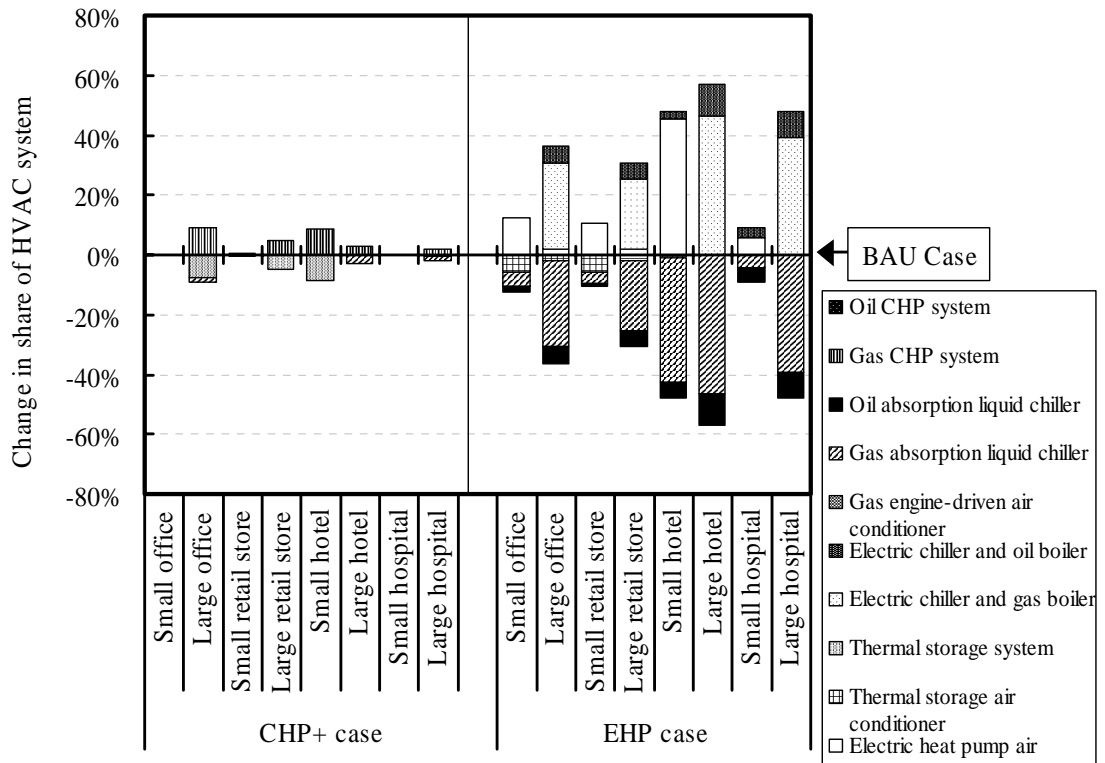


Figure 7 Estimated change in stock share of HVAC system

Table 6 Estimated electricity and energy demand in FY2010 and annual growth rate

	BAU		CHP		CHP+		EHP		EHP2	
Electricity (GWh)	70111	1.4%	69662	1.3%	68487	1.1%	71575	1.6%	71128	1.5%
City gas (TJ)	124344	0.7%	127943	0.9%	137189	1.7%	107072	-0.8%	106349	-0.9%
Fuel oil (ML)	776	4.0%	776	4.0%	776	4.0%	648	2.1%	634	1.9%

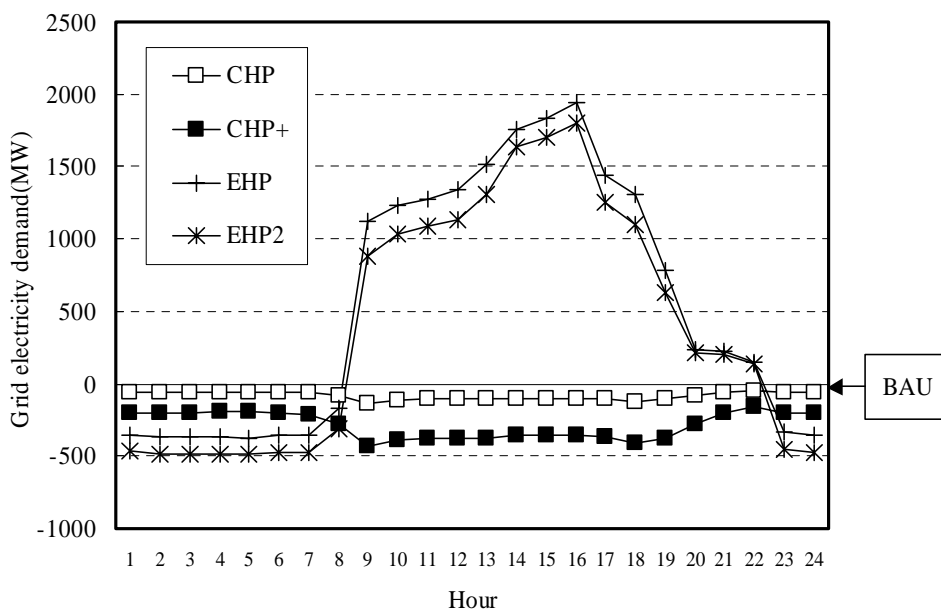


Figure 8 Change of electricity load curve on peak load day in summer, FY2010

### 5.3 Impact on carbon emission level and reduction cost estimation

The load dispatch analysis is performed by the power generation mix model to estimate the change of carbon emission level from grid electricity and a social cost in carbon emission reduction. Figure 9 shows the estimated capacity of power plants that are newly built or disused during FY2000-2010 for five cases. The figure indicates that, the HVAC system switch assumed in this model analysis results in deferment or acceleration of replacement investment in a single power-generating unit of advanced gas combined cycle of 1500MW, comparable to peak shifts in Figure 8. Note here that a type of generation resource to be deferred or accelerated depends on the utility's original power generation development plan. The original plan of TEPCO includes advanced gas-combined cycle (AGCC) and nuclear power only in the next decade, not coal-fired nor oil-fired thermal power plants.

In addition to the capacity development, generated electricity of each power generation resource is estimated through the cost-minimizing dispatch, and carbon emission from the grid is the sum of that from the existing and new generation resources. The overall carbon emission of electricity and energy use in the objective area is the sum of carbon emission from the grid electricity estimated and that from gas and fuel oil consumption of customer's HVAC systems. Table 7 shows the change of overall carbon emission from four simulated cases to BAU case.

In CHP case of low subsidy for the CHP system, the overall carbon emission decreases from that of BAU case, because the CHP system penetrates to the market segments in which CHP system is energy efficient as well as economical by effective utilization of waste heat. In contrast, in CHP+ case of high subsidy for the CHP system, the overall carbon emission increases from that of BAU case. In this case, timing of start in operation of AGCC is deferred and the CHP systems are economical but energy efficiency is not achieved because of wasted heat for some applications where heat demand is not sufficient for CHPs.

In EHP case, the overall carbon emission decreases from that of BAU case. The EHP penetration results in acceleration of timing of start in AGCC operation and reduction of electricity generated from the existing power plants, which improve carbon emission factor of grid electricity and decrease the overall carbon emission. Similarly, in EHP2 case when the energy efficiency improvement rate of EHP system doubled, the overall carbon emission also decreases.

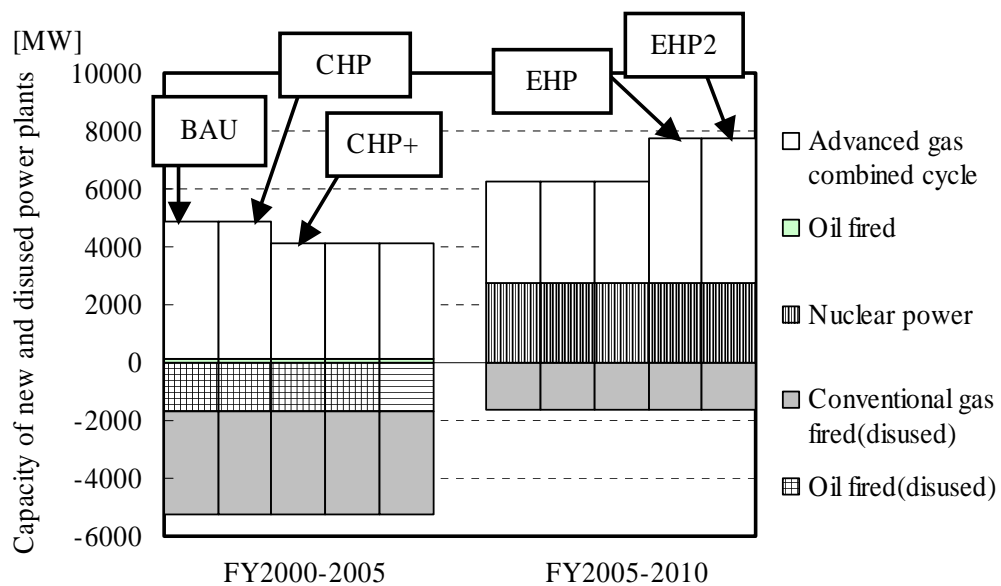


Figure 9 Capacity of new and disused power plants during FY2000-2010

Table 7 Change in overall carbon emission by HVAC system switch

[10000 ton-C]

		CHP	CHP+	EHP	EHP2
Grid electricity	New power plants(AGCC)	-0.67	-46.50	38.92	37.11
	Existing power plants(average)	-5.30	39.60	-31.51	-34.85
City gas and fuel oil consumption(customers)	HVAC systems	5.52	19.71	-35.89	-38.01
<b>Total</b>		-0.45	12.81	-28.48	-35.75

Finally, we estimated the social cost of carbon emission reduction related with HVAC system switch, which is a criterion for evaluation of carbon reduction options. Table 8 shows the estimated reduction cost of carbon emission, which is the sum of the utility's investment in power generation capacity, fuel cost for power generation and the customer's switch cost of HVAC systems. The carbon emission reduction cost divided by amount of reduced carbon emission comes to a marginal reduction cost of carbon emission, approximately.

The CHP case has a negative marginal reduction cost, and in CHP+ case the marginal cost is indefinable because of increase in carbon emission level to BAU case. That implies that, when low CHP penetration, the CHP system might be economical and energy efficient and so the subsidy is justified, however, when high CHP penetration, the CHP system might be energy inefficient and so the subsidy might be not justified.

Both EHP case and EHP2 case have positive values of marginal reduction cost, meaning that EHP system promotion is not economical under the current cost condition. The former marginal cost has a higher value than a carbon tax level under public discussions in Japan, that is, approximately 3000 yen (25 US dollars) per ton-C, on the other hand, the latter marginal cost has a reasonable value comparable to it.

This numerical result implies that, promotion of EHP system accompanied with policy measures of acceleration of energy efficiency improvement is one of cost-effective options to reduce carbon emission level in commercial sector.

Table 8 Estimated marginal reduction cost of carbon emission related with HVAC system switch

Million yen		CHP	CHP+	EHP	EHP2
Electric Utility	Investment in new AGCC	0	-7900	7600	7600
	Fuel cost of power generation	-2200	-2800	2900	1000
Customer's switching cost of HVAC systems		1111	4754	-5263	-6753
<b>Total</b>		-1089	-5946	5237	1847
<b>Yen per t-C</b>					
Marginal reduction cost of carbon emission		-243510	n.a.	18389	5167

## 6. CONCLUSIONS

We studied the impact of HVAC system switch in the commercial sector on the overall carbon emission level by integrated analysis incorporated with end-use energy demand model and power generation planning model. The end-use energy demand model we developed is able to estimate future

electricity and energy demand based on market details and technological developments by a bottom-up approach. The dynamical switch in HVAC system is driven by choices of end users with various choice criteria, which is a unique feature of our model. The load dispatch analysis is performed by power generation mix model to estimate change in carbon emission from grid electricity by the HVAC system changes.

As a case study, we focused on four commercial segments, that is, office building, retail store, hotel and hospital in the Tokyo metropolitan area, which is one of the major commercial energy markets in Japan. The carbon emission change is analyzed in cases that either gas CHP system or advanced EHP system is promoted separately, both of which are recognized as key energy efficient technologies to reduce carbon emission from commercial energy use in Japan.

The numerical results show that, if AEEI assumed, the CHP promotion does not always lead to overall carbon emission reduction, because high CHP penetration defers investment in advanced gas combined cycle and the carbon emission factor does not decrease than the present level. On the other hand, the EHP promotion leads to overall carbon emission reduction because EHP penetration accelerates start of AGCC operation and makes carbon emission factor decreased. Amount of carbon emission reduced by EHP penetration is estimated more than that by CHP penetration. In addition to that, marginal cost of carbon emission reduction by EHP promotion is reasonable if acceleration of energy efficiency improvement of EHP system is accompanied beyond AEEI. The combination of advanced EHP system and AGCC is a key of overall carbon emission reduction. The EHP system as well as CHP system would be one of cost-effective options to mitigate carbon emission.

## REFERENCE

- [1]Japan Cogeneration Center, [http://www.cgc-japan.com/english/e\\_top.html](http://www.cgc-japan.com/english/e_top.html)
- [2]Tokyo Electric Power Company, <http://www.tepco.co.jp>
- [3]Tokyo Gas, <http://www.tokyo-gas.co.jp>
- [4]Takahashi, M. and Asano, H.: Development of a proto-type of end-use energy model for commercial sector and its application to demand analysis of HVAC and hot-water supply systems, Rep. No. Y03001, CRIEPI, June 2003 (in Japanese)
- [5]Green, P.E. and Srinivasan, V. (1978): Conjoint Analysis in Consumer Research: Issues and Outlook, J. Consumer Res., Vol.5
- [6]Goett, A.A., Hudson, K. and Train, K.E. (2000): Customers' Choice Among Retail Energy Suppliers: The Willingness-to-Pay for Service Attributes; The Energy Journal Vol. 21, No.4
- [7]Takahashi, M., Asano, H. and Nagata, Y.: Optimal Penetration and Cost-Effectiveness of Demand-side Technologies in an Electric Power System by Integrated Resource Planning Model, In Proceeding of the 19<sup>th</sup> Annual North American Conference of the USAEE/IAEE, Albuquerque, p84-92, 1998
- [8]Meyers, S., Marnay, C., Schumacher, K. and Sathaye, J.: Estimating Carbon Emissions Avoided by Electricity Generation and Efficiency Projects: A Standardized Method (MAGPWR), LBNL-46063, Berkeley National Laboratory, July 2000