Developing a simulation model to forecast Heating/Cooling demand in the Japanese residential sector

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1. SYNOPSIS

We developed a structural model which integrate income, price, climate, housing, household, energy efficiency and other factors to project future heating/cooling demand of Kansai area.

2. INTRODUCTION

Energy consumption in the residential sector continues to grow in Japan, which is also the case in other industrialized countries. Heating and cooling energy demand accounts for one-third of the energy consumption in Japan's residential sector, and it is still increasing.

Conventional methods for projecting the heating/cooling energy demand quite often depend upon the use of simple reduced forms, and do not take essential structural factors into account.

On the basis of historical data covering 22 years (1970-1992), the authors developed a structural model that explicitly takes the aforementioned factors into account. This model enabled the authors to properly project heating/cooling demand in the Kansai area up to the year 2010.

3. MODEL STRUCTURE

The model consists of six major blocks: cf Figure.1

3.1. Satisfactory Level of Air Conditioning+

Japanese use of air conditioning significantly differs from that of Europe and North America in that such appliances are used only in the room currently occupied. People turn off air conditioning when they leave their homes or a room. Even when a room is occupied, its temperature is often far below (winter) or above (summer) the comfortable level. When people go to bed, they turn off the air conditioning, except for extremely hot summer nights. However, the recent trend shows some changes in the use pattern due to the increased diffusion of air conditioners. People have started to use air conditioners in such a way as to keep a room comfortable (a satisfactory level) whenever it is occupied, which causes an increase in energy consumption for air conditioning. Therefore, when one makes projections for future air conditioning energy consumption, it is extremely important to develop a method that reflects changes in the use pattern of air conditioners.

The authors estimated the satisfactory levels of air conditioning heat load in three stages. First, the heat and cooling load for air conditioning is calculated for 150 cases, based on the cross sectional data on dwelling areas, thickness of insulation, type of dwelling (single-family or multi-family), the number of household members, and the degree of user-set room temperature as independent variables. Utilizing the ordinary least square analysis, we reduced these results in one equation, namely we estimated the parameters of equations representing space heating/cooling load, by types of dwellings.

Space heating load (for single-family dwellings)

SHL=-54.914+2.909,3*HT+2.408,2*PH-3.518,6*INS(1/3)
(-14,17) (18,63) (9,36) (-21,94)
+124,37*HS (1)
(15,49)
R2=0,93507 S/D=2.887,2 D/W=1,205 (T Value) N=150

Cooling load (for single-family dwellings)

SCL=61.561-2.318,3*CT+1.562,9*PH+48,48*HS ----- (2)
(20,65) (-21.36) (17.96) (17.86)
R2=0,95383 S/D=797,4 D/W=2,043 (T Value) N=150

Where

SHL: heat load (MJ per household per year)
SCL: cooling load (MJ per household per year)
HT: user-set space heating temperature (degree C)
CT: user-set space cooling temperature (degree C)
PH: number of household members (persons per household)
INS: thickness of insulation material (mm)
HS: dwelling area space (m2)
0

3.2 Substitution of Satisfactory Level for Air Conditioning Energy Consumption into the Model

The second stage involves estimating the satisfactory levels for space heating/cooling for past years. In this stage, time-series data for the average number of household members and the average dwelling area space, as well as data for user-set space heating/cooling temperatures are fed into equation to obtain data for heat load and cooling load, respectively.

Finally, we composed an equation to obtain the weighted average of the satisfactory space heating/cooling per household. The proportions of dwelling types (single-family and multi-family dwellings), and the diffusion rate of insulated dwellings are incorporated as weights.

This equation allows us to calculate the hypothetical amount of energy needed to satisfy the required level for space heating with central heating appliances. The difference between the actual consumption and the estimated satisfactory consumption level can be attributed to the diffusion and efficiency rates of space heating appliances, energy prices, and weather conditions. Thus, the dwelling structure, the number of household members, diffusion and efficiency rates of appliances, energy prices, weather factors, and the user-set room temperature can explicitly be taken into account in our model.

3.3 Estimating Energy Consumption for Space Heating, by Fuel Type

The energy consumption of the ith energy for space heating is estimated as the function of energy consumption for space heating, energy prices, and diffusion rate for space heating appliances. Concerning data for energy prices, we use Pi or Pi/Ph, where Pi is the price of the ith energy and Ph is the weighted average energy price for heating. As the indicator to epresent the diffusion rate of particular appliance, we use the ratio of Dij/Dcj where Dij is the diffusion rate of the jth type of appliance using ith energy source, and Dcj is the weighted average diffusion rate of the same type of appliance using competing energy sources.

LH=(SHL(50)*IS/100+SHL(0)*(1-H)/100
+(MHL(30)*IM/100+MHL(0)
*(1-IM)/100)*H/100 (3)

Wher

LH:	satisfactory level for heating energy consumption (MJ per household per year)
SHL(x):	space heating load for single-family dwellings with insulation thickness of x mm (MJ per household per year)
MHL(x):	space heating load for multi-family dwellings with insulation thickness of x mm (MJ per household per year)
IS:	diffusion rate of insulated single-family dwellings (%)
IM:	diffusion rate of insulatied multi-family dwellings (%)
H:	diffusion rate of multi-family dwellings (%)

0

For example, *the satisfactory level for space heating can be shown as follows:*

Note that equation (E.3) allows us to calculate the hypothetical amount of energy needed to satisfy the required level for space heating with central heating appliances.

The quation for estimated energy consumption for space heating is as follows:

HT=5.810,3-210,6*PH/CPI
(3,69) (-4,28)
+0,0000486*LH*(DHP/EF*90+DFH*90+DS*25)
(4,78)
+3,816*HDD-1.097*DUM1-784,77*DUM2--(4)
(4,94) (-5,31) (-3,13)
R2=0,92188 S/D=230,3 D/W=2,998 (T Value)

Where

HT:	energy consumption for space heating (MJ per household per year)
PH:	energy price for space heating (ECU/MJ)
CPI:	consumer price index (1990=100)
DHP/EF:	diffusion rate of heat pumps (units per 100 households
DFH:	diffusion rate of forced-air space heaters (units per 100 households)
DS:	diffusion rate of other portable room heaters (units per 100 households)
HDD:	heating degree day (deg.day)

0

4. RESULTS OF SIMULATION

4.1 Results of Simulation: Energy Consumption for Space Heating and Cooling in Future Years

Simulation results indicate that the energy consumption for space heating per household will grow slightly, from 9.316 MJ per household per year in 1992 to 10.480 MJ per household per year in 2010. Annual average growth rates during the periods from 1992-2000 and from 2000-2010 are 1,5% and 0,5%, respectively. Among energy types, electricity consumption will grow most rapidly, by 2,3% per year during the period from 1992- 2010. The annual growth rate of other energy consumption will be below 1%. The high growth of electric power consumption is due to the increased diffusion of air conditioners using heat pumps, which will overwhelm the increase in their efficiencies.

The satisfactory level for space heating will decline from 21.776 MJ per household per year to 18.924 MJ per household per year due to increased insulation. On the other hand, the useful energy delivered for space heating will increase from 12.690 MJ per household per year in 1992 to 16.843 MJ in 2010. The ratio of satisfactory level for space heating to useful energy will converge, from 1:0,58 in 1992 to 1:0,75 in 2010. As this shows, the convergence of useful energy with the satisfactory level, as well as the increase in energy prices and the improvement in dwelling insulation and the appliance efficiency, contributes to the slow growth rates in the annual average energy consumption for space heating.

The energy consumption for space cooling per household will grow from 1.135 MJ per household per year in 1992 to 1.419 MJ household per year in 2010. Its annual average growth rate will be 2,2%, slightly above that for space heating. The ratio of satisfactory level of space cooling to the useful energy consumed for space cooling will converge, from 1:0,44 in 1992 to 1:0,7 in 2010.

Table 1.Exogenous Variables

		2000/1992	2010/2000
Real economic growth rate		2,85%	3,35%
Crude oil price growth rate		3,78%	1,44%
Consumer price growth rate	2,04%	3,17%	
Official discount growth rate		3,56%	1,52%
Rate of increase in number of household		1,22%	1,22%
Rate of increase in household members		-1,0%	-1,0%
Rate of increase in number of single-family dwelling housing starts		0,44%	0,44%

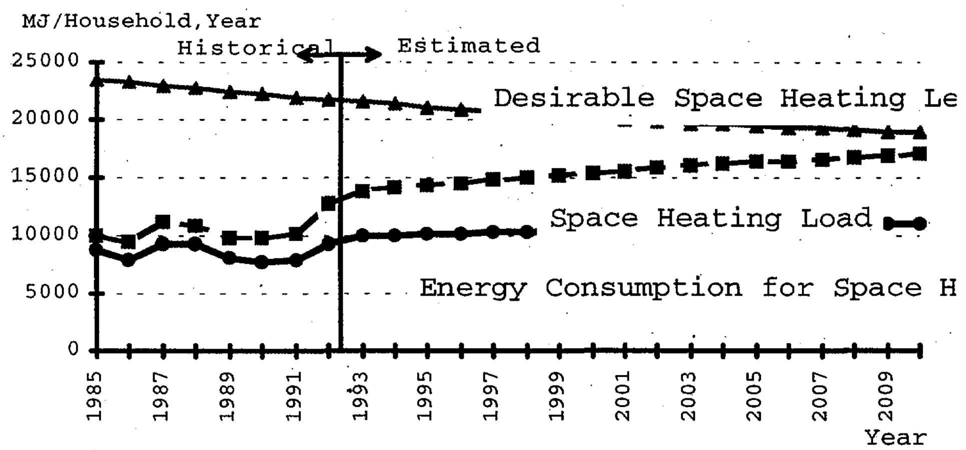

Figure 2.Results for Kanasai Region: Energy Consumption for Space Heating

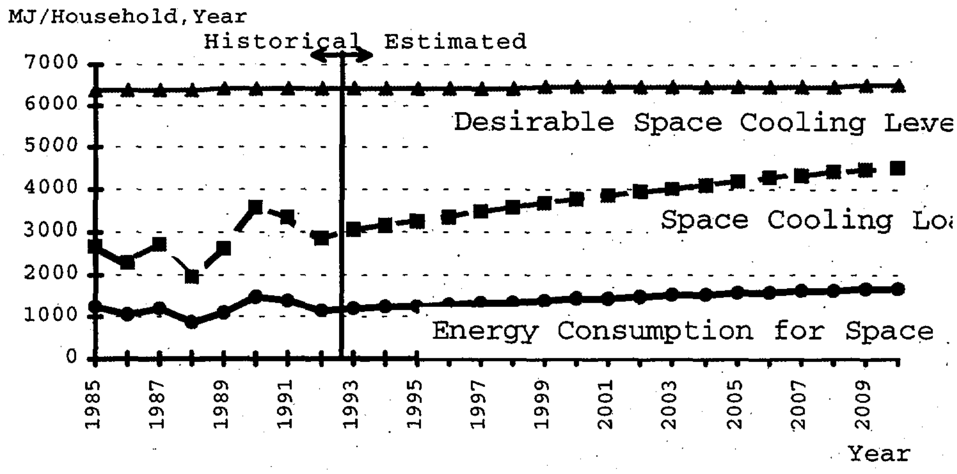

Figure 3.Results for Kansai Region: Energy consumption for Space Cooling

Energy demand for space heating and cooling is one of the major factors pushing the peak electric power demand upwards in summer & winter. Since the actual consumption for space heating/cooling is below the satisfactory level, the former is likely to grow henceforth, pushing the peak electric power demand further upwards. The current move toward deregulating the electric power utility industry in Japan is primarily aimed at decreasing electric power prices, not at improving energy conservation. Bearing in mind the below-satisfactory level of actual energy consumption for space heating/cooling and its implications for future energy demand, energy conservation warrants more attention in the discussion on deregulation. Our model allows the interested parties to assess explicitly the implications of changes in the structural factors, as well as changes in economic environment and energy prices, in the context of energy conservation. Our model will prove extremely useful in promoting energy conservation and considering strategies for deregulation in Japan.

Table 2 Estimation Results

	Energy Consumption (MJ per household per year)			Annual average growth rate
	1992	2000	2010	2010/1992
Space heating	9.316	10.480	11.066	0,96
Electricity	1.931	2.484	2.900	2,29
City Gas	2.069	2.304	2.453	0,95
LPG	674	796	791	0,89
Kerosene	4.642	4.896	4.922	0,33
Space Cooling	1.135	1.415	1.671	2,17

5. DISCUSSION

Energy demand for space heating and cooling is one of the major factors pushing the peak electric power demand upwards in summer & winter.
The current move toward deregulating the electric power utility industry in Japan is primarily aimed at decreasing electric power prices, not at improving energy conservation.
Our model allows the interested parties to assess explicitly the implications of changes in the structural factors, as well as changes in economic environment and energy prices, in the context of energy conservation. Our model will prove extremely useful in promoting energy conservation and considering strategies for deregulation in Japan.

6. ENDNOTE

1. The term "useful energy consumption" means the amount of work delivered from energy consumption through the use of appliances with various efficiencies.

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