Electricity or gas? Evaluation of energy saving, CO_2 reduction, and cost saving potentials in residential house in Japan

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Abstract
Japan's energy consumption accounts for approximately 6 % of the world. Various countermeasures are being applied to reduce the energy consumption and the CO_2 emission consequently. But we are not successful to suppress increase in the energy consumption, especially in residential, commercial, and transportation sectors. This paper shows energy saving, CO_2 reduction, and cost saving potentials of a typical residential house in Japan by adopting recent commercially available techniques and equipment for household. The energy consumption of the residential sector accounts for 15 % of the total of Japan. In order to clarify priorities of countermeasures of energy saving for the residential sector, the potentials are classified into heating, cooling, hot water, cooking, and refrigerators.

In heating and cooling, effectiveness of thermal insulation and air tightness for residential house are evaluated. In heating, hot water, and cooking, electric and gas fired appliances are compared. In electric appliances, the newest models are compared with current ones. These evaluations are carried out from the viewpoint of reduction in primary energy consumption, CO_2 emission, and energy charge. In the analysis, the latest technical improvement and invention of electric and gas fired appliances, such as a heat pump water heater with CO_2 refrigerant which have made an outstanding progress in efficiency of electricity usage, are taken into account. The primary energy saving, CO_2 reduction, and energy cost saving rates through use of these energy saving techniques and equipment are calculated at about 28 %, 34 %, and 41 % respectively.

Energy Consumption in Residential Sector in Japan
The end-use energy consumption in the Japan's residential sector accounts for 15 % of the total of the country. It is increasing by 1.2 % yearly in the last decade. *Figures 1 to 3* are the breakdowns by purposes of energy use, sources of energy, and household electric appliances as of FY2004 respectively. The electrification rate is currently 45 % [1]. It is supposed to be increased accompanied with spread of energy saving housing or highly insulated and airtight housing.

Where Energy Saving Comes in
This section describes how much energy can be saved by employing currently available technologies for heating, hot water supply, cooking, and refrigeration. However, we're not going to mention energy conservation that involves doing without, which sacrifices the benefit of the appliances. We're only going to mention effective utilization of energy where reduced energy consumption assumes that the benefits of the appliances are maintained, or even enhanced.

The following two areas are the main areas for effective energy utilization in residential sector:

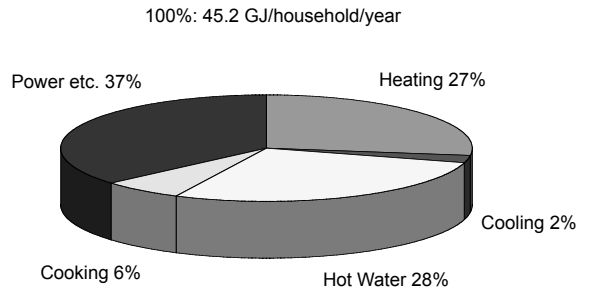

Figure 1. End-use energy consumption by purposes (FY2004)[1]

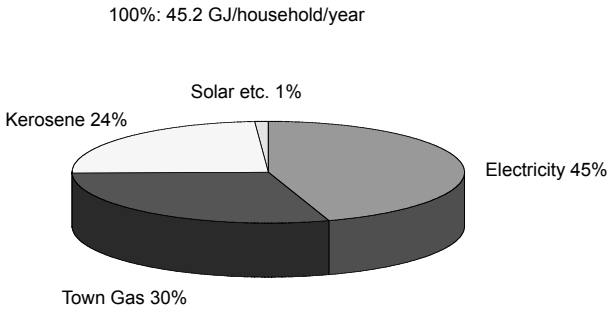

Figure 2. End-use energy consumption by sources (FY2004)[1]

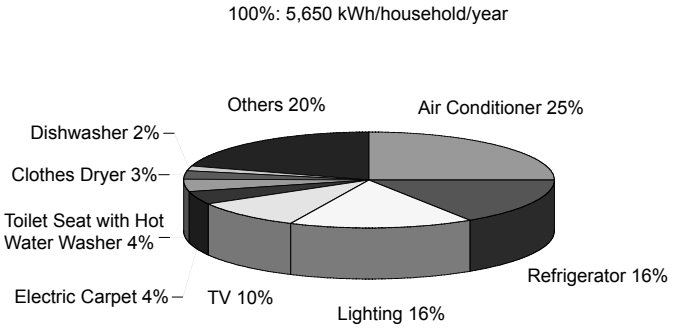

Figure 3. End-use electricity consumption by household electric appliances (FY2004)[2]

1. Promotion of energy saving housing (highly insulated and airtight housing)
2. Improvement of the energy efficiency of household appliances and promotion of high-efficiency devices

Energy saving plays its part in the following areas:

1. Reduction of heating and cooling energy in energy saving housing
2. Reduction of heating and cooling energy with high-efficiency heat pump air conditioners
3. Reduction of hot water supply energy with heat pump water heaters
4. Reduction of energy for cooking with high-efficiency cooking ranges
5. Reduction of energy with high-efficiency refrigerators

The Primary energy saving, CO_2 reduction, and energy cost saving rates through use of these energy saving techniques and equipment are calculated at about 28 %, 34 %, and 41 % respectively, as shown in *Table 1* and *Figures 4 and 5*.

These calculations were made based on the following assumptions:

a) The conversion efficiencies from primary energy to electricity and town gas at demand end are 37 % [3] and 100 % respectively.
b) The coefficients of performance (COP) of the appliances supposed to be are as shown in *Table 2*.
c) The CO_2 emission and energy cost per calorific value are as shown in *Table 3*.

The details of the analyses for individual techniques and equipment are as follows:

ENERGY SAVING HOUSING

The energy saving housing, or the highly insulated and airtight housing, can cut heating energy significantly. In our calculations for the Tokyo region, a 2×4 detached house with a total floor area of 120 m^2 built according to the next-generation energy standards in Japan enacted in 1999 shows reductions in heating load by 27 % compared to that built based on the earlier

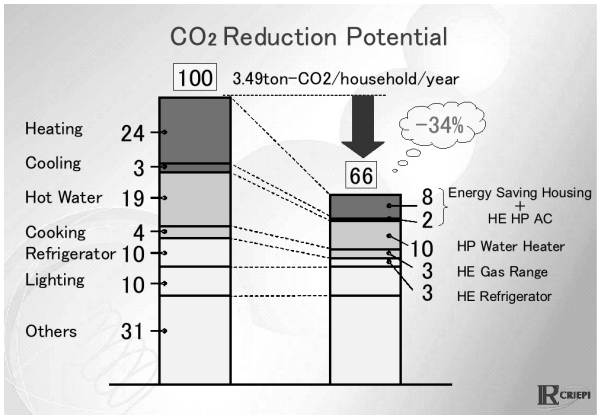

Figure 4. CO_2 reduction potential

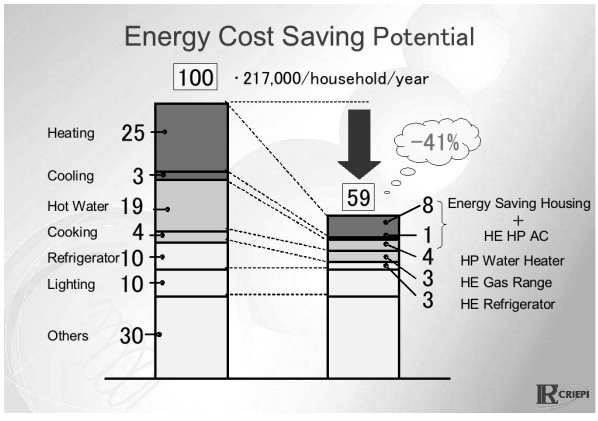

Figure 5. Energy cost saving potential

Table 1. Breakdown of primary energy saving potential, "Where energy saving comes in?" (100: Total primary energy consumption of 19.3Gcal/household/year)

Purposes	Energy Saving Measures		Primary Energy Consumption [Relative Value to 100]		
			Initial Value	→ [Energy Saving]	After Adopting Energy Saving Measures
Heating	Energy Saving Housing (Energy Saving Rate 27%)	Gas Heater ↓ High-Efficiency Heat Pump Air Conditioner (Energy Saving Rate 57%)	Gas 13	→ [-9]	Electricity 4
		Heat Pump Air Conditioner Installed 10 Years Ago ↓ High-Efficiency Heat Pump Air Conditioner (Energy Saving Rate 35%)	Electricity 9	→ [-5]	Electricity 4
Cooling	Energy Saving Housing (Energy Saving Rate 16%)	Heat Pump Air Conditioner Installed 10 Years Ago ↓ High-Efficiency Heat Pump Air Conditioner (Energy Saving Rate 42%)	Electricity 3	→ [-1]	Electricity 2
Hot Water Supply	Conventional Gas Water Heater ↓ Heat PumpWater Heate (Energy Saving Rate 30%)		Gas 16	→ [-5]	Electricity 11
Cooking	Conventional Gas Cooking Range ↓ High-Efficiency Gas Cooking Range (Energy Saving Rate 21%)		Gas 4	→ [-1]	Gas 3
Refrigerator	Refrigerator Installed 10 Years Ago ↓ High-EfficiencyRefrigerator (Energy Saving Rate 65%)		Electricity 11	→ [-7]	Electricity 4
Lightings	-		Electricity 11	→	Electricity 11
Others	-		Electricity 33	→	Electricity 33
Total			100	→ [-28]	72

Table 2. COP of appliances [4 - 10]

Purpose	Appliance	COP
Heating	Gas Heater	0.8
	High-Efficiency Heat Pump Air Conditioner	5.0
	Electric Heater	1.0
Hot Water Supply	Conventional Gas Water Heater	0.78
	Latent Heat Recovery Gas Water Heater	0.95
	Heat Pump Water Heater	3.0
	Conventional Electric Water Heater	1.0
Cooking	Conventional Gas Cooking Range	0.33
	The Latest Gas Cooking Range	0.42
	Induction Heating Cooking Range	0.75

Table 3. CO_2 emission and energy cost per calorific value [11, 12]

Source	CO_2 Emission [g-CO_2 /MJ]	Cost (FY2002) [JPY/MJ]
Electricity	105	6.38
Electricity (Night-Only)	-	2.52
Town Gas	51	3.25
LPG	-	4.99
Kerosene	68	1.19

Table 4. Specifications of housings

	Earlier energy saving standards	Next-generation energy standards
Coefficient of heat loss	3.81 W/m^2/K	2.50 W/m^2/K
Coefficient of solar gain	0.074	0.044
Air changes per hour	0.86 (1F) 0.65 (2F)	0.54 (1F) 0.54 (2F)

energy saving standards from 1980. In addition, it cuts cooling load by 16 %. Also, it keeps the temperature inside more even, making a more pleasant thermal environment. *Table 4* shows the specifications of the housings used in the calculation. The additional construction costs for it is at least JPY 500,000.

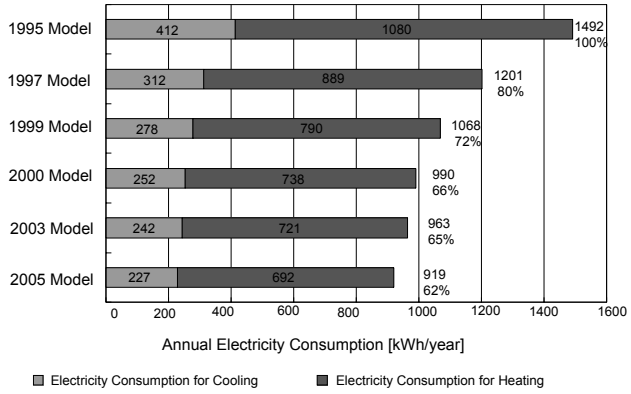

Figure 6. Efficiency improvement of heat pump air conditioner[13]

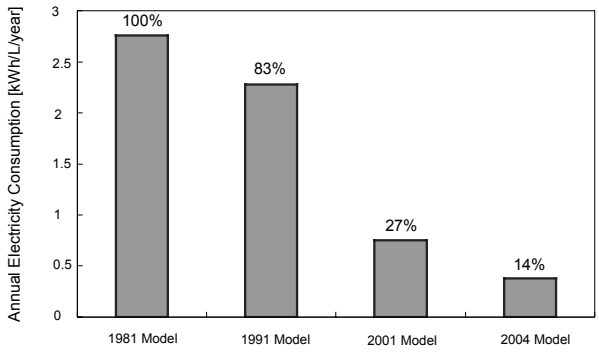

Figure 7. Efficiency improvement of fridge-freezer[14]

HIGH-EFFICIENCY HEAT PUMP AIR CONDITIONERS

Thanks to the unique "Top Runner" energy saving policy enacted in 1998 and the efforts of manufacturers, the coefficient of performance (COP) of heat pump air conditioners is improving greatly each year. As shown in *Figure 6*, air conditioners with equivalent capacity have cut power consumption for heating by 36 % in the last decade, while power consumption for cooling has been reduced by 45 % [13]. The upper row of *Table 5* shows the comparisons in primary energy consumption, CO_2 emission, and energy cost among gas heater, high-efficiency heat pump air conditioner, and conventional electric heater. If a gas heater with COP of 0.8 is replaced by a high-efficiency heat pump air conditioner with COP of 5.0, primary energy consumption, CO_2 emission, and energy cost are reduced by 57 %, 67 %, and 69 % respectively.

HEAT PUMP WATER HEATERS

The COP of conventional gas water heaters is 0.78. Although conventional electric water heaters offer significant economic benefits by using cheap midnight power, and are quiet since there is no operating noise, as with heating with an electric heater, they are not particularly rational from the point of view of effective primary energy utilization because the conversion efficiency from primary energy to electricity is 37 %.

In search of a breakthrough, Central Research Institute of Electric Power Industry (CRIEPI), Tokyo Electric Power Company (TEPCO), and Denso Corporation took the worldwide lead in developing a heat pump water heater using carbon dioxide as a refrigerant. The heat pump water heater achieves an annual average COP of 3.0. It heats water using more heat than the primary energy which is an input to electricity generation. The heat pump water heater is an innovative device that brings energy rationality to heating water with electricity. Also "latent heat recovery" gas water heaters with COP of 0.95 are now on the market. If conventional gas water heaters are replaced with heat pump water heaters, as the middle row of *Table 5* shows, primary energy consumption, CO_2 emission, and energy cost are reduced by 30 %, 47 %, and 80 % respectively.

LATEST GAS COOKING RANGE

Gas rings that prevent the flame from extending far beyond the bottom of the cooking pot are now on the market. It improves heat efficiency from 33 % to 42 %. If conventional gas rings are replaced with high-efficiency gas rings, as the lower row of Table 5 shows, primary energy consumption, CO_2 emission, and energy cost are reduced by 21 %.

HIGH-EFFICIENCY REFRIGERATOR

As with air conditioners, combustion stoves, and combustion water heaters, similarly refrigerators is covered by the Top Runner program, and in recent years there have been some eye-opening improvements in efficiency. *Figure 7* shows the trend in annual power consumption per unit of inner volume of fridge-freezers. In the last 23 years it has reached one seventh.

Table 5. Primary energy saving, CO_2 reduction, and energy cost saving potentials in heating, hot water supply, and cooking

Purpose	Appliance	Primary Energy Consumption [Relative Value]	CO_2 Emission [Relative Value]	Energy Cost [Relative Value]
Heating	Gas Heater	100	100	100
	High-Efficiency Heat Pump Air Conditioner	43	33	31
	Electric Heater	216	164	157
Hot Water Supply	Conventional Gas Water Heater	100	100	100
	Latent Heat Recovery Gas Water Heater	82	82	82
	Heat Pump Water Heater	70	53	20
	Conventional Electric Water Heater	211	160	61
Cooking	Conventional Gas Cooking Range	100	100	100
	The Latest Gas Cooking Range	79	79	79
	Induction Heating Cooking Range	118	90	86

It is one third from 1991 to 2001. In this 10 years, inner volume has increased by about 7 %, but even after this is subtracted, energy saving has made dramatic advances. By replacing a refrigerator bought about 10 years ago with the latest high-efficiency refrigerator, we can cut energy consumed by the refrigerator by 65 % or more.

Conclusion

This paper shows energy saving, CO_2 reduction, and cost saving potentials of a typical residential house in Japan by adopting recent commercially available techniques and equipment for household. In order to clarify priorities of countermeasures of energy saving for the residential sector, the potentials are classified into heating, cooling, hot water, cooking, and refrigerators. In heating and cooling, effectiveness of thermal insulation and air tightness for residential house are evaluated. In heating, hot water, and cooking, electric and gas fired appliances are compared. In electric appliances, the newest models are compared with current ones. In the analysis, the latest technical improvement and invention of electric and gas fired appliances, such as a heat pump water heater with CO_2 refrigerant which have made an outstanding progress in efficiency of electricity usage, are taken into account. The primary energy saving, CO_2 reduction, and energy cost saving rates through use of these energy saving techniques and equipment are calculated at about 28 %, 34 %, and 41 % respectively.

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