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A Simulation Analysis of the Environmental Effects of Energy Saving Housing*

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Abstract

Much energy is consumed by household sector, especially in heating and cooling. CO_2 emission constitutes about 27% from household consumption per person. The construction related sectors such as cement, transportation, cray and stone have also very high intensities of energy consumption and CO_2 emission. Therefore, for the preservation of the environment, it is important to reduce housing and construcion activities related energy consumption. We show that simple heat insulated housing construction has significant reduction effects on energy consumption and CO_2 emission. The construction of energy saving housing induces CO_2 emission of 102kg per annum, but it reduces CO_2 emission by 689kg. Thus, CO_2 reduction amounts to 587kg per house. If energy saving construction is applied to all residential and commercial buildings, about 4% of the total CO_2 emission can be reduced.

1. Introduction[1]

The government of Japan has promised that the emissions of CO_2 after the year 2000 are to be maintained at the emission level of 1990. We are left with only several years to accomplish this goal, and we have to consider measures both from the aspects of technology and economic policy.

The introduction of environmental tax can be considered as one of the main economic policy for the maintenance of the environment[2]. However, it is doubtful if various countries in the world have fallen into step with the introduction of CO_2 tax, and whether the emission of CO_2 could be minimized effectively without negative effects on economic growth. In any case, it may not be feasible to depend on economic policy alone in reducing the level of CO_2 emission.

Hence, it is necessary to consider if it is possible to reduce CO_2 emission through the introduction of substitutative or new technology. In this case, we have to first consider to what extent the substitutative technology can effectively reduce the emission of CO_2. Second, we also have to know the exact amount of the additional CO_2 emitted from the raw materials and facilities used when the substitutative technology is introduced. This

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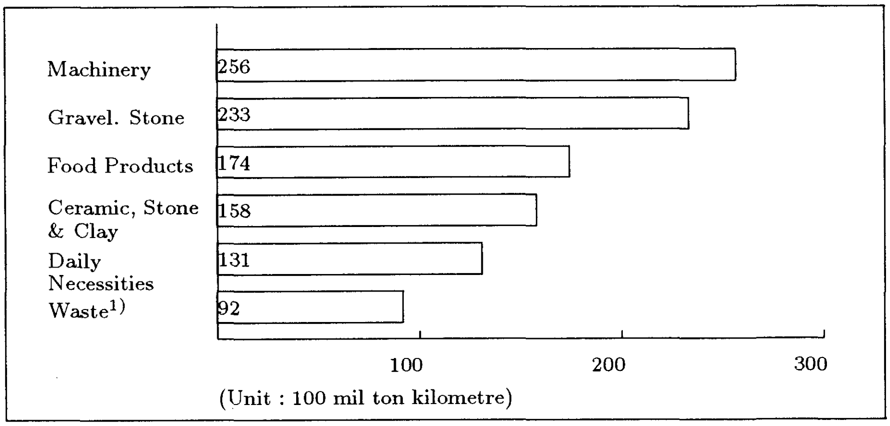
[1] This paper is originally published as [5] in Japanese. The sources of data used in this paper are from Misawa Home Institutes of Research and Development CO., Ltd. and Mr. Hidetoshi Nakagami at Jyuukankyo Research Institute (Living Environment and Planning Research Institute Co.), we are grateful these information. Needless to say, any errors remain the authors responsibilities.

[2] Kuroda and Shimpo[1] provides a comprehensive discussion regarding this topic.



Notes : 1)Waste includes sand and gravel.

Data Source : Land Transport Statistics 1991

Figure 1: Land Freight: Top Six Positions in terms of Quantity

is because if the technology is not highly effective and its introduction requires many additional inputs, the impact on environmental maintenance could be negative.

The input-output analysis could be considered as the most comprehensive and effective tool for evaluating the general effects of the introduction of the various new technologies. We need to examine the effects of the various new technologies in reducing the emission of CO_2, and in this paper we investigate the effects of energy saving housing on environmental maintenance.

In the past four years, we have being compiling the Input-Output Table for Environmental Analysis[3]. Based on our estimations, the emission of CO_2 in Japan amounted to 1,002 million (CO_2 conversion) ton per annum, of which, the emission from the construction industry amounted to 8.5 million ton, constituting only 0.84% of the total emission. It seems that the construction industry is thus not the major sector contributing to the environmental problems.

On the other hand, the construction industry could be seen as an industry with numerous backward linkages. This is because firstly, materials with high energy intensities (and hence high level of CO_2 emission) such as cement and metallic products are widely used in the construction sector.

Table 1 shows the induced CO_2 emission from per million yen production of the major inputs used in the construction industry. As shown in the right hand side of Table 1, the CO_2 emission level of these inputs fell in the top one-third portion in the ranking of the 406-commodity classifications.

For instance, cement ranked first, followed by raw concrete, other sanitary services (public), and hot rolled steel. As per million yen of the 1985 GNE has an average CO_2 emission of 3,030 kg, the CO_2 emission levels of the materials listed in Table 1 are higher than the average. Only timber and plywood have emission levels that are lower than the average.

[3]See for example [3], [4], [5]

Table 1: CO_2 emission of the major inputs used in the construction industry

CO_2kg/million yen in 1985 producers prices[1)]

	Domestic CO_2 Emission (excluding import) $[I-(I-\hat{M})A]^{-1}$	Total CO_2 Emission (including import) $[I-A]^{-1}$	Ranking of Total CO_2 Emission in 406
Gravel and quarry	4,220	4,761	120
Crushed stones	5,379	6,068	81
Timber	1,081	1,706	345
Plywood	1,855	2,555	264
Coated paper and paper converted	7,229	8,347	61
Plastic products	3,401	4,230	150
Sheet glass and safety glass	6,163	6,847	71
Glass fibre and glass products, n.e.c.	7,528	8,367	60
Cement	76,423	77,782	1
Ready mixed concrete	18,984	19,722	10
Cement products	15,304	15,965	16
Hot rolled steel	16,544	18,918	12
Rolled aluminium products	4,454	8,515	57
Metal products for construction[2)]	5,119	5,940	83
Metal products for architecture[3)]	3,837	5,114	107
Gas and oil appliances and heating	5,296	6,267	79
Electric lighting fixtures and equipmemt	3,237	3,943	170
Other sanitary services (public)	18,835	19,018	11
Other sanitary services (industrial)	9,803	10,013	45
Road freight transport	3,770	4,130	158
Self-freight transport by private motor	10,664	11,965	29

- Average CO_2 emission from GNE componetns is 3,030kg/million yen.
- Including iron frames of buildings.
- Including alminium sash of residential constructions.

Secondly, as shown in Figure 1, with regard to transport activities which constitute one of the major problems in environment issues, the transportation of gravel and quarry, machinery, and ceramic, stone and clay, which have high actual shares measured in terms of kilometre-tons, are closely related to the construction industry.

Hence, the activities in the construction industry are thus closely related to environmental problems. Therefore there is no doubt that the construction industry should also play a crucial role in investment activities concerning energy saving and the prevention of air pollution. Consequently, it is important that the construction industry should become 'more friendly' to the environment, while maintaining the size of its activities.

There are two major ways in which the above problem could be solved. The first method is to reduce the environmental pollutants produced directly and indirectly from construction activities. The second method involves reducing the energy consumption levels of the products of the construction industry, such as housing and office buildings when they are put into use. In other words, this implies making products which are 'more friendly' to the environment. The second method is thus the focus of this paper.

With regards to energy saving housing, various proposals have been made by the large prefabricated housing makers and the general construction companies. However, these proposals have not received high attention mainly because the effects of energy saving housing on the environment as a whole have not be made clear. In particular, it is hard to dismiss the doubt that while it is possible to build energy saving houses, however, if a large amount of energy is required in their construction, their overall energy saving effects are questionable. The aim of this paper is to provide some answers to the above issues. We intend to show, based on experimental data, the overall effects of energy saving housing quantitatively. Energy saving housing is believed to be able to reduce the household energy consumption of electricity, gas and kerosene, and thus reducing the annual emission of CO_2. On the other hand, as energy saving housing requires improvement in the heat insulating facilities, and the demand of these insulating materials has the effect of increasing both directly and indirectly the emission of CO_2. Hence, we evaluated the total effects of energy saving houses by comparing their energy saving effects with the above additional emission divided by the duration period of these houses.

2. Simulation Results of Energy Saving Housing

This section shows our estimation of the overall effects of energy housing facilities on the environment using the input-output table for environmental analysis, based on the experimental data obtained from house designing technicians. However, these estimates[4] are restricted to the effects of prefabricated energy saving housing, and hence we need to examine the effects produced by other housing such as office buildings in our future studies[5].

2.1. CO_2 Emission from the Production of Materials Used in the Construction of Energy Saving Housing

There are various ways in which the energy saving capacity in housing facilities could be improved. For example, the use of the solar water heater, the heat pump system and the heat recovery system can be considered as effective ways of utilizing energy[6]. Raising the

[4] Data on energy saving housing used in this section is based on information from the Environment and Energy Laboratory of the Misawa Homes Institute of Research and Development CO., Ltd.

[5] We would be grateful if readers could provide us experimental data regarding office buildings.

[6] In this system, heat energy obtained from the atmosphere is used in heaters and water boilers.

Table 2: Components of Heat Insulation of Housing

	Case I	Case2
Outer Wall	Insulater(Glass wool 100mm)	Insulater(Glass wool 100mm +Styrofoam 150mm)
Window	Resinoid frame Normal paired glass	Wooden frame Coated paired glass
Door	Wooden	Wooden
Heat Loss Coefficient (kcal/m^{2}h^{o}C)	1.2	0.8

Table 3: Unit Price of Construction Materials

Name of Part	Name of Material	I/O Code	Unit Price[1)]	Source of Data
Ceiling	Glass wool	2512-011	312Yen/kg	Input-out Table
External wall	Wood	1611-011	47425Yen/m^3	Input-output Table
	Glass wool	2512-011	312Yen/kg	Input-output table
	Styrofoam	2211-013	14539Yen/m^3	Input-output Table
floor	Wood	1611-011	47425Yen/m^3	Input-output Table
	Glass wool	2512-011	312Yen/kg	Input-output Table
Window	Aluminium	2722-021	118300Yen/m^3	Misawa Homes
	Plastic	2211-014	109000Yen/m^3	Misawa Homes
	Wood	1611-011	54500Yen/m^3	Misawa Homes
	Glass	2511-011	79500Yen/m^3	Input-output Table
Door	Aluminium	2722-021	118300Yen/m^3	Misawa Homes
	Wood	1611-011	47425Yen/m^3	Input-output Table
	Glass wool	2512-011	312Yen/kg	Input-Output Table

Note : 1)In 1985 producers prices.

heat insulation level of building will increase the heat efficiency of the air conditioning and heating system installed and hence it helps to achieve the objective of energy saving. Equipment (lighting, air conditioning and heating facilities, etc.) installed in buildings could also be replaced with those that have higher energy efficiencies. The following is a simulation analysis of the effects of raising the heat insulation level of housing facilities.

Table 2 compares two types of modified housing with high levels of heat insulation. The heat insulation of housing could be improved through the use of heat insulating materials in the construction of walls, floor and ceiling, the installation of multi-layered glasses in windows and replacing window frames and doors from aluminium to other materials. In the case of prefabricated housing, heat insulation could be improved through changes showed in Table 2.

The results of the above changes are revealed in the heat loss coefficient, an indicator of heat insulation, which is reduced from the usual 2.9 to 1.2 in Case I and 0.8 in Case II[7].

The unit prices of materials used in housing construction are shown in Table 3 and materials required in the construction of one unit of housing are shown in Table 4.

[7] The heat loss coefficient indicates the total heat loss from housing per square meter per hour for every degree of temperature difference between the internal and external. The smaller this coefficient is, the higher is the heat insulation level of the house.

Table 4: Quantity of Construction Materials Per Unit of Housing [1)]

Name of Parts [2)]	Name of Material	Quantity of Materials		
		Conventional Housing	Energy Saving Housing	
			Case 1	Case 2
Ceiling	Glass wool	31.0kg	198.6kg	298.0kg
External wall	Wood	$7.3m^3$	$7.87m^3$	$7.87m^3$
	Glass wool	72.5kg	232.7kg	232.7kg
	Styrofoam	$0.0m^3$	$0.0m^3$	$10.9m^3$
Floor	Wood	$3.5m^3$	$3.81m^3$	$4.44m^3$
	Glass wool	31.0kg	91.6kg	215.0kg
Window	Aluminium	$0.24m^3$	$0m^3$	$0m^3$
	Plastic	$0.00m^3$	$0.48m^3$	$0.00m^3$
	Wood	$0.00m^3$	$0.00m^3$	$0.94m^3$
	Glass	$0.07m^3$	$0.14m^3$	$0.21m^3$
Door	Aluminium	$0.006m^3$	$0.000m^3$	$0.000m^3$
	Wood	$0.00m^3$	$0.01m^3$	$0.01m^3$
	Glass wool	0.00kg	0.06kg	0.06kg

1. Assuming a construction area of $125m^2$ per house.
2. Summation of parts related to energy saving housing.
3. Source: Misawa Home Institutes of Research and Development CO., Ltd.

Table 5: Cost of Construction Materials[2)] per Unit of Housing[1)]

Name of Part [3)]	Name of Material	Cost of Materials(yen)				
		Conventional Housing	Energy Saving Housing		Differences Compared to Conventional Housing	
			Case 1	Case 2	Case 1	Case 2
Ceiling	Glass wool	9672	61963	92976	+52291	+83304
External wall	Wood	346202	373235	373235	+27032	+27032
	Glass wool	22620	72602	72602	+49982	+49982
	Styrofoam	0	0	158474	0	+158474
Floor	Wood	165987	180689	210567	+14702	+44579
	Glass wool	9672	28579	67080	+18907	+57408
Window	Aluminium	28392	0	0	-28392	-28392
	Plastic	0	52320	0	+52320	0
	Wood	0	0	51230	0	+51230
	Glass	5565	11130	16695	+5565	+11130
Door	Aluminium	710	0	0	-710	-710
	Wood	0	474	474	+474	+474
	Glass wool	0	19	19	+19	+19
Total Costs of Construction Materials		588821	781012	1043352	192191	454532
Cost of materials per annum		29441	39051	52168	9610	22727

1. Assuming a construction area of $125m^2$ per unit of house.
2. In 1985 producers prices.
3. Summation of parts related to energy saving housing only.

Table 6: CO_2 Emission Coefficients of Materials Used in House Contruction

Name of Parts	Name of Materials	I/O Code	CO_2 Emission Coefficient (Unit : CO_2kg/million Yen[1])
Ceiling	Glass Wool	2512-011	7528.3
External Wall	Wood	1611-011	1080.6
	Glass Wool	2512-011	7528.3
	Styrofoam	2211-013	3400.5
Floor	Wood	1611-011	1080.6
	Glass Wool	2512-011	7528.3
Window	Aluminium	2722-021	4453.8
	Plastic	2211-014	3400.5
	Wood	1611-011	1080.6
	Glass	2511-011	6163.4
Door	Aluminium	2722-021	4453.8
	Wood	1611-011	1080.6
	Glass Wool	2512-011	7528.3

1. 1985 producers prices.

The data in Table 5 are estimated by multiplying the unit prices in Table 3 and the material requirements in Table 4. As shown in Table 5, the additional materials required to increase the heat insulation level of housing amounted to 192,191 yen per unit in Case I and 454,532 yen per unit in Case II. Assuming the duration of these housing be 20 years, the additional cost per year is extremely small, amounting to 9,610 yen per year in Case I and 22,727 yen per year in Case II[8]. However, question on the implications of raising the heat insulation level of housing on the environment remains. We need to know if the additional consumption of glass wall and rosin will produce additional pollutants to the environment. We thus estimated the additional CO_2 emission level of the materials used in the construction of energy saving housing by multiplying the material inputs (in producers prices) with the CO_2 emission coefficients of the respective materials.

Table 6 shows the CO_2 emission coefficients of the various materials, which are the total direct and indirect CO_2 emissions from the production and consumption of 1 million yen (producers prices) of the respective goods.

The estimation of the CO_2 emission coefficient is as follows,

$$C_j = E^{prod}_{CO_2} \cdot (I - A)^{-1} F_j + E^{fuel}_{CO_2} \cdot F_j \tag{1}$$

C_j :CO_2 emission induced from 1 million yen consumption of jth good

$E^{prod}_{CO_2}$:a row vector showing the CO_2 emission coefficient per 1 million yen of production (CO_2 conversion kg/1 million yen, in 1985 producers prices)

A :the input coefficent matrix for 406 sectors

[8] A duration of 20 years is not the average life span of houses. In general, houses are replenished or reconstructed while they are still usable in conjunction to changes in the life-styles of the inhabitants. Hence, the duration of 20 years is shorter than the actual physical life span of houses.

This value does not include value added from the construction firms (for instance, research and development expenditure and labour costs) and the costs of transporting construction materials to construction sites. Hence, additional payments alone may not be large enough to act as an incentive for the production of energy saving housing. Therefore, costs in the realization of energy saving housing will be larger than the values indicated above. However, on the other hand, higher costs may in turn discourage the consumers from changing to energy saving housing.

Table 7: CO_2 Emission from the Production of Materials used in House Construction(Per Unit[1])

Name of Parts 2)	Name of Materials	CO_2 Emission(CO_2kg))				
		Conventional Housing	Energy Saving Housing		In Comparison to Conventional Housing	
			Case 1	Case2	Case 1	Case 2
Ceiling	Glass Wool	72.81	466.48	699.95	+393.66	+627.14
External Wall	Wood	374.11	403.32	403.32	+29.21	+29.21
	Glass Wool	170.29	546.57	546.57	+376.28	+376.28
	Styrofoam	0.00	0.00	538.89	0.00	+538.89
Floor	Wood	179.37	195.25	227.54	+15.89	+48.17
	Glass Wool	72.81	215.15	505.00	+142.34	+432.18
Window	Aluminium	126.45	0.00	0.00	-126.5	-126.5
	Plastic	0.00	177.91	0.00	+177.91	0.00
	Wood	0.00	0.00	55.36	0.00	+55.36
	Glass	34.30	68.60	102.90	+34.30	+68.60
Door	Aluminium	3.16	0.00	0.00	-3.16	-3.16
	Wood	0.00	0.51	0.51	+0.51	+0.51
	Glass Wool	0.00	0.14	0.14	+0.14	+0.14
Total		1033.30	2073.93	3080.18	+1040.63	+2046.87

1. Assuming a construction area of $125m^2$ per house.
2. Summation of parts related to energy saving housing only.

I :a unit matrix

$E^{fuel}_{CO_2}$:a row vector showing the CO_2 emission coefficient of the final demand of fuels(CO_2 conversion kg/1 million yen, in 1985 producers prices)

F_j :a vector indicating per unit (1 million yen) of jth good(the jth element as 1 and the other elements as 0)

Table 6 shows the CO_2 emission coefficients of the various materials (in CO_2 conversion kg/per million yen in 1985 producers prices).

The amounts of CO_2 emitted from the production of construction materials require in the construction of one housing unit are showed in Table 7. Data in Table 7 is obtained by multiplying the CO_2 emission coefficients in Table 6 by the material requirements shown in Table 5. Thus, as shown in Table 7, the CO_2 emissions from the production of materials used in energy saving housing are higher than that required in conventional housing. The additional CO_2 emission from energy saving housing amount to 1041kg per unit in Case I and 2047kg per unit in Case II.

Data in Table 8 are calculated from Table 7, assuming that houses have a duration of 20 years. As shown in Table 8, the additional CO_2 emission per housing unit per year amounts to 52kg in Case I and 102kg in Case II. The additional CO_2 emissions are mainly contributed by the additional consumption of heat insulating materials (wall glass, Styrofoam). This amounts to 45.6kg per year in Case I and 99kg per year in Case II. On the other hand, the effect of converting the materials used in window frames and doors from aluminum to rosin or wood is a 2.4kg increase in CO_2 emission in Case I and a 3.7kg decrease in CO_2 emission in Case II.

Table 8: CO_2 Emission from the Production of Materials Used in House Contruction(per annum[1) • per unit[2))

Name of Parts 3)	Name of Material	CO_2 Emission per annum(CO_2kg)				
		Conventional Housing	Energy Saving Housing		In Comparison to Conventional Hosuing	
			Case 1	Case 2	Case 1	Case 2
Ceiling	Glass Wall	3.64	23.32	35.00	+19.68	+31.36
External Wall	Wood	18.71	20.17	20.17	+1.46	+1.46
	Glass Wool	8.51	27.33	27.33	+18.81	+18.81
	Styrofoam	0.00	0.00	26.94	0.00	+26.94
Floor	Wood	8.97	9.76	11.38	+0.79	+2.41
	Glass Wall	3.64	10.76	25.25	+7.12	+21.61
Window	Aluminium	6.32	0.00	0.00	-6.32	-6.32
	Plastic	0.00	8.90	0.00	+8.90	0.00
	Wood	0.00	0.00	2.77	+0.00	+2.77
	Glass	1.71	3.43	5.14	+1.71	+3.43
Door	Aluminium	0.16	0.00	0.00	-0.16	-0.16
	Wood	0.00	0.03	0.03	+0.03	+0.03
	Glass Wool	0.00	0.01	0.01	+0.01	+0.01
Total		51.67	103.70	154.01	+52.03	+102.34

1. Assuming the duration of housing being 20 years.
2. For housing with a contruction area of $125m^2$.
3. Summation of parts related to energy saving housing only.

3. CO_2 Emission from the Energy Consumption of Energy Saving Housing

This section overviews the energy consumption pattern of living in energy saving housing and its impact on the environment.

As heat loss is greatly reduced through improvement in the level of heat insulation, the energy consumption of air conditioner and heater is expected to be reduced considerably. Hence, the question is to what extent the negative effects of CO_2 emission, could neutralize the positive effects as reviewed in the previous section. Comparing the above positive and negative effects will enable us to evaluate the overall effects of the energy saving housing on the environment. Table 9 shows the household energy consumption of prefabricated housing drawn up by designing technicians.

As shown in Table 9, the energy consumption of air-conditioner and heater is reduced by raising the heat insulation level of housing. The experimental results showed that in contrast to the conventional household energy consumption of 41170Mcal per annum, this is greatly reduced to 20630Mcal per annum in Case I (50.1% of the conventional case) and 16760Mcal per annum in Case II (40.7% of the conventional case). Of which, the energy consumption of air-conditioner and heater is reduced to 11600Mcal per annum in Case I and 7730Mcal per annum in Case II, as compared to 32140Mcal per annum in the conventional case. However, it should be noted that the energy consumption data shown in Table 9 is estimated assuming 24 hours utilization of air-conditioners and heaters, which is different from actual statistical data.

While the estimated reduction effects are shown in Table 9, we also need to know the actual energy consumption of households. Table 10 shows results estimated using actual

Table 9: Energy Consumption Per Housing Unit[1] Per Annum[2] by Uses Estimation by Design Technicians

Uses	Conventional Housing(Mcal)	Energy Saving Housing(Mcal)		Conditions
		Case 1	Case2	
Water Heating System	6000	6000	6000	An average usage of 650l of hot water at 40°C per day.
Heater	16480	6200	4130	Room temperature set at 22°C, 24 hours per day from Nov to Mar.
Air-conditioner	15660	5400	3600	Room Termperature set at 26°C, 24 hours per day from Jun to Sep.
Others	3030	3030	3030	An average consumption of 1.7 kwh per day.
Total	41170	20630	16760	

1. Assuming that these houses are located in areas with similar weather as that of Tokyo. Further, the work load of heater and air-conditioner includes the heat energy dissipated from lighting system and from electrical products used inhouseholds.
2. Assuming a construciton area of $125m^2$ per house.

Table 10: Household Energy Consumption by Uses

Uses	National Average (Mcal)	Energy Saving Housing(Mcal)	
		Case 1	Case 2
Water Heating System	3571.0	3571.0	3571.0
Heater	2660.0	1000.7	666.6
Air-conditioner	198.0	68.3	45.5
Others	3399.0	3399.0	3399.0
Total	9828.0	8039.0	7682.1

1. Estimated based on statistical data on the actual energy consumption of households.
2. National average obtained from *Residential Energy Statistical Yearbook* (1990).
3. The estimates for energy saving housing are calculated based on the estimation by design technicians and data from *Residential Energy Statistical Yearbook*.

Table 11: Household Energy Consumption by Usage and by Fuel Category

Usage	Electricity	Gas	LPG	Kerosene	Coal	Total
Hot water	0.075	0.491	0.246	0.188	0.000	1.000
Heating	0.093	0.115	0.045	0.745	0.002	1.000
Cooling	1.000	0.000	0.000	0.000	0.000	1.000
Light etc.	0.716	0.144	0.140	0.000	0.000	1.000

1. Source:Jyuukankyo Research Institute ed. *Residential Energy Statistical Yearbook*, 1990.

statistical data on household energy consumption[9]. Data in Table 10 shows the national average of annual family energy consumption in 1990 by usage[10].

The average family energy consumption amounted to 9,828Mcal per annum per household, one-quarter of the assumed energy consumption of the conventional prefabricated housing.

The difference between the above two figures is mainly contributed by the differences in the energy consumption of air-conditioners and heaters. The national average is 2,660Mcal per annum per household for the use of heater and 198Mcal per annum per household for air-conditioner[11].

The column on the energy consumption of energy saving housing in Table 10 shows the energy saving effects of these housing, estimated based on actual household energy consumption pattern. Table 10 shows that higher heat insulation lead to saving in the energy consumed by air-conditioner and heater as in the former case, assuming a similar rate of reduction.

As showed in Table 10, the national average for household energy consumption is reduced from 9,828Mcal per annum in 1990, to 8,039Mcal per annum in Case I (81.8% of the 1990's value) and 7,682Mcal per annum in Case II (78.2% of the 1990's value).

However, we also need to know the extent which energy saving housing helps to reduce the household's energy expenditure, and the extent CO_2 emission from household energy consumption is being reduced. In the next section, we estimate the above effects assuming that the average household has an energy consumption pattern similar to the national average.

Firstly, energy consumption by usage in Table 10 are aggregated into 5 categories of fuel. For this calculation, the conversion matrix shown in Table 11, obtained from the Residential Energy Statistical Yearbook, is used. Table 11 shows the household energy consumption by usage and by fuel category.

Table 12 summaries the energy consumption per annum per house unit classified by fuel types, which calculated from data in Table 10 and Table 11.

The household energy consumption expenditure is obtained by multiplying the household's energy consumption classified by fuel category, with the price of the unit heat value of the respective fuels. Table 13 shows the 1985 producers prices of the respective fuels.

[9] Data concerning energy consumed in households are based on Jyuukankyo Research Institute (ed.), *Residential Energy Statistical Yearbook*.

[10] This is the average value for all households. Hence, the differences between detached housing and clustered housing (the energy consumption of clustered housing is 2/3 that of detached housing), and the differences between housing in Hokkaido and Kyushu have been averaged out.

[11] The difference between the calculated values and statistical data are as follows. For statistical data, they are equivalent to the usage of heater in the period from November to March in half of the house for 7.8 hours per day, or the usage of air-conditioner from July to August in one quarter of the house for 2.4 hours per day.

Table 12: Household Energy Consumption by Type of Fuel (Mcal/per unit • per annum)

Type of Energy	National Average(Mcal)	Energy Saving Housing(Mcal)	
		Case 1	Case 2
Electricity	3147	2863.2	2809.4
Gas	2546	2354.5	2315.9
LPG	1475	1400.8	1385.8
Kerosene	2655	1418.0	1169.0
Coal	05	02.5	02.0
Total	9828	8039.0	7682.1

1. Source: National average obtained from *Residential Energy Statistical Yearbook*
2. The estimates for energy saving housing are calculated based on the estimation of design technicians and data from *Residential Energy Statistical Yearbook*

Table 13: 1985 Producers Prices of the Respective Fuels

Energy	yen/10^4 kcal(1985)
Electricity	283.09
Gas	144.76
LPG	52.78
Kerosene	62.09
Coal	18.69

Table 14: Annual Energy Consumption Per Unit of Housing

Type of Energy	Amount of Consumption(Yen)				
	National Average	Energy Saving Housing		Difference in Comparison with National Average	
		Case 1	Case 2	Case 1	Case 2
Electricity	89,089	81,055	79,532	8,034	9,557
Gas	36,856	34,084	33,526	2,772	3,330
LPG	7,785	7,393	7,314	392	471
Kerosene	16,486	8,805	7,258	7,681	9,227
Coal	9	5	4	5	6
Total	150,224	131,341	127,634	18,883	22,591

Table 15: CO_2 Emission Coefficient by Type of Energy

Energy	CO_2 kg/million yen
Electricity	19,379.5
Gas	18,241.1
LPG	49,676.8
Kerosene	45,355.8
Coal	202,052.1

Table 16: Induced CO_2 Emission per House Unit per Annum induced from Household Energy Consumption

Type of Energy	CO_2 Emission(CO_2kg)				
	National Average	Energy Saving Housing		Difference in Comparison to National Average	
		Case 1	Case 2	Case 1	Case 2
Electricity	1726.50	1570.80	1541.29	155.70	185.20
Gas	672.29	621.72	611.54	50.57	60.75
LPG	386.71	367.25	363.33	19.46	23.38
Kerosene	747.72	399.36	329.21	348.36	418.51
Coal	1.89	0.95	0.76	0.94	1.13
Total	3,535.11	2,960.08	2,846.13	575.03	688.98

Table 14 thus shows the energy consumption expenditure of households (per house unit, per annum) calculated from the data in Table 12 and Table 13, classified by fuel types. As shown in Table 14, for household with national average energy consumption pattern, the energy saving effects obtained from per unit of energy saving housing amounted to 18,883 yen per annum (1,574 yen per month) in Case I and 22,591 yen per annum (1,882 yen per month) in Case II. If the household energy consumption expenditure in the 1985 Input Output Table is divided by the total population, this amounts to 1,540,000 yen per capita, or 6,180,000 yen per household (assuming an average household size of 4 persons). Hence, energy saving housing resulted in a 0.3–0.4% reduction in total consumption expenditure per household.

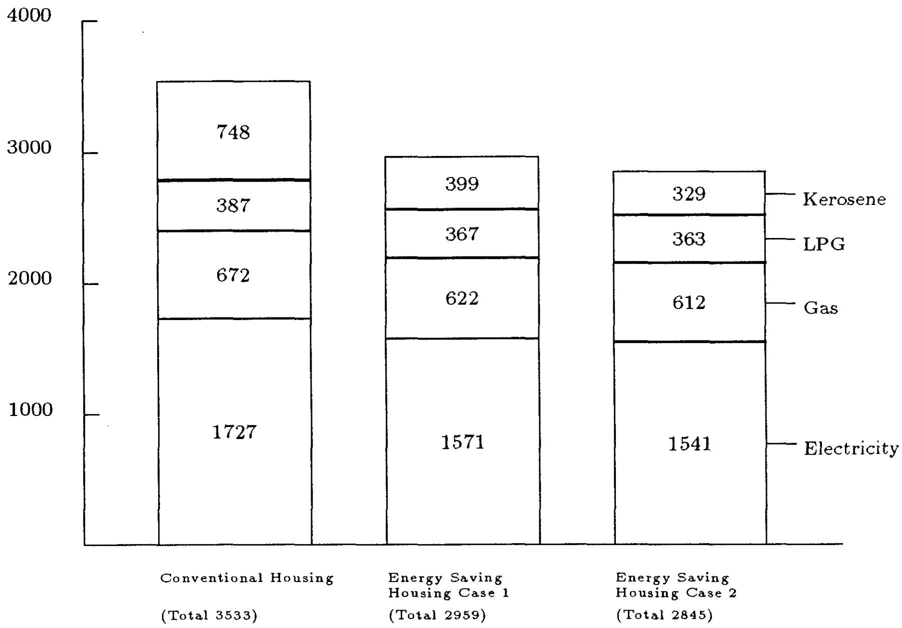
Further, by multiplying consumption expenditure of the respective fuels by the respective CO_2 emission coefficients, we can obtain the induced CO_2 emission from the energy consumption of households. The CO_2 emission coefficients used are shown in Table 15.

Table 16 shows the induced CO_2 emission per house unit per annum induced from household energy consumption. It shows that the induced CO_2 emission amounts to 575kg per annum per household for Case I and 689kg per annum per household for Case II, thus reducing the amount of emission by 16–20%.

Based on these estimations, we need to know how could this contribute to the improvement of the environment. In 1985, the induced CO_2 emission per capita from consumption was 3.9t[12]. Hence, the induced CO_2 emission from consumption per household (average 4 persons) amounted approximately to 15.6t. Thus, 3.6% to 4.4% of the normal CO_2 emission could be reduced with the introduction of energy saving housing.

Figure 2 shows the induced CO_2 emission from energy consumption of the conventional housing and energy saving housing Case I and Case II, respectively, classified in terms of

[12] See [5].



Unit: $kgCO_2$ /year, unit

Figure 2: CO_2 Emission From Household Energy Consumption

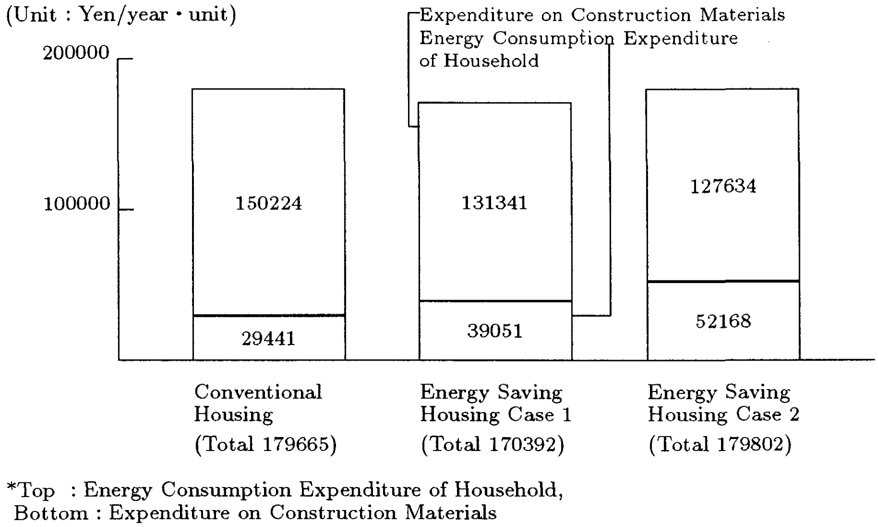


Figure 3: Annual Expenditure Per Unit Energy Saving Housing

fuel types, namely kerosene, LPG, gas and electricity. As shown in Figure 2, the amount of induced CO_2 emission is the greatest from the consumption of kerosene, follows by that from electricity consumption.

4. The Composite Effects of Energy Saving Housing

In the previous section, we have analyzed the effects when energy saving housing are constructed and during when they are occupied. In this section, we attempt to analyze the combined impact of the above two effects.

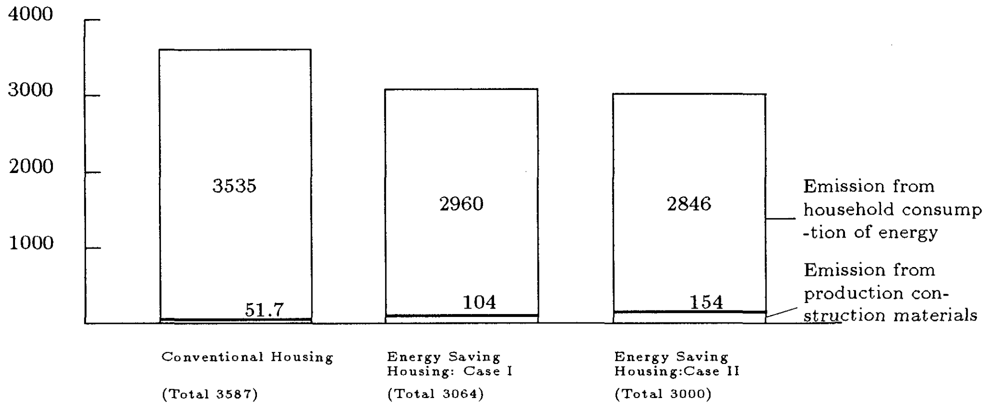
Firstly, we examine the case in which a household with an average energy consumption pattern is turned into energy saving housing. The combined effect of construction and living in energy saving housing on household expenditure and the amount of induced CO_2 emission are showed in Figure 3 and Figure 4, respectively.

Figure 3 shows the total expenditure of the construction materials used in the construction of per unit of conventional and energy saving housing, respectively, and the annual energy consumption expenditure per unit when the conventional and the energy saving housing are utilized, respectively[13].

The bar chart in Figure 3 consists of 2 portions. The lower portion shows the material costs and the upper portion indicates the household energy consumption expenditure.

As shown in Figure 3, the energy consumption expenditure per household per annum amounts to 150,224 yen for conventional houses, as compared to 131,341 yen for energy saving houses in Case I and 127,634 yen for energy saving houses in Case II. Energy saving housing has a lower energy consumption expenditure. On the other hand, in contrast to the cost of constructing per unit of conventional housing which amounts to 209,441 yen, similar cost is higher at 309,051 yen for energy saving housing Case I and 502,168 yen in the case of energy saving housing Case II. Therefore, the combined expenditure amount to 179,665

[13]Materials related to energy saving housing only. Annual costs calculation based on an assumed duration period of 20 years.



Unit: $kgCO_2$ /year. unit

Top: CO_2 emission from household consumption of energy,

Bottom: CO_2 emission from production of construction materials

Figure 4: Annual CO_2 Emission from Per Unit of Energy Saving Housing

yen for conventional housing, compared to 170,391 yen in energy saving housing Case I and 179,802 yen in energy saving housing Case II. Therefore, the combined expenditure is 9,274 yen lower in the case of energy saving housing Case I but 137 yen higher in Case II[14].

Figure 4 shows the combined effects of the induced CO_2 emission from the production of the materials used in per unit construction of conventional and energy saving housing respectively, and the annual induced CO_2 emission from utilizing per unit of these two types of housing, respectively.

The bar chart in Figure 4 is again divided into 2 portions. The lower portion indicates the induced CO_2 emission from the production of materials used in the construction of per unit of housing, while the upper portion indicates the induced CO_2 emission from the household consumption of energy.

As shown in Figure 4, in contrast to the annual induced CO_2 emission from the household consumption of energy which amounts to 3,535kg in conventional housing, similar emission is lower at 2,960kg for energy saving housing Case I and 2,846kg for energy saving housing Case II[15]. On the contrary, the induced CO_2 emission from the production of the materials used in the construction of conventional housing amounted to 52kg, while similar emission amounts to a much higher 104kg in the construction of energy saving housing Case I and 154kg in the case of energy saving housing Case II. Hence, in terms of composite CO_2 emission, both types of energy saving housing have a lower level of CO_2 emission as compared to conventional housing. For instance, the composite emission from conventional housing amount to 3,587kg, whereas the composite emission of energy saving

[14] However, it should be noted that the expenditure saving effect is greater, the higher the energy consumption level due to the more frequent usage of heater and air-conditioner.

[15] This includes only the CO_2 emissions induced from the production of materials used in the construction of energy saving housing. This is the annual emission amount calculated based on a duration period of 20 years.

housing Case I is 3,064kg and that from energy saving housing Case II is 3,000kg. In other words, the reduction in CO_2 emission amounts to 523kg in Case I and 587kg in Case II.

The latest statistical data reported that there are 37.41 million houses in Japan[16]. If all of these houses are to be converted to energy saving housing, the annual induced CO_2 emission from all households in Japan are estimated to be able to reduce by 19.57 million ton to 21.96 million ton.

Further, in terms of expenditure, Case I has an overall expenditure reducing effect of 347.9 billion yen[17]. Thus, we are able to conclude that the energy saving housing has an important effect in reducing the CO_2 emission induced from household expenditure. Furthermore, the additional costs incurred is almost negligible. Hence, the realization of these energy saving housing could be considered favourable both from the ecological and the economic points of view. This is due to the fact that the reduction in CO_2 emission resulted from the introduction of energy saving housing implies not only that the CO_2 emission from construction materials is reduced, but the CO_2 emission induced from household expenditure is also reduced tremendously. The increment and reduction in CO_2 emission when energy saving housing Case II is introduced is illustrated in Figure 5.

As shown in Figure 5, the increase in CO_2 emission resulted from increasing heat insulation or using doubled-layered glasses does not exceed 106kg per annum per house unit. However, with the increase in the heat insulation of the house, this leads to a reduction in the consumption of energy used in air-conditioner and heater, with the CO_2 emission induced form household expenditure is reduced by 689kg per annum per house unit. Further, replacing the materials used for window frames and doors from aluminum to wood also reduced the CO_2 emission by 3.7kg, thus the total reduction in CO_2 emission amounted to 692.7kg per annum per household. This is 6.5 times larger than the increased emission mentioned previously. Therefore, the overall reduction in CO_2 emission per house unit amount to 586.7kg per annum.

With respect to expenditure, the effect caused by energy saving housing is much smaller than its reduction effect on CO_2 emission. Further, in the actual construction of energy saving housing, besides the material costs mentioned above, the value added (R & D expenditure and labour costs) of the construction sector need to be paid as well. Consequently, if these expenditures are included, then the saving in expenditure from energy saving housing will become even smaller. However, the energy saving housing has the characteristic that through a small increase in the induced CO_2 emission during the construction process, the CO_2 emission during its utilization could be greatly reduced. Hence, it is worth noting that this will be able to reduce the overall CO_2 emission in Japan by 2.0–2.2%. This is particularly important for the realization of 'sustainable development'.

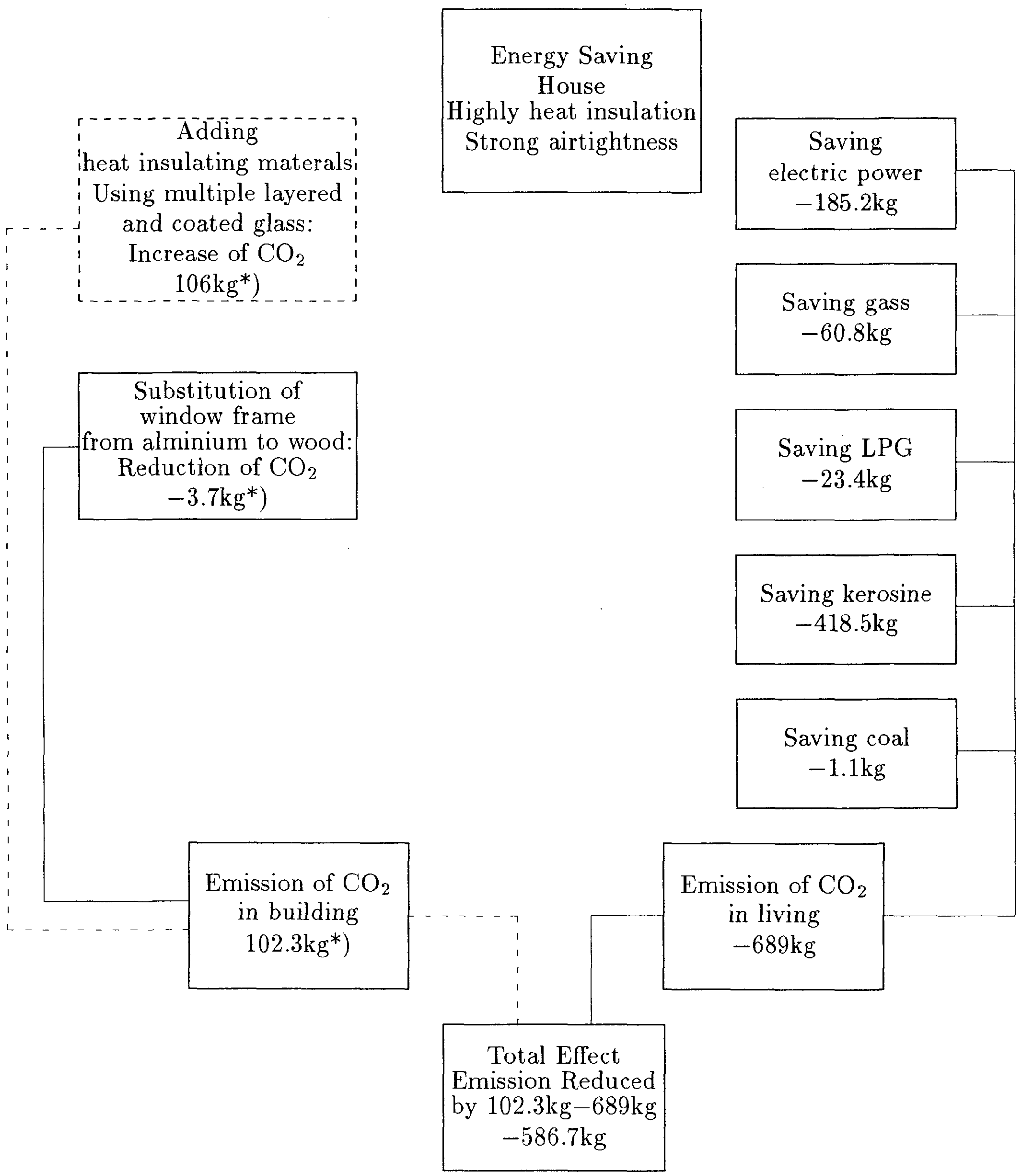
5. Conclusions

In this paper, we have analyzed the effects of constructing and living in energy saving housing respectively.

As reviewed in the previous sections, the total induced CO_2 emission of Japan could be reduced by 2.0–2.2% through the introduction of energy saving housing. Moreover, while the general impression is that to attain the reduction in CO_2 emission is a difficult task, this could be achieved through the replacement of relatively simple construction materials as shown in Table 3. Further, even if the existing houses are not reconstructed, through

[16] The figure is obtained from the *Reports on Residential Statistics*(1988).

[17] Similarly, the additional expenditure for the whole of Japan in Case II amounts to 5.24 billion yen.



Note: Dashed line means increase of CO_2 emission by building energy saving house.
Note:*) Discounted by the life of the house, 20 years.

Figure 5: Reduction of CO_2 emission from the energy saving housing compared with a traditional housing

simple replenishment works such as the strengthening of heat insulation, the saving of energy could also be attained to a considerable degree. Thus, to reduce CO_2 emission through the implementation of energy saving facilities in all housing is not a program impossible to attain. Further, this reduction effect could be attained while maintaining the present comfortable living conditions.

This point is of great importance when the preservation of the environment is to be maintained for a long term. With the modification of construction criteria, the strengthening of heat insulation in newly constructed housing has become compulsory. Hence, we hoped that the energy saving standard in existing housing could also be improved in the future. Thus for this purpose, appropriate policy inducement is required in reducing the cost associated with the replacement of insulating materials.

However, what is analyzed in this paper is limited to the energy saving effects obtained from raising the heat insulation of prefabricated housing. Nevertheless, the overall CO_2 emission in Japan could be reduced by about 2%. In addition, besides energy saving housing, there are various other new technologies and some of them are already in the implementation stages. If the effects of these other new technologies are considered as well, the effectiveness of energy saving housing could further be enhanced.

Furthermore, according to the input-output table for environmental analysis, the energy consumption of offices and shops is estimated to be 1.1 times that of household energy consumption[18]. In general, assuming that offices and shops have the same energy saving effects as prefabricated housing, then another 2.2% reduction in CO_2 emission could be obtained through the saving of energy in offices and shops. Consequently, the reduction in CO_2 emission in Japan could amount to 4.2% through energy saving in both residential and commercial buildings.

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[18] According to the table on energy consumption by sector in the Input-output Table for environmental analysis, in contrast to the household energy consumption of 300 Pal (excluding petroleum and light-oil), the value for services related sectors (the 20-22th sectors and the 24-29th sectors in the main classification) is 318 Pal.