# LIFE CYCLE $CO_2$ EMISSION CONCERNING HOUSING AND DAILY LIFE

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## ABSTRACT

The high thermal insulation of housing construction has been spreading all over Japan, for the improvement of indoor environment and the efficiency of energy consumption. From the view point of global warming, it is acknowledged that the high thermal insulation reduces $CO_2$ emission in the heating and cooling phase, but it increases $CO_2$ emission at construction phase since the amount of materials for thermal insulation increases. In this study, the effect of the high thermal insulation, simulated on the condition of both phases, is taken into consideration.

In the meantime, $CO_2$ is emitted through many activities in daily life. In order to have more effective countermeasures against $CO_2$ emission, it is important to grasp the amount of $CO_2$ emission at the phase of daily activities as well as construction, improvement and disposal. The portion of each amount is also simulated in this study.

## INTRODUCTION

In Japan, more than 35% of the total amount of $CO_2$ emission is supposed to be emitted during the construction phase and the building's use phase, and half of this 35% is supposed to be emitted by residences. In order to reduce $CO_2$ emission effectively, it is necessary to clarify some proportions of $CO_2$ emission on the housing life cycle. In this study, we calculated the influence of some factors concerning both housing and activities on daily life, which we have put into two categories.

One is the examination of the effect by raising the thermal insulation performance on housing. This is one of the effective ways for reducing heating/cooling energy. In Japan, there is "The Criteria for Owner's Judgment on the Energy Efficient Utilization in Residential Buildings" (i.e. the standard) announced by the Ministry of International Trade and Industry and the Ministry of Construction. This was established in 1980 and was amended in 1992 and 1999. The standard contains the criteria for the efficiency of thermal insulation. After this was established, high thermal insulation of residential housing gradually spread to all of Japan.

The high thermal insulation decreases $CO_2$ emission because of the reduction of energy consumption on heating and cooling. However that is supposed to increase $CO_2$ emission, because the amount of heat insulation materials and glass, etc. increases in the construction phase. It is necessary to examine both these influences in order to evaluate the effect of the high thermal insulation on the reduction of $CO_2$ emission. In present Japan especially, the influence of $CO_2$ emission in the construction phase might be large compared with the use phase, because the housing life cycle term is short. In order to confirm this, we calculated some cases numerically.

Another is the examination of the proportion of $CO_2$ emissions on various stages in the housing life cycle. It is known that an enormous amount of $CO_2$ is emitted on the energy consumption phase through heating, cooling, lighting, cooking, hot water supply, etc., more than through the construction, improvement and disposal phase. There are, however, many activities in the use phase, and $CO_2$ should be emitted during these activities, for example purchasing food, newspapers and clothing, using water and disposing of household waste. We calculated each $CO_2$ emission on these activities.

For these studies, we use $CO_2$ Intensity Units calculated using the Input-Output table of Japan (Ref.[1]). It is given as kg-$CO_2$ per unit of weight, energy, money and so on, and contains the quantity discharged from the production and transportation activities of imported article.

# 1.THE REDUCTION EFFECT BY HIGH THERMAL INSULATION

## 1-1.Methodology

Figures 1 and 2 show models for two different housing units. Figure 1 shows a detached house of wooden construction (Ref.[2]), and figure 2 shows an apartment of concrete structure (Ref.[3]). Figure 3 shows the five cities where we performed simulations. In the standard, Japan is divided into six districts, and each district has different criteria. In this study, we simulated in five districts using three standards (1980,1992 and 1999) except for Okinawa Prefecture. Thermal insulation specification, which satisfies each standard, are shown in Table 1. In all cases, mineral wool (10K) and aluminum sash, which are the most popular materials in Japan, were assumed.

Under these conditions, we estimated material quantities: mineral wool, aluminum sash, glass, and airtight sheet. Then, these quantities were multiplied by each $CO_2$ Intensity Unit, and we obtained $CO_2$ emission during the construction phase.

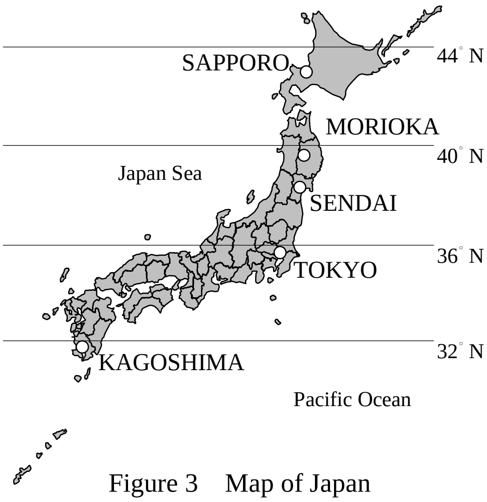



Figure 3 Map of Japan

Figure 4 shows the schedule condition of heating/cooling for the thermal load simulation. We used the program "SMASH", developed by the Building Research Institute (Ministry of Construction) for thermal simulation.

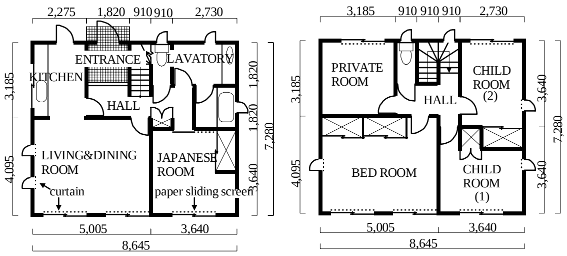
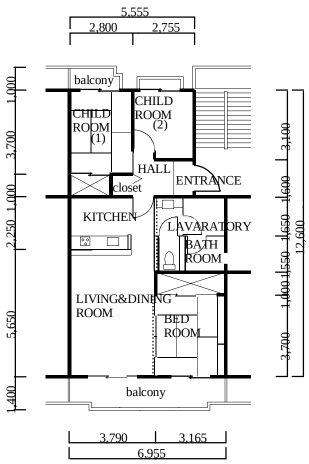



Figure 1 Plan of detached house




The total floor area
Detached house 125㎡
Apartment 81㎡

Figure 2
Plan of apartment

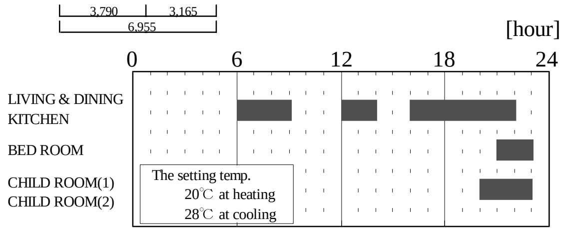



Figure 4 Schedule of heating/cooling

Table 1 Specification of model houses

| CITY | STANDARD | MINERAL WOOL 10K (mm) | | | COMBINATIONS OF WINDOWS(Types of windows) | NATURAL VENTILATION RATE(times/hour) |
|---|---|---|---|---|---|---|
| | | CELL | WALL | FLOOR | | |
| SAPPORO | 1980 | 140 | 110 | 110 | Double(single+double) | 0.5 |
| | 1992 | 230 | 135 | 135 | Triple(single+single+single) | 0.5 |
| | 1999 | 300 | 175 | 175 | Triple(single+single+single) | 0.5 |
| MORIOKA | 1980 | 65 | 45 | 40 | Single(double) | 1.5 |
| | 1992 | 150 | 100 | 100 | Double(single+double) | 1.0 |
| | 1999 | 210 | 115 | 175 | Triple(single+single+single) | 0.5 |
| SENDAI | 1980 | 65 | 45 | 40 | Single(single) | 1.5 |
| | 1992 | 100 | 100 | 100 | Single(double) | 1.0 |
| | 1999 | 210 | 115 | 115 | Double(single+double) | 0.5 |
| TOKYO | 1980 | 45 | 30 | 25 | Single(single) | 1.5 |
| | 1992 | 100 | 70 | 50 | Single(single) | 1.0 |
| | 1999 | 210 | 115 | 115 | Single(double) | 0.5 |
| KAGOSHIMA | 1980 | 25 | 0 | 0 | Single(single) | 1.5 |
| | 1992 | 100 | 45 | 30 | Single(single) | 1.0 |
| | 1999 | 210 | 115 | 115 | Single(double) | 0.5 |

The calculated heat load is divided at energy consumption of electricity, gas, and kerosene, using energy composition rate obtained by field studies and equipment efficiency of the heating/cooling equipment. These energy consumption were multiplied by each $CO_2$ Intensity Unit, and we obtained $CO_2$ emission during the heating/cooling phase. Expressions are as follows.

$$CEc = \Sigma\ (W_i \cdot I_i)/A$$
$$CEh = \Sigma\ (Rh_j \cdot I_j/Eh_j) \cdot Lh/A$$
$$CEc = \Sigma\ (Rc_j \cdot I_j/Ec_j) \cdot Lc/A$$

NOMENCLATURE

- CEc :$CO_2$ emission during the construciton phase [kg-$CO_2$/$m^2$]
- CEh/CEc:$CO_2$ emission during the heating/cooling phase [kg-$CO_2$/$m^2$・year]
- i :a kind of material;airtight sheet, mineral wool ,aluminum and glass
- j :a kind of energy;electricity,gas and kerosene
- A :the total floor area[$m^2$]
- $W_i$ :weight of material-i [kg]
- $I_i$ :$CO_2$ Intensity Unit of material-i [kg-$CO_2$/kg]
- $Rh_j$/$Rc_j$ :composition rate of energy-j in heating/cooling load[-] ($\Sigma Rh_j=1$, $\Sigma Rc_j=1$)
- $Eh_j$/$Ec_j$ :equipment efficiency of the heating/cooling equipment[-]
- $I_j$ :$CO_2$ Intensity Unit of energy-j [kg-$CO_2$/kWh]
- Lh/Lc :Heating/Cooling Load [kWh/year]

## 1-2.Results and Considerations

Figures 5 and 6 show $CO_2$ emission increases per unit of floor area during the construction phase. “Three bars representing each city” show the differences in the standards. The increment of aluminum sash, glass, mineral wool, and airtight sheet is considered in the simulation. These quantities are increments based on a house that is not using heat insulating material and is using single glazing. To raise the high thermal insulation level results in increasing the $CO_2$ emission, especially, the rates of aluminum sash and mineral wool.

Figures 7 and 8 show annual $CO_2$ emission reductions per unit of floor area during the heating/cooling phase. Three bars depicting each city show the differences in the standard similar to Figures 5 and 6. Each bar is composed of heating and cooling components. The proportion of heating and cooling is different in the five cities. However, to

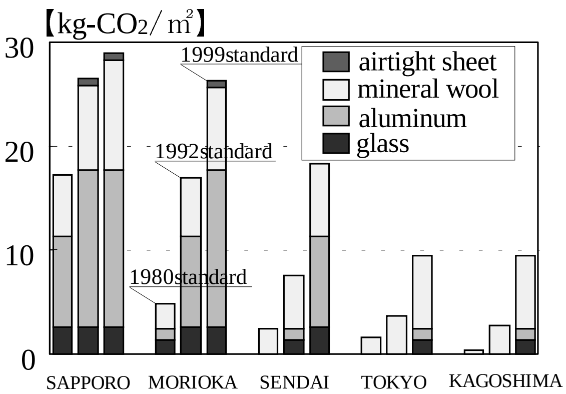



Figure 5 The increment of $CO_2$ emission during construction phase (detached house)

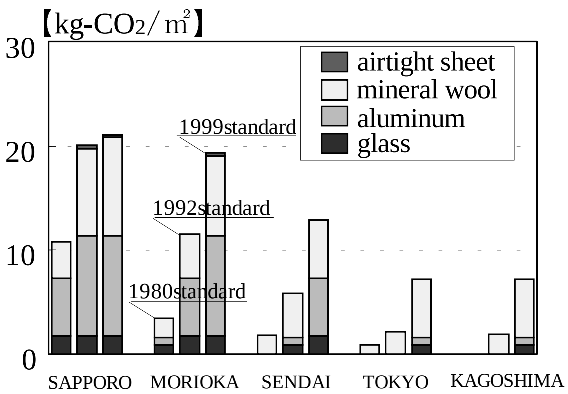



Figure 6 The increment of $CO_2$ emission during construction phase (apartment)

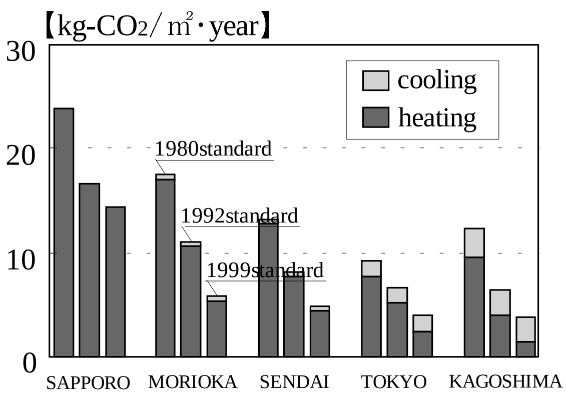



Figure 7 The annual $CO_2$ emission during heating/cooling phase (detached house)

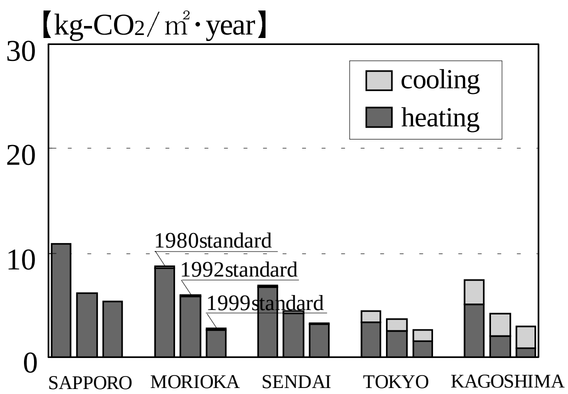



Figure 8 The annual $CO_2$ emission during heating/cooling phase (apartment)

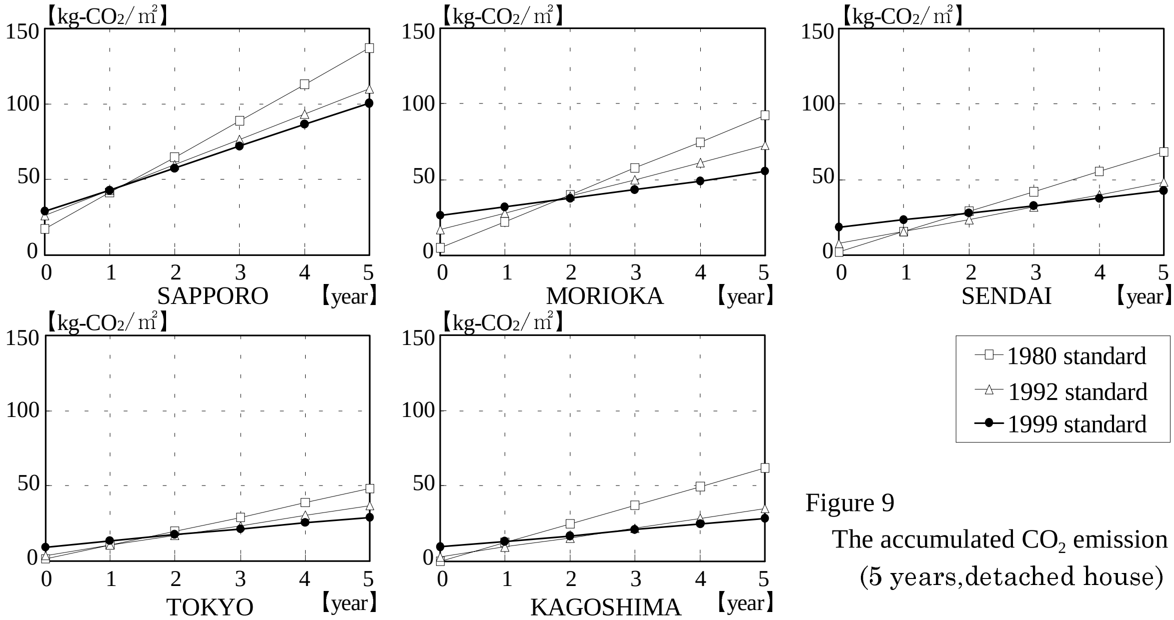



Figure 9
The accumulated $CO_2$ emission
(5 years,detached house)

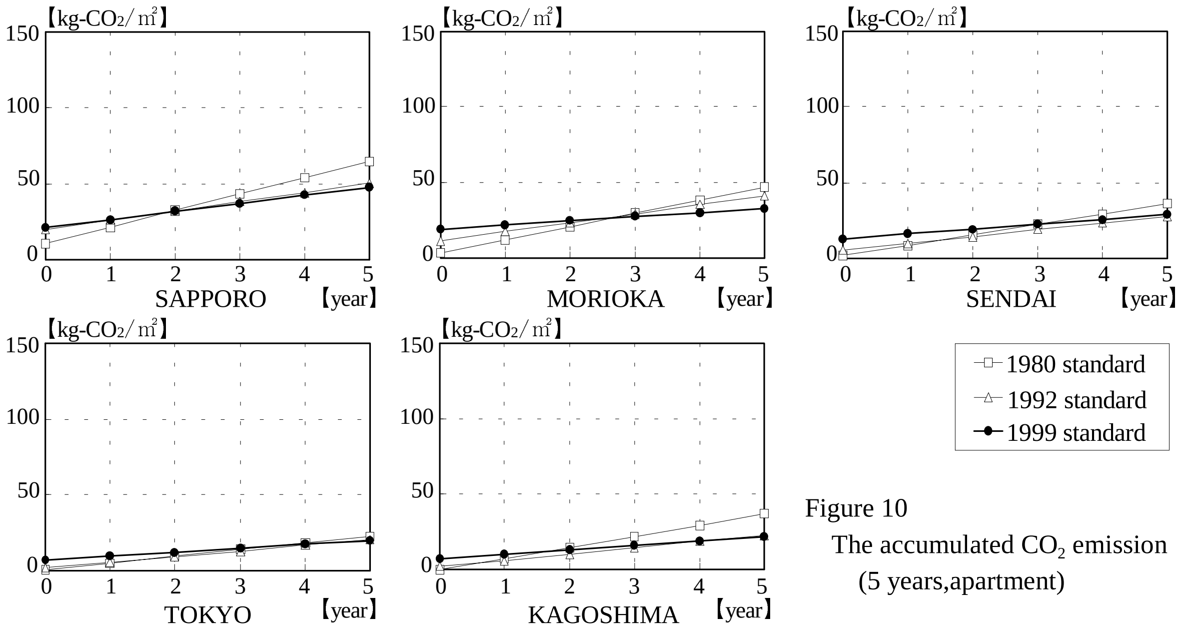



Figure 10
The accumulated $CO_2$ emission
(5 years,apartment)

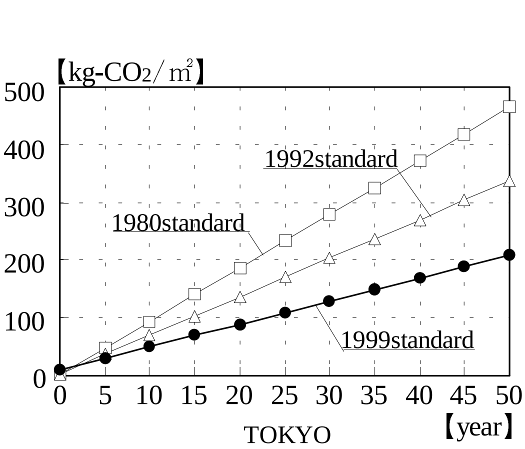



Figure 11 The accumulated $CO_2$ emission
(50 years,detached house)

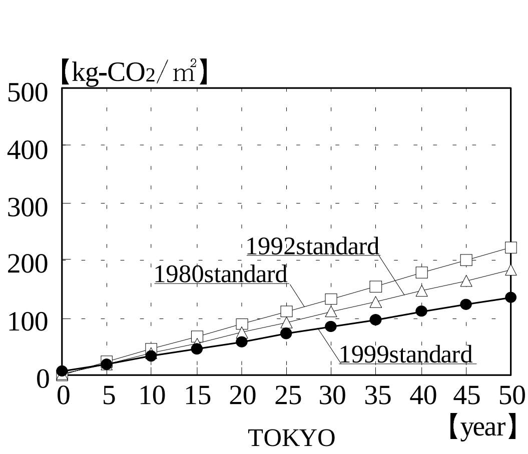



Figure 12 The accumulated $CO_2$ emission
(50 years,apartment)

raise the high thermal insulation level results in decreasing the total $CO_2$ emission.

Figures 9 and 10 show the amount of annual changes which accumulate $CO_2$ emission during the heating and cooling phase with the increment of that during the construction phase. In the graphs, the variables have respectively shown three standards. It shows that the increment of $CO_2$ emission during the construction phase is retrievable by the reduction of that during heating and cooling phase within several years.

Annual changes, in the long term, as the life of the dwelling, are shown in Figures 11 and 12. In the life of the structure, it is shown that the influence of the increment on the construction phase is considerably small.

## 2.$CO_2$ EMISSION FROM THE DAILY LIFE

### 2-1.Methodology

In this study, we estimated the annual $CO_2$ emission from the daily life of a single family. We obtaind the data about the annual expenditure of a single family from “The Annual Report on the Family Income and Expenditure Survey” issued by the Management and Coordination Agency (Ref.[4]). The survey results arranged the data from approximately 8000 households in Japan except for the single person household, the households which are involved in agriculture, fishing, and so on. It reports about 550 kinds of expenditure items.

In this study, we fundamentally limited the objective activities to inside a residential house. The report contains various expenditure items. Then we omitted some items as follows: expenditures for transportation, eating out, education and entertainment, insurance premiums, ceremonial occasions, and so on. Some items were omitted because of outside activities, and others were omitted because the relationship between expenditure and $CO_2$ emission seems to be complex and uncertain. However, we added some items related to private automobiles, because these are activities which can be controlled by the residents.

Thus we chose 351 items, and arranged these into 12 classifications such as "Food and drink", "Durable goods", "Electric appliances" and so on. A part of the chosen items and 12 classifications are shown in Table 2. These items were multiplied by each $CO_2$

Table 2 The classifications and some examples of calculated items

| | CLASSIFICATIONS | ITEMS EXAMPLE | ITEMS NUMBER |
|---|---|---|---|
| ANNUAL REPORT ON THE FAMILY INCOME AND EXPENDITURE SURVEY | Housing improvement | Repairs&maintenance,Tools for repairs& maintenance, Plumbing,Outer wall&fence,Gardening,etc. | 7 |
| | Electricity | Electricity | 1 |
| | Gas | Gas | 3 |
| | Kerosene | Kerosene | 1 |
| | Waterworks and sewerage | Water & sewerage charges | 1 |
| | Food and drink | Rice,Bread,Noodles,Sardines ,Shrimps,Oysters,Smoked fish, Canned fish,Beef,Ham,Fresh milk,Cheese,Eggs,Cabbage, Potatoes,Pickled radishes,Apples,Lemons,Oranges, Salt,Sugar, Edible oil,Cakes,Chocolate,Tea,Coffee,Beer,Wine,etc. | 176 |
| | Durable goods | Chests of drawers,Dining tables & chairs,Clocks,Beds, Curtains,Quilts,Bowls & dishes,Clothing,Bycycles, Bags,Piano,Accessories,etc. | 73 |
| | Electric appliance | Microwave oven,Refrigerators,Vacum cleaners,TV sets, Parsonal computers,Room air conditioners,Stove & fan heaters,Washing machines,etc. | 23 |
| | Newspapers and books | Newspapers,Magazines & weekly magazines,Books, Other reading | 4 |
| | Articles for consumption | Tapes,Garden plants & gardening goods, Lipsticks,Toilet soap, Medicines,Paper diapers,Stationery,etc. | 42 |
| | Others services | Tailoring charges,Washing charges,etc. | 13 |
| | Automobile | Automobiles,Other vehicles,Automotive parts,Articles related to private transportation,Automotive maintenance&repairs, Vehicular maintenance & repairs | 6 |
| | Gasoline | Gasoline | 1 |
| OTHERS | Refrigerant of air conditioners and refrigerators | It is calculated by following: The quantities and kinds of refrigerant, Retention number of air conditioners and refrigerators per single-family, and GWP values of refrigerant. | |
| | Household waste | It is calculated by following: The quantities of household waste and CO2 Intensity Unit. | |

Intensity Unit, and the calculated results were accumulated with each classification.

We added "Refrigerant of air conditioning units and refrigerators" and "Household waste" to the above items, because these are of a great concern, especially regarding the influences on global warming. To know the quantities and the kinds of refrigerants, we investigated manufacturer companies, and we also investigated the number of air conditioners and refrigerators per single family. To know the quantity of housing waste, we used the investigated reports from the Ministry of Health and Welfare and Tokyo Metropolis. The total classifications came to 15.

## 2-2.Results and Considerations

The average household in a Tokyo Metropolis ward is shown in Figure 13, and that of all of Japan is shown in Figure 14. The 15 classifications shown in Table 2 are in Figure 13 and 14, in the upper part of the “0”-axis. In addition to these, the $CO_2$ emissions calculated by $CO_2$ Intensity Units during the construction and the disposal phase are shown in the lower part of Figure 13 and 14. The results are calculated on the condition that the housing life cycle is 30 years and the floor area shown in Figure 13 and 14 are of average size in each area, Tokyo and all of Japan. These items are classified into 4 categories; “Automobile”, ”Various activities”, ”Energy consumption” and “Housing”, and these are shown at the left in Figure 13 and 14.

Both results show that the proportion of “Housing” occupied as small as about 10% of the whole, particularly in case of wooden structure, which is most popular in Japan. Though the proportion of “Energy consumption” is comparatively large, it should be noticed that the influence of the “Various activities” is also large.

There is a difference in "Energy consumption" and " Automobile " on the comparison between Tokyo Metropolis and all of Japan. Concerning "Energy consumption", it is considered that the heating method and thermal load are different resulting from

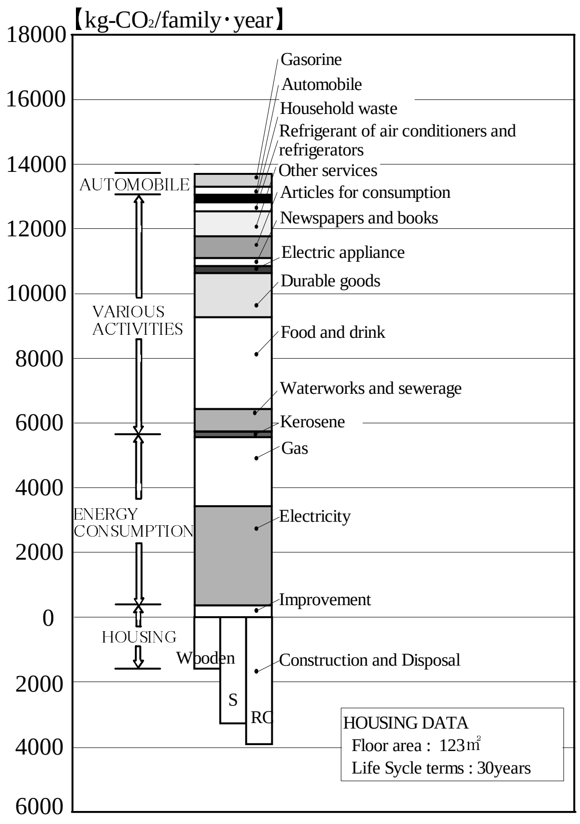



Figure 13 Annual $CO_2$ emission per family (Tokyo Metropolis ward)

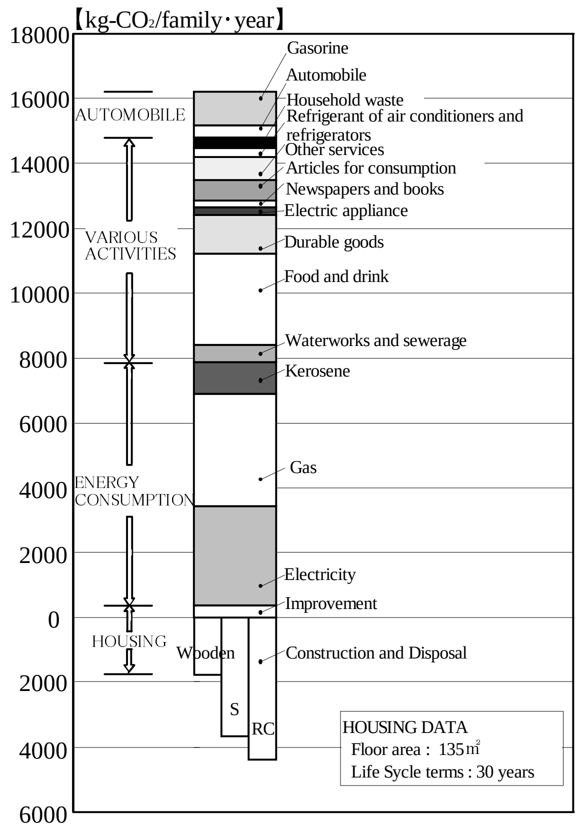



Figure 14 Annual $CO_2$ emission per family (All of Japan)

outdoor conditions. In terms of " Automobile ", it is considered that the number and mileage are different according to lifestyle.

## 3.CONCLUSIONS

In this report, we examined the reduction effect of $CO_2$ emission by high thermal insulation and all life cycle $CO_2$ proportion including the activities of residential daily life. It is confirmed that the high thermal insulation decreases total $CO_2$ emission including the construction phase and the heating/cooling phase. However, these occupied proportions are only a part in all life cycle $CO_2$ proportions. The reduction of these phases is essentially important. However, these result suggest that the improvement of the residential life style is also important for the general reduction of the $CO_2$ emission related to housing and daily life.

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