THE EXISTING HOUSING TYPOLOGY IN JAPAN AND PROPOSALS TO IMPROVE INSULATION PERFORMANCE LEVELS

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Summary

Detailed field studies were carried out on a sample of 346 detached houses in Japan during 2002-2004 to determine their typical specifications of heat insulation according to geo-climatic region. Based on this research, effective methods of improving heat insulation have been elaborated according to the region and the age of the building, and an Existing Housing Typology was thereby developed. Next, the macroscopic effect of reducing CO_2 emissions through implementation of improved thermal insulation has been calculated for each region, and a projection is given of the possible resulting reduction in CO_2 emissions by 2020.

1. Background

Postwar housing policies in Japan have focused on new construction and the average life-span of a detached house is very short (25-30 years) in comparison with houses in occidental countries. Currently, there are ca. 45 million dwelling units in Japan, but there is hardly any basic information about their performance in terms of energy efficiency. Such information is indispensable for developing new policies to improve the efficient use of energy and other resources, as well as for enhancing the quality of life in the residential built environment on a national and local level. This especially important given that Japan has a rapidly ageing society and renewing homes accordingly should be a priority. Providing nationwide information about such energy efficiency will also contribute to the reduction of Japan's CO_2 emissions.

2. Objectives

Our study was carried out paying regard to prior research by the City of Duisburg, Germany (cf. Reference1) in order to investigate and compare the actual conditions of the existing housing stock in Japan according to geo-climatic region, especially in terms of heat insulation performance. The results were used to estimate the effect of the proposed thermal insulation improvement on a regional level.

3. Existing Housing Typology and proposed methods of improving heat insulation

3.1 Study method

In order to systematically investigate the actual specifications and performance of thermal insulation of existing detached houses according to the geo-climatic divisions of the National Energy Conservation Standard 1999 (hereinafter referred to as ECS; cf. *Figure 1*), research was conducted during 2002-2004 through (a) inviting responses to an online questionnaire, and (b) field research on site. The general characteristics of each detached house in the study were investigated (ECS region, year of completion and construction method), as well as the specifications of its components (finishing, substrate and insulation) in five major building elements (roof, ceiling of the top storey, external walls, windows, and floor of the bottom storey) to be insulated. Only houses built after the Second World War were studied, and these were categorized into four groups according to the years when ECS standards became effective and when they were amended: Period 1 (1945-1981), Period 2 (1982-1991), Period 3 (1992-1998), and Period 4 (1999-2004).

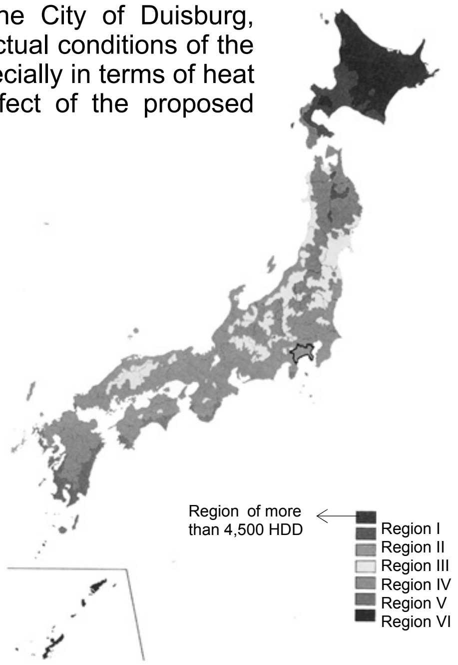


Figure1: Geo-climatic regional division of the National Energy Conservation Standard 1999 (cf. Reference 2):
according to the value of Heating Degree Days D_{18-18}

3.2 Location and numbers of houses studied

A total number of 346 detached houses were studied, located in 15 municipalities in the regions I, III, IV, V and VI (cf. Tables 1, 2). Detailed analysis was carried out on the 240 of these houses that were built with the most common and conventional timber frame method. To estimate the effect of improving heat insulation in these houses, the specifications and performance of existing heat insulation in major building elements was analyzed over time, and future projections of performance were developed.

Table 1: Location of houses in the study

Region	City/PREFECTURE
Region I	Asahikawa, Iwamisawa/HOKKAIDO
Region II	None
Region III	Aomori /AOMORI , Iida/NAGANO
Region IV	Iwaki/FUKUSHIMA, Tokyo Metropolitan Area, Yokohama/KANAGAWA, Yamanash/YAMANASHI, Tottori/TOTTORI, Shizuoka/SHIZUOKA, Gifu/GIFU
Region V	Kagoshima, Ibusuki, Sendai/KAGOSHIMA
Region VI	Naha/OKINAWA

Table 2: Number of houses according to region and construction method (Total: 346)

Region	Construction Method					
	Conventional Timber Frame	2×4 Wooden	RC	Steel	CB	Hybrid Structure
Region I	47	4	1	0	1	3
Region III	60	2	0	0	0	1
Region IV	67	15	5	4	0	1
Region V	66	0	16	5	0	2
Region VI	0	0	41	0	2	3
Total	240	21	63	9	3	10

3.3 Condition of existing timber frame houses

In Japan, postwar industrial production of the major parts of conventional timber frame houses has allowed diversification and improvement of their performance. Our study has revealed that heat insulation measures, among other improvements, have spread widely since the 1990s. Regions I and IV in particular have a stock of houses with high heat insulation. In Region IV, the performance of external walls is high and nearly 80% of investigated houses recorded a performance level higher than the National Energy Conservation Standard 1992. Fewer than 10% of the investigated houses recorded a lower level of heat insulation than the previous ECS, regarding the major building parts, except for the bottom floor. In addition, *Figure 3* shows that the roof, the ceiling of the top floor and the external walls have had more than 1.00m^{2}K/W of heat transmission resistance even since Period 1, and that the performance of roofs and ceilings improved by nearly 400% between period 1 and 4.

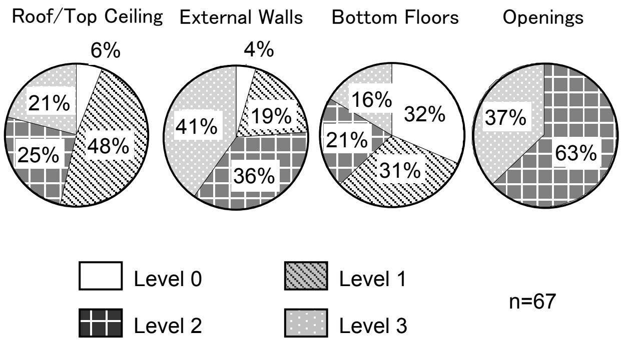


Figure 2: Heat insulation ratios of the houses studied in Region IV, compared with ECS requirements

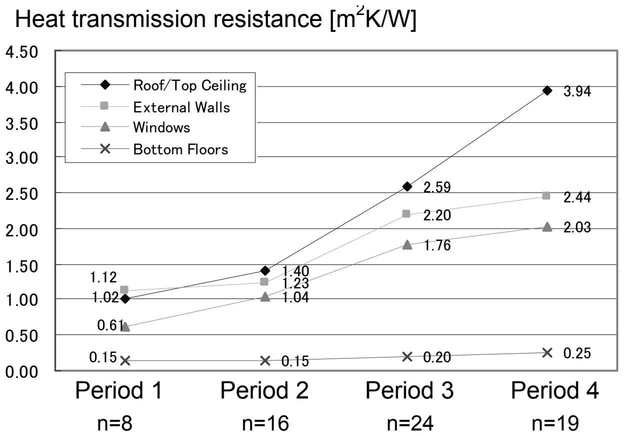


Figure 3: Transition of Heat Transmission Resistance regarding each Major Building Part of Houses in Region IV

In this study, the performance levels of heat insulation are defined as Level 1 to 3 according to the requirement of the National Energy Conservation Standard, which was established in 1980 followed by upgrading in 1992 and in 1999. Level 0 represents that of BaU (business as usual) before 1980. (cf. Table 3)

Table 3: Performance levels of Heat Insulation according to the Energy Conservation Standards

Level 0	No Energy Conservation Standard
Level 1	Energy Conservation Standards 1980
Level 2	Energy Conservation Standards 1992
Level 3	Energy Conservation Standards 1999

3.4 Housing typology of existing detached timber frame houses

From the results of the above investigations, the most common building materials, components and insulation were extracted according to major building element and region. This basic information was compiled into an Existing Housing Typology, including the typical specifications and performance of major building elements according to the region and age of existing houses. Table 4 shows these results for Region IV.

Table 4: Housing Typology of Existing Conventional Detached Timber Houses in Region IV

	Typical House Selected	Major Specification		Heat Transmission Coefficient (W/m^2k)
Period 1: 1946～1981	**Mean completion year: 1977**  Conventional layout with continued rooms along a southern interior verandah	Roof	-Japanese roof tile	1.11
		Ceiling (Top floor)	-Perforated acoustic board -Heat insulation: Glass wool 10K 25 mm	
		External wall	- Lysine sprayed, on the lath mortar bedding	0.84
		Internal wall	-Coated plywood board -Heat insulation: Glass wool10K 50 mm	
		Floor (Bottom floor)	-Flooring board -Heat insulation：None	2.44
		Opening	-Aluminum sash, with single-glazing	6.51
Period 2: 1982～1991	**Mean completion year: 1987**  Modern layout of LDK + Individual Bedrooms, keeping the conventional design aspects of the 1st generation	Roof	- Japanese roof tile	0.78
		Ceiling (Top floor)	-Vinyl cloth on plaster board bedding -Heat insulation: Glass wool 10K 50 mm	
		External wall	-Lysine sprayed, on the lath mortar bedding	0.77
		Internal wall	-Vinyl cloth on plaster board bedding -Heat insulation: Glass wool 10K 50 mm	
		Floor (Bottom floor)	-Flooring board -Heat insulation: Polystyrene foam 20mm	1.02
		Opening	-Aluminum sash, with single-glazing	6.51
Period 3: 1992～1998	**Mean completion year: 1995**  Strong influences from the industrialized housing design	Roof	- Industrial cement roof tile	0.44
		Ceiling (Top floor)	-Vinyl cloth on plaster board bedding -Heat insulation: Glass wool 10K 100 mm	
		External wall	- Industrial cement siding	0.45
		Internal wall	-Vinyl cloth on plaster board bedding -Heat insulation: Glass wool 10K 100 mm	
		Floor (Bottom floor)	-Flooring board -Heat insulation： Polystyrene foam 50mm	0.58
		Opening	-Aluminum sash, with single-glazing	6.51
Period 4: 1999～2005	**Mean completion year: 2001**  Strong influences from the industrialized housing design	Roof	-Roof tile	0.35
		Ceiling (Top floor)	-Vinyl cloth on plaster board bedding -Heat insulation: Glass wool 24K 100 mm	
		External wall	-Industrial cement siding	0.45
		Internal wall	-Vinyl cloth on plaster board bedding -Heat insulation: Glass wool 10K 100 mm	
		Floor (Bottom floor)	-Flooring board -Heat insulation： Polystyrene foam 45mm	0.48
		Opening	-Aluminum sash, with double -glazing	4.65

3.5 Improved methods of heat insulation and related construction costs

Methods to improve heat insulation were selected according to the criteria that they followed generally established construction techniques in Japan, and that work could be carried out while the residents remained living in the house. This gave eleven improvement methods for the four major building elements shown below in Table 5. The performance of thermal insulation was set to meet the requirements of specification standard provided in ECS 1999 for each building part to be repaired. The related construction costs were estimated on the basis of the standard model house shown in *Figure 4*.

Table 5: Improved Methods of Heat Insulation (cf. Reference 3)

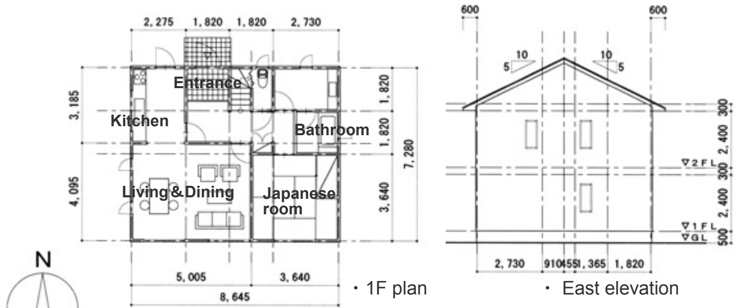
Building Element	Improved Method of Heat Insulation	Specification & Performance of Heat Insulation	Approx. Cost per House*
1. Roof / Ceiling of top floor	1) External heat insulation of roof: The roofing material is removed to install insulation beneath. The work can be done from the outside without affecting the residents. ➢ Existing heat insulation on ceiling is removed	Heat Insulation: Polystyrene foam t=115mm Thermal conductivity: 0.028W/m・K Thermal resistance: 4.10 m^2・K/W	1,508,000 yen 16,150 yen/m^2
	2) Insulation for blowing onto attic ceiling: The work is done in the attic alone. ➢ Existing heat insulation on ceiling can be preserved, when it is still in good condition.	Heat Insulation: Glass wool 20K t=200mm Thermal conductivity: 0.049W/m・K Thermal resistance: 4.08 m^2・K/W	282,000 yen 4,500 yen/m^2
2. External Walls	3) External insulation added to the external walls: The work can be done from the outside without affecting the residents. ➢ Only applicable when there is no internal condensation or decay in wall structure ➢ Existing wall insulation can be kept if in good condition.	Heat Insulation: Polystyrene foam t=50mm Thermal conductivity: 0.028W/m・K Thermal resistance: 1.79 m^2・K/W	1,945,000 yen 12,960 yen/m^2
	4) Insulation added within the external walls: The external wall finishing is removed, and the work is done from the outside. ➢ Existing insulation inside the walls is to be removed	Heat Insulation: Polystyrene foam t= 50mm Thermal conductivity: 0.028W/m・K Thermal resistance: 1.79 m^2・K/W	2,669,000 yen 17,800 yen/m^2
3. Bottom Floor / Foundations	5) Under floor insulation (A): The work is done within the cavity without removing the floors. ➢ Existing insulation can be kept if it is in good condition.	Heat Insulation: Glass wool 32 ㎏ t=80 Thermal conductivity: 0.036W/m・K Thermal resistance: 2.22 m^2・K/W	186,000 yen 3,200 yen/m^2
	6) Under floor insulation (B): Flooring must be removed to conduct the work. ➢ Existing insulation in the floors is to be removed	Heat Insulation: Polystyrene foam t= 65mm Thermal conductivity: 0.028W/m・K Thermal resistance: 2.32 m^2・K/W	732,000 yen 12,670 yen/m^2
	7) Heat insulation to the rise of the foundation: The work is done either externally or internally. ➢ Existing insulation is to be removed	Heat Insulation: Polystyrene foam t= 50mm Thermal conductivity: 0.028W/m・K Thermal resistance: 1.79 m^2・K/W	194,000 yen 10,200 yen/m^2
4. Openings	8) Replacement of glazing: Existing glazing are replaced by new glazing of higher performance leaving the existing window frames.	Glazing: Attachment type FL3＋A6＋FL3 Heat transmission coefficient: 3.36W/m^2・K	442,000 yen 16,400 yen/m^2
	9) Double glazing: A second glazing layer is added to the inside of each window.	Window: Existing single-glazed aluminum ＋ new single glazed resin frame window Heat transmission coefficient: 2.91W/m^2・K	1,309,000 yen 48,000 yen/m^2
	10) Replacement of entire window with one that has better insulating properties.	New aluminum frame window・FL3＋A6＋FL3 Heat transmission coefficient: 3.36W/m^2・K	2,258,000 yen 79,000 yen/m^2
	11) Shading: Heat and glare from sunlight reduced by adding shading in relevant areas.	Aluminum eave: D=450 Adjustable aluminum louver	127,000 yen 42,300 yen/part

＊Approximate Cost in RegionⅣ in 2004.

Based upon the above typology of existing housing, a model of a typical house was developed in order to calculate the Q value, or heat loss coefficient, to indicate the performance of the house before insulation is improved. (cf. Table 6) The plan of the model house was made (cf. *Figure 4*) taking into consideration "the standard model" of the Architectural Institute of Japan, since it is the most representative academic body in the field in Japan.

Table 6: Q value of model house before Improvement

	Region Ⅲ	Region Ⅳ	Region Ⅴ
Period 1	9.03 Level 0	4.97 Level 1	9.03 Level 0
Period 2	3.65 Level 1	3.84 Level 2	4.82 Level 1
Period 3	3.17 Level 1	3.11 Level 2	4.72 Level 1



Total floor area: 126m^2 Height of ceiling: 2.4m Opening ratio: 24%

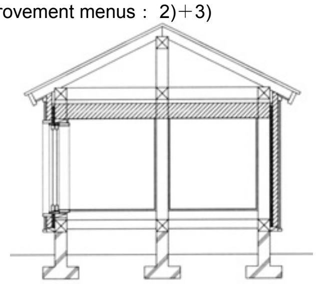
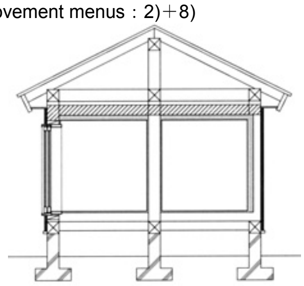
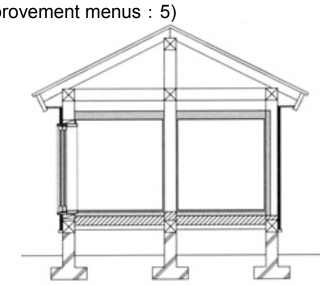
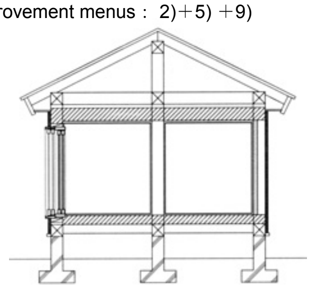
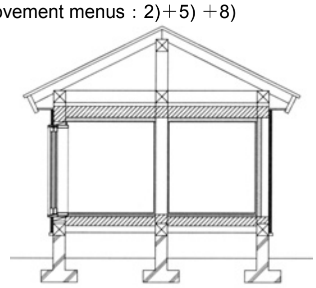
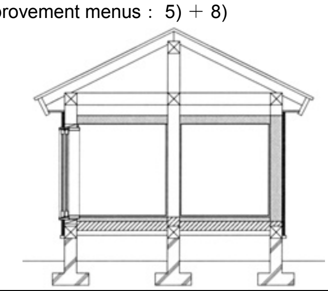
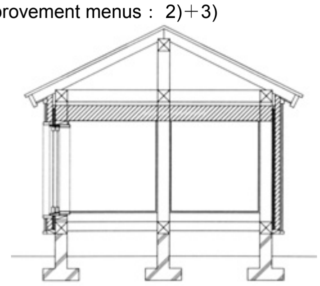
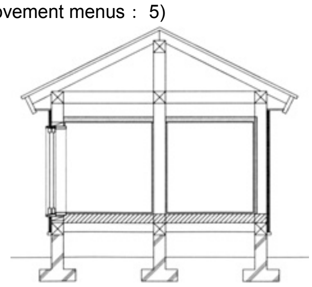
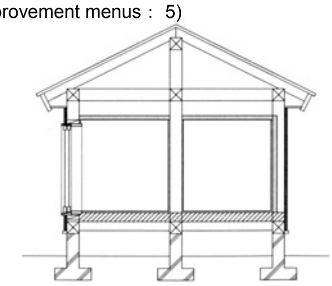
Figure 4: Outline of Model House (cf. Reference 4)

3.6 Proposed menu of heat insulation improvements

The next part of the study focused on the 193 houses in Regions III, IV and V, where most sample houses were located. A proposed menu of improvement insulation methods was developed for these homes, targeting especially older houses which had the lowest levels of existing insulation.

A diverse combination of improvement methods is available according to regional characteristics. In this study, between 90 and 130 possible combinations of improvement methods were examined for houses of each age period, and the Q value of the improved house has been calculated in order to compare it with the original Q value (ΔQ value). In addition, the construction costs were estimated to analyze the cost performance of the proposed improvement menu. Table 7 shows the best combinations of improvement methods in terms of cost performance (ΔQ value/improvement cost) according to region.

Table 7: Best Menus of Heat Insulation Improvement for Conventional Detached Timber Frame Houses

Region III Conventional Detached Timber Frame House		
Period 1 (1945-1981)	Period 2 (1982-1991)	Period 3 (1992-1998)
III-1 Level 0(No ECS) ➔ Level 2 (ECS 1992) Improvement menus： 2)＋3)	III-2 Level 1 (ECS 1980) ➔ Level 2 (ECS 1992) Improvement menus：2)＋8)	III -3 Level 1 (ECS 1980) ➔ Level 2 (ECS 1992) Improvement menus：5)
		
Q value=3.00, ΔQ value=6.03, Cost=¥1,993,000 , ΔQ /Cost=3.025$\times10^{-6}$ ※Repair of external walls included.	Q value=3.05 ΔQ value=0.60 Cost=¥648,000 , ΔQ /Cost=0.925$\times10^{-6}$	Q value=3.03 , ΔQ value=0.14 Cost=¥166,000 , ΔQ /Cost=0.843$\times10^{-6}$
Region IV Conventional Detached Timber Frame House		
Period 1 (1945-1981)	Period 2 (1982-1991)	Period 3 (1992-1998)
IV-1 Level 1(ECS1980) ➔ Level 3(ECS 1999) Improvement menus： 2)＋5) ＋9)	IV-2 Level 2(ECS 1992) ➔ Level 2' (ECS 1992) Improvement menus：2)＋5) ＋8)	IV-3 Level 2 (ECS 1992) ➔ Level 3 (ECS 1999) Improvement menus： 5) ＋ 8)
		
Q value=2.53 , ΔQ value=2.44 Cost=¥1,777,000 , ΔQ /Cost=1.373$\times10^{-6}$	Q value=2.77 , ΔQ value=1.07 Cost=¥909,000 , ΔQ /Cost=1.177$\times10^{-6}$	Q value=2.54 , ΔQ value=0.57 Cost=¥627,000 , ΔQ /Cost=0.909$\times10^{-6}$
Region V Conventional Detached Timber Frame House		
Period 1 (1945-1981)	Period 2 (1982-1991)	Period 3 (1992-1998)
V-1 Level 0 (No ECS) ➔ Level 2 (ECS 1992) Improvement menus： 2)＋3)	V-2 Level 1 (ECS 1980) ➔ Level 2 (ECS 1992) Improvement menus： 5)	V-3 Level 1 (ECS 1980) ➔ Level 2 (ECS 1992) Improvement menus： 5)
		
Q value=3.00 , ΔQ value=6.03 Cost=¥1,659,000 , ΔQ /Cost=3.634$\times10^{-6}$ ※Repair includes external walls	Q value=3.59 , ΔQ value=1.23 Cost=¥138,000 , ΔQ /Cost=8.913$\times10^{-6}$	Q value：3.59 , ΔQ value=1.13 Cost=¥138,000 , ΔQ /Cost=8.188$\times10^{-6}$

Existing heat insulation　　Added heat insulation

3.7 Data on Existing Housing Typology

All the above results were compiled together into a “before-and-after” format to show effects of improved insulation and estimates of related construction costs (cf. *Figure 5*). This format clarifies the information to make it easier for users to refer to the appropriate house type and age that is similar to a case they might be considering. In the example below, the left half of the chart shows basic details of a typical house before improvement, while the right half includes all the alternative proposals and the estimated data after improvement. The cost performance of the respective building elements is also shown for each method of improved insulation, which allows the expected reduction in energy consumption to be indicated for the various combinations of the proposed improvement methods. In this way, the charts can contribute to promoting the more efficient use of resources.

Existing Housing Typology：Conventional Wooden Detached House of Period 1 〈BEFORE〉

Regional Devision：Region IV Tsuzuki Ward, Yokohama
Year of Compeletion：1945～1981
Building Method：Conventional Wooden

This type has conventional layout with continued rooms along a southern interior verandah. Also the characterristics of the 1st generation are:sliding shutters, large low sash sliding windows, dry-built balconies, etc.

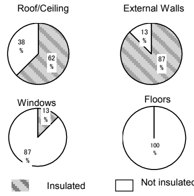


Figure 1 Heat Insulation Ratio of the researched houses in Region IV. Where the ratio is low, such as window and floor of the bottom floor, is recommended to be improved for the renovation.

Existing Housing Typology：Conventional Wooded Detached House Renovation Model from Level 1 to Level 3 〈AFTER〉

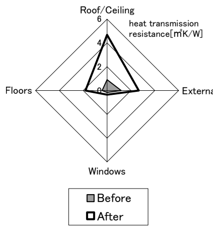


Figure 2：Comparison of heat transmission resistance to BEFORE and AFTER.

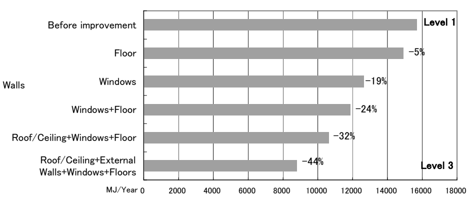
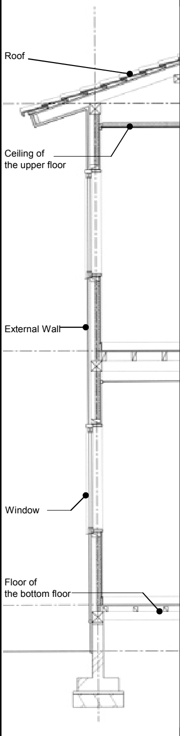


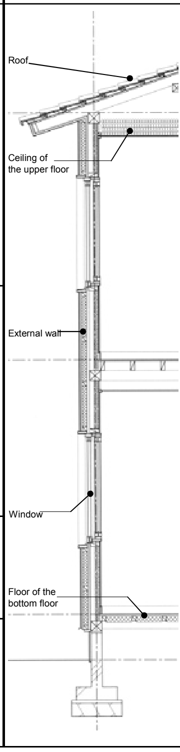
Figure 3 Comparison of annual thermal loading of BEFORE and AFTER. When the heat insulation of all parts improved, annual thermal loading is estimated to be reduced to ca. 44 %.

Sectional Detail before Renovation



Description		Heat Transmission Coefficient [W/m²K] (ECS1982 for Region IV)
Roofing	Japanese roof tile	1.11 (0.92)
Substrate 1	asphalt roofing	
Substrate 2	Sheathing roof board t=12mm	
Heat insulation	None	
N.B.		
Ceiling finish	perforated acoustic board t=9mm	
Substrate	Suspended timber frame	
Heat insulation	Glass wool 10K 25mm	
N.B.		
External wall finish	Lysine sprayed	0.84 (1.29)
Substrate 1	Mortar t=20	
Substrate 2		
Substrate 3		
Heat insulation	Glass wool 10K 50mm	
Internal substrate		
Internal finish	coated plywood board t=4.5mm	
N.B.		
Sash	Aluminum	6.51 (6.98)
Glazing	Single glass	
N.B.		
Floor finish	Flooring board t=12mm	2.44 (1.26)
Substrate 1		
Heat insulation	None	
N.B.		

Sectional detail after renovation



Description		HTC after renovation [W/m²K]	Renovation Cost [Yen/m²]	Annual gain of running cost [Yen]
Roofimg	Japanese roof tile	0.21	5,500-4,500	2,100
Substrate1	asphalt roofing			
Substrate 2	Sheathing roof board t=12mm			
Heat insulation	None			
N.B.	The status quo			
Ceiling finish	perforated acoustic board t=9mm			
Substrate	Suspended timber frame			
Heat insulation	GW for blowing 20k t=200mm			
N.B.	Reinforcement of the ceiling suspension			
External wall finish	Cement siding t=15mm	0.38	18,000-13,000	3,100
Substrate 1	Furring strips t=18mm			
Heat insulation1	Polystyrene foam t=50mm			
Substrate2	Lysine sprayed on Mortar t=20			
Heat insulation	Glass wool 10K 50mm			
Internal substrate				
Internal finish	coated plywood board t=4.5mm			
N.B.	External insulated layer to be added to the existing walls			
Sash	Aluminum+Resin sash	2.91	53,000-48,000	5,100
Glazing	Single glazing			
N.B.	Internal windows to be added to the existing windows			
Floor finish	Flooring board t=12mm	0.55	8,200-3,200	1,300
Substrate 1				
Heat insulation	Glass wool 32K t=80mm			
N.B.	The heat insulator is filled between the floor joists.			

Figure 5: “Before-and-after” Data Sheet in Region IV

4. Estimating the macroscopic effects of improving housing insulation

4.1 Conditions of the estimate

Based on the detailed studies described so far, estimations were made of the macroscopic effects when the relevant improvement of housing heat insulation is carried out in the relevant regions. This could be extrapolated to show the expected nationwide energy savings and reduction of CO_2 emissions, which are essential in Japan’s contributions to coping with the problems of global warming. The total amounts of energy saving as well as CO_2 emission reduction in three regions have been estimated according to the following conditions:

1. Subject of estimate: All detached wooden houses in Nagano (Region III), Kanagawa (Region IV) and Kagoshima (Region V)

2. Period of estimate: 2000-2020 (Measures to be implemented after 2005)

3. Details of improvements: the menu illustrated in Table 7.

Table 8 shows the composition of the existing housing stock to be improved, according to region. The amount of turnover in the housing stock in the period 2000 to 2020 was estimated on the basis of the actual numbers in 1998 (cf. Reference 5), an estimate of the total housing stock in each prefecture, and the annual amount of new houses that are expected to be built (cf. Reference 6). It was also assumed that all houses built before 1981 would be demolished by 2020.

Table 8: Changes in housing stock composition

		2000		2005		2010		2015		2020	
		Number of houses	%	Number of houses	%	Number of houses	%	Number of houses	%	Number of houses	%
Nagano	Period 1	246,999	52.7%	222,081	45.6%	193,643	38.8%	153,049	30.3%	110,687	21.8%
	Period 2	117,800	25.2%	117,800	24.2%	117,800	23.6%	117,800	23.3%	117,800	23.2%
	Period 3	86,900	18.6%	86,900	17.8%	86,900	17.4%	86,900	17.2%	86,900	17.1%
	Period 4	16,601	3.5%	60,727	12.5%	100,948	20.2%	147,323	29.2%	192,570	37.9%
	total	468,300	100%	487,508	100%	499,292	100%	505,072	100%	507,957	100%
Kanagawa	Period 1	584,464	48.7%	490,076	38.8%	383,307	29.6%	221,240	16.9%	51,806	4.0%
	Period 2	317,500	26.4%	317,500	25.1%	317,500	24.5%	317,500	24.3%	317,500	24.5%
	Period 3	239,000	19.9%	239,000	18.9%	239,000	18.5%	239,000	18.3%	239,000	18.5%
	Period 4	60,336	5.0%	217,909	17.2%	355,270	27.4%	527,535	40.4%	686,771	53.0%
	total	1,203,300	100%	1,264,485	100%	1,295,077	100%	1,305,275	100%	1,295,077	100%
Kagoshima	Period 1	241,085	55.1%	223,487	50.0%	201,184	45.0%	165,045	37.6%	126,769	29.7%
	Period 2	110,500	25.2%	110,500	24.7%	110,500	24.7%	110,500	25.2%	110,500	25.9%
	Period 3	79,300	18.1%	79,300	17.7%	79,300	17.7%	79,300	18.1%	79,300	18.6%
	Period 4	7,015	1.6%	34,102	7.6%	56,286	12.6%	84,267	19.2%	109,677	25.7%
	total	437,900	100%	447,389	100%	447,269	100%	439,112	100%	426,246	100%

Next, the implementation ratio of insulation improvement to the total housing stock in each region was examined. Taking into account the fact that such work is rare in Japan at present, the ratio was set 0% for the period of 2000-2005. After 2005, three patterns of implementation were proposed, and the macroscopic effects of each pattern were calculated. Those patterns apply equally to all the regions (cf. Table 9).

Table 9: Implementation Ratio of Insulation Improvement to Total Housing Stock

Base reference case （No improvement of insulation）	Insulation measures are applied only to new construction（according to ECS 2000), while no such work is carried out on the existing housing stock.
Scenario 1	Heat insulation improvement is applied to;
Period 1 (1945-1981):	1% of the total annual housing stock of the Period 1
Period 2 (1982-1991):	2005-2010: 0.5% of the total annual housing stock of the Period 2, and after 2010: 1%
Period 3 (1992-1998):	2005-2010: none, and after 2010: 0.5% of the total annual housing stock of the Period 3
Period 4 (1999-2005):	None
Scenario 2	Insulation improvement is applied to;
Period 1 (1945-1981):	5% of the total annual housing stock of the Period 1
Period 2 (1982-1991):	2005-2010: 2.5% of the total annual housing stock of the Period 2, and after 2010: 5%
Period 3 (1992-1998):	2005-2010: none, and after 2010: 2.5% of the total annual housing stock of the Period 3
Period 4 (1999-2005):	None

4.2 Result of the assumption

Based on the above condition and the annual thermal loadings of respective improvement menus shown in Table 7, the amount of energy consumption and CO_2 gas emission have been calculated (cf. *Figure.6* and Table 10). The reduction effect through improvement is highest in Kagoshima, followed by Nagano and Kanagawa. In the case of Kagoshima, the reduction rate of energy consumption in 2020 is 4.0% by Scenario 1 and 17.9% by the Scenario 2. Even in Kanagawa, where the resulting effect is the lowest, the reduction rate is 2.4% by Scenario 1, while 6.2% by the Scenario 2.

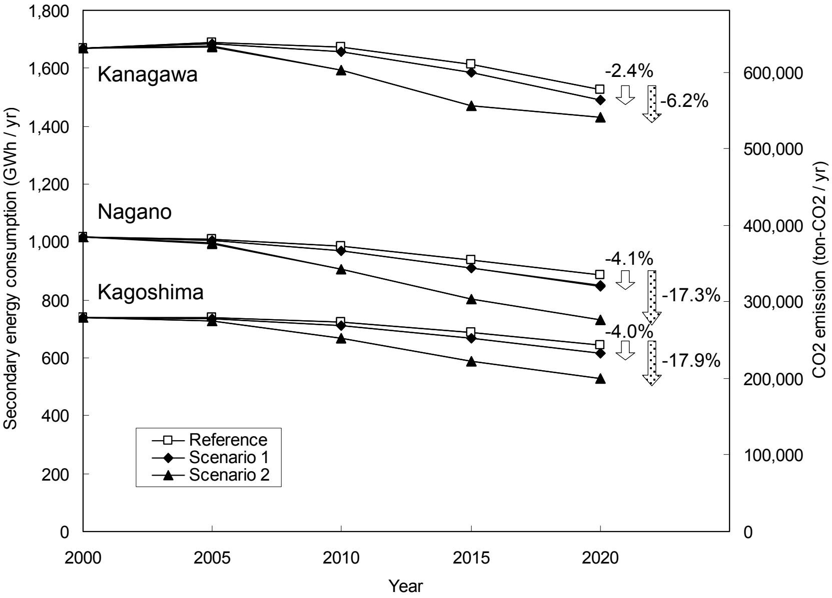


Figure 6: Estimated Total Amount of Energy Consumption and CO_2 Emissions by Region

Table 10: Estimated Reduction volume and rate of secondary energy and CO2 emission in 2020

	Reduction volume and rate from Reference Case		
	Secondary Energy (MWh)	CO_2 Emission (t-CO2)	Reduction rate
Kanagawa			
Scenario 1	36,323	17,730	-2.4%
Scenario 2	94,920	35,880	-6.2%
Nagano			
Scenario 1	36,713	152,811	-4.1%
Scenario 2	13,838	57,763	-17.3%
Kagoshima			
Scenario 1	26,008	115,148	-4.0%
Scenario 2	9,831	43,526	-17.9%

Note:

Conversion rate from annual heat loading to secondary energy (electricity) is 3.6MJ/kWh (SI unit)

Conversion rate from electricity to CO_2 is 0.378(kg-CO_2/kWh) (cf. Reference 7)

4.3 Analysis on the result

As shown in *Figure 6* and Table 10 above, it was discovered that Scenario 2 in particular would provide extremely high improvements in every region. However, given that improved insulation is seldom installed in Japanese houses at present, it seems unlikely that either Scenario will be implemented immediately. Nevertheless, this data is valuable in making clear that improving thermal insulation in the housing stock could be an effective way of reducing energy use. In addition, the percentage of detached houses in the Region III, IV and V among the total housing stock is 88.2%. This further underscores the fact improving thermal insulation in houses in those regions would have a major impact on efforts to reduce energy consumption in Japan as a whole.

5. Conclusions

This study revealed the actual, detailed conditions of various types of detached house in different regions of Japan, examined optimal heat insulation improvement models conforming to the characteristics of each region, and provided an estimate of the macroscopic effects of implementing such improvement measures. Given its ageing society, it is presumed that Japan will experience a drastic decrease in the construction of new houses in future, while repair or renovation works will become a major issue. Therefore, energy saving measures for detached houses will very much depend on improving insulation in existing stock. Further detailed research of housing in other regions of Japan, as well as more elaborate estimates of energy-saving results, need to be undertaken. Meanwhile, the authors hope that this study will contribute to effective policy-making that will help lead to a sustainable future.

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