ESTIMATION OF EFFECT OF INJECTING POLYURETHANE FOAM INTO WALLS AND RENOVATING WINDOWS IN HOUSES IN JAPAN UP TO 2020 STUDY ON REDUCTION OF GREENHOUSE GASES FROM RENOVATING THERMAL INSULATION IN HOUSES

Kazuhiko MIZUTA[1†], Toshiharu IKAGA[2], and Shuzo MURAKAMI[2]

[1]*Chemical & Industrial Products Materials Development Department, Bridgestone Corporation*
[2] *Dr. Eng., Professor, Faculty of Science and Technology, Keio University*

ABSTRACT

This research describes the effects of injecting rigid polyurethane foam into walls and fitting double glazing or inner panes to sash windows as simple renovation methods for houses, based on estimations of CO_2 emissions from heating/cooling and $LCCO_2$ (Life Cycle CO_2). We estimated CO_2 emissions and $LCCO_2$ up to 2020 in Japan and obtained the following results.

(1) Injecting rigid polyurethane foam into walls in detached houses, where there is little thermal insulation, reduces the $LCCO_2$ significantly. (2) In regions with mild climates like Tokyo, renovating windows brings higher $LCCO_2$ reductions in houses insulated to 1992 Criteria for the Rational Use of Energy in Houses[1)] than in those insulated to conventional levels or the 1980 criteria. (3) When choosing one of the two methods above, we should take into account the initial insulation level, the house structure, and the region. (4) Domestic CO_2 emissions for houses in Japan can be reduced by 13% to 19% by 2020 with the use of simple renovation methods for thermal insulation.

KEYWORDS

Global Warming, Life Cycle Assessment, Renovation, Thermal Insulation

1. INTRODUCTION

The number of existing houses in Japan amounted to more than 46 million in 2003[2)] and this number has been increasing, with 1.2 million new houses being constructed every year. However, the insulation levels in existing houses has not been high enough. It is essential to raise the insulation level in existing houses to conserve the amount of energy used for heating/cooling. Actually renovation of thermal insulation has some problems from the practical viewpoint, due to the complicated construction work involved. This paper considers simple renovation methods that destroy neither the interior walls nor the existing windows. We estimate by how much these methods could reduce greenhouse gases by applying thermal insulation throughout Japan up to 2020 with a macro simulation method.[3)] We study how effectively these simple renovation methods could reduce greenhouse gas emissions if applied to all the houses in Japan.

2. METHODS OF THERMAL RENOVATION

The purpose of this study is to raise insulation levels in existing houses over a short working period to reduce the burden on residents. To avoid demolishing the interior,

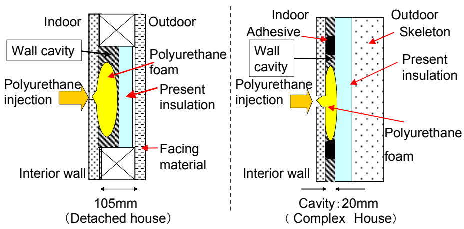


Figure 1. Cross-sectional View of Outer Wall

† Kazuhiko MIZUTA:
Tel: +45 825 7531; Fax: +45 825 7664
Email: mizuta-k@bridgestone.co.jp

the renovation focuses on injecting polyurethane foam into the outer wall cavity, fitting existing windows with double glazing, and adding an inner pane. Outer walls of detached houses all appear to be cavity walls, except in the Hokkaido region when the insulation level is low or there is no insulation (Fig. 1). Filling these cavities with thermal insulation materials increases the thermal insulation. In this study we injected rigid polyurethane foam into the cavity after making a hole in the inside surface of the outer wall. For windows, the basic methods are: 1) addition of an inner pane, 2) double glazing the existing window.

3. ESTIMATING THE RENOVATION EFFECT FOR A STANDARD MODEL HOUSE

3.1 Specifications for Thermal Insulation

Insulation levels at the newly-built point are either set to the conventional standard, or the 1980 or 1992 criteria for the rational use of energy related to houses.[1)] The targets for renovation are the outer walls and windows. During the renovation we did not aim to achieve the insulation levels in the energy saving criteria; instead we applied “simple renovation methods” such as injecting polyurethane foam into the outer wall cavity, fitting an inner pane or replacing the existing glass with double glazing to increase the insulation. Table 1 shows of the specifications of the insulation materials installed into new houses. Since there are different generations of blowing agents used to spray the polyurethane foam, CFC11 blown foam was used in housing complexes insulated to the 1980 criteria, and HCFC141b blown foam was used in them insulated to the 1992 criteria. Table 2 shows the specifications of the outer wall. The thickness for the conventional insulation level in Hokkaido was set to give the same heat loss coefficient as the 1980 criteria in Tokyo. This paper recommends injecting spray-type non-Freon urethane foam utilizing the existing insulation materials for renovation. We estimated the thickness of the injected materials as equal to the value obtained by subtracting the thickness of the existing insulation layer from the thickness of the main column (assumed to be 105 mm) for detached houses, and injected into the 20 mm-thick cavities between the existing insulation and the plaster board in apartments in housing complexes. The specifications and thermal transmittance of the windows before and after renovation are shown in Fig. 3. Specific renovation methods for windows are: fitting an inner pane, double glazing the existing window, or replacing the window with one made of plastic or wood.

3.2 CO_2 Emissions due to Space Heating/Cooling

We calculated the CO_2 emissions due to heating/cooling using the model house before and after renovation. Cities used for our estimation were Sapporo, Morioka, Sendai, Tokyo and Kagoshima, which are representative of the areas divided by the energy saving standards of Japan. We selected the Architectural Institute of Japan (AIJ) standard model for detached houses (2-story, floor area: 125.86m^2) and the Institute of Building Environment and Energy Conservation (IBEC) model for apartments in housing complexes (floor area: 74.3m^2). Table 4 shows the set-point temperature for heating/cooling. We calculated the annual energy consumption for heating/cooling with the Simplified Analysis System for Housing Air-Conditioning Energy (SMASH), a heat load simulation program for houses; the energy consumption was converted for each type of energy source from the breakdown ratio of household energy and the efficiency of the heating/cooling equipment, and multiplied each type of energy source by the unit CO_2 emissions shown in Table 5. We use the improved AIJ standard schedule[4)] as the operating schedule for the heating/cooling.

3.3 Comparison of Renovation Effect

Tables 6 and 7 show the changes in CO_2 emissions brought about by heating/cooling. The changes in Tokyo are shown in Fig. 2. Injecting polyurethane foam was more effective in both detached houses and in housing complexes when the initial insulation was at the conventional level; this was especially noticeable in detached houses. CO_2 emissions after injecting urethane decreased by an average of 40% in detached houses, and 14% in apartments in housing complexes over the five cities. Renovating windows was more effective in about half of the results when the initial insulation level was higher. When both polyurethane injection and renovation of windows was carried out, CO_2 emissions decreased by 40-70% in detached houses and by 60-90% in housing complexes in many cases.

Table 1. Specifications of Insulation Materials

	Initial Insulation			Renovation
	Detached House	Complex House		Detached / Complex House
Insulation Material	GW	XPS	PU-S	PU-I
Application Site	Ceiling・Floor・Wall	Ceiling	Wall	Wall
Thermal Conductivity (W/mK)	0.050	0.034	0.026	0.034(Non Freon)
Foam Density (kg/m^3)	10	30	40	25

GW:Glass Wool XPS:Extruded Polystyrene PU-S:Polyurethane Spray PU-I:Polyurethane Injection

Table 2. Outer Walls Specification

		Initial Insulation Level					
		Conventional Type		1980 Criteria		1992 Criteria	
City	Renovation	Before	After	Before	After	Before	After
Sapporo	Detached House	GW(20)	GW(20)+PU-I(85)	GW(105)	-	GW(105)	-
		1.16	0.31	0.41	0.41	0.41	0.41
	Complex House	GW(10)	GW(10)+PU-I(20)	PU-S(25)	PU-S(25)+PU-I(20)	PU-S(45)	PU-S(45)+PU-I(20)
		1.65	0.90	0.73	0.54	0.47	0.38
Morioka	Detached House	No Insulation	PU-I(105)	GW(45)	GW(45)+PU-I(60)	GW(50)	GW(50)+PU-I(55)
		2.70	0.30	0.74	0.33	0.69	0.34
	Complex House	No Insulation	PU-I(20)	PU-S(15)	PU-S(15)+PU-I(20)	PU-S(25)	PU-S(25)+PU-I(20)
		2.45	1.10	1.02	0.67	0.73	0.54
Sendai	Detached House	No Insulation	PU-I(105)	GW(45)	GW(45)+PU-I(60)	GW(50)	GW(50)+PU-I(55)
		2.70	0.30	0.74	0.33	0.69	0.34
	Complex House	No Insulation	PU-I(20)	PU-S(15)	PU-S(15)+PU-I(20)	PU-S(25)	PU-S(25)+PU-I(20)
		2.45	1.10	1.02	0.67	0.73	0.54
Tokyo	Detached House	No Insulation	PU-I(105)	GW(30)	GW(30)+PU-I(75)	GW(45)	GW(45)+PU-I(60)
		2.70	0.30	0.94	0.32	0.74	0.33
	Complex House	No Insulation	PU-I(20)	PU-S(10)	PU-S(10)+PU-I(20)	PU-S(20)	PU-S(20)+PU-I(20)
		2.45	1.10	1.26	0.78	0.85	0.60
Kagoshima	Detached House	No Insulation	PU-I(105)	No Insulation	PU-I(105)	GW(30)	GW(30)+PU-I(75)
		2.70	0.30	2.70	0.30	0.94	0.32
	Complex House	No Insulation	PU-I(20)	No Insulation	PU-I(20)	PU-S(15)	PU-S(15)+PU-I(20)
		2.45	1.10	2.45	1.10	1.02	0.67

GW:Glass Wool XPS:Extruded Polystyrene PU-S:Polyurethane Spray PU-I:Polyurethane Injection
Upper:Specification ( )Thickness:mm Lower:Thermal Transmittance (W/m^{2}K)

Table 3. Windows Specifications Before and After Renovation

	Initial Insulation Level					
	Conventional Type		1980 Criteria		1992 Criteria	
City	Before	After	Before	After	Before	After
Sapporo	Single+Single	Single+Pair H	Single+Single H	Single+Pair H	Single+(L) Pair	
	3.49	2.33	2.91	2.33	2.33	—
Morioka	Single+Single	Single+Pair H	Single+Single	Single+Pair H	Single+Single H	Single+(L) Pair
	3.49	2.33	3.49	2.33	2.91	2.33
Sendai	Single	Single+Single	Single	Single+Single	Single+Single	Single+Pair H
	6.51	3.49	6.51	3.49	3.49	2.33
Tokyo	Single	Single+Single	Single	Single+Single	Single	Single+Single
	6.51	3.49	6.51	3.49	6.51	3.49
Kagoshima	Single	Single+Single	Single	Single+Single	Single	Single+Single
	6.51	3.49	6.51	3.49	6.51	3.49

H:Wooden or Plastic Sash, (L)Pair:Low-E Pair Glass, Upper:Specifications, Lower:Thermal Transmittance(W/m^{2}K)

Table 4. Set-point Temperature for Space Heating/Cooling

Temperature,℃	Insulation Level		
	Conventional Type	1980 Criteria	1992 Criteria
Heating	15.5(17.5)	15.5(17.5)	15.5(17.5)
Cooling	28	27	26

( ):Sapporo

Table 5. Unit CO_2 emissions on each Energy Type (2000)

Electricity (kg-CO_2/kWh)	City Gas (kg-CO_2/MJ)	LPG (kg-CO_2/MJ)	Oil (kg-CO_2/MJ)
0.378	0.0513	0.0586	0.0685

Table 6. Comparison of CO_2 Emissions by Heating/Cooling of Detached House (Index for BAU)

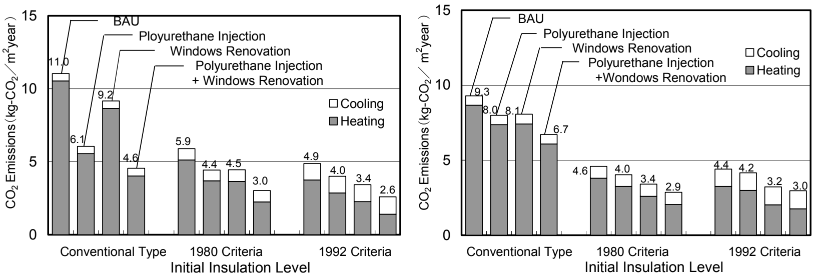
	Initial Insulation Level (Before Renovation)											
	Conventional Type				1980 Criteria				1992 Criteria			
	BAU	PU-I	Windows Renv.	PU-I and Windows Renv	BAU	PU-I	Windows Renv.	PU-I and Windows Renv	BAU	PU-I	Windows Renv.	PU-I and Windows Renv
Sapporo	1.00	0.69	0.93	0.62	1.00	-	0.94	-	1.00	-	-	-
Morioka	1.00	0.57	0.96	0.52	1.00	0.77	0.90	0.67	1.00	0.71	0.98	0.68
Sendai	1.00	0.60	0.88	0.46	1.00	0.82	0.73	0.54	1.00	0.72	0.86	0.59
Tokyo	1.00	0.57	0.87	0.43	1.00	0.75	0.75	0.51	1.00	0.82	0.70	0.53
Kagoshima	1.00	0.57	0.88	0.44	1.00	0.57	0.96	0.42	1.00	0.77	0.78	0.58

PU-I:Polyurethane Injection, Windows Renv:Windows Renovation

Table 7. Comparison of CO_2 Emissions by Heating/Cooling of Complex House (Index for BAU)

	Initial Insulation Level (Before Renovation)											
	Conventional Type				1980 Criteria				1992 Criteria			
	BAU	PU-I	Windows Renv.	PU-I and Windows Renv	BAU	PU-I	Windows Renv.	PU-I and Windows Renv	BAU	PU-I	Windows Renv.	PU-I and Windows Renv
Sapporo	1.00	0.85	0.93	0.79	1.00	0.91	0.95	0.87	1.00	0.95	-	-
Morioka	1.00	0.86	0.97	0.83	1.00	0.91	0.92	0.82	1.00	0.93	0.99	0.92
Sendai	1.00	0.87	0.88	0.74	1.00	0.93	0.74	0.66	1.00	0.93	0.90	0.83
Tokyo	1.00	0.86	0.87	0.72	1.00	0.88	0.74	0.62	1.00	0.94	0.73	0.68
Kagoshima	1.00	0.87	0.87	0.73	1.00	0.83	0.84	0.67	1.00	0.95	0.80	0.76

PU-I:Polyurethane Injection, Windows Renv:Windows Renovation



(a) Detached House in Tokyo (b) Apartment in Tokyo

Figure 2. Reduction in CO_2 Emissions for Heating/Cooling

4. ESTIMATING THE LCCO$_2$

4.1 Evaluation Scope

The subject of this study was the global warming effect due to insufficient thermal insulation material for walls and windows. The scope is: 1) production of insulation materials; 2) fluorocarbon diffusion (converted to CO_2) during material production and while under construction; 3) operation of heating/cooling; 4) fluorocarbon diffusion (convert to CO_2) while in service; 5) production of insulation materials to be used for renovation; 6) operation of heating/cooling after renovation. This study did not include CO_2 emissions from transportation, recycling, or waste. Renovation is normally carried out 20 years after a house is built. The total evaluation period was set at 100 years.

4.2 Estimation Method During Each Stage in the Life Cycle

The method used for CO_2 emissions at production is shown in Table 8. GW-10K (glass wool), plastic foam (blown by fluorocarbon) was used in detached houses and apartments as shown in Table 1. Non-Freon (blown with CO_2) spray polyurethane foam was used for renovation. Fluorocarbon diffusions from XPS (extruded polystyrene) and spray polyurethane foam during material production and while under construction were calculated as shown in Table 9. The method used to calculate CO_2 emissions from heating/cooling is given in Section 3.2. We looked at five cities: Sapporo, Morioka, Sendai, Tokyo, and Kagoshima. Fluorocarbon diffusion from plastic foam materials was evaluated after converting the global warming effect to CO_2 as shown in Table 10. All the fluorocarbon from the plastic foam materials was emitted into the atmosphere within the evaluation period.

Table 8. Caluculation Method of CO_2 Emission at Production

1. Unit CO_2 Emission (kg-CO_2/kg)
   (1) Insulation Materials[5)] ・GW（Glass Wool）10K：2.033 ・XPS and Urethane Foam：2.533
   (2)Windows/Sash[6)] ・Sash：1.413 ・Glass：0.809
   [Weight per area for window：kg/m^2] (Aluminum sash) Single： 4.39 Pair：5.03
   (Glass) Single：7.5 Pair： 15
2. Calculation of CO_2 Emission
   (1)Insulation Material： (Working Area)×(Thickness)×(Density)×（Unit CO_2 Emissions）
   (2) Window：（Weight per area）[7)]×(Area)×（Unit CO_2 Emissions)
   [XPS：Extruded Polystyrene]

Table 9. Calculation Conditions of Fluoro-carbon Emissions

1. Initial content of blowing agent[8)]
   Extruded polyatyrene foam：HCFC142b 9.6(wt%)
   Spray polyurethane foam CFC11：15(wt%) HCFC141b：13(wt%)
2. Emission s at Production and under Construction[8)]
   Extruded polystyrene：10％ Spray Urethane Foam：13%
   (Construction Area)×(Thickness)×（Density)×(Fluoro-carbon Content)×(Fluoro-carbon Emissions)× GWP
3. Emissions in Service
   (Construction Area)×（Thickness）×(Density)×(Initial Fluoro-carbon Content)×GWP
   all fluoro-carbon shall emit to the atmosphere completely in service
   [GWP：Global Warming Potenntial]

Table 10. GWP of Blowing Agents

	Polyurethane Foam		XPS(Extruded Polystyrene Foam)	
Fluorocarbon blown	CFC11	4600	CFC12	10600
	HCFC141b	700	HCFC142b	2400
	HFC245fa	950	HFC134a	1300
	HFC365mfc	890		
Non Fluoro-carbon blown	CO_2	1	Hydrocarbon	23
	Hydrocarbon	23		

GWP: IPCC Report in 2001

4.3 LCCO_2 Reduction Effect

LCCO_2 was reduced effectively with thermal renovation. Figures 3 and 4 show the renovation effect for conventional insulation levels, and the three initial insulation levels used in Tokyo respectively. Reduction of CO_2 emissions from heating/cooling after renovation has a large influence on the reduction of LCCO_2.The effect of injecting polyurethane foam into the walls was outstanding in detached house insulated to conventional levels in all five cities. The average LCCO_2 reduction rate among the five cities was approximately 30%. Renovating windows was as effective as injecting polyurethane foam in detached house in Tokyo when the initial insulation was to the 1980 criteria (Fig. 4). But it was more effective when the initial insulation was to the 1992 criteria. In housing complexes, renovating the windows was also more effective than injecting foam where initial insulation levels were higher than the 1980 criteria. When we choose whether to inject urethane foam or to renovate the windows, we have to take into account the fact that the effects vary with the initial insulation level, the structure: detached house or apartment, and the region in which the house is.

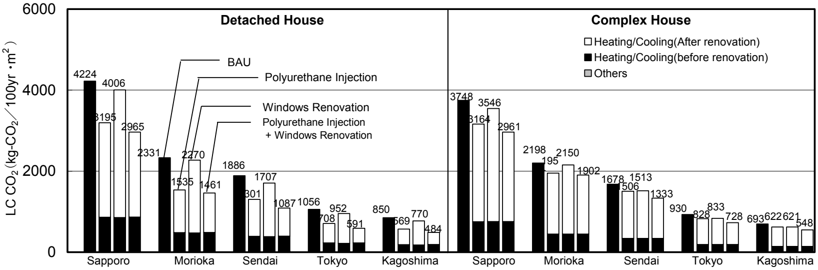


Figure 3. Estimation of $LCCO_2$ Renovated from Conventional Type of Insulation Level

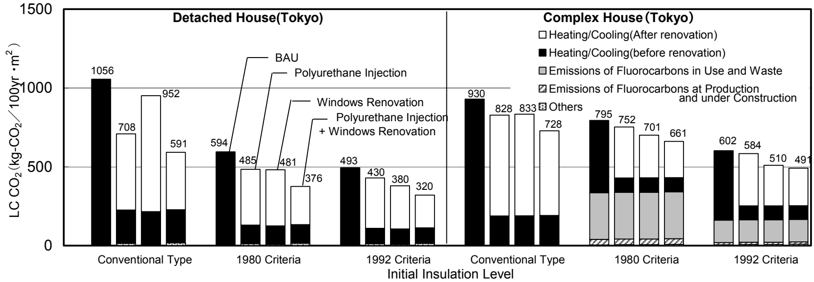


Figure 4. Estimation of $LCCO_2$ Renovated from every Insulation Level (Tokyo)

5. ESTIMATING THE RENOVATION EFFECT FOR ALL HOUSES IN JAPAN

5.1 Simulation Method

On the basis of estimation results with the house models, we estimated the reduction in greenhouse gas emissions from all houses in Japan from the simple renovation method. We applied the macro simulation method[2)] to add up greenhouse gas emissions (CO_2 emissions and fluorocarbon diffusions) from all houses related to insulation for every five years from 1990 to 2020. The scope of evaluation was as follows: 1) production of insulation material; 2) fluorocarbon diffusion (converted to CO_2) in material production, during construction and while in service, and waste; 3) operation of heating/cooling The method allowed us to estimate greenhouse gas emissions allowing for the change in the type of dwelling unit, initial insulation levels, the numbers of demolition broken down by all regions, type of insulation material, and type of blowing agent.[9),10)] Energy consumption due to heating /cooling takes into account variables such as the specific heat loss coefficient, the room temperature, average floor area, climate, number of household members, number of households, percentage of houses existing at each insulation level, and the coefficient of performance (COP) of the equipment. This paper considers the transition of blowing agents for extruded polystyrene and polyurethane foam shown in Table 11. We set the target rate for annual house renovation from 2007 to 2020 as shown in Table 12. When the annual rate of renovation is set at 10% for the conventional insulation level, 10% of those existing houses would be renovated in a year. And 10% of the rest would be renovated next year. Priority is given to houses with lower insulation levels.

5.2 Greenhouse Gas Emissions Related to Thermal Insulation from All Houses in Japan

Figures 5-8 show the relationship between the renovation and the results for greenhouse gas emissions from all houses in Japan. In CASE-1 in Table 12 we set neither injecting polyurethane nor renovating windows. The greenhouse gas emissions would increase by 34.6% in 2005, 22.5% in 2010, 5.7% in 2020 compared to 1990. After 2000, they would decrease because of increasing the insulation level to that of new houses, decreasing the number of household members, increasing the COP for heating/cooling equipment, and improving the unit CO_2 emissions for electricity generation. When we just injected polyurethane into the outer walls as shown in CASE-2, the rate of increase could be controlled to 21.5% in 2010, 6.1% in 2015, and a decrease of 7.4% in 2020 compared to 1990 (Fig. 6). Similarly when we just renovated the windows, the rate of increase could be controlled to 22.2% in 2010, 11.8% in 2015, and a decrease of only 0.3% in 2020 compared to 1990 (Fig. 7). When we both injected polyurethane foam into the outer wall cavities and renovated the windows after 2007 as in CASE-2, greenhouse gas emissions decreased faster. In that case, the rate of increase could be controlled to 21.3% in 2010, 3.4% in 2015 and a decrease of 13.3% in 2020 compared to 1990 (Fig. 8). Thus injecting polyurethane into the outer wall cavities and renovating the windows can achieve a reduction of more than 10 million t-CO_2/yr emissions by 2020. Furthermore the scenario in CASE-3, where the target renovation rate was set twice as high as for CASE-2, the greenhouse gas reduction rate is much faster (Table 12). As CO_2 emissions during the production of the insulation materials increase, the effects of renovation would be cancelled out by 2010. Total greenhouse gas emissions could increase by 21.7%. However, they could decrease by 3.8% in 2015, and by 18.6% in 2020. Here the reduction in greenhouse gas emissions could be more than 20 million t-CO_2/yr.

Table 11. Application Ratio of Blowing Agents

	XPS(Extruded Polystyrene Foam)				Polyurethane Foam							
					Spray				Board			
Year	CFC	HCFC	HFC	HC	CFC	HCFC	HFC	CO_2	CFC	HCFC	HFC	HC
～1989	100	0	0	0	100	0	0	0	100	0	0	0
1990	62.5	37.5	0	0	100	0	0	0	100	0	0	0
1995	0	100	0	0	100	0	0	0	100	0	0	0
2000	0	100	0	0	0	100	0	0	0	100	0	0
2005	0	0	100	0	0	0	100	0	0	0	100	0
2010	0	0	0	100	0	0	90	10	0	0	50	50
2015～	0	0	0	100	0	0	0	100	0	0	0	100

Table 12. Greenhouse Gas Emissions in each Scenario

	Scenario	Initial Insulation Level	Annual Renovation Ratio of Target Houses（%）			Greenhouse Gas Emission〔millon t-CO_2/yr〕 ( ) Percentage of Increace/Decreace to 1990		
			2007-2010	2011-2015	2016-2020	2010	2015	2020
CASE-1	・No Renovation	Conventional Type	0	0	0	64.90（+22.5）	60.73（+14.6）	56.00（+5.7）
		1980 Criteria	0	0	0			
		1992 Criteria	0	0	0			
CASE-2	・Renovation Implemented	Conventional Type	1	10	20	64.26（+21.3）	54.77（+3.4）	45.93（-13.3）
		1980 Criteria	1	5	10			
		1992 Criteria	1	5	10			
CASE-3	・Renovation pace doubled	Conventional Type	2	20	40	64.50（+21.7）	50.99（-3.8）	43.13（-18.6）
		1980 Criteria	2	10	20			
		1992 Criteria	2	10	20			

Renovation with Polyurethane Injection to Outer Wall and Windows Exchange

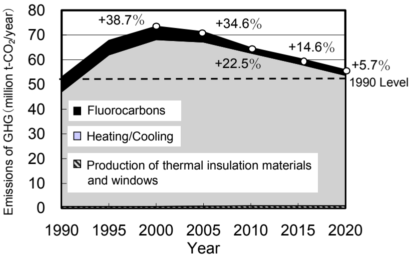


Figure 5. Emissions of Greenhouse Gas in Japan Concerning Thermal Insulation Materials（CASE-1）

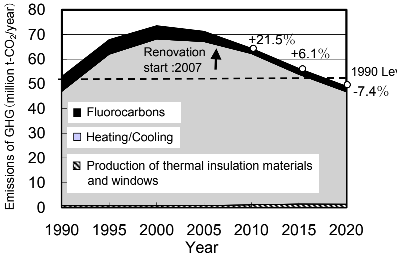


Figure 6. Emissions of Greenhouse Gas in Japan Concerning Thermal Insulation Materials（CASE-2：Polyurethane Injection）

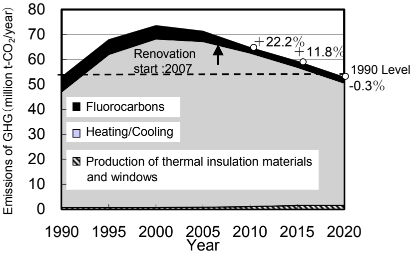


Figure 7. Emissions of Greenhouse Gas in Japan Concerning Thermal Insulation Materials (CASE-2: Windows Renovation)

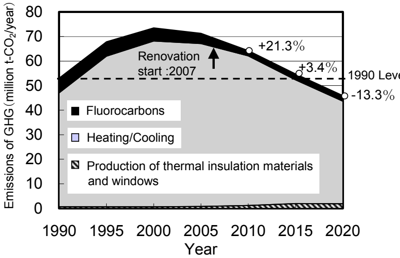


Figure 8. Emissions of Greenhouse Gas in Japan Concerning Thermal Insulation Materials (CASE-2: Polyurethane Injection and Windows Renovation)

6. CONCLUSIONS

We estimated by how much simple renovation methods such as injecting polyurethane into the outer wall cavities, adding inner window panes, and double glazing the windows could reduce greenhouse gas emissions, and obtained following results.

1) The effect of injecting polyurethane into the wall cavities was outstanding in detached houses initially insulated to the conventional level in all the cities we studied. $LCCO_2$ decreased by approximately 30% on average among the five cities.
2) Renovating the windows was more effective than injecting polyurethane for houses where the initial insulation level was higher.
3) When choosing whether to inject polyurethane into the wall cavities or renovate the windows, we have to take into account the fact that the results vary according to the initial insulation level, and the structure: detached house or apartment, and the region.
4) In 2020, greenhouse gas emissions from all houses in Japan will increase by 5.7% compared to 1990 if nothing is done to increase the insulation levels. However, these simple renovation methods enable more than a 10% reduction in greenhouse gas emissions by 2020 if renovation is carried out at a constant annual rate from 2007. We could even achieve a 20% reduction in emissions if we set a higher annual renovation rate.
5) It is essential to standardize the work procedure for polyurethane foam injection.

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