Intensity Calculation Using Input-Output Table and Case Study Regarding Embodied Energy/CO₂ in Japan

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Abstract: The objective of this research is to quantify the EEC (embodied energy/CO₂) of a building. The EEC represents the energy consumption and CO₂ emissions at individual phases of a building's life-cycle, such as construction (including manufacture of materials and equipment), renewal (including repair work) and demolition. Energy and CO₂ emission intensities in terms of 401 sectors were calculated, using the 2005 I-O (input-output) table in Japan. According to our case study conducted from the construction phase to demolition, the EC (embodied CO₂) of an office building used for 60 years is 12,044 t-CO₂ and 1,093 kg-CO₂/m² in total. CO₂ equivalent emissions (CO_{2e}) by Freon gases, contained in building materials, equipment and devices, were also calculated. As the results, CO_{2e} by insulators was 2% of the building's EC and CO_{2e} by refrigerants was 9%~12% of the building's EC. It is important to keep reducing emissions of Freon gases contained in refrigerators.

Key words: I-O table, intensity of energy and CO₂, embodied energy/CO₂.

1. Introduction

The energy consumption/CO₂ emissions in the civilian sector business have been increasing, indicating that further energy-saving efforts are very important [1]. Consequently, the ZEB (zero energy building) target has been announced in order to achieve zero net energy consumption and zero CO₂ emissions in a building during operation [2]. Achieving the ZEB helps reduce CO₂ emissions due to the energy consumption for the operation. Consequently, in order to further reduce CO₂ emissions, it is important to reduce those caused by factors other than the operational energy. This is where the EEC (embodied energy/CO₂) assessment becomes important. Under such circumstances, IEA (The International Energy Agency)/EBC (Energy in

Buildings and Communities Programme)/Annex 57 is attempting to develop an international guideline [3].

The EEC represents the energy consumption and CO₂ emissions through the entire life-cycle of a product from its manufacture, construction, repair/renewal and demolition, including procurement of raw materials and transport. Methods for creating a database necessary for the EEC assessment are classified mainly as follows: a database based on investigations regarding the material balance, energy balance and the like, in the manufacturing process of materials (process model), a database based on the input-output analysis (I-O (input-output) model) and the hybrid calculation method. So far, researchers have conducted a number of studies regarding development of intensities and building assessments. Hacker et al. [4] conducted a study for reducing life-cycle CO₂ emissions by comparing the EC (embodied CO₂) when different building materials are

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used for a house, with the EC when the building is actually in operation. Chang et al. [5] selected a multistorey building for educational purposes as a model building and compared an intensity developed by combining the process model and the I-O model, with another one based solely on the I-O model, from which they demonstrated that the calculation result of the combined intensity is slightly larger than that of the I-O model. Suzuki and Oka [6] compared the life-cycle energy consumption and CO₂ emissions between multiple buildings having different scales and facilities, in which the operational energy was added to the EEC. Hammond and Jones [7] attempted to further optimize intensities by selecting the most appropriate one from existing literatures and providing feedback about the calculation result. Yokoyama et al. [8] calculated the intensity of resource consumption in terms of major materials used for buildings based on the Japanese I-O table in order to obtain the amount of resource consumption and the EEC through the entire life-cycle of an office building. Kaido et al. [9] calculated intensities in individual countries using I-O tables in Japan and the United States, where they compared various EEC values in the building industry. There are also many other studies regarding the EEC calculation [10].

On the other hand, Freon gases are used in some of the insulators and refrigerants for refrigerators used in buildings. CFCs (chlorofluorocarbons) and HCFCs (hydrochlorofluorocarbons) were the most commonly used compounds in the past [11], after the Montreal Protocol was ratified [12], such compounds have been gradually replaced with HFCs (hydrofluorocarbons) and the consumption of HFCs has been steadily increasing since then [13, 14]. However, the GWP (global warming potential) of HFCs far exceeds that of CO₂. Therefore, in addition to the conventional EEC assessment, it is also necessary to consider how much the EC is affected by Freon gases used in building materials, equipment and devices [11, 15].

In this research project, since the Japanese I-O table

has 401 industrial sectors, the authors determined that the EEC intensities could be calculated using the I-O table and so the 2005 I-O table in Japan was used. As a case study, in which the intensity obtained by the procedure described above is actually used, the EC in each phase during the life-cycle of an office building, such as construction, renewal and demolition, which revealed characteristics of the construction work, structural materials, finishing materials and equipment, was calculated. Additionally, it was also calculated how much the embodied carbon dioxide equivalent (CO_{2e}) is affected by Freon gases released into the atmosphere, which are used in building materials, equipment and devices.

2. Intensity of Energy Consumption and CO₂ Emission Factors of Industrial Sectors

2.1 Inverse Matrix Based on Competitive Imports Assumption

The basic transaction table of 2005 I-O table in Japan classifies Japanese industry into a 520 × 407 matrix. The items having unmatched industrial sectors in the rows and columns of this matrix were integrated into a 401 × 401 square matrix, in order to obtain a competitive import-style Leontief inverse matrix. Provided with the final demand vector $F_{(D)}$, the ultimate gross domestic product vector X , which includes spillover effects, would be expressed in the following equation:

$$X = \{I - (I - M)A\}^{-1}((I - M)F_{(D)} + F_{(E)}) \quad (1)$$

where, X : gross domestic product vector (JPY/year); $\{I - (I - M)A\}^{-1}$: Leontief inverse matrix (-); I : unit matrix (-); M : import matrix (-); A : activity matrix (-); $F_{(D)}$: final demand vector (JPY/year); $F_{(E)}$: export vector (JPY/year).

$$M = \begin{bmatrix} m_1 & \cdots & 0 \\ \vdots & \ddots & \vdots \\ 0 & \cdots & m_i \end{bmatrix} \quad (2)$$

$$m_i = M_i / C_i \quad (3)$$

where, m_i : coefficient of import (-); M_i : import of i product (JPY/year); C_i : domestic demand of i product

(JPY/year).

$$A = \begin{bmatrix} a_{11} & \cdots & a_{1j} \\ \vdots & \ddots & \vdots \\ a_{i1} & \cdots & a_{ij} \end{bmatrix} \quad (4)$$

$$a_{ij} = x_{ij} / X_j \quad (5)$$

where, a_{ij} : activity from j product to i product (-); x_{ij} : product from i sector to j sector (JPY/year).

2.2 Calculation of Intensity

The Japanese I-O table has a physical quantity table that lists the physical quantity consumption and price in terms of 134 kinds of products consumed in individual industrial sectors in the basic table. Using the physical quantity table, the direct energy consumption and CO₂ emissions of each industrial sector per GDP (gross domestic product) of 1 million yen are calculated by Eqs. (6) and (7), respectively. Table 1 shows various kinds of fuels used in the calculation as well as calorific values and CO₂ emission factors in the industrial process [16].

$$E_i = \sum KE_j \times MAT_{ij} \quad (6)$$

$$CO_{2i} = \sum KCO_{2j} \times MAT_{ij} \quad (7)$$

where, E_i : direct energy consumption per manufacturer price of 1 million yen in i sector (MJ/(Mil. JPY)); CO_{2i} : direct CO₂ emissions per manufacturer price of 1 million yen in i sector (kg-CO₂/(Mil. JPY)); MAT_{ij} : physical quantity j injected into i sector; KE_j : unit calorific value of j substance (Table 1); KCO_{2j} : CO₂ emission factor of j substance (Table 1).

CO₂ emissions from cement production is assumed 0.44 kg-CO₂/limestone-kg.

By multiplying the direct energy consumption per manufacturer price of 1 million yen and the direct CO₂ emissions, obtained by Eqs. (6) and (7), respectively, by the Leontief inverse matrix expressed in Eq. (1), the ultimate intensity having spillover effects should be determined:

$$IE = E(I - (I - M)A)^{-1} \quad (8)$$

$$ICO_2 = CO_2(I - (I - M)A)^{-1} \quad (9)$$

where, IE : energy consumption intensity with spillover effects per manufacturer price of 1 million yen in each industry (MJ/(Mil. JPY)); ICO_2 : CO₂ emission intensity with spillover effects per manufacturer price of 1 million yen in each industry (kg-CO₂/(Mil. JPY)); E : direct energy consumption row vector per manufacturer price of 1 million yen in each industry (MJ/(Mil. JPY)); CO_2 : direct CO₂ emission row vector per manufacturer price of 1 million yen in each industry (kg-CO₂/(Mil. JPY)).

Values used in Eqs. (8) and (9) are based on the manufacturer price. Therefore, by adding the commercial margin and distribution margin indicated in the I-O table to these values, values based on the consumer price are obtained, which are used for adjusting the intensity per consumer price of 1 million yen. The EEC values per 1 million yen in major industrial sectors engaged in construction businesses are listed in Table 2.

3. Calculation Methods for EC

3.1 Calculation of Embodied CO₂

3.1.1 Construction Phase

Embodied CO₂ in the construction phase may be calculated either by multiplying the quantity (unit) of

Table 1 Calorific values and CO₂ emission factors by fuel and industrial process [16].

Fuel	Unit	Calorific value	CO ₂ emission factor	
		MJ/unit	kg-CO ₂ /unit	kg-CO ₂ /MJ
Coal	kg	28.9	2.506	0.0867
Crude oil	L	38.2	2.613	0.0684
Natural gas	m ³	40.9	2.020	0.0494
Gasoline	L	34.6	2.322	0.0671
Jet fuel	L	36.7	2.463	0.0671
Kerosene	L	36.7	2.492	0.0679
Light oil	L	38.2	2.624	0.0687
A heavy oil	L	39.1	2.710	0.0693
B/C heavy oil	L	41.1	2.922	0.0711
Naphtha	L	34.1	2.271	0.0666
LPG	kg	50.2	3.002	0.0598
Coke	kg	30.1	3.251	0.1080
Limestone	kg	-	0.440	-

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Table 2 Energy consumption/CO₂ emission intensity (listing only major industrial sectors engaged in construction business from all the 401 types of industry: 1 Mil. Yen = 9,091 US\$, year 2005).

Part	Industrial sector	Energy (MJ)	CO ₂ (kg-CO ₂)	Unit
		Per consumer price of Mil. JPY	Per consumer price of Mil. JPY	Quantity of material for consumer price of Mil. JPY
1	Gravel and quarrying	52,153	3,626	287.5 t
2	Timber	13,621	952	22.68 m ³
3	Plywood	22,697	1,599	7.0 m ³
4	Paints and varnishes	71,604	4,937	-
5	Plastic products	56,893	3,971	-
6	Sheet glass and safety glass	36,902	2,636	1,413 m ²
7	Glass fiber and glass fiber products	71,691	4,842	-
8	Cement	315,036	80,992	124.4 t
9	Ready mixed concrete	81,093	16,745	62.6 m ³
10	Cement products	43,193	5,994	-
11	Ceramic	54,376	3,500	-
12	Hot rolled steel	189,779	18,271	13.47 t
13	Steel pipes and tubes	119,963	11,182	6.158 t
14	Coated steel	90,489	7,958	9.002 t
15	Cast iron pipes and tubes	102,598	8,701	8.061 t
16	Electric wires and cables	22,562	1,611	0.645 conductor-t
17	Rolled and drawn copper and copper alloys	25,609	1,803	1.255 t
18	Metal products for construction	63,388	5,577	-
19	Metal products for architecture	35,353	2,878	-
20	Bolts, nuts, rivets and springs	45,000	3,859	-
21	Metal containers, fabricated plate and sheet metal	45,951	3,798	-
22	Boilers	22,980	1,832	-
23	Refrigerators and air conditioning apparatus	23,502	1,808	-
24	Pumps and compressors	27,127	2,238	-
25	Electric transformer	21,509	1,727	-
26	Relay switches and switch boards	22,878	1,780	-
27	Electric lighting fixtures and apparatus	24,345	1,770	284 p
28	Batteries	28,099	2,026	5091 p
29	Air conditioning equipment for consumer use	21,210	1,577	11.13 p
30	Residential construction (wooden)	19,921	1,707	6.318 m ²
31	Residential construction (non-wooden)	29,055	2,704	5.527 m ²
32	Non residential construction (wooden)	21,103	1,835	7.749 m ²
33	Non residential construction (non-wooden)	29,644	2,704	6.844 m ²
34	Repair of construction	27,466	2,436	-
35	Waste disposal services (public)	44,332	3,155	-
36	Waste disposal services (industrial)	26,296	1,880	-
37	Building maintenance services	7,753	548	-
38	Civil engineering and construction services	11,234	801	-

each building component used for construction by the CO₂ emission intensity (kg-CO₂/unit) or by multiplying the CO₂ emission intensity of the industrial sector applicable to each building component (kg-CO₂/(Mil. JPY)) by the construction

expense (Mil. JPY) (Eq. (10)):

$$CO_2 = k_{is} \times C_{is} \quad (10)$$

where, CO_2 : embodied CO₂ (kg-CO₂); k_{is} : CO₂ emission intensity (kg-CO₂/(Mil. JPY), kg-CO₂/unit); C_{is} : construction expense or physical quantity (Mil.

JPY, unit).

Industrial sectors applicable to the major building components used for construction are as follows: steel frames and reinforcing bars: hot rolled steel; concrete: ready mixed concrete; wooden materials: timber; glass: sheet glass and safety glass; refrigerators: refrigerators and air conditioning apparatus; plumbing: steel pipes and tube; and wiring: electric wires and cables.

This calculation uses quantities of components in steel frames, reinforcing bars and concrete, and prices in other materials and devices.

Energy consumed at the construction site is calculated as the electricity consumption per total floor space 22.2 kWh/m² (CO₂ emission factor: 0.555 (kg-CO₂/kWh)) [17, 18].

3.1.2 Renewal Phase

EC in the renewal phase (including repair) is calculated using the renewal ratio which represents the ratio of EC at the renewal time to EC at the time of construction. Table 3 shows the number of years before repair or renewal and the renewal ratio in terms of major building components, which are calculated according to the repair factor/renewal factor and the repair cycle/renewal cycle provided in Ref. [19]. In

this case, the repair factor and renewal factor respectively represent a ratio of the expense for a one-time repair/renewal to the expense at the time of the initial construction. The repair cycle/renewal cycle indicates the number of years until the next repair/renewal. The renewal ratio is obtained by multiplying “repair/renewal factor of each component” by “number of repairs/renewals”. When determining the number of repairs/renewals, the duration of use of a building is calculated as 60 years. Repair work will not be conducted when the number of years until the next scheduled renewal or the expiry of the duration of use is less than half of the repair cycle. Similarly, when the number of years until the expiry of the duration of use is less than half of the renewal cycle, the calculation will be conducted assuming that the renewal will not be necessary. Taking a refrigerator (air-source heat pump) for example, the repair factor is 0.23, the number of repair is 4, the renewal factor is 1.1, and the number of renewal is 3. Therefore, the renewal ratio of the refrigerator is calculated as $0.23 \times 4 + 1.1 \times 3 = 4.22$.

3.1.3 Demolition Phase

EC at the time of demolition is, according to Ref. [17],

Table 3 Renewal ratio.

Construction item	Material item	Factor [19]		Cycle (year) [19]		Number of times ^{*1}		Renewal ratio
		Repair	Renewal	Repair	Renewal	Repair	Renewal	
Structure	Steel frame	0	0	-	-	0	0	0
	Concrete	0	0	-	-	0	0	0
	Reinforcing bar	0	0	-	-	0	0	0
	Metal fitting	0.04	1	5	30	10	1	1.4
	Interior wall	0.05	1	10	30	4	1	1.2
	Tile	0.015	1	10	-	5	0	0.075
Air conditioning	Refrigerator (air-source heat pump)	0.23	1.1	10	15	4	3	4.22
	Plumbing	0	1.2	-	25	0	1	1.2
	Duct	0	1	-	30	0	1	1
Sanitary	Pumping	0.36	1.1	7	20	6	2	4.36
	Plumbing	0	1.2	-	25	0	1	1.2
	Sanitary fitting	0.243	1.1	5	30	10	1	3.53
Electric	Receiving and transforming	0.2	1	10	30	4	1	1.8
	Wiring	0	1	-	30	0	1	1
	Lighting	0.347	1	10	20	3	2	3.041

^{*1}Duration of use of the building is calculated as 60 years.

Table 4 Densities of insulators, types of Freon gases and their content rates [15].

	Thermal conductivity (W/(m·K))	Density (kg/m ³)	Type of Freon	GWP (-)	Content rate (%)
Expanded polystyrene	0.034	29	HFC-134a	1,430	2.7
Urethane foam (board-shaped)	0.028	30	HFC-245fa	1,030	4.7
Urethane foam (foamed on-site)	0.028	30	HFC-245fa	1,030	7.3

Table 5 Emission factor and collection rate at the time of disposal by refrigerator.

Sub-application	CO ₂ emission factor		Recovery efficiency
	IPCC ^{*1} Guideline [20]	Japan ^{*2} [21]	Japan [22]
Chillers	2%~15%	6%~7%	
Medium and large Commercial refrigeration	10%~35%	12%~17%	30%
Residential and commercial A/C including heat pump	1%~10%	2%~5%	

^{*1}IPCC (the United Nations Intergovernmental Panel on Climate Change);

^{*2}Including refrigerants collected at the time of maintenance and emissions due to accidents and equipment failures.

calculated as 73 kg-CO₂/m² per total floor space.

3.2 Impact of Freon Gases Used in Insulating Materials

There are still some foam insulations in which Freon gases are used, though they are hardly used in major countries any longer. At any rate, we calculate the impact on EC when insulators containing Freon gases are used in an office building. The CO₂ equivalent emissions CO_{2e} (kg-CO₂) is expressed in Eq. (11). Table 4 shows the density and initial content of Freon gases in terms of major insulating materials [15].

$$CO_{2e} = A_{ins} \times L_{ins} \times e \times f \times GWP \quad (11)$$

where, CO_{2e}: CO₂equivalent (kg-CO₂); A_{ins}: area covered by insulator (m²); L_{ins}: thickness of insulator (m); e: density of insulator (kg/m³); f: initial content of Freon gases (%); and GWP: global warming potential (-).

3.3 Impact of Refrigerants

Electric refrigerators use Freon gases as refrigerants. Freon gases may be released into the atmosphere when there is a leak in devices or pipes during operation, or the renewal/disposal is conducted improperly. The CO₂ equivalent emissions CO_{2e} (t-CO₂) from a refrigerator is expressed in Eq. (12). Table 5 shows leak rates and collection rates of

various refrigerating apparatuses [20-22].

$CO_{2e} = [(W \times h_o \times t) + W \times (1 - h_d/100)] \times GWP \quad (12)$
where, CO_{2e}: CO_{2e} (t-CO₂); W: initial filling amount of refrigerants (t); h_o: leak rate of refrigerants (%); h_d: collection rate at the time of disposal (%); and t: number of years used (year).

4. Case Study

EC in terms of a model office building was calculated. Table 6 shows the construction overview of the model office building subject to the calculation.

4.1 Calculation Result of EC

Table 7 shows the calculation result of EC in the model office building. Fig. 1 shows the EC value per total floor space at the time of construction, renewal and demolition, respectively. Firstly, EC at the construction time was 666 kg-CO₂/m². Details by construction item consist of construction site 7%, structure 58%, finishing 17% and equipment 18%, the result of which indicates that structure has a significant impact. Secondly, EC at the renewal time was 355 kg-CO₂/m². The breakdown, including structure 3%, finishing 35% and equipment 62%, indicates that equipment has the largest impact. Finally, EC at the time of demolition was 73 kg-CO₂/m². The total EC was 1,093 kg-CO₂/m², the

Table 6 Construction overview.

Building overview		
Building	Purpose	Office
	Height	6 stories and 1 basement
	Structure	Steel (partially reinforced concrete)
	Floor area	11,015 m ²
	Car park	1,143 m ²
Equipment	Heating, ventilating and air conditioning	Air-source heat pump chiller : 998 kW Air handling unit and ceiling duct
	Sanitary	Water supply : 83 m ³ /day
	Electric	Power receiving capacity: 1,700 kVA
		Battery: 250 kW Private power generation: 200 kVA

Table 7 Calculation results of embodied CO₂.

Work		Cost (Mil. JPY)	Construction EC (t-CO ₂)	Renewal EC (t-CO ₂)	Demolition EC (t-CO ₂)	Total EC (t-CO ₂)	Reference	Unit
Structure	Steel frame	279	1,544	0	-	1,544	784	t
	Reinforced bar	83	728	0	-	728	522	t
	Concrete	207	1,504	0	-	1,504	4,791	Concrete m ³
	Others	195	457	101	-	557	-	-
	Subtotal	765	4,233	101	-	4,333	-	-
Finishing	Metal	216	638	745	-	1,384	-	-
	Interior	103	336	378	-	714	-	-
	Outer wall	53	90	7	-	96	3,511	m ² (wall area)
	Others	93	217	242	-	460	-	-
	Subtotal	465	1,282	1,372	-	2,654	-	-
Building materials total		1,230	5,515	1,473	-	6,987	-	-
Equipment	Heating, ventilating, and air conditioning	350	602	1,489	-	2,091	998	kW (cooling capacity)
	Sanitary	68	167	266	-	432	83	m ³ /day (water use)
	Electrics	338	522	680	-	1,232	1,700	kVA (substation)
Equipment total		755	1,321	2,435	-	3,755	-	-
Construction site		221	497	0	-	497	-	-
Total (cost and each CO ₂ emission)		2,206	7,332	3,908	804	12,044	11,015	m ² (total floor)
Total (unit/m ²)		0.200	0.666	0.355	0.073	1.093	-	-

details of which consist of construction 61%, renewal 32% and demolition 7%.

4.2 Calculation Result of Freon Gases in Building Materials, Equipment and Devices

Table 8 shows values used in the calculation and its result in terms of Freon contained in insulating materials [15]. CO_{2e} due to insulators having Freon gas (HFC-245fa) is 26 kg-CO₂/m². This is, as shown

in Fig. 2, equivalent to 2% of the building's EC (1,093 kg-CO₂/m²). We assume that the outer wall surface is relatively small compared to the total floor space, which makes the impact rather small. Even though the building's EC is not so much affected by insulators, we could still reduce CO_{2e} by about 2% by using Freon-free products.

Table 9 shows values used for the calculation of refrigerants and the results. The calculation was

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Fig. 1 Embodied CO₂ (60 years).

Table 8 Specifications of insulator and results.

Item	Specification	
Type of insulator	Urethane foam	HFC-245fa
Surface covered A_{ins}	5,050	m ²
Thickness L_{ins}	0.025	m
Density e	30	kg/m ³
Initial content rate f	7.3	weight%
GWP	1,030	-
CO _{2e}	285	t-CO ₂
	26	kg-CO ₂ /m ²

Fig. 2 Embodied CO₂ due to insulators and refrigerants.

Table 9 Specifications of refrigerant and results.

Item	Air-source heat pump	Multi-type air conditioner
Type	R410A	R410A
Initial filling amount W	375 kg	408 kg
	0.376 kg/kW	0.402 kg/kW
Leak rate H_o	2%/year	1%/year
Collection rate at the disposal time h_d	30%	30%
GWP	2,090	2,090
CO _{2e}	1,489 t-CO ₂	1,109 t-CO ₂
	135 kg-CO ₂ /m ²	101 kg-CO ₂ /m ²

conducted in terms of a model office building (11,015 m²), assuming two situations in which an air-source heat pump (central system) and a multi-type air

conditioner for office buildings (individual system) are installed, respectively.

When a refrigerator is used for 60 years, CO_{2e} due to refrigerants of an air-source heat pump is 135 kg-CO₂/m², whereas CO_{2e} due to a multi-type air conditioner for office buildings is 101 kg-CO₂/m², which means 9% of the total EC.

This is, as shown in Fig. 2, equivalent to 12% of the total EC, indicating that CO_{2e} attributed to refrigerants of an air-source heat pump has a significant impact on the total EC.

4.3 Comparison with a Residential Building

An office building and a residential building were compared since CO_{2e} in insulators and refrigerants affects them differently. The comparison focuses on CO₂ emissions per square meter at the time of construction. CO₂ emissions per square meter of a residential building are, according to Table 2, 270 kg-CO₂/m² (= (1,707 kg-CO₂/(Mil JPY))/(6.318 m²/(Mil JPY))). Table 10 provides calculation conditions regarding insulators used in a residential building. CO_{2e} attributed to Freon gases in insulators (urethane foam) is 451 kg-CO₂/m² (= 0.2 (m³/m²) × 30 kg/m³ × 0.073 kg/kg × 1,030). As shown in Fig. 3, in a residential building, the impact of Freon gases used in insulators is the same or greater than the EC at the time of construction. Unlike office buildings, residential buildings have a large outer wall surface for the total floor space and they also use insulators having an increased thickness in order to enhance the

Table 10 Calculation conditions of insulators for residential buildings.

Item	Specifications	Notes
Floor area	128 m ²	Two-stories
Type of insulator	Urethane foam	HFC-245fa
		Walls 0.06 m
		Floors 0.085 m
		Ceilings 0.14 m
Amount used	0.2 m ³ /m ²	
Density e	30 kg/m ³	-
Initial content rate f	7.3 weight%	-
GWP	1,030	-

Table 11 Calculation conditions of refrigerants in air conditioners for residential buildings.

Item	Specifications	Notes
Floor area	128 m ²	Tow-stories
Amount of refrigerants used per m ²	0.047 kg/m ²	Refrigerant: R410A 1 kg/machine Installing: 6 machines
GWP	2,090	-
Leak rate h_o	1%/year	-
Duration of use	60 year	-

Fig. 3 Embodied CO₂ due to Freon gases (comparison between a residential building and an office building).

energy-saving performance during operation, both of which seem to have contributed to the greater impact.

Next, Table 11 provides calculation conditions regarding refrigerants used in air conditioners for residential buildings. CO_{2e} due to the emission of refrigerants used in air conditioners for residential buildings was 59 kg-CO₂/m² ($= 0.047 \text{ kg/m}^3 \times 2,090 \times 0.01 \text{ kg/kg} \times 60 \text{ year}$). As shown in Fig. 3, the impact is not so much as insulators, however, CO_{2e} due to Freon gases used in refrigerants for air conditioners accounts for 22% of EC at the construction time.

5. Conclusions

Conclusions can be drawn as follows:

(1) The calculation method of the EEC based on the 2005 I-O table in Japan was demonstrated and the intensities in terms of 401 sectors were obtained;

(2) The total EC for a general office building was calculated. The EC at the time of renewal is equivalent to 53% of the EC for construction.

Particularly, in terms of equipment, the EC at the time of renewal generates approximately 1.8 times as much EC as construction. This is because equipment has a short renewal cycle compared to structure and finishing, indicating that a life-cycle extension of equipment would be important;

(3) The impact that Freon gases contained in building materials and those used in equipment and devices have on the EC was calculated. When insulators containing HFC-245fa are used in a model building, the equivalent CO₂ (CO_{2e}) is 2% of the building's EC. The percentage may look low. However, we still need to use Freon-free materials and to control Freon products appropriately.

In terms of refrigerators installed in the model building, during the life-span of 60 years, refrigerators emit the CO_{2e}, accounting for 9%~12% of the building's EC. It is important to keep reducing emissions of Freon gases into the atmosphere by improving quality during manufacture and construction (reducing leakage during operation), and conducting a thorough and proper control at the time of maintenance and demolition. It is also effective to reduce the installed capacity through energy-saving efforts in the building;

(4) CO_{2e} due to Freon gases contained in materials used in residential buildings is, unlike the result of an office building, greatly affected by insulators. The further activities using the insulation materials which does not include Freon gases are important.

Acknowledgments

The present study was supported in part by the IBEC (Institute for Building Environment and Energy Conservation).

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