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The Effectiveness of Life Cycle Assessment for Building Using Inventory Database "IDEA" in Japan

Yosuke TANAKA [1*] , Yoshiyuki SUZUKI [2] , kensuke KOBAYASHI [3]

[1] *Construction Headquarters, Project Promotion Office, HAZAMA ANDO CORPORATION, Japan, E-mail address: tanaka.yosuke@ad-hzm.co.jp*
[2] *Technical Research Institute, Decarbonization Technology Development Department, HAZAMA ANDO CORPORATION, Japan, E-mail address: suzuki.yoshiyuki@ad-hzm.co.jp*
[3] *Assoc, Prof, Dept, of Environmental Science, Faculty of Life and Environmental Science, Prefectural University of Hiroshima, Dr.Eng, Japan, E-mail address: kensuke@pu-hiroshima.ac.jp*

Abstract: Reducing the environmental impact in the construction industry is essential for a sustainable future, and life cycle assessment (LCA) should be effectively conducted to reduce the environmental impact. The construction industry is one of the fields that emits a large amount of Greenhouse Gas (GHG). It is also characterized by many material inputs and a one-off single production. Therefore, it took a lot of effort to evaluate all the input materials, and it was difficult to implement a detailed LCA. There is need to solve these problems and to establish a fair and reliable evaluation method.
In order to solve this problem, it is proposed to establish a common rule for calculating environmental loads of buildings, such as carbon dioxide emissions. In addition, by effectively utilizing the Inventory Database for Environmental Analysis (IDEA) database, which is an inventory database developed in Japan. It can evaluate not only carbon dioxide but also various environmental substances, and analyze how the environmental impact is correlated with each building and its constituent materials.
Furthermore, by analyzing the actual buildings of 83 projects, the differences in the tendency of building type and materiall was clarified. A database was constructed to help reduce the environmental impact during the early stages of construction project and for different types of buildings.

Key words: Life cycle assessment (LCA), Inventory Database for Environmental Analysis (IDEA), Environmental Product Declaration (EPD), Carbon Footprint of Products (CFP), Multi-criteria Assessment

1. INTRODUCTION

There is a global trend towards achieving a carbon-neutral society. In order to realize a carbon-neutral society, it is important to reduce emissions throughout the supply chain, and the use of LCA methods is essential for planning environmentally friendly buildings. However, there have been few examples of LCA calculations based on industry-unified rules for buildings, and calculations that depend on the interpretations of calculation clients and implementers have resulted in different calculation results for the same building. Therefore, there is a need to promote the use of calculation methods that emphasize transparency and fairness based on third-party certified environmental product declarations (EPDs) under uniform ISO-compliant rules.

In this paper, a case study is described in a Carbon Footprint of Products (CFP) and an EcoLeaf (EL) were derived through the implementation of LCA based on PCR within an actual building context.

Reporting on the diverse environmental impact analysis results (multi-criteria evaluation) scrutinized utilizing IDEA as background data.

2. METHODOLOGY

In this section, the LCA methodology for buildings and the database used for the calculation are described. Then, a Product Category Rule (PCR), which is common rule for calculation, is proposed to realize environmental declarations, and the method of obtaining CFP and EL for representative properties using IDEA is described.

2.1 Research Summary

LCA is a method for quantitatively evaluating the environmental impact of a product over its lifetime, from resource extraction and raw material production to product manufacturing, distribution, use, disposal, and recycling.

In 1997, the international standard ISO14040 was established, and the Japanese architectural community demanded its immediate practical application. 1997 saw the establishment of the "Global Environmental Action Plan" by the Architectural Institute of Japan, which positioned LCA as a priority research field. The LCA Guideline Development Subcommittee then proceeded with its deliberations, issuing a draft version of the "LCA Guidelines for Buildings" in 1999, followed by the official publication of the "LCA Guidelines for Buildings" in 2003[1].

The 'LCA Guidelines of the Building Society of Japan' include approximately 400 data numbers as background data for environmental assessment, and LCA can be conducted for six substances, including CO_2. On the other hand, IDEA is available for the inventory database, which has the largest number of data in Japan. Therefore,in this study, to expand the number of target substances for assessment and to perform multi-criteria LCA assessment, LCA was conducted using IDEA[2], developed by the National Institute of Advanced Industrial Science and Technology (AIST) [3].

2.2 Inventory Database

IDEA is a comprehensive inventory database developed in Japan. It includes various items constructed by non-manufacturing industries such as agriculture, forestry, and fisheries, as well as by manufacturing industries such as food and beverages, textiles, chemicals, ceramics, building materials, metals, and machinery.

The latest IDEA Ver 3.3 is a database that can quantify environmentally hazardous substances in all Japanese products and services, including approximately 5,000 types of agricultural, forestry, fishery, and industrial products. There are approximately 1,000 types of assessable environmental impact substances, including emissions of chemical substances such as CO_2, NOx, SOx, PM2.5, arsenic, cadmium, chromium, and lead, as well as iron and copper. In addition to providing numerical values for the amount of environmental impact per functional unit, it also provides input and output data for the manufacturing process of each product[4].

The IDEA includes a Japanese damage assessment method called the Life cycle Impact assessment Method based on Endpoint modeling (LIME) [5]. This method was developed by the Life Cycle Assessment Research Center of the National Institute of Advanced Industrial Science and Technology (AIST) in collaboration with the LCA Project Impact Assessment Study Group. By utilizing LIME, the number of items requiring weighting can be minimized. This is achieved through assessing the amount of damage at the endpoint level, such as human health, biodiversity, social assets, and primary productivity. Subsequently, a damage calculation type assessment can be performed to integrate these items through comparison.

2.3 Assessment Framework

In Japan, there are two frameworks quantitatively visualizing product environmental information using the LCA method. ISO/TS 14067 (Greenhouse gases - Carbon footprint of products - Requirements and guidelines for quantification and communication) and ISO 14025 (Environmental labels and declarations - Type III environmental declarations - Principles and procedures).

And also, “The Japan EPD Program by SuMPO” is operated by The Sustainable Management Promotion Organization (SuMPO) [6]. The general incorporated association is operated 2 type labels.

Carbon Footprint of Products (CFP) declaration is based on ISO/TS 14067, while another type, EcoLeaf (EL) is the Type III environmental declarations and is based on ISO 14025 [7]. Each of these declarations are a mechanism for quantitatively disclosing the impact of climate change across the entire lifecycle of products and services, from raw material procurement to disposal and recycling. They are displayed on products and services in an easy-to-understand manner. When creating these declarations, it is necessary to calculate by Product Category Rules (PCR)[8]. That define EPD rules and requirements for each target product category.

2.4 Project

Figure 1 shown The summary and photo of the completed building. It comprises an branch office for Hazama Ando Corporation's own use and a rental housing building. The office portion is certified as Net-ZEB (over 100% energy reduction) and the rental housing portion is certified as ZEH-M Oriented (over 20% energy reduction) [9].

Project Item	Description
Building Type	Office and apartment
Floors	1 Basement Floor,10
Structure	Steel Frame
Construction Location	Sendai, Miyagi, Japan
Building Area	931.9㎡
Total floor area	7,932.2㎡
Useful life of building	65 years

Figure 1　Building summary and photo

2.5 CFP /EL Calculation Method, Scope

LCA calculations were conducted based on the PCR (PA-241000-AA-09) [10] for "buildings" within the "SuMPO Environmental Label Program" operated and managed by SuMPO. This PCR, publicly available for buildings, allows evaluation of the entire life cycle, including facility construction and operational phases.

Figure 2 shown the scope of the LCA calculation, which includes the following phases.

・Material manufacturing phase.
(A1 raw materials supply, A2 transportation of raw materials, A3 manufacturing)
・Construction phase. (A4 transportation, A5 construction)
・Use phase. (B3 repair, B4 renewal, B6 operation, B7 water use)
・Demolition and waste processing phase.
(C1 demolition, C2 transportation, C3 waste processing, C4 landfill).

For the calculation, each building material input amount for this building is based on the cost estimate statement as foreground data. IDEA Ver2.1.3 was used for background data. If the unit defined in IDEA is different from the unit in the accumulation statement, it is necessary to match the unit.

For unit conversions, the LCA Subcommittee of the Architectural Institute of Japan utilized the "Unit Conversion Database Ver1.0", along with data from the end of the book "Evaluation of Building Renovation Work PCM Series V" (BSIJ, 2023), published by the Building Survey Institute of Japan (BSIJ). In addition, the websites of the manufacturers providing the materials for the products were also cited.

The data used in this study was IDEA Ver2.2. The figures registered and published as EPDs are the result of using IDEA Ver2.1.3, and there are slight differences from the figures presented in this paper.A review panel of inspectors conducts a review, and those that pass the review are notified of their verification numbers, and the procedure is then made public.

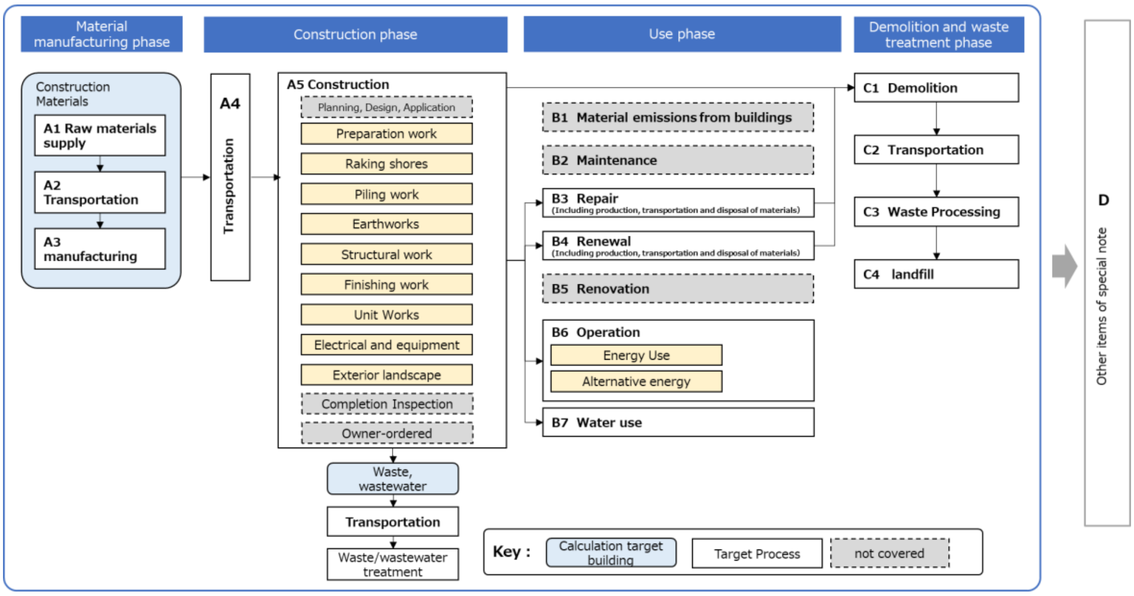

Figure 2 Scope of the LCA calculation

3. FINDINGS AND DISCUSSION

3.1. EPD Registration Information

The EPD calculation results are shown in Figure 3 [11] [12]. Regarding the contribution rate of each process in the entire life cycle of the building, GHG emissions during the operation phase showed a high contribution (54%) over the 65-year service life. This was followed by the material manufacturing phase and the repair/renewal phase with similar contribution rates (22% and 18%, respectively). In the material production stage, steel frames, the main structural component, accounted for 43% of the production, followed by concrete at 14%. For the repair and renewal phase, the impact of equipment-related activities was particularly significant.

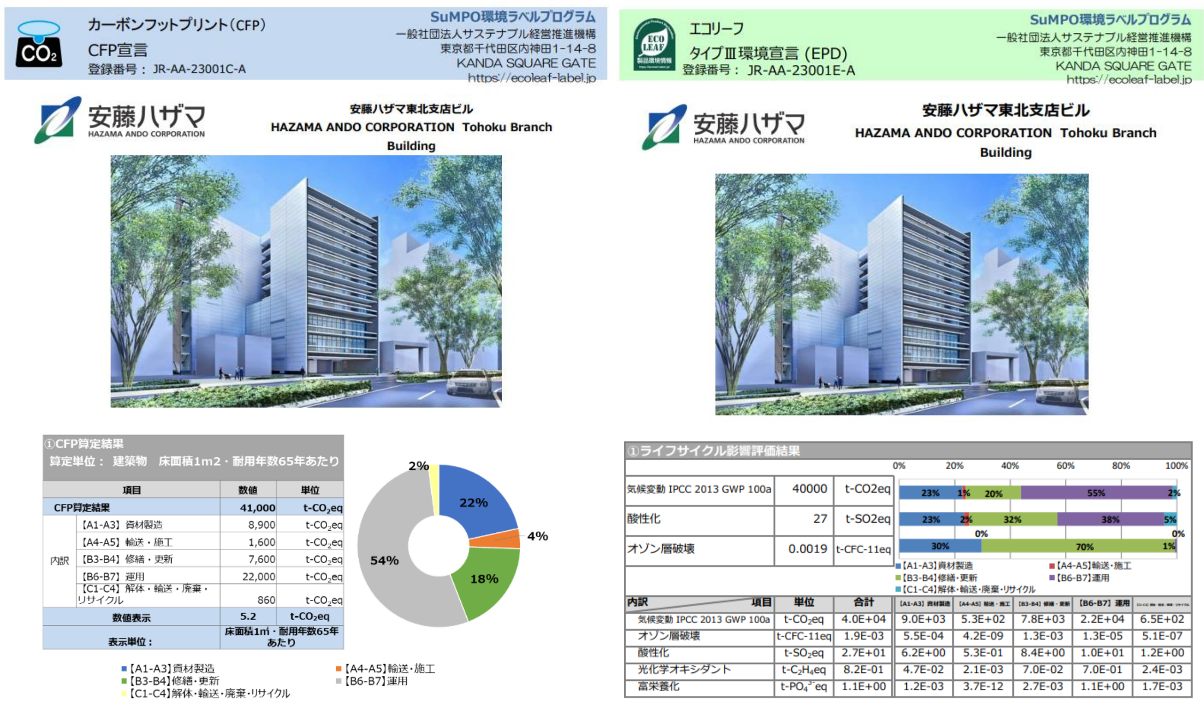

Figure 3 EPD calculation result (CFP/EL)

3.2. Multi-criteria analysis

Figure 4 shows the results of the EL calculation and the results of 17 target impact areas that can be evaluated using IDEA. In addition to climate change, acidification and ozone depletion were registered as EPDs in this study. The contribution rate of each process in the total life cycle is also presented.

The acidification result was highest in the operation phase, followed by the material production phase and the repair/renewal phase, showing the same trend as that of climate change. On the other hand, for ozone depletion, the highest contribution rate (66%) was observed in the repair/renewal phase, and this factor was influenced by the usage rate of gypsum board products during manufacturing and repair/renewal. Photochemical oxidants were influenced by gas use, and eutrophication was influenced by the rate of sewage use, with a high percentage of contribution (over 85%) in the operational phase, showing a different trend from climate change.

Integration is the contribution of the material manufacturing phase (16%), the transportation phase (16%), the repair and refurbishment phase (14%), with the contribution of Embodied (A1-A5, B3-B4, C1-C4) (73%) exceeding that of Operational (B6-B7) (27%)

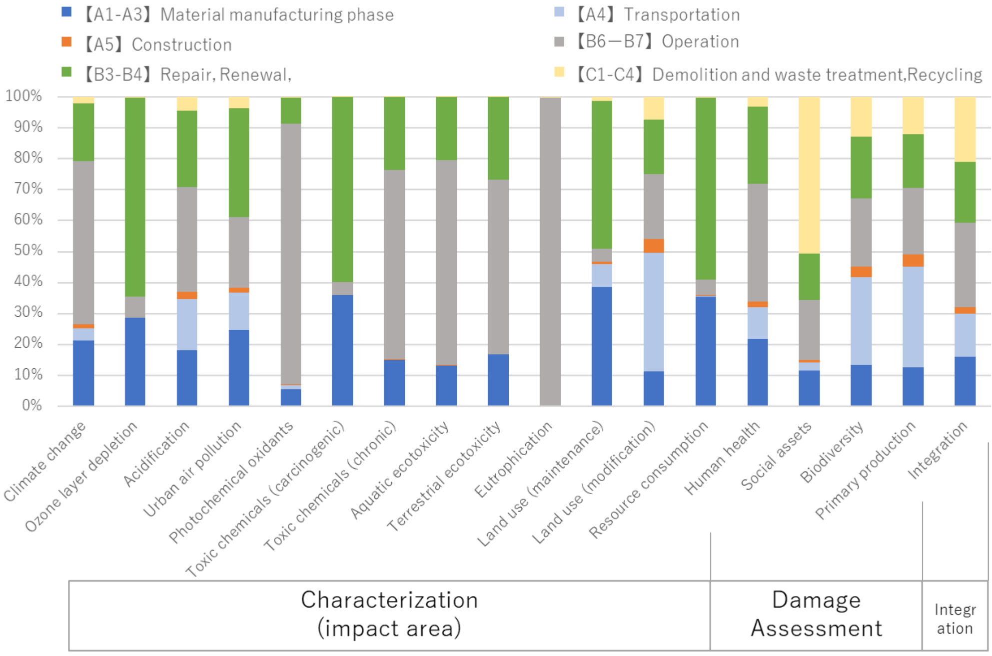

Figure 4 EL calculation result

Figure 5 shows the results of the extraction of dominant factors for each environmental domain and integration result.

For toxic chemicals (carcinogenic), the contribution of the materials manufacturing stage exceeded 40%. This is attributed to the influence of power cables, air conditioners, and copper-coated wires(Figure 5(a)).

For land use (maintenance), the contribution rate of the material manufacturing stage also exceeded 40%, mainly due to the use of plywood and wooden window frame products, showing a different trend from that of organic chemicals(Figure 5(b)). It was noted that the reforestation rate of the wood used has a significant impact on the results of primary production and integration, and it is essential to procure materials from properly managed reforested forests.

In addition to ozone depletion, the repair and renewal phase resulted in organic chemicals (carcinogenic), land use (maintenance), and resource consumption contributing to more than 60% of the total. For resource consumption, stainless steel, power cables, steel frames, and gypsum boards each accounted for 10% of the total, with these materials affecting about half of all materials(Figure 5(c)).

In terms of integration factors, trucking services (18%), electricity (18%), and landfill disposal services (13%) accounted for about half of the total(Figure 5(d)).

Figure 6 shows the damage assessment for each protected target. The protected area with the highest impact on integration was human health, accounting for 39%, followed by social assets with 28%, primary production with 19%, and biodiversity with 14% impact.

IDEA Name	Toxic chemicals (carcinogenic) /kg-C6H6eq	Contribution Rate (%)
Power cable, Conductor weight conversion	1,388.770	40.8
Air conditioners (except window type and separate type)	392.790	11.5
Copper-coated wire, Conductor weight conversion	380.397	11.2
Communication cables, Conductor weight conversion	319.271	9.4
Refrigeration equipment	199.247	5.9
Electric power, Tohoku Electric Power Company, FY2015	123.646	3.6
Cooling tower	106.419	3.1
Gas water heaters	94.446	2.8
Copper products	72.967	2.1
Valves and cocks for water supply and drainage	45.615	1.3
Bare copper wire	43.963	1.3
Bronze wrought copper products	42.100	1.2
Primary copper smelting and refining products, 4-digit	40.651	1.2
Switchboards	37.391	1.1
Control Units	21.539	0.6

(a) Toxic chemicals (carcinogenic)

IDEA Name	Land (maintenance) /m2a	Contribution Rate (%)
Regular Plywood	643,373.48	34.4
Special plywood	470,150.79	25.1
Wooden window frame	188,460.86	10.1
Trucking service, 10 ton, loading_rate_average	181,255.80	9.7
Particleboard	140,089.53	7.5
Electricity, Tohoku Electric Power Company, FY2015	36,923.84	2.0
Gypsum board and similar products	32,683.48	1.7
Water supply	28,386.24	1.5
Silicone rubber, Compound	19,118.16	1.0
Metal silicone	13,443.47	0.7
Steel frame	12,831.54	0.7
Sanitary ware	11,985.48	0.6
Shoji paper, calligraphy paper	11,483.83	0.6
Metal sashes and doors	6,503.25	0.3
Sewage treatment services	5,269.57	0.3

(b) Land use (maintenance)

IDEA Name	Resource consumption /kgSb-eq	Contribution Rate (%)
Hot-rolled stainless steel sheet	192.836	11.4
Power cable, Conductor weight conversion	191.382	11.3
Steel frame	167.610	9.9
Gypsum board and similar products	132.298	7.8
Air conditioners (except window type and separate type)	65.689	3.9
Plastic sheets, 0.2 mm or thicker and soft	62.627	3.7
Hot-dip galvanized steel sheet	61.454	3.6
Rigid plastic foam products, thin sheets, less than 3mm	53.233	3.1
Copper-coated wire, Conductor weight conversion	52.560	3.1
Electricity, Tohoku Electric Power Company, FY2015	52.374	3.1
Gas water heaters	52.266	3.1
Communication cables, Conductor weight equivalent	44.391	2.6
Stainless steel shapes	39.987	2.4
Stainless steel (including heat-resistant steel), 4 digits	37.150	2.2
Valves and cocks for water supply and drainage	34.590	2.0

(c) Resource consumption

IDEA Name	Integration /JPY(yen)	Contribution Rate (%)
Trucking service, 10 ton, loading_rate_average	63,092,253	18.2
Electricity, Tohoku Electric Power Company, FY2015	62,286,107	17.9
Landfill disposal service, Industrial waste	44,036,973	12.7
Steel frame	20,644,305	5.9
Natural gas combustion energy	12,028,339	3.5
Industrial waste disposal service, debris	10,098,361	2.9
Power cable, Conductor weight conversion	9,218,623	2.7
Electricity, Tohoku Electric Power Company, FY2014	8,601,542	2.5
Aluminum extrusions, small	6,816,915	2.0
Water	6,813,843	2.0
Aluminum rolled products	6,232,701	1.8
concrete	5,419,278	1.6
Gypsum board and similar products	5,131,018	1.5
Polymethylene polyphenyl polyisocyanate (PMPPI)	4,772,510	1.4
Sewage treatment services	4,636,231	1.3

(d) Integration asses

Figure 5 Dominant factor extraction (environmental domain, integrated assessment)

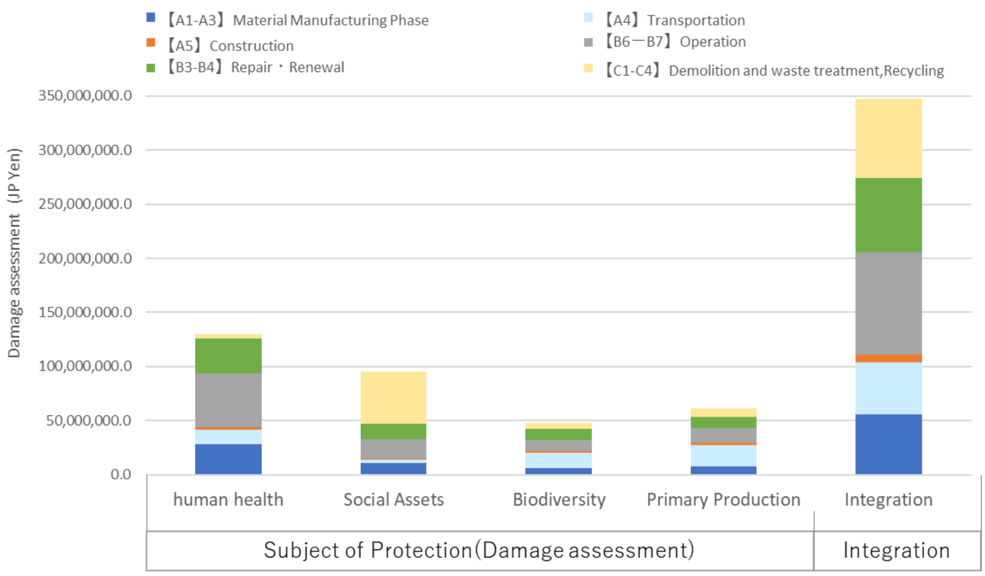

Figure 6 Integration and protected objectives (damage asessment) results

4. TENDENCY ANALYSIS

4.1 83 Project Evaluation Methods

Table 2 shows the target building for trendency analysis, 83 of which were evaluated for their environmental impact in order to obtain basic data for conducting LCAs for buildings. These buildings were constructed in various areas in Japan and include a wide variety of building sizes, structures, and designer types.The scope of the study included the analysis of CO_2 emissions and the integration of embodied carbon in nine construction phases: A1-3 (manufacturing), A4 (transportation), A5 (construction), B3 (repair), B4 (renewal), C1 (demolition), C2 (transportation), C3 (treatment), and C4 (landfill). Structures and finishing materials were evaluated in this analysis, while equipment and exterior structures were excluded. LCA calculation rules and cutoff criteria were in accordance with the EPD calculation rules, and background data were performed using IDEA Ver 3.3.

Table 2 83 Project building type

Building type	Number of properties
Logistics Center, Distribution Warehouse	9
Production facilities	22
Office, Government building	17
School	11
Hospital	12
Hotels, Residence	12
Total	83

4.2 Result

Figure 7 shows the trend of CO_2 emissions for each building type. When looking at median values, Logistics warehouses had the lowest CO_2 emissions per floor area, followed by production facilities and office and government building types. For schools, hospitals, hotels and condominiums, the trend was observed to exceed 1,000 kg-CO_2 per floor area. The impact of steel frames, reinforcing bars, and concrete used in frame construction is high for all applications, but for other materials, the trend differs among the different applications. Shutters contribute more to logistics warehouses, aluminum sashes to offices and schools, and gypsum board to hotels and condominiums.

Figure 8 shows the trend of the integration analysis for each of the building types. When looking at median values, logistics warehouses showed the lowest trend of integration valuation per floor area, followed by production facilities office and government building types. For schools, hospitals, hotels and condominiums, a trend of over $100 per floor area was observed. Integrated analysis also showed that the materials with the greatest impact for each type of use were different from those for CO_2. For example, stainless steel structures had the highest impact on production facilities, while gypsum board had the highest impact on offices, government buildings, and hospitals. In addition to gypsum board, the contribution of ordinary plywood was high in schools.

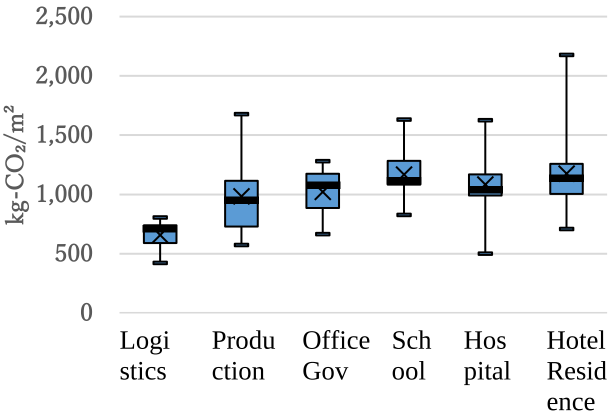

Figure 7 CO_2 emissions per building type

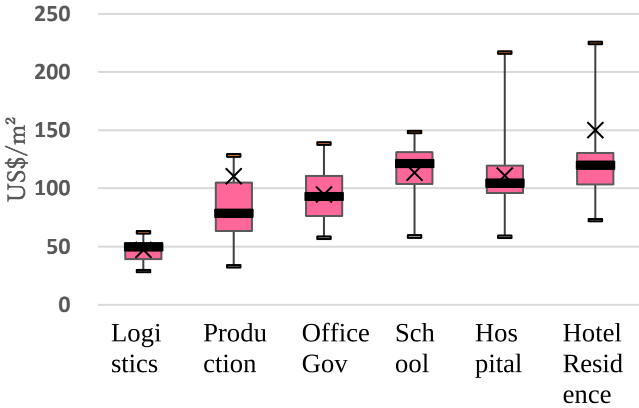

Figure 8 Integration per building type

5. CONCLUSIONS

In this paper, assumptions and examples of the examination of life cycle assessments of buildings in Japan, as well as the analysis results and considerations of actual buildings, are described.Using IDEA, various environmental analyses were conducted to clarify the degree of influence of processes in the building life cycle for each impact area, the different materials with high contribution rates, as well as the percentage of damage for each protected area and the results of the integrated assessment.

In addition, the dominant factors that have a large environmental impact for each use were analyzed for 83 actual buildings. Based on the results of these various analyses, it is important to consider comprehensive environmental impact reduction measures that take into account not only GHG but also multiple environmental aspects.

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