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Investigation of relationship between carbon emission and building energy performance index for carbon neutrality

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ABSTRACT

There have been various environmental regulations established according to United Nations Framework Convention on Climate Change (UNFCC), and the industry of construction is no exception to those regulations. Although the industry of construction in Korea has been blamed as the biggest cause of global warming and environment pollution for emitting carbon dioxide (CO_2), it is now seeing the severity of the problem and is about to change. Those new environmental regulations are, however, not mandatory, but just recommendations, and criteria for CO_2 reduction are still insufficient, compared to their importance. The purpose of this study is to understand the relationship between the reduction of CO_2 emission and the score of Energy Performance Index (EPI), which is regulations on energy performance, so that it can be possible to check how much CO_2 is reduced as the score of EPI increases, and then to derive a regression equation. The objectivity of this study is to analyze the relationship between the amount of CO_2 reduction and EPI, which is stipulated in Standards for energy conservation being enforced in Korea, and then to draw a regression equation. For that objectivity, the amounts of CO_2 emission and reduction were checked as the scores of EPI items increase, with Visual DOE which is a building energy interpretation program, and those items affecting CO_2 reduction were gathered separately and regression equations for them were derived.

Keywords: building; energy performance index (EPI); CO_2; performance evaluation; carbon neutrality

Introduction

To remedy the problem of global warming that has been an international issue since the 1980s, United Nations Framework Convention on Climate Change (UNFCC) was announced in 1992 and lots of environmental regulations have been established since then. According to World Energy Outlook reported by International Energy Agency, Korea was ranked ninth in the amount of CO_2 emission (500,009 thousand tons) and ranked second in the yearly rate of increase as 198.7%, which was such disgraceful as the second largest after China. In addition, the emission of greenhouse gases increased by 80.7% in the construction business of Korea while it decreased by 3% in that of the developed countries. The recent situation has shown that changing the domestic industry of construction is the most urgent matter [1, 2]. 2030 NDC(2030 Nationally Determined Contribution) are intermediate goals for the realization of carbon neutrality by 2050, determined by the participating nations themselves, based on the Paris Agreement. The Republic of Korea plans to reduce its GHG emissions by 40%, by 2030, compared to the levels in 2018 [3-5]. The government, as a measure to overcome the situation, has implemented a project of "2050 Carbon Neutrality of the Republic of Korea" through the green growth national strategies and plan and has declared solemn pledge for green growth by setting up a 2050 national goal for greenhouse gas reduction [6-8]. Carbon Neutrality is our nation-wide vision and new global paradigm. Preparing for the transition into a carbon-neutral society is of the utmost importance. We need an implementation system to promote the transition into a carbon-neutral society in all fields, not only the economy and industry, but across the entire society. However, most of the environmental regulations are still recommendatory and such measures as criteria for CO_2 reduction and methods to quantify the emission are incomplete even though CO_2 has been given much attention as the main culprit of global warming [9-11].

This study aimed to make quantitative assessment of the amount of CO_2 emission in the construction industry, through the regulations on construction environment being currently enforced in Korea. For that, it made research into the relationship between the amount of CO_2 reduction and Energy Performance Index (EPI) provided in Standards for energy conservation and derived a regression equation. The method of research is as follows.

Of the regulations on construction environment being enforced in Korea, those strictly observed and applied to a wide range were found. Standards for energy conservation and methods to calculate EPI points were reviewed and a reference building was selected. A building energy interpretation program was used in simulating the amount of CO_2 emission from the building selected as an object of assessment. Based on the assessment results, regression analysis was carried out on the relationship between the amount of CO_2 reduction and the rise in the EPI score, and then a relational expression was drawn.

Theoretical Consideration on Building Energy Assessment

Standards for Energy Conservation

The standards for energy saving of domestic buildings are based on Building Code, Law for Rationalization of Energy Use and so on, and 'Energy Consumption of Buildings and Usage of Waste Materials' (Article 59 of Building Code) and 'Prevention of Thermal Loss of Buildings' (Article 21 of Regulations for Facility Standards of Buildings, Etc.) have been implemented. Of measures to regulate the energy performance of buildings to a specific level for the sake of energy saving, Standards for energy conservation control an overall energy performance of a structure at the stage of designing and allows a flexible design of the structure, whatever techniques a designer use, if a specific level of energy performance is secured. The system of submitting a 'Plan for Energy Saving' has been implemented to buildings that consume a considerable amount of energy since 1985. EPI, which is to regulate the aggregate amount of energy consumption, was put into effect in 1995, and Standards for energy conservation were revised at the time. 'Standards for energy conservation in Buildings' revised and announced in 2001 include general provisions, compulsory matters on Standards for energy conservation and an EPI review report. In particular, when the total score on the EPI review report is larger than 60 points, the design of a building is judged to be suitable. Submitted design plans and other documents are reviewed when a design is scored per item of the EPI review report [12].

Energy Performance Index

Energy Performance Index (EPI) is a measure to regulate energy performance of a building to a specific level for the purpose of energy saving. Energy performance of a building is scored according to EPI on a plan for energy saving. The amount of energy consumption of a building is set up simply as '100' and the energy performance of the building is regulated against the amount of consumption, so that the system is easy to understand by whoever interested. In other words, it is just to select on a chart some of the items provided by Standards for energy conservation and to apply them in a design. In case all of the items are applied, the EPI score of the building becomes 100 points. The index helps a designer to decide what to select among techniques of energy saving in order to get more than the base score, i.e., 60 points. The systems to assess buildings with EPI that are being enforced are 'Building Energy Rating System, 2002', 'Housing Performance Grading indication system, 2006', 'Green Building Certification System, 2006 ' 'Seoul City Green Building, 2007 ' and so on [12, 13]. Also, Seoul city amended the regulations in 2008 so that it is obligatory public buildings of smaller than 3,000 m^2 obtain more than 67 points in the EPI score and those of larger than 10,000 m^2 achieve more than 81 points. EPI is, thus, thought to be suitable for regulating the energy performance of buildings, for it enables an assessment of major energy factors in the spheres of architecture, facilities and electricity and applies to a wide range of buildings. Table 1 shows the relations between EPI and the energy saving system.

Analysis on Relationship Between EPI and CO_2

Overview

To analyze the relationship between the rise in the EPI score of a building and the amounts of reduction of energy consumption and CO_2 emission, the amount of energy consumption was derived through a building energy simulation per item and a simulation was carried on. Then, through the simulation with the visual-DOE, the amount of reduction of CO_2 emission was analyzed. The amount of CO_2 emission was measured according to the change in the amount of energy that occurred due to change in the conditions of

Table 1. Relations between EPI and Building Rating Systems

System	Description
Standards for energy conservation	Suitable in case the EPI score is more than 60 (inclusive) points
Housing Performance Grading indication system	1st grade in case of the EPI score more than 81 (inclusive) points 2nd grade in case of the EPI score more than 74 (inclusive) and less than 81 points 3rd grade in case of EPI score more than 67 (inclusive) and less than 74 points 4th grade in case of the EPI score more than 60 (inclusive) and less than 67 points
Green Building Certification System	The energy sector (12 points) is scored by EPI points (When the EPI score is more than 85 (inclusive) points, a full mark is given to the sector.) Score of assessment on energy consumption $Y = 12 \times \frac{(EPIscore - 60)}{25}$
Seoul City Green Building	Permitted when ranked above the stage III (EPI score more than 81 (inclusive) points) and the stage IV (EPI score more than 74 (inclusive) and less than 81 points
Building Energy Rating System	The items of extra points in the Building Energy Rating System are similar to EPI assessment items.

the building. As for the unit amounts of CO_2 emission per energy source, the data provided in the guideline (proposal) for reducing CO_2 emission for Sejong city buildings were referred to. The weather data reported by Korean Solar Energy Society were converted to those fit for files of DOE-2 weather data for simulation.

Based on the assessment results, regression analysis was done on relations between the rise in the EPI score per item and the reduced amount of CO_2 emission and a relational expression was derived.

Method

The energy simulation of buildings is to calculate the amount of energy consumed by machines and electric facilities in a building and, furthermore, to estimate energy costs. Since many variables like characteristics of a building structure should be considered in the calculation, it is general to use a computer. European countries and the United States have analyzed and assessed the energy performance of buildings for efficient management of energy saving. The European Union published a memorandum on 'Directive on the Energy Performance of Buildings on a purpose that the energy performance certification system applies to all of the structures; in the United States, the guideline for energy simulation (90.1.1-2004 Appendix G Modeling Guideline) designated by American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) is recommended for the stages of architecture design and construction. Simulation techniques and building modeling also have been given increasing attention through the USGBC LEED (Leadership in Energy and Environmental Design) certification system. And, lots of programs on practices have been developed according to the simulation guideline and to the environment-friendly certification systems [14].

In this study, Visual DOE was used, which is often employed in research in Korea for its fast calculation. Visual DOE is one of the commercial DOE-2 programs that are developed on the basis of the essential energy interpretation algorithm, DOE-2. Since the 1960s when DOE started to be developed by the support from the Department of Energy, there has been a constant research lasting for more than 30 years, with Lawrence Berkley National Laboratory as the center of research. Visual DOE, based on such a DOE engine, is a typical dynamic energy simulation program that is able to perform energy interpretation for residential or commercial buildings in Figure 1 [14, 15].

simulation was conducted with a 25-storied building as its object which was estimated to be a general type,

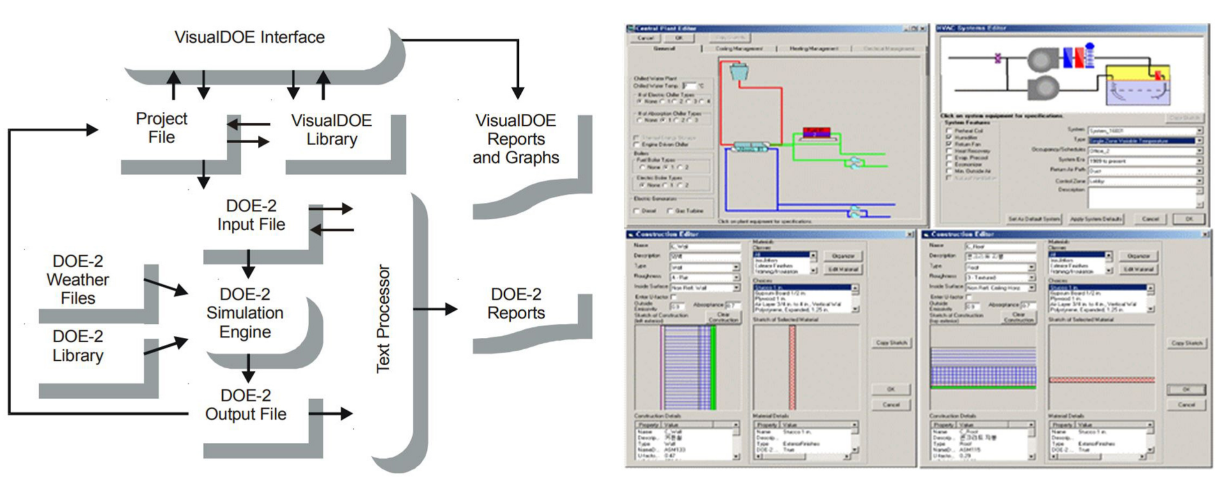

Figure 1. Energy Simulation Assessment Process.

Table 2. Description of the Target Building

Division		Description	
Building Area	1,500 ㎡		
Gross Area	37,500 ㎡		
Story	25 stories above ground		
Cardinal Points	Southward		
Construction Structure	Reinforced concrete		
Height of 1st Floor	6.0 m	Ceiling Height of 1st Floor	4.4 m
Height of Reference Floor	4.2 m	Ceiling Height of Reference Floor	2.8 m
Heating Source	District heating and an absorption chiller by district heating		
Air Conditioning	Constant air volume single duct system		
EPI Score	60.8 points		

Table 3. Constitution of the Target Building

Division	Constitution
Outer Wall	Bead-method heat insulating board of 50 mm, Heat transmission coefficient of 0.466 W/㎡K
Windows and Doors	Heat transmission coefficient of 2.8 W/㎡K, Shading coefficient of 0.83
Roof	Bead-method heat insulating board of 90 mm, Heat transmission coefficient of 0.288 W/㎡K
Floor	Bead-method heat insulating board of 70 mm, Heat transmission coefficient of 0.398 W/㎡K
Insulation	Concrete of 160 mm + Bead-method heat insulating board of 50 mm, inside insulation structure
Air Conditioning	Absorption chillers driven by hot water of district heating

for the purpose for analyzing the relationship mentioned above. The building is depicted briefly in Table 2.

A building that meets the base score, 60 points, stipulated in the Standards for energy conservation was modeled with Visual DOE. As for the number of occupants per floor area, the values used in designing air-conditioning facilities were used. ASHRAE STANDARD 90.1 "Energy Efficient Design of New Building Except Low-Rise Residential Building" was referred to for schedule, caloric value of the human body, lighting power density (LPD) and other electric power densities (EPD). ASHRAE STANDARD 62.1 was referred to for amount of ventilation. Table 3 shows the constitution of the object building. The amount of CO_2 emission was measured according to change in the amount of energy that occurred due to change in the conditions per EPI item.

Analysis of Assessment Results

The unit CO_2 emission of the target building was computed to be 177.8 kg-CO_2/㎡, which was found with the criteria consisting of 9 items of energy performance and 7 items of element technologies. As a result of the analysis of how much CO_2 is reduced as the EPI score increases by 1 point from the reference score (60 points), the mean reduction of CO_2 was found to be 3.686 kg- CO_2/㎡ per unit point. Table 4 shows the results of the energy simulation with the 16 EPI items. Of the 7 items that allow the assessor to check change in performance, except those to check whether there is application or not, 3 items were found out to have great effects on the reduction of CO_2.

Table 4. Simulation Results per EPI Item

Div.	Item	Score (Points)	Applied Amount of Carbon Emission (kg-CO_2 /m²)	Reduced Amount (kg-CO_2 /m²)	Reduced Amount per Point	Comment
Construction	Outer Wall	19	158.4	19.40	2.553	■
	Roof	6	177.5	0.30	0.125	■
	Floor	5	177.6	0.20	0.100	■
	Outside Insulation	6	177.1	0.70	0.292	■
	Windows /Doors	6	176.2	1.60	0.800	■
	Roof Garden	1	177.4	0.40	0.400	□
Machinery	Air Conditioner	4	152.9	24.90	15.563	■
	Ventilator	4	169.3	8.50	5.313	■
	Pump Efficiency	2	177.2	0.60	0.750	■
	Outdoor Air Cooling	3	163.8	14.00	4.667	□
	Partition of Operation	2	176.5	1.30	0.650	□
	Variable Air Volume	2	144.1	33.70	16.850	□
	Waste Heat Recovery	2	177.0	0.80	0.400	□
	Variable Displacement Pump	2	173.3	4.50	2.250	□
Electricity	Motor	2	177.3	0.50	0.625	■
	LED	1	175.1	2.70	6.750	■

Notes: □ = Element Technology; ■ = Performance

Analysis of Relationship

To find out the relationship, regression analysis was conducted with analysis data. The analysis was made on the 3 items of performance assessment that were found to have noted effects on the reduction of CO_2.

Before the regression analysis, the correlation between the individual factors was examined by correlation analysis. SigmaStat 3.5 of Jandel Scientific Software was used as an analysis program. As a result of the analysis, the mean heat transmission coefficient of the outer wall, the coefficient of performance (COP) of the air-conditioning facility, and the efficiency of the ventilator were found to be the variables having a significant correlation with CO_2 within the significance level of 5%. The mean heat transmission coefficient of the outer wall (Ue) had a strong positive correlation as 0.972; and the coefficient of performance (COP) of the air-conditioning facility and the efficiency of the ventilator had a strong negative correlation as 0.947 and 0.816 in Figure 2, respectively. A multiple regression analysis was carried out on the relationship between the 3 EPI items and CO_2.

Analysis of CO_2 - EPI Credit

Regression analysis was done with the 3 credits affecting the amount of CO_2 (yCO_2) emission: the heat transmission coefficient (α), the COP of the air-conditioning facility (β), and the efficiency of the ventilator (γ). The adjusted coefficient of determination (R^2) of the model was 86.3%. All the variables were found to be significant as the p-value was less than 0.05 and the t value was more than 2 in all of the variables. And, there was no multi-collinearity as Tol>0.1 and VIF<10.

$$yCO_2 = 259.527 + 20.607\alpha - 160.64\beta - 58.482\gamma \quad (1)$$

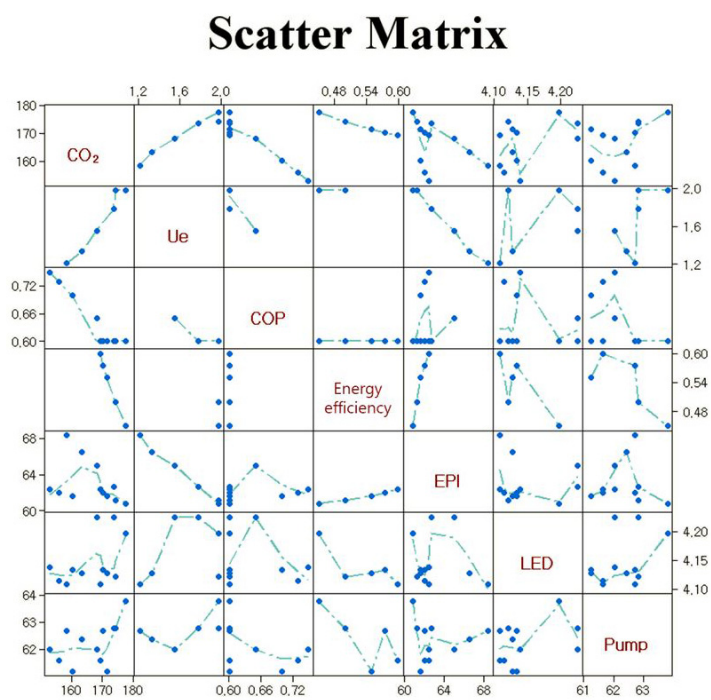

Figure 2. EPI & CO_2 Factor Scatter matrix.

Analysis of CO_2 EPI Score

A regression equation of a EPI score was derived with the major items, but multi-collinearity was found as VIF > 10. To make up for it, the items showing the multi-collinearity were excluded and only EPI(x) and CO_2 (yCO_2) were analyzed. The coefficient of determination (R^2) was 60.4%.

$$yCO_2=170.1+2.02x- 0.0319x^2 \quad (2)$$

Conclusions

In this study, a simulation was carried out to derive a relational expression on the amount of CO_2 reduction after the rise of an EPI score, and the results of the simulation are as follows:

1. A multiple regression analysis on EPI and CO_2 was conducted to have a relational expression.
2. Those having a close relationship with CO_2 emission among the EPI items were found to be the mean heat transmission coefficient of the outer wall, the coefficient of performance (COP) of the air-conditioning facility, and the efficiency of the ventilator.
3. The unit CO_2 emission of the target building was analyzed to be 177.8 kg- CO_2/㎡. The amount of CO_2 reduction when the EPI score increases by 1 point from the base score (60 points) was averagely 3.686 kg- CO_2/㎡ per unit point.

Since the above is the results of a simulation with a virtual building, there might be difference in the amount of CO_2 reduction according to the scale of a building, purpose of a facility or characteristics of operation. It is, thus, judged that further complementary research needs to be made.

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References

[1] J. Giesekam, J.R. Barrett, and P. Taylor, *Construction sector views on low carbon building materials.* Build. Res. Inf. 44(4) (2016), pp. 423-444.

[2] B. Jung and K. Lim, *Analysis through Development Trend of Nuclear Power and Renewable Energy*. Journal of Next-generation Convergence Technology Association. 3(4) (2019), pp. 158-164.

[3] R. Kim, M.K. Lim, S. Roh, and W.J. Park, *Analysis of the Characteristics of Environmental Impacts According to the Cut-Off Criteria Applicable to the Streamlined Life Cycle Assessment (S-LCA) of Apartment Buildings in South Korea*. Sustainability. 13(5) (2021), 2898.

[4] S. Kwon, *Effect of mineral admixture on CO_2 emissions and absorption in relation to service life and varying CO_2 concentrations.* Int. J. Sustain. Build. Technol. Urban Dev. 7(3-4) (2016), pp. 165-173.

[5] S. Lim and J. Moon, *A Study on the Characteristics of Eco-Friendly Plates using Lanfill Ash*. Journal of Next-generation Convergence Technology Association. 5(6) (2021), pp. 1046-1055.

[6] R. Zhao and S. Zhong, *Carbon labelling influences on consumers' behaviour: A system dynamics approach.* Ecol. Indic. 51(41) (2015), pp. 98-106.

[7] S. Melanta, E. Miller-Hooks, and H.G. Avetisyan, *Carbon Footprint Estimation Tool for Transportation Construction Projects.* J. Constr. Eng. Manag. 139(5) (2013), pp. 547-555.

[8] W.J. Park, R. Kim, S. Roh, and H. Ban, *Identifying the Major Construction Wastes in the Building Construction Phase Based on Life Cycle Assessments*. Sustainability. 12(19) (2020), 8096.

[9] W.J. Park, R. Kim, S. Roh, and H. Ban, *Analysis of Major Environmental Impact Categories of Road Construction Materials.* Sustainability. 12(17) (2020), 6951.

[10] S. Roh, R. Kim, W.J. Park, and H. Ban, *Environmental Evaluation of Concrete Containing Recycled and By-Product Aggregates Based on Life Cycle Assessment*. Appl. Sci. 10(21) (2020), 7503.

[11] R. Kim, *The Current Status of Green Building Materials based on Changing of Materials and Resources in G-SEED.* Magazine of Recycled Construction Resource. 15(4) (2020), pp. 48-57.

[12] Korea Energy Agency (KEA), *Energy-saving Standard for Architectural Design guideline,* 2009.

[13] S. Lee, D. Cho, and T. Ahn, *Comparative Study on the Energy Conservation Standard in Building Sectors in Korea and other Developed Country.* The Korea Architecture Institute. 16(4) (2000), pp. 85-92.

[14] International Energy Agency (IEA), World Energy Outlook 2016, 48, 2016.

[15] S. Lee and D. Cho, *Development of Bypass Air Conditioning System with variable air volume System.* Korea: Ministry of Knowledge Economy. 1 (2002), pp. 27-46.