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Research paper

Development of BIM-Framework for evaluating the Energy-Saving Design Criteria in South Korea

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Abstract

Although South Korea introduced ‘Energy-saving design criteria’ for efficient building energy management, floor plan processing is required because a detailed item evaluation is performed based on 2D floor plans, which leads to a decrease in work productivity. Therefore, the purpose of this study is to develop an evaluation framework based on the BIM model to save time and increase efficiency in order to prepare energy saving plans in South Korea, and verify its effectiveness through a comparative analysis with conventional evaluation methods. The results are as follows. 1) The process and input/output information was derived by classifying the evaluation items according to BIM data requirement information, and the BIM evaluation framework was developed based on Architecture Revit 2015. 2) For each item, error rates occurred for the calculated value of the BIM-based evaluation framework compared to conventional evaluation methods. 3) The score for each item of the BIM-based energy saving design criteria evaluation framework was the same as the conventional evaluation method. Therefore, the BIM-based evaluation framework developed in this study was considered to be a method to evaluate the energy saving design criteria.

Keywords: *Energy-saving design criteria, Building information automation system, Framework, Input/Output information, Performance evaluation*

1. Introduction

1.1. Background and purpose of the study

Building energy consumption accounts for 23% of the total industrial energy consumption[1], and in order to address this issue, South Korea is developing government-wide scientific evaluation technologies for greenhouse gas and energy evaluation management with the aim of reducing carbon emission in the building section by 26.9% compared to BAU by 2030[2,3]. In addition, South Korea is currently pursuing energy-saving design criteria, energy efficiency rating certification systems, total energy consumption cap, and green remodeling projects with the aim of mandating zero energy buildings by 2025[4,5,6,7].

Since 1985, South Korea has introduced the “energy-saving design criteria for buildings” for the efficient energy management of buildings, and standards for policies and technologies are being gradually reinforced and implemented to reduce energy consumption. It is stipulated that Energy-saving design requirements, energy performance index (EPI), energy consumption evaluation sheets, and supporting data must be attached for building permits[8]. However, floor plan processing is required because the detailed item evaluation is performed based on 2D blueprints prepared during actual work, and because the ECO2-OD, BESS programs for quantitative and convenient purposes are input/output-based evaluation tools[9], a decrease in work productivity occurs as a result of reprocessing floor plans.

Recently, BIM (Building Information Modeling) is attracting much attention as a key technology that can drive green growth in the construction industry by improving productivity related to building information, and studies are actively underway to improve BIM compatibility with conventional energy simulation tools in the field of evaluation and management of building greenhouse gas and energy[10,11,12,13,14]. The previous research by Lee Se-Ip et al. demonstrated the convenience of the building process according to the development of the BIM framework[15], and the research by Lee, Seoung Yun et al. proved that the BIM framework saved time for BIPV application. Therefore, BIM is a program that can contribute to saving time as a building process automation system. Furthermore, BIM-based design is being activated for large projects such as public buildings[16].

Therefore, this study develops an energy-saving design criteria evaluation framework that works together with BIM that is capable of saving working hours required to prepare energy saving plans in South Korea. In addition, the effectiveness of the framework developed in this study is verified through a comparative analysis with a conventional evaluation method using the energy saving criteria evaluation model.

1.2. Method and procedure of the study

The development and evaluation comparative analysis of the BIM-based energy-saving design criteria evaluation framework for buildings proposed in this study, as shown in Fig. 1, was performed according to the following procedures. First, the evaluation data of the energy-saving design criteria (requirements, EPI, total consumption) for the framework development was carried out by analyzing the items evaluated in South Korea through consideration of the energy saving design criteria[4,5]. Second, based on the contents reviewed, the process derivation and input/output information was determined by adopting the applicable items, and the BIM-based energy-saving design criteria framework was developed. Third, an energy-saving criteria evaluation case was set up as an analysis model, and a comparative analysis was performed with the framework developed in this study through a performance evaluation.
However, among the items of evaluation presented in the energy-saving design criteria (building, machinery, electricity, new and renewable energy), framework development and performance evaluation regarding only the building and machinery sections were undertaken in this study.

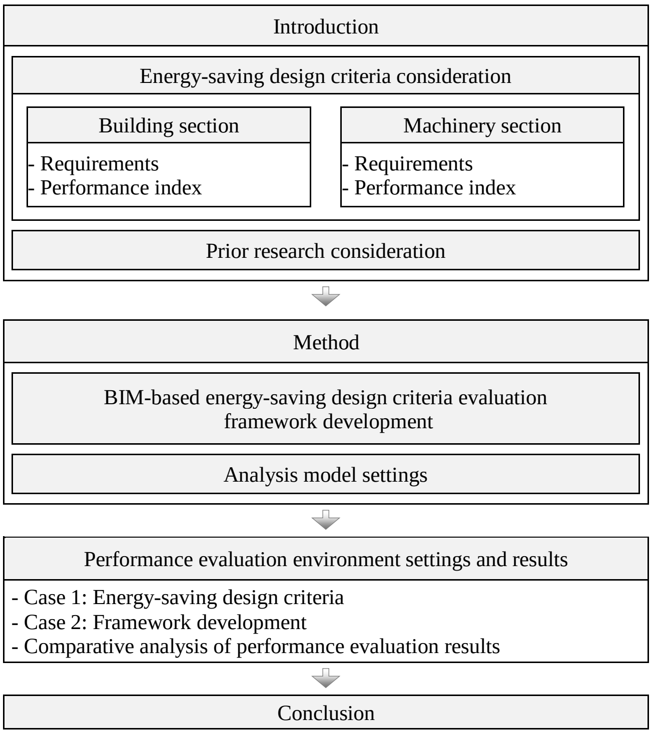


Fig. 1: Study procedure

2. Consideration of energy-saving design criteria in South Korea

2.1. Study of Energy-saving design criteria requirements

The energy-saving design criteria regulated by South Korea presents the evaluation criteria to efficiently manage the energy of buildings. The evaluation index of the energy-saving design criteria is divided into energy-saving design criteria, energy performance index, and energy consumption evaluation, and the detailed categories are divided into the building, machinery, electricity, and renewable energy sections. As such, the development of a framework for the building and machinery sections was prioritized in this study.
The requirements of the energy-saving design criteria in the building section consist of 7 items as shown in Table 1. Items 2 and 6 can be evaluated only after the evaluation of the energy performance index, so the energy performance index should be considered as a priority when developing the framework proposed in this study. The other items are related to the adoption of insulation, airtightness, and the application of vapor barriers, which are mandatory in the design.
The machinery section, as presented in Table 2, consists of 5 items, in which items 1, 2 and 3 are evaluation items related to applications and are mandatorily applied to the design of machinery. Items 4 and 5 are items in which the energy performance index is given priority consideration, and in this study, the development of the energy performance index is deemed necessary prior to the development of the framework.

Table 1: Energy-saving design criteria requirements: building section

No	Item
1	It complies with the insulation measures under Article 6-1.
2	It acquired a score of 0.6 or more for the 1st item in the construction section of the energy performance index under Article 6-2.
3	It complies with the installation method of insulation materials in the floor heating under Article 6-3.
4	The vapor barriers were installed under Article 6-4.
5	Entrance doors that are directly exposed to open air and connected to the 1st floor or the ground comply with the wind resistant structure under Article 5-9. (except for the entrance doors of the facilities that fall under each subparagraph of Article 6-4)
6	Windows with level 1~5 air tightness performance are applied to windows that are directly exposed to the open air of the living room.
7	It acquired a score of 0.6 or more for item 8 of the construction section.

Table 2: Energy-saving design criteria requirements: Machinery section

No	Item
1	The outdoor air conditions for design that were used to calculate the capacity of heating and cooling facilities complied with the content of Article 8-1. (Excluding those cases in which no heating and cooling facilities are present)
2	Pumps were adopted only if the product presented efficiencies equal or greater to those presented in KS Standards or KS certified products. (Concerns only new or exchanged pumps)
3	The device pipes and ducts were insulated using insulating materials having a heat resistance that meets or exceeds the standards determined in the Standard Specifications of Building and Machine Facilities. (Concerns only new or exchanged appliance pipes and ducts)
4	A score of 0.6 points or higher was acquired in item No. 10 of the machinery section of the energy performance index for public organizations. (Concerns only those buildings subject to the regulations of Article 10 of the 「Regulations on the Initiative to Rationalize Energy Usage by Public Organizations」)
5	A score of 0.9 points or higher was acquired in items No. 1 and No. 2 of the machinery section of the energy performance index for public organizations concerning uses as outlined in Article 14-2. (Excluding cases in which there are no heating and cooling facilities; Excluding item 1 in the event that a score is acquired for item No. 15 of the machinery section of the energy performance index; Excluding item 2 in the event that more than 60% of the cooling facility loads are supplied through district (local) cooling)

2.2. Study of Energy performance index (EPI)

The energy performance index (EPI) of the building section is divided into 14 items as shown in Table 3. For items 6, 7, 10, 11, and 13, only the applicability is evaluated, and for other items, they are divided into 5 levels ranging from 1~0.6, by a score of 0.1 for evaluation. The machinery section as shown in Table 4 is divided into a total of 15 items, in which items 1,2,3 and 4 are indexes to evaluate the efficiency of the machinery and items 10 and 11 calculate the application ratios. Other items were considered based on their application.
In order to develop the framework proposed in this study, each item of the energy performance index (EPI) was used as an index to divide into the stages of object input, object calculation, the final score, and score evaluation.

Table 3: Energy performance index (EPI): Building section

No	Evaluation method	Item
1	Ue(W/m^2K)	Average thermal transmittance of the outer wall (including windows and doors)
2	Ur(W/m^2K)	Average thermal transmittance of the roof (excluding ceiling and transparent envelope)
3	Uf(W/m^2K)	Average thermal transmittance of the living room on the bottom floor
4	%	Adoption of external insulation construction methods (external insulation construction ratio, when the area ratio of windows and doors is less than 50%)
5		Air tightness of windows and doors, quantity of airflow
6	applicability	Natural light opening (swimming pool), installation of openable windows facing the open air in the main living room (other buildings)
7	applicability	Night-time insulation equipment installed on windows
8	%	Installation of awning device to reduce the cooling load (installation ratio of awning equipment to the light transmitting area in living rooms facing south and west)
9	W/m^2	Average solar heat gain of per living room envelope area to reduce the cooling load
10	applicability	Wind resistant room or revolving door installation at the main entrance facing open air
11	applicability	Installation of wind resistant room at the entrance of each household in apartment houses
12	-	Pitch of building ratio to the height of buildings facing each other
13	applicability	Light openings of more than 2m2 must be installed for every 300m2 in the underground parking lot of apartment houses (excluding under 2 basement levels), and the lighting facility should be capable of automatic flickering or controlled by schedule for each lighting group according to the brightness of the surroundings to save lighting energy
14	-	Compensation points for machinery section 15 and building section 13 for when the underground parking lot is not installed

Table 4: Energy performance index (EPI): Machinery section

No	Evaluation method	Item
1	%	Heating Facility Efficiency
2	COP	Cooling Facility Efficiency
3	%	Ventilator Efficiency
4	%	Pump Efficiency
5	applicability	Whether 60% of the sum of all outdoor air intake volumes has been applied
6	applicability	Whether 60% of the sum of all outdoor air intake volumes for ventilation using recovered waste heat and floor heat has been applied
7	applicability	Whether insulation 20% or greater than outlined in the Standard Specifications has been applied
8	applicability	Whether multiple units to handle partial loads, proportional controls, or multi-level controls have been applied at levels of 60% or greater to the heat source facilities of all heat source facilities
9	applicability	Whether energy saving control methods to drive all fans of the air conditioner have been applied at levels of 60% or greater

10	%	Application of thermal storage type electrical cooling, gas and fuel consuming cooling, district (local) cooling, and small-scale co-generated cooling, and application ratios of cooling methods using new and renewable energy (cooling load ratios)
11	%	Ratio of excellent efficiency facility loads regarding total rapid heating boiler loads (the rapid heating boilers of excellent efficiency are given points if they retain grade 1 energy consumption efficiency or are highly energy efficient appliances)
12	applicability	Whether energy saving control methods such as heating and heating and cooling cycling pump multi-unit controls or variable speed controls are applied at levels of 60% or more of the total power consumption of the pumps.
13	applicability	Whether an energy saving control method such as water supply pumps or pressurized water supply pump heating and heating and cooling cycling pump multi-unit controls or variable speed controls are applied at levels of 60% or more of the total power consumed by all pumps
14	applicability	Adoption of energy saving control method facilities to the machine ventilated ventilation fans for underground parking lots
15	applicability	Whether levels of 60% or greater for all heating facility loads in the event that items 1 and 8 cannot be applied upon adopting incinerator utilizing waste heat systems, small scale gas co-generation systems, or districting heating were applied
	applicability	Whether levels of 60% or greater for all heating facility loads have been applied in the event that items 8 and 12 cannot be applied upon adopting individual heating or individual heating and cooling methods

2.3. Consideration of prior studies

A total of 6 prior studies were conducted for the BIM-based energy-saving design criteria, as shown in Table 5. Studies on the BIM-based energy-saving design criteria have been conducted on the BIM-based energy performance analysis program and IFC compatibility review, but only a few studies were conducted on the error rate and performance evaluation method through BIM self-evaluation. Therefore, this study attempts to analyze the error rate through performance evaluation by classifying the required evaluation items and extracting evaluation data of the energy-saving design criteria in conjunction with the BIM object configuration and property information system.

Table 5: Prior studies of BIM-based energy-saving design criteria

Title	BIM-based			
	Input value extraction	Utilization method	Framework development	Performance evaluation
A Study on Improvement of Energy Performance Index in Green Building Certification System using BIM (2011) [16]	-	-	-	-
A Comparative Study on Possibility of Applying BIM based Assessment Method to Energy Performance Index Assessment (2011) [17]	○	○	-	○
Code check for EPI using open-BIM (2014) [18]	○	-	-	-
Improvement of Open BIM-based Building Permission Process Using EPI (2015) [19]	○	○	-	-
Framework of Building Information Modeling for Energy-Saving Design Criteria of Building (2016) [20]	○	○	-	-

3. BIM-based energy-saving design criteria evaluation framework development

3.1. BIM data required information item classification for energy-saving design criteria evaluation items

In order to evaluate the Energy Performance Index (EPI) of the energy-saving design criteria for the building section, machinery section and to derive required information of BIM data for mandatory evaluation items, the characteristics were defined and the items were classified based on input method, variable characteristics, and dimension information utilization.

The information required to establish the method of entering each item in the building section was as presented in Table 6 and Table 7. For BIM data characteristic definition and item classification of mandatory required information, items 2 and 7 are items that can be input only when the EPI evaluation data index is preconfigured and were set to utilize EPI evaluation data, while items 3, 4, and 5 are related to applicability, and are set to check the variable characteristics using a direct input method. In addition, items 1 and 6 are related to the application of insulation and air-tightness level, so they can be automatically calculated during modeling when building the BIM-based database. In terms of BIM-data characteristic definition and item classification of required information for EPI, item 5 was selected by the direct input selection method due to the difference in performance according to the product catalog, and items 10 and 11 were adopted by the direct input selection method because the wind resistant room of BIM could not be recognized. All other items were configured for automatic calculation during framework development.

Table 6: BIM data characteristic definition and item classification of mandatory required information: Building section

Item (mandatory)		Input method	Variable characteristics	Dimension information utilization
1	. Compliance with Article 6-1 insulation methods	Automatic calculation	Function value	○
2	. Acquired a score of 0.6 or higher for EPI building item 1	-	Utilize EPI evaluation data	-
3	. Compliance with Article 6-3 floor heating insula-	Direct input	Y/N	○

	tion material installation method			
4	. Vapor barrier installation	Direct input	Y/N	×
5	. Wind resistant structure for entrances directly facing open air	Direct input	Y/N	×
6	. Application of air tightness level for windows directly facing open air	Automatic calculation	%(ratio)	×
7	. Acquired a score of 0.6 or higher for EPI building item 8	-	Utilize EPI evaluation data	-

Table 7: BIM data characteristic definition and item classification of EPI required information: building section

Item(EPI)			Input method	Variable characteristics	Dimension information utilization
1		. Average thermal transmittance of outer wall	Automatic calculation	Function value	○
2		. Average thermal transmittance of roof	Automatic calculation	Function value	○
3		. Average thermal transmittance of the bottom floor living room	Automatic calculation	Function value	○
4		. Adoption of external insulation construction methods	Automatic calculation	% (ratio)	○
5		. Installation of air-tight windows and doors, air tightness level and quantity of air flow (㎥/h ㎡)	Direct input	Setting value	×
6		. Installation of openable windows facing the open air in the main living room	Automatic calculation	% (ratio)	○
7		. Night-time insulation equipment installed on windows	Automatic calculation	% (ratio)	○
8		. Installation of awning device to reduce the cooling load	Automatic calculation	% (ratio)	○
Apartment houses	9	. Average solar heat gain of per living room envelope area to reduce the cooling load	Automatic calculation	Function value	○
	10	. Wind resistant room or revolving door installation at the main entrance facing open air	Direct input	Y/N	×
	11	. Installation of wind resistant room at the entrance of each household in apartment houses	Direct input	Y/N	×
	12	. Pitch of building ratio to the height of buildings facing each other	Automatic calculation	Function value	○
	13	. Light openings of more than 2m^2 must be installed for every 300m^2 in the underground parking lot of apartment houses, and the lighting facility should be capable of automatic flickering or controlled by schedule for each lighting group according to the brightness of the surrounding to save lighting energy	Automatic calculation	Y/N	○

The information utilized to extract input methods for each item of the machinery section was as presented in Table 8 and Table 9. For required information, items 4 and 5 must have the EPI evaluation data indexes configured to allow input, and a method of direct entry was used to indicate applications for items 1, 2 and 3 using a method of checking off Y/N. The energy performance index items could be automatically calculated upon recognizing a machine facility, and were set to be automatically calculated during the development of the framework for the machinery section.

Table 8: BIM data characteristic definition and item classification of mandatory required information: Machinery section

Item (mandatory)		Input method	Variable characteristics	Dimension information utilization
1	. Compliance of outdoor air conditions for design according to set standards	Direct input	Y/N	×
2	. Compliance of pump efficiency that meets or exceeds the KS Standard	Direct input	Y/N	×
3	. Application of insulation materials to pipes and ducts having a heat resistance that meets or exceeds the Standard Specifications	Direct input	Y/N	×
4	. Acquisition of a score of 0.6 points or greater in item No. 10 of EPI Machinery	Automatic calculation	Utilize EPI evaluation data	×
5	. Acquisition of a score of 0.9 points or greater in items No. 1 and 2 of EPI Machinery	Automatic calculation	Utilize EPI evaluation data	-

Table 9: BIM data characteristic definition and item classification of EPI required information: Machinery section

Item(EPI)		Input method	Variable characteristics	Dimension information utilization
1	. Efficiency of Heating Facility	Automatic calculation	% (ratio)	×
2	. Cooling Facility COP		Function value	×
3	. Ventilator Efficiency		% (ratio)	×
4	. Pump Efficiency		% (ratio)	×
5	. Outer Air Cooling System (Application of 60% or more of the sum of wind volumes of the entire outdoor air intake)		Y/N	×
6	. Waste Heat Recovering Ventilation Device (Application of 60% or more of the sum of wind volumes of the entire outdoor air intake)		Y/N	×
7	. Application of insulation 20% or more than outlined in the Standard Specifications		Y/N	×

8	. Operation of heat source multi-unit load applications, proportional controls, and multi-level controls (application levels of 60% or greater for all heat source facilities)		Y/N	×
9	. Adoption of energy saving control methods for the air-conditioner fan (application levels of 60% or greater for all fan driving mechanisms)		Y/N	×
10	. Ratio of thermal storage type electrical cooling, gas and fuel consuming cooling, district (local) cooling, small-scale co-generated cooling, and cooling methods using new and renewable energy (%)		% (ratio)	×
11	. Ratio of rapid heating boiler loads that are excellent efficiency facility loads (%)		% (ratio)	×
12	. Cooling and heating pump energy saving control method (60% or more of total power)		Y/N	×
13	. Water supply pump energy saving control method (60% or more of total power)		Y/N	×
14	. Underground parking lot ventilation fan energy saving control method (60% or more of total power)		Y/N	×
15	. District (local) heating, small-scale gas co-generation, incinerator utilizing waste heat system (60% or more of total heating facility loads)		Y/N	×
	. Application of individual cooling and heating at a level of 60% or more of total heating facility load		Y/N	×

3.2. BIM data required information item classification for energy-saving design criteria evaluation items

The method for deriving the defined variables of the Energy Performance Index (EPI) evaluation and the mandatory evaluation items involves defining the parameters and deriving data utilization systems such as calculation formulas using the parameters.

The established system of utilizing BIM data in the building section was as presented in Table 10 and Table 11. In terms of BIM data utilization system of the mandatory evaluation items in the building section, items 3, 4, and 5 are related to location and application, and other items are input through calculation results of EPI evaluation data and parameters. For the BIM data utilization system of the Energy Performance Index (EPI) items, the utilization system was derived by classifying evaluation items focused on heat transfer methods such as conduction, convection, and radiation. By calculating the thermal transmittance for the insulation performance by part, the data utilization system is classified in the same way as items 1, 2, 3, 4, and 7 are related to the mechanism of heat conduction. Items 5 and 6 are related to the installation of openings and the quantity of airflow, so they were classified as the same items because they can be evaluated as a convection mechanism. Because item 9 is related to solar heat gain, the framework was classified and developed based on the thermal radiation mechanism in that it can be evaluated by adding the additional data of the outer wall area to item 8.

Table 10: BIM data utilization system of mandatory evaluation items: building section

Item	Parameters	Data utilization system	Remarks
1	-Area -Thermal transmittance	Individual average thermal transmittance=[The sum of (Sum of individual area × Individual thermal transmittance)] /[Sum of individual total area]	Calculate individual average thermal transmittance
2	Utilize item 1 from EPI evaluation data		Calculate average thermal transmittance
3	Y/N		Direct input after reviewing insulation location
4	Y/N		Direct input after reviewing vapor barrier location
5	Y/N		Direct input after reviewing application of wind resistant room
6	Utilize item 6 from EPI evaluation data		Calculate average quantity of airflow of window
7	Utilize item 8 from EPI evaluation data		Awning equipment installation rate

Table 11: BIM data utilization system of EPI items: building section

Item	Parameters	Data utilization system	Remarks
1	-Area -Location -Thermal transmittance	Outer wall average thermal transmittance = [∑(Per corresponding area (Wall, Window, Door) Area×Thermal transmittance per corresponding area)] / [Sum of total outer wall area (Wall, Window, Door)]	Calculate average thermal transmittance
2	-Area -Location -Thermal transmittance	Roof average thermal transmittance = [(Roof area directly facing open air × Corresponding area thermal transmittance) + (Roof area indirectly facing open air × Corresponding area thermal transmittance)] / Total roof area	Calculate average thermal transmittance
3	-Area -Location -Thermal transmittance	Floor average thermal transmittance = [(Floor area directly facing open air × Corresponding area thermal transmittance) + (Floor area indirectly facing open air × Corresponding area thermal transmittance)] / Total floor area	Calculate average thermal transmittance
4	-Area -Location -Thermal transmittance	External insulation application ratio = (External insulation application area / Wall area excluding window area) × 100	Calculate external insulation area ratio
5	-Level(quantity of airflow) -Area	Average quantity of airflow of window=[Sum of (Individual window area×quantity of airflow)]/Total window area	Grade of window and door

6	-Location -Window type	Ratio of windows facing open air=((ΣOpenable window area)/Floor area)×100	Window installation applicability
7	-Window area -Equipment status	Night-time insulation equipment ratio = (Sum of night-time insulation equipment installed window area / Total window are) × 100	Installation status
8	-Area -Location(azimuth)	Awning installation ratio = (Sum of window area with awning / Sum of window area facing South & West) × 100	Application of 80% or more facing south & west
9	-Area -SHGC	Average Solar Heat Gain= [(Sum of area per corresponding area (Wall, Window, Door) × Sum of solar heat gain per corresponding area)] / [Sum of total outer wall area (Wall, Window, Door)]	Calculate average solar heat gain

The established system of utilizing BIM data in the machinery section was as presented in Table 12 and Table 13. In terms of mandatory items, items 1, 2 and 3 are items to evaluate the compliance/non-compliance through data and items 4 and 5 are input using the EPI evaluation data calculation results. The BIM data utilization system of the EPI classified the evaluation items into the categories of heat sources (items 1, 2, 3, 8, 11), ventilators (items 3, 5, 9 and 15), pumps (items 4, 13 and 14), pipes and ducts (item 7), and waste heat recovery facilities (items 6, 10).

Table 12: BIM data utilization system of mandatory evaluation items: Machinery section

Item	Data utilization system	Remarks
1	Compliance of outdoor air conditions for design according to set standards	Database utilization
2	Compliance of pump efficiency meets or exceeds the KS Standard	Review of property information of each library
3	Application of insulation materials to pipes and ducts having a heat resistance that meets or exceeds the Standard Specifications	Review of property information of each library
4	Utilization of item no. 10 of the EPI evaluation data machinery section	Calculation of responsible cooling load ratios
5	Utilization of items nos. 1,2 of the EPI evaluation data machinery section	Efficiency and COP calculations

Table 13: BIM data utilization system of EPI items: Machinery section

Item	Parameters	Data utilization system	Remarks
1	- Loads	Heating Efficiency=∑(Load×No. Of Units×Points) / ∑(Load×No. Of Units)	% efficiency calculation
2	- Loads	Cooling Efficiency=∑(Load×No. Of Units×Points) / ∑(Load×No. Of Units)	COP calculation
3	- Power - Efficiency	Ventilator Efficiency=∑(Power×Efficiency×No. Of Units) / ∑(Power×No. Of Units)	% efficiency calculation
4	- Format - Output - A characteristic efficiency - B characteristic efficiency	Basic efficiency (%) = a×[lnX]^2 + b×[InX] + c (X=Output) Coefficient to calculate basic efficiency of a, b and c Product efficiency / basic efficiency = each pump score Weight average score of pump = Σ{output(㎥/min)×No. Of Units×Points of each pump}/Σ{Output(㎥/min)×No. Of Units}	% efficiency calculation
5	- Whether outdoor air cooling has been applied - Air conditioner air supply volume	∑(Outdoor air cooling volume) / ∑(total air volume)	Ratio % calculation
6	- Whether waste heat recovery type - Equipment air volume	∑(Applied ventilation volume) / ∑(total air volume)	Ratio % calculation
7	- Thickness of insulation - Type of insulation material	Design thickness / thickness of each area > 1.2	Comparison of thickness
8	- Control method - Loads - Whether the method has been applied	∑(Applied load×No. of units) / ∑(Load×No. Of Units)	Ratio % calculation
9	- Control method - Power consumed - Whether the method has been applied	∑(Applied load×No. of units) / ∑(Load×No. Of Units)	Ratio % calculation
10	- Loads - Whether the method has been applied	∑(Applied load×No. of units) / ∑(Load×No. Of Units)	Ratio % calculation
11	- Loads - Whether it is a high efficiency energy appliance - Whether grade 1 energy consumption efficiency	∑(Load×No. Of units×Points) / ∑(Load×No. Of Units)	Ratio % calculation
12	- Control method - Power consumed - Whether the method has been applied	∑(Applied Load×No. Of units) / ∑(Load×No. Of Units)	Ratio % calculation
13	- Control method - Power consumed - Whether the method has been applied	∑(Applied Load×No. Of units) / ∑(Load×No. Of Units)	Ratio % calculation
14	- Control method - Power consumed - Whether the method has been applied	∑(Applied Load×No. Of units) / ∑(Load×No. Of Units)	Ratio % calculation
15	- Loads	∑(Applied Load×No. Of units) / ∑(Load×No. Of Units)	Ratio % calculation
	- Loads	∑(Applied Load×No. Of units) / ∑(Load×No. Of Units)	Ratio % calculation

3.3. The process of using mandatory information according to the design process

As shown in Fig. 2, Fig. 3, each item of the building section of the energy-saving design criteria was derived for each level of information utilization to develop the utilization algorithm. In order to minimize repeated evaluations during the development of the BIM framework, the evaluation process first evaluates items 1, 2, 3, 4, and 7(conduction) by dividing them by similar items and evaluates items 5 and 6(convection), and items 8 and 9(radiation). The evaluation process for each item is as follows.

First, items 1, 2, and 3 are related to the calculation of the average thermal transmittance of the outer wall, roof, and bottom floor, and the calculated value is derived by calculating the coefficient of the thermal transmittance, area, and exposure-to-open-air by the material information of each area. The average thermal transmittance value is then calculated by dividing the calculated value by the sum of the area.

Second, item 4 is related to the external insulation construction ratio, and the window area ratio is calculated by calculating the outer wall area and opening area. When the window area ratio is less than 50%, the external insulation area ratio to the total outer wall area is derived by calculating the external insulation area.

Third, item 7 is related to the night-time insulation equipment application to the window, and the calculation formula is shown in (1). When installed, the total window area is divided by the window area with the insulation equipment installed, and then multiplied by 100, and finally, the score is calculated if the value is 20 or less.

Fourth, item 5 is related to the installation of air-tight windows and doors, the value calculated by dividing the multiplied value according to the area and air-tightness level by the sum of the total area is set as the area-weighted score.

Fifth, item 6 is related to the installation of an openable window facing the open air in the living room, and if the value obtained by multiplying the sum of the outer floor area by 0.1 is equal or less than the sum of the opening and closing window area, an evaluation score of 1 is awarded. If it is equal or more, the score is set to 0.

Sixth, item 8 is related to the installation ratio of awning equipment to the light transmitting area according to the azimuth (facing south, west), and the required parameters are derived by the P/H value calculated according to the installation locations of the horizontal fixed outer awning, vertical fixed outer awning, and movable awning, and the area, and the solar heat gain coefficient of the awning. When the required parameters are calculated, if the solar heat gain coefficient of the awning is 0.6 or less, the ratio is derived as shown in Equation (2), and then the score is applied according to each area.

Seventh, item 9 is related to the average solar heat gain per living room envelope area, and is calculated as in Equation (3). The solar heat gain coefficient of the solar radiation control system is calculated after multiplying the installation locations of the horizontal fixed outer awning, vertical fixed outer awning, and movable awning, and the solar heat gain according to the light transmitting area.

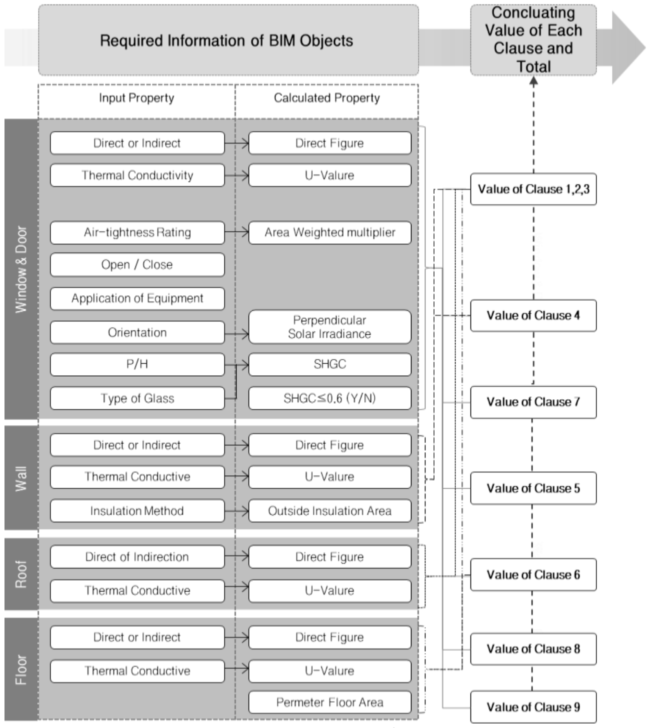


Fig. 2: Process according to BIM object information: Building Section

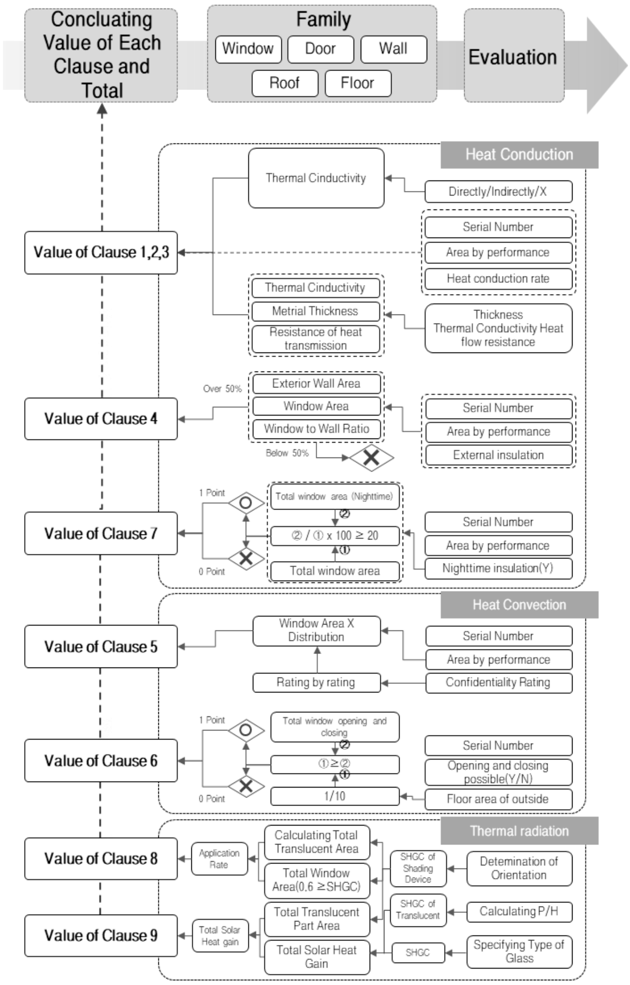


Fig. 3: Process according to the BIM data utilization system: Building Section

Upon classifying the items of each of the information utilization stages as shown in Fig. 4, the developed algorithm for the machinery section of the energy-saving design criteria was established. When developing the BIM framework, as the machinery section involves a process that is automatically calculated using the property information, information entered by the user is not included. The conclusions are as follows.

First, items 1, 2, 8, 11 and 12 relate to the source and calculate cooling, heating, and rapid heating machine application ratios and load weighted averages. The equation [∑(Load×No. Of Units×Points)/ Total Load] is calculated upon applying scores to the facilities. Mandatory items 4 and 5 require prioritized calculations of the source of the EPI, and thus were sequentially prioritized for calculation in the algorithm.

Second, items 3, 5, 9 and 15 relate to the fan and calculate the outdoor air application ratios of the ventilation system and the load weighted average of the air conditioner. The equation used to calculate the load weighted average is [∑(applied load×no. of units)/ total load], and the outdoor air cooling volume application is calculated using [∑(outdoor air cooling volume/ total air volume)].

Third, items 4, 13 and 14 relate to the pump and assess whether control methods and efficient facilities have been adopted.

Fourth, item 7 relates to pipes and ducts, and a point score is assigned upon assessing whether 20% or greater insulation material applications have been fulfilled.

Fifth, items 6 and 10 relate to the waste heat recovering facilities, whereby the waste recovering device application status of each item (Source, Fan, Pump, Pipe/Duct) is assessed. The items above relate to those items that must be calculated as a priority, and for the last step, the algorithm was configured.

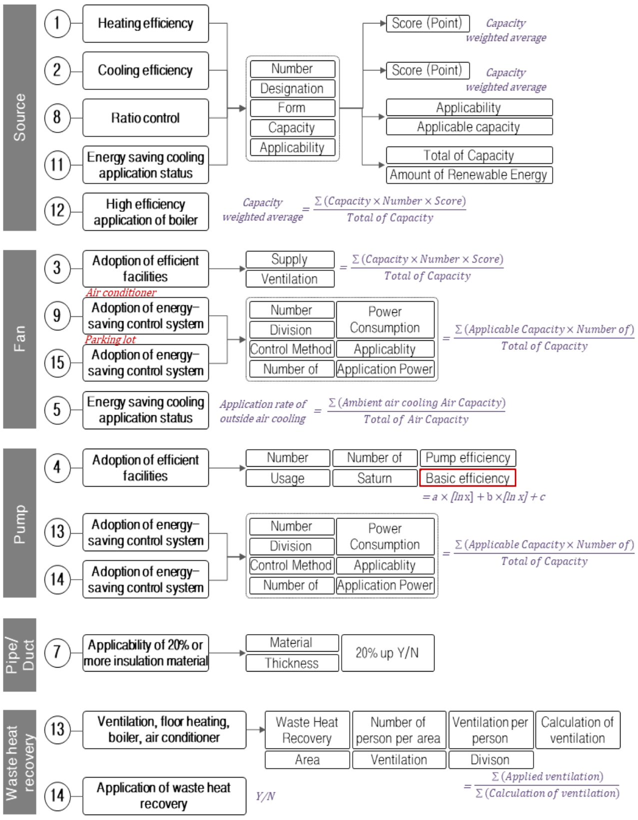


Fig. 4: System Utilization Process According to Machine Property Information Classifications Machinery section

3.4. BIM framework input/output information

In order to develop the framework proposed in this study, the classification contents of the object input/output information system were configured into the setting files, where the extraction, analysis, evaluation, and output modules were developed. By using Autodesk Revit, a tool used in BIM practice, a building was modeled through conventional methods to evaluate the energy performance index, and the Add-in program was developed and applied to the building model for automatic evaluation of BIM-based building energy-saving design criteria. The add-in program was implemented by using C# (programming language), which is the open API (Application Programming Interface) of Revit.

The extraction module, as shown in Fig. 5, is classified into application object selection, object property information selection, selective data filtering, and execution file extraction, and when application object is selected, the object for the evaluation of a specific item is designated and the data is ‘loaded’ into the object input/output information system and executed. When the object property information is selected, the property information is selected for selectively extracting data only for the specific item evaluation of the designated object, and then the item evaluation analysis is performed on the data selected. The process of extracting the result value into an execution file is performed by classifying and grouping object and property/configuration information to load into the analysis and evaluation modules, and the extracted data is designated as an object of the method through the variables for calculation in the analysis and evaluation module.

The evaluation information of the extracted data can be stored by extracting the data for the evaluation of each item, and data information analyzed by layer is also classified and stored. In addition, during output, the output module was implemented so that evaluation results can be checked in real-time during the modeling process under the BIM authoring tool, and it is also possible to implement an Excel format conversion output module according to the format in which the result values were calculated.

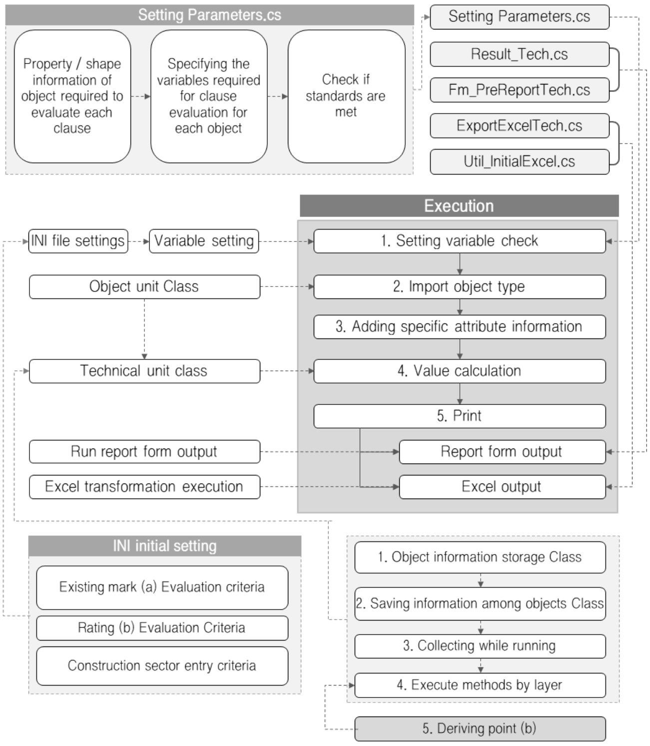


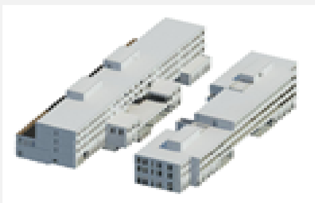
Fig. 5: BIM-based energy-saving design criteria evaluation framework input/output information

4. Performance evaluation method and results

4.1. Performance evaluation setting

In order to perform a comparative analysis between the evaluation results of the BIM-based energy-saving design criteria proposed in this study and the conventional 2D-based energy-saving design criteria, as shown in Table 14, modeling was performed on Architecture Revit 2015 based on the S education research complex construction project. The thermal transmittance of the opening and envelope material were applied in the range of 0.194~0.504 (W/m^{2}k) for the wall, 0.132 (W/m^{2}k) for the roof, and 0.133~0.470 (W/m^{2}k) for the floor, and the windows were set as 16mm triple pane windows injected with Low-e, Argon. In addition, the air-tightness performance of the doors was set in the range of level 0~2. The area was derived from the figures calculated by Architecture Revit.

Table 14: BIM model setting for performance comparison analysis

<table>
<tr><td colspan="3">Performance evaluation environment settings</td></tr>
<tr><td rowspan="3">Thermal transmittance</td><td>Wall</td><td>0.194~0.504 (W/m²k)</td></tr>
<tr><td>Roof</td><td>0.132 (W/m²k)</td></tr>
<tr><td>Floor</td><td>0.133~0.470 (W/m²k)</td></tr>
<tr><td colspan="2">Direction</td><td>Southwest, southeast,
northwest, northeast</td></tr>
<tr><td colspan="2">Window</td><td>16mm+Triple (Low-e+Argon)</td></tr>
<tr><td colspan="2">Door</td><td>Air-tightness level(0~2)</td></tr>
<tr><td colspan="3">Modeling</td></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><td colspan="2">Project Photo</td><td>BIM Modeling</td></tr>
</table>

4.2. Performance evaluation results and comparative analysis: Building section

The results of the energy-saving design criteria evaluation platform of the BIM-based building section developed in this study and the energy-saving design criteria evaluation of the conventional building section are shown in Table 15.

For items 1, 2, 3, 4, 5, 6, 7, 8, and 9, the error rates for the calculated values of the evaluation framework developed in this study were 0.44%, 0%, 0.72%, -0.29%, 0.03%, 0%, 0%, 0%, and 0%, respectively, in comparison with the conventional evaluation method. The analysis is as follows.

First, in terms of the thermal transmittance calculation of items 1 and 3, it is thought that an error rate occurred in the calculation of the outer wall area and floor area according to the difference in perception of the grid baseline (Out line, Center line, In line) of the floor plan, which is the standard for the area value. Item 4 has different results depending on the opening area and the outer wall area, and as the error rate is (-), it is thought that a larger value was calculated than the conventional evaluation method due to the difference in recognition of the reference line when calculating the external insulation construction outer wall area. In terms of item 5, differences in the calculated values when calculating the opening occur because an error rate occurs according to the opening area. The error rate of items 6, 7, 8, and 9 are 0%, which is considered to be capable of deriving accurate calculation values for the calculation of solar heat gains.

Second, the score for each item of the BIM-based energy-saving design criteria evaluation framework was the same as the conventional evaluation method. Even if an error rate of the calculated value occurred, it did not affect the score because it was a small error in the calculation.

Therefore, the results of the BIM-based energy-saving design criteria evaluation framework presented in this study showed an error rate regarding the calculated value, but the score result was the same, and by improving the error rate it can be used as an energy-saving design criteria evaluation method.

Table 15: Comparison of performance evaluation results: building section

Output information		Conventional evaluation method		Developed evaluation framework		Error rate
Item	Detailed information	Output value	Overall score	Output value	Overall score	
1	Outer wall average thermal transmittance (W/m^2K)	0.452	21	0.454	21	0.44%
2	Roof average thermal transmittance (W/m^2K)	0.132	7	0.132	7	0%
3	Bottom floor average thermal transmittance (W/m^2K)	0.139	5	0.140	5	0.72%
4	External insulation ratio (%)	75.55	4	75.33	4	0.29%
5	Area weighted score (-)	0.96	5	0.99	5	0.03%
6	Outer floor area (Y/N)	Y (209≥2080)	Y	Y (209≥2080)	Y	0%
7	Total area of windows with night-time insulation equipment installed (%)	87.58	Y	87.58	Y	0%
8	SHGC of awnings facing south and west (%)	54.61	3.2	54.16	3.2	0%
9	Average solar heat gain per envelope area (W/m^2)	19.39	2.4	19.39	2.4	0%

4.3. Performance evaluation results and comparative analysis: Machinery section

The results of an evaluation using the BIM-based energy-saving design standard evaluation framework developed in this study for the machinery section are presented in Table 16, in which items 1, 2, 3, 4, 5, 6, 8, 9, 11, 13 and 14 presented margins of error compared to calculations of values under the existing evaluation method of 0%, 0%, 0%, 0%, 0%, 0%, 0%, 0%, 0%, 0% and 0%. However, items 7, 10 and 12 were excluded, in that they were not applied to the subject building. In the case of the machinery section, these analysis results typically present margins of error according to how the facilities applied to a building are recognized upon utilizing the property values of the machine facilities. Therefore, as the framework developed in this study did not present any margins of error, this indicated that the machine facilities were recognized accurately, and that the framework can be effectively used as a means of evaluating the energy-saving design standard.

Table 16: Comparison of performance evaluation results: Machinery section

Output information		Conventional evaluation method		Developed evaluation framework		Error rate
Item	Detailed information	Output value	Overall score	Output value	Overall score	
1	Load-weighted average efficiency of heating facilities	0.978×8	7.82	0.978×8	7.82	0%
2	Load-weighted average efficiency of cooling facilities	0.934×6	5.60	0.934×6	5.60	0%
3	Load-weighted average efficiency of ventilators	75.3%	3.00	75.3%	3.00	0%
4	Load-weighted average efficiency of pumps	0.72	1.40	0.72	1.40	0%
5	Outdoor air cooling application ratio of the air conditioner	100%	3.00	100%	3.00	0%
6	Waste heat recovering ventilation device ratio	121%	2.00	121%	2.00	0%
8	Ratio of operations of heat source facility multi-unit applications, proportional controls, or multi-level controls	0.84	2.00	0.84	2.00	0%
9	Ratio of energy saving control method adoption for air handling unit fans	100%	2.00	100%	2.00	0%
11	Calculation of the application ratios of gas cooling and new and renewable energy	0.84	1.60	0.84	1.60	0%

	utilized cooling					
13	Application ratios of energy saving control method adopting cycling pumps for cooling or heating	100%	2.00	100%	2.00	0%
14	Application ratios of energy saving control methods for water supply pumps or pressurized water supply pumps	100%	1.00	100%	1.00	0%

5. Conclusion

This study develops a BIM-based energy-saving design criteria evaluation framework to save working hours required to prepare energy saving plans in South Korea. In addition, the purpose of this study is to perform a comparative analysis with the evaluation results of the developed framework through an energy saving criteria evaluation case, and the conclusion is as follows.
First, in order to develop the BIM evaluation framework for the building section, the evaluation items specified in the energy-saving design criteria are classified into thermal conduction, thermal convection, and thermal radiation according to the BIM data required information. Items 1, 2, 3, 4, and 7 were classified as items for evaluating the insulation performance by thermal conduction, items 5 and 6 to evaluate the optimal ratio of openings by thermal convection, and items 8 and 9 to calculate the solar heat gain coefficient using the azimuth information according to thermal radiation.
Second, to develop the BIM evaluation framework for the machinery section, the evaluation items were classified into Source, Fan, Pump, Pipe/Duct, and Waste Heat Recovery facilities according to the property information of the evaluation item. Items classified as having Source properties included items 1, 2, 8, 11 and 12. Items classified as having Fan properties included items 3, 5, 9, 15. Items classified as having Pump properties included items 4, 13 and 14. Items classified as having Pipe/Duct properties included item 7. Items having Waste Heat Recovery Facility properties included items 13 and 14.
Third, the utilization system and process were derived based on the classification method, and the BIM evaluation framework was developed by implementing input/output information in C# based on Architecture Revit 2015.
Fourth, the building section evaluation results for items 1, 2, 3, 4, 5, 6, 7, 8, and 9, the error rates for the calculated values of the BIM-based energy-saving design criteria evaluation framework were 0.44%, 0%, 0.72%, -0.29%, 0.03%, 0%, 0%, 0%, and 0%, respectively, in comparison with the conventional energy-saving design criteria evaluation method.
Fifth, the evaluation results for the machinery section indicated that the calculated values from the developed framework accurately matched the calculated values of the existing energy saving design standard evaluation method.
Fourth, the score for each item of the BIM-based energy-saving design criteria evaluation framework was the same as the conventional evaluation method
In light of this, the developed BIM-model-based energy saving design criteria evaluation framework performance comparison results indicated a complete match for the machinery section, and if further improvements are made to the building section margin of error, it is expected that the developed framework will be applicable as an evaluation framework for energy design criteria. However, the energy-saving design criteria of this study considered only the building and machinery section EPI evaluation. Future research that considers developments in the electrical section and new and renewable energy section of the energy saving design criteria is deemed necessary.

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