A study on the evaluation method of SW test items to quantify BEMS quality

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***Abstract*—This paper presents the evaluation metrics for each SW test item for quantifying building energy management system quality. As the building energy management system market grows, many products are being instituted, but SW quality verification and validation are not conducted during installation or operation of the building energy management system. To solve these problems, in this paper, requirements were extracted by reflecting generalized software evaluation criteria, which are domestic and international standards. The standard-applied requirements are extracted, and the test cases are made through the extracted requirements. Based on this, we propose metrics to quantify the evaluation results. Using this metric, it is expected that the metric can be used for SW verification and validation activities required for building energy management system.**

Keywords— Building Energy Management System, Quality assurance, Software testing

I. INTRODUCTION

Abnormal high temperatures and fossil fuel depletion are emerging as issues around the world. Accordingly, the paradigm of energy production and consumption is changing. The energy prosumer market is expanding through ICT-based technology, and the transition to eco-friendly energy such as wind power and solar power is accelerating. Moreover, as there is an international consensus on the need for greenhouse gas reduction, it is urgent to find countermeasures and strategies.

According to International Energy Agency's 2018 Global Status Report, building construction and operation accounted for 36% of global final energy use and 39% of energy-related carbon dioxide (CO_2) emissions in 2017, as shown in Fig 1 [1].

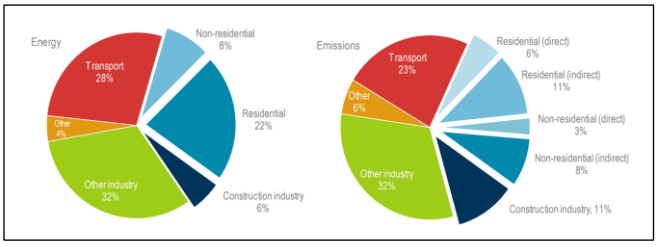

Fig 1. Global share of buildings and construction final energy and emissions, 2017

Each country is establishing standards for energy saving and strengthening related policies. Accordingly, the building energy management system market is expanding, and the introduction of evaluation criterion to improve the reliability of building energy management system is emerging as an important task.

In this study, functional requirements are derived based on 'KS F 1800-1:2014' and 'KS F 1800-2:2021', which are Korean domestic standards reflecting international standards 'ISO 16484-1:2010 – Part 2: Hardware' and 'ISO 16484-3:2005 – Part 3: Functions'. Non-functional requirements apply 'ISO/IEC 25023' and 'ISO/IEC 25051', international standards related to SW quality used for generalized SW quality evaluation. Through this, we propose an evaluation criteria regardless of the type of building.

Requirements are extracted. The extracted requirements are used to select test cases. After this, we derive metrics from the selected Test case. To finish with, the metric is applied to a commercial building energy management systems to check the applicability of the metric.

II. METHOD

Functional testing should be performed accord with installation purpose. In addition, tests suitable for the actual environment should be conducted. In order to perform a discriminatory evaluation, planned and systematic quality activities based on international standards must be carried out.

Section Ⅱ Method introduces the process of creating metrics for performing quality activities, focusing on the requirements presented in the standards.

A. SQuaRE Standard-ISO/IEC 25010&25023

ISO/IEC 25000 series, also known as SQuaRE (System and Software Quality Requirements and Evaluation) series, it is a set of standards covering quality model, quality measures and quality evaluation of system, software, data and service products. ISO/IEC 25023 provides a set of quality measures to measure the quality of systems and software products[2]. It consists of 9 quality characteristics and 32 quality sub-characteristics, as shown in Fig 2 [3].

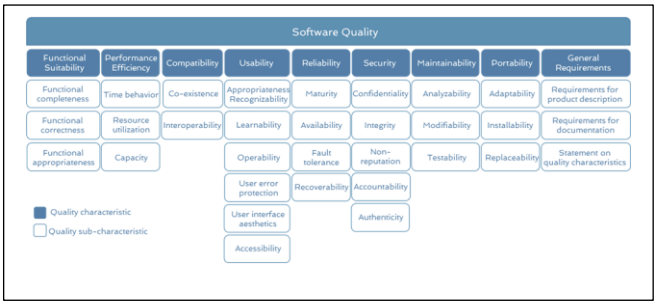

Fig 2. SW Quality model

B. KS F 1800-1:2014

Building Energy Management System – Part 1 : Function and data processing procedure provides nine building energy management system functional requirements as TABLE I [4].

TABLE I. FUNCTIONAL REQUIREMENTS OF KS F 1800-1:2014

No.	functions	contents
1	Data collection and display	Management and display of the entire building's energy
2	Monitoring	Monitoring and managing energy informations collected from monitoring and control point
3	Data display	Display of data collected by building energy management system
4	Analysis of energy consumption	Identifying the level of energy consumption, and analyzing the factors of increase or decrease
5	Analysis of facility performance and efficiency	Analysis of the performance and efficiency of facilities using energy and deduction of energy efficiency plan
6	Provide indoor and outdoor environment conditions	Analysis of outdoor climate and indoor conditions (air quality, moisture, thermal et cetera)
7	Prediction of energy consumption	Predicting and managing energy consumption according to the operation of the building
8	Display and analysis of energy costs	Identify the energy cost of the building and derive a cost reduction plan
9	Interworking with the control system	Control the facility efficiently through building energy management system

C. KS F 1800-2:2021

Building Energy Management System – Part 2 : Selection of data points, management and determination of energy savings provides six building energy management system function requirements needed to calculate energy saving as TABLE II [5].

TABLE II. FUNCTIONAL REQUIREMENTS OF KS F 1800-2:2021

No.	functions	contents
1	Selection of monitoring and control point	Selection and management of monitoring and control point necessary to building energy management system
2	Management of monitoring and control point information	Making and management of monitoring and control point lists
3	Implementation and Management of tags	Implementation and effectiveness management of tags
4	Classification and composition of data	Classification and management of reference information, operation information, and statistical analysis information
5	Management of data	Collecting and storing data based on tags
6	Calculate the amount of energy saved	Implementation of energy performance improvement action, improvement and documentation of energy performance in buildings

III. RESULT & DISCUSSION

First, based on the nine requirements of KSF 1800-1: 2014, functional and performance requirements were extracted, and the test cases were selected by reflecting the extracted requirements. Functional suitability and performance efficiency evaluation metrics were defined based on reference allocation and the pass rate of the selected test case. Resources mentioned in the performance requirements refer to CPU and memory.

For other quality characteristics, the requirements applicable to the building energy management system among the generalized software evaluation criteria were extracted, and the test cases were selected by reflecting the extracted requirements.

A. Extract functional and performance requirements

In the data collection and display function, 5 functional requirements and 2 performance requirements. In the case of FR-001-003, individual meter reading should be preceded. Some of the extracted requirements are as follows TABLE Ⅲ.

The performance requirements were based on performance efficiency, which is the characteristic of ISO/IEC 25023 SW Quality model, and were composed based on time behavior and resource utilization, which are sub- characteristics.

It was configured as a requirement to check whether BEMS properly utilizes system resources by measuring CPU, memory and response time while executing the designated functions according to functional requirements.

TABLE III. REQUIREMENTS OF DATA COLLECTION AND DISPLAY

ID	Requirements
FR-001-003	**Functional Requirements:** Data should be collected and displayed by classifying five or more types of building energy uses (heating, ventilation, & air conditioning, et cetera).
PR-001-001	**Performance Requirements:** (Resource utilization) Resources should be used constantly when collecting and displaying data.

In monitoring function, 4 functional requirements and 6 performance requirements were extracted, and some of them are introduced to the TABLE Ⅳ.

TABLE IV. REQUIREMENTS OF MONITORING

ID	Requirements
FR-002-001	**Functional Requirements:** Reference values for factors[a] affecting five or more types of energy management should be set.
PR-002-002	**Performance Requirements:** (Time behavior) The input reference value should be stored without delay within the expected time.

[a.] examples of factors: usage by energy source, CO2 concentration upper limit, et cetera.

In data display function, 3 functional requirements and 4 performance requirements like TABLE Ⅴ were extracted.

TABLE V. REQUIREMENTS OF DATA DISPLAY

ID	Requirements
FR-003-002	**Functional Requirements:** The displayed data should be downloadable to a general file (text, spreadsheet, et cetera).
PR-003-003	**Performance Requirements:** (Resource utilization) Resources used when downloading file should be returned after completion of function performance.

In Analysis of energy consumption function, 5 functional requirements and 6 performance requirements like TABLE Ⅵ were extracted. In the case of FR-004-005, a baseline period should be set according to the calculation purpose. The baseline period can be set to 1 month, summer/winter, et cetera.

TABLE VI. REQUIREMENTS OF ANALYSIS OF ENERGY CONSUMPTION

ID	Requirements
FR-004-005	**Functional Requirements:** The difference in building energy usage according to changes in three or more building energy influential factor[b] should be displayed together.
PR-004-005	**Performance Requirements:** (Resource utilization) When displaying changes in building energy usage, resources should be returned after completion of function performance.

[b.] examples used in schools: the number of events, the number of teachers and students, home time

In analysis of facility performance and efficiency function, 4 functional requirements and 4 performance requirements like TABLE Ⅶ were extracted. In particular, in order to calculate the performance presented in FR-005-001 and FR-005-002, the electric power quantity measurement function of the facility is required.

TABLE VII. REQUIREMENTS OF ANALYSIS OF FACILITY PERFORMANCE AND EFFICIENCY

ID	Requirements
FR-005-001	**Functional Requirements:** The performance and efficiency of each system of primary heat source facilities for cooling, heating, and domestic hot water use should be analyzed and displayed.
FR-005-002	**Functional Requirements:** The performance and efficiency of each equipment of primary heat source facilities for cooling, heating, and domestic hot water use should be analyzed and displayed.
PR-005-001	**Performance Requirements:** (Resource utilization) When displaying analysis values for each system and equipment, resources should be returned after completion of function performance.

In provide indoor and outdoor environment conditions function, 2 functional requirements and 2 performance requirements like TABLE Ⅷ were extracted.

TABLE VIII. REQUIREMENTS OF PROVIDE INDOOR AND OUTDOOR ENVIRONMENT CONDITIONS

ID	Requirements
FR-006-002	**Functional Requirements:** Indoor environmental information[c] should be collected and displayed by space.
PR-006-002	**Performance Requirements:** (Time behavior) Environmental information should be displayed without delay within the expected time.

[c.] light intensity, CO_2 concentration, CO concentration, fine dust concentration, et cetera

In Prediction of energy consumption function, 3 functional requirements and 4 performance requirements like TABLE Ⅸ were extracted.

TABLE IX. REQUIREMENTS OF PREDICTION OF ENERGY CONSUMPTION

ID	Requirements
FR-007-001	**Functional Requirements:** The target values of energy consumption should be set.
PR-007-001	**Performance Requirements:** (Resource utilization) When storing the target values and the comparison values, the resources used should be returned after completion of function performance.

In display and analysis of energy costs function, 5 functional requirements and 10 performance requirements like TABLE Ⅹ were extracted.

TABLE X. REQUIREMENTS OF DISPLAY AND ANALYSIS OF ENERGY COSTS

ID	Requirements
FR-008-005	**Functional Requirements:** Energy cost optimization measures[d] should be derived and displayed.
PR-008-010	**Performance Requirements:** (Time behavior) The energy cost optimization plan should be displayed without delay within the expected time.

[d.] Example of measure: When electricity is supplied, facility operation such as power control is calculated as a cost, and create an optimized operation schedule.

In interworking with the control system function, 4 functional requirements and 6 performance requirements like TABLE XI were extracted. These functional requirements are essential for interworking with the control facilities. In addition, in FR-009-004, the Human-Machine Interface monitoring and control screen may be required to apply the control plan to the facility.

TABLE XI. REQUIREMENTS OF INTERWORKING WITH THE CONTROL SYSTEM

ID	Requirements
FR-009-004	**Functional Requirements:** The derived control plan for the facility should be automatically applied to the facility.
PR-009-005	**Performance Requirements:** (Resource utilization) When applying the derived control plan for the facility, the resources used must be returned after completion of function performance.

B. Design test cases

In section B, we derive test cases based on the requirements for each quality characteristic extracted from section A.

Functional suitability and performance efficiency test cases were extracted by functional and performance requirements in Section A, while other compatibility, usability, reliability, security, maintainability, portability, general requirements reflected 'ISO/IEC 25023' and 'ISO/IEC 25051' characteristics. Introduce some of the derived test cases by quality characteristics (TABLE XII to Table XIX).

TABLE XII. TEST CASE OF FUNCTIONAL SUITABILITY

categories	contents
ID	FR-001-001 (Functional Requirements-001-001)
test scenario	Check whether building energy data is collected periodically (15 minutes or less) and stored in DBMS.
test step	Periodically check the collected/stored building energy data table on DBMS.
expected result	Building energy data is collected and stored periodically.
test result (P/F)	P (Pass)

TABLE XIII. TEST CASE OF PERFORMANCE EFFICIENCY

categories	contents
ID	PR-002-004 (Performance Requirements-002-004)
test scenario	Check whether the reference values and control values on the DBMS are displayed without delay within the expected time on the screen.
test step	Move to the display screen of the reference values and the control values.
expected result	The reference value and the control values are displayed without delay.
test result (P/F)	F (False)

TABLE XIV. TEST CASE OF COMPATIBILITY

categories	contents
ID	Co-003-003 (Compatibility-003-003)
test scenario	Check whether data is exchanged through csv, excel download/upload, et cetera.
precondition	MS-Office program installed.
test step	Download/upload data in csv and xlsx format.
expected result	Data exchanged normally.
test result (P/F)	P (Pass)

TABLE XV. TEST CASE OF USABILITY

categories	contents
ID	Us-004-052 (Usability-004-052)
test scenario	Check that a warning/verification function is provided to prevent erroneous manipulation before performing the entire deletion or overwrite function.
test step	Delete all data and overwrite data.
expected result	Warning/confirmation message provided
test result (P/F)	P (Pass)

TABLE XVI. TABLE 1. TEST CASE OF RELIABILITY

categories	contents
ID	Re-005-001 (Reliability-005-001)
test scenario	Check if the product can be used even if a serious or fatal failure occurs.
test step	Causing error handling situation.
expected result	Error is normally treated as an exception, and the product is working.
test result (P/F)	P (Pass)

TABLE XVII. TEST CASE OF SECURITY

categories	contents
ID	Se-006-024 (Security -006-024)
test scenario	Check whether user authentication is performed according to the specified authentication methodg.
test step	Move to the login screen.
expected result	User authentication is performed according to the specified authentication method.
test result (P/F)	P (Pass)

[e.] ID/Password, fingerprint, et cetera

TABLE XVIII. TEST CASE OF MAINTAINABILITY

categories	contents
ID	Ma-007-004 (Maintainability-007-004)
test scenario	After changing the software or changing the configuration, check whether the function works correctly.
test step	Change the configuration or software version.
expected result	After the change, the function works correctly.
test result (P/F)	F (False)

TABLE XIX. TEST CASE OF PORTABILITY

categories	contents
ID	Po-008-005 (Portability-008-005)
test scenario	Check that the actual installation time is more efficient than the expected installation time.
test step	Installing software.
expected result	The actual installation time converges to the expected installation time.
test result (P/F)	P (Pass)

The test result was applied to the actual BEMS product, and it passed overall, but the resolution was not reflected after changing the environment setting, resulting in failure at Ma-007-004.

C. Metrics

The evaluation metric defined the test cases based on the functional and performance requirements of KS F 1800 series. The functional suitability quality score is calculated by multiplying the degree of function requirement achievement by the reference score. The performance efficiency quality score is calculated by multiplying the degree of performance requirement achievement by the reference score.

The degree of requirement achievement is calculated as the ratio of the total number of requirements and the number of test results pass. The evaluation grade is calculated by multiplying the degree of requirement achievement by allotment, as in:

$$(a / b) * c = \mathbf{r_n} \quad (1)$$

Finally, the quality score for the functional suitability, which is the quality characteristics is calculated by summing all the calculated evaluation grades (TABLE XXIX).

TABLE XX. QUALITY MATRIC OF FUNCTIONAL SUITABILITY

evaluation score items	allotment	evaluation grade
a: The number of items from FR-001-001 to FR-001-005 whose performance result is Pass. b: The total number (FR-001-001 to FR-001-005).	10	(a/b)*10 = r_1
a: The number of items from FR-002-001 to FR-002-004 whose performance result is Pass. b: The total number (FR-002-001 to FR-002-004).	15	(a/b)*15 = r_2
a: The number of items from FR-003-001 to FR-003-003 whose performance result is Pass. b: The total number (FR-003-001 to FR-003-003).	5	(a/b)*5 = r_3
a: The number of items from FR-004-001 to FR-004-005 whose performance result is Pass. b: The total number (FR-004-001 to FR-004-005).	15	(a/b)*15 = r_4
a: The number of items from FR-005-001 to FR-005-004 whose performance result is Pass. b: The total number (FR-005-001 to FR-005-004).	15	(a/b)*15 = r_5
a: The number of items from FR-006-001 to FR-006-002 whose performance result is Pass. b: The total number (FR-006-001 to FR-006-002).	10	(a/b)*10 = r_6
a: The number of items from FR-007-001 to FR-007-003 whose performance result is Pass. b: The total number (FR-007-001 to FR-007-003).	10	(a/b)*10 = r_7
a: The number of items from FR-008-001 to FR-008-005 whose performance result is Pass. b: The total number (FR-008-001 to FR-008-005).	10	(a/b)*10 = r_8
a: The number of items from FR-009-001 to FR-009-004 whose performance result is Pass. b: The total number (FR-009-001 to FR-009-004).	10	(a/b)*10 = r_9
Total score		$= \sum_{k=1}^{9} r_k$

The evaluation metric of the quality characteristics excluding functional suitability and performance efficiency is

based on the requirements of the ISO/IEC 25000 series. The quality score is calculated by multiplying the degree of function requirement achievement.

Among the derived metrics, the compatibility quality evaluation metrics are shown in Table XXX.

TABLE XXI. QUALITY MATRIC OF COMPATIBILITY

quality sub-characteristics	Evaluation score items	evaluation grade
Co-existence	a: The number of items from Co-003-001 to Co-003-003 whose performance result is Pass. b: The total number (FR-003-001 to FR-003-003).	(a/b)*100 = r_1
Interoperability	a: The number of items from Co-003-004 to Co-003-005 whose performance result is Pass. b: The total number (FR-003-004 to FR-003-005).	(a/b)*100 = r_2
Total score		= $(r_1+r_2) / 2$

IV. CONCLUSION

In this paper, in order to perform a discerning evaluation, a metric was derived based on the requirements with the highest weight in Korean domestic standards. The test was conducted using metric for a commercial building energy management system, and although it was a product that already had a supplier, it was evaluated with a fairly low score (TABLE XXII).

TABLE XXII. EVALUATION RESULTS USING METRIC

quality characteristics	Evaluation score items	score
Functional Suitability	= 8+7.5+3.3+12+11.25+5+6.67+8+10	66.72
Performance Efficiency	= 10+13.2+5+12+7.5+5+5+6.7+0	64.40
Compatibility	= (100+100) / 2	100.00
Usability	= (100+83+97+88) / 4	92.00
Reliability	= (100+0) / 2	50.00
Security	= (86+50+100+100) / 4	84.00
Maintainability	= (100+0) / 2	50.00
Portability	= (100+50) / 2	75.00

Among them, the evaluation results of the functional suitability quality characteristic are described in detail as follow.

TABLE XXIII. EVALUATION RESULTS USING FUNCTIONAL SUITABILITY AND METRIC

evaluation score items	allotment	evaluation grade
a: The number of items from FR-001-001 to FR-001-005 whose performance result is Pass. b: The total number (FR-001-001 to FR-001-005).	10	(4/5)*10 = r_1 r_1 = 8.00
a: The number of items from FR-002-001 to FR-002-004 whose performance result is Pass. b: The total number (FR-002-001 to FR-002-004).	15	(2/4)*15 = r_2 r_2 = 7.50
a: The number of items from FR-003-001 to FR-003-003 whose performance result is Pass. b: The total number (FR-003-001 to FR-003-003).	5	(2/3)*5 = r_3 r_3 = 3.30
a: The number of items from FR-004-001 to FR-004-005 whose performance result is Pass. b: The total number (FR-004-001 to FR-004-005).	15	(4/5)*15 = r_4 r_4 = 12.00
a: The number of items from FR-005-001 to FR-005-004 whose performance result is Pass. b: The total number (FR-005-001 to FR-005-004).	15	(3/4)*15 = r_5 r_5 = 11.25
a: The number of items from FR-006-001 to FR-006-002 whose performance result is Pass. b: The total number (FR-006-001 to FR-006-002).	10	(1/2)*10 = r_6 r_6 = 5.00
a: The number of items from FR-007-001 to FR-007-003 whose performance result is Pass. b: The total number (FR-007-001 to FR-007-003).	10	(2/3)*10 = r_7 r_7 = 6.67
a: The number of items from FR-008-001 to FR-008-005 whose performance result is Pass. b: The total number (FR-008-001 to FR-008-005).	10	(4/5)*10 = r_8 r_8 = 8.00
a: The number of items from FR-009-001 to FR-009-004 whose performance result is Pass. b: The total number (FR-009-001 to FR-009-004).	10	(2/4)*10 = r_9 r_9 = 5.00
Total score = $\sum_{k=1}^{9} r_k$		= 66.72

In the case of Korean domestic authentication, there is no problem in obtaining authentication even if only the lowest weight is satisfied [6]. For this reason, it is believed that the cause of the low evaluation score is that most of the development companies are developing products with the lowest weight [7].

In order to proceed with the test, it seems that the weight of the score criterion needs to be modified according to the actual development and delivery market situation. Afterwards, when deriving the requirements on which the metric is based, the weight is changed for each requirement, and the metric expansion to the BAS field is improved.

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