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Mobile application to evaluate existing university buildings using building information

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ABSTRACT

Purpose: The purpose of this study is to provide information on building's energy consumption and efficiency for general building users through a mobile application. **Method**: This paper presents a mobile application process and building energy assessment models for general users to understand easily. There are two assessment models, one is based on the energy consumption. The other is based on the architectural planning factors of a building. The assessment models are proposed to understand buildings' energy efficiency and to compare the energy consumption level for general users. The applicability of proposed application has been evaluated by conducting a case study. The case study is targeting university buildings. **Result**: Energy efficiency potentials were proposed using weighting factor which was calculated by the impact on energy consumption of a building according to parameters. The mobile application used the simple energy assessment model by energy efficiency potentials and was developed for a smartphone By using the mobile application, numerous general users of smartphones can easily and conveniently access information pertaining to buildings, energy consumption, and reductions in energy consumption. The proposed application enables user to find more energy efficient buildings by comparing energy status and energy efficiency potential by given information.

KEYWORD

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University campus
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Simple assessment
Energy consumption

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1. Introduction

Greenhouse gas emissions are mainly caused by energy consumption. In Korea, 25% of all greenhouse gas emissions are discharged from the operational processes of buildings, and the building sector accounts for 21.2% of total energy consumption, so reductions in greenhouse gas emissions and energy consumption should be made essential.[1)] Accordingly, the Government enacted the Green Building Composition Supporting Act in order to reduce greenhouse gas emissions by systematically strengthening the policies and regulations related to building energy. It has also been implementing ways of bringing about energy savings and reductions in greenhouse gas emissions in the building sector, such as its "Total quantity control system in building energy consumption", a "Certification system in building energy consumption", in its "Mandatory requirements of energy efficiency grade assessments", and so on. In addition, efforts at energy saving are being made by building owners and users, with their growing interests in building energy management and due to the mandatory requirements which have been imposed regarding submission of energy-saving plans and mandatory certification of 2016 building energy efficiency grades. Voluntary participation has been encouraged by providing preferential treatments in the application of floor area ratio or financial incentives such as the Green Card System when putting energy-saving efforts into practice.

As stated in the national survey report of the total energy consumption,[2)] educational buildings such as university buildings are one of the biggest energy consumers among large structures. University complexes consist of multiple buildings with various purposes such as libraries, research centers, social and administrative facilities, athletic complex , and housings whose occupancy schedule and ratio of occupants also differ from each other.[3)] Having multiple users at the same time makes controlling the energy use of these buildings difficult. In order to encourage renovation of existing buildings to low-energy buildings, not only the specialist but also all general occupants shold be made aware of a building's energy consumption, by having access to relevant information such as monthly energy consumption data and causes of energy consumption.[4)]

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The building energy consumption is determined by its architectural design characteristics and the use characteristics of its occupants. However, energy assessments are made on the basis of the final energy consumption, so it is difficult to assess the building characteristics and the occupants' characteristics separately. For the assessment of the energy consumption characteristics of a building, it is necessary to conduct assessments of building energy efficiency potential by assessing the architectural design characteristics of the building.[5]

In addition, to encourage the construction of low-energy buildings, the easy understanding of and access to the relevant information should be provided for ordinary users who are not specialists in building energy matters.[6] Recently, due to the widespread development of the IT industry and of smart devices, mobile applications have enabled users to obtain a variety of information, providing easy and simple features to make their use convenient; they are widely used in various fields. Using a mobile application as a tool for performance evaluation can provide users with relevant information quickly and easily, in a convenient and simple way.

Mobile applications are being developed in many fields and are already being used in the building sector in such areas as information visualization, digital content development, construction management, design support, and building environment analysis and control. Kvan[7] conducted an experimental study into employing Augmented Reality (AR) as a training aid in architectural design, urban planning, structural planning, etc. Uddin proposed an energy monitoring system using a smart phone and evaluated the feasibility of energy monitoring system of home appliances.[8] Jumphon[9] utilized AR technology in construction process management as well as in building simulation; Ryu placed residential buildings under 3D environment in a residential complex and utilized AR technology in examining the actual realization or not in the real environment via experiments.[10] Malkawi conducted a study providing actual gas stream flow patterns on the screen.[11] Weiss[12] built a web based the smart electricity meter and developed a mobile phone interface to allows users to monitor and control their appliance. By providing users the electricity feedback users have an opportunity to decease their energy consumption.

This study attempts to contribute to the realization of a low-carbon green society through promoting savings in building energy usage, and improving awareness of energy usage by presenting building energy consumption and building assessment information to ordinary users via mobile applications. To this end, the study presents a building energy assessment process through mobile applications and proposes a database assessment model of building energy consumption and architectural design factors. The study implemented the proposed assessment model through mobile applications and conducted case studies, using the results obtained to verify the applicability and feasibility of mobile applications.

2. Development of the Pilot Application

2.1. Energy consumption potential assessment model

Energy consumption data reflecting all parameters including climate, physical features of a building, and occupant characteristics, is the key indicator for the evaluation of energy consumption. It is also the most used and easily understood indicator for general users, who obtain energy consumption information from energy bills. Users must first know the current status of energy consumption in order to save energy; however, in university buildings, users do not have access to this information. To tackle this problem, the final energy consumption level of a building was compared with that of the other buildings within the same campus and also the buildings in other universities. Since university buildings operate according to a different curriculum each semester, the standards for energy efficiency rating for a general office or residential building cannot be applied. Therefore, in line with a previous study, the actual average energy consumption of 190 kWh/m^{2}yr, presented in the report of the total energy survey, was used as the standard energy consumption leve l.[13] If the actual average consumption of a building is within ±10%

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of the standard,[14] the building is classified as average. Buildings are classified as excellent, good, poor, or very poor, based on their deviation from the standard. (Table 1).

Table 1. Classification by Final Energy Consumption

Class	Scope	Energy Consumption per Unit Area (kWh/m²yr)
Excellent	-30% or less	Less than 133
Good	-10~-30%	133~171
Average	-10~+10%	171~209
Poor	+10~+30%	209~247
Very Poor	30% or more	Greater than 247

The energy consumption of a building depends on two types of factors.[15] One relates to architectural planning such as building orientation, window area ratio by each orientation, and thermal performance of windows and envelope. The other relates to equipment factors such as type, capacity, or efficiency of air-conditioning system and lighting density. Building energy consumption is synthetically influenced by various parameters such as the thermal properties of the building skin, the occupancy schedule and load of each room, and the heating and cooling systems needed to keep the indoor environment comfortable. It is difficult for general occupants to estimate the potential energy usage based on simple but essential parameters without the required technical knowledge. Given this, the input parameters of the building energy use analysis simulation tools are investigated to utilize the main parameters when the energy assessment model is developed.[16] Table 2 shows the list of essential input parameters of the energy analysis program. These parameters present three levels: energy guzzling, average, and energy efficient, based on the effect of each variable on energy consumption. This is because the energy consumption by buildings are influenced by complicated interactions of various factors. Since quantity and quality of data are obtained by parameters during the collection of information of parameters, the data should be divided into three steps and evaluated. The energy efficiency potential grades according to the parameters in a previous study[17] are listed in Table 3. The energy efficiency potentials according to parameters have indicators that are different from those of energy consumption. Thus, it is difficult for general occupants estimate energy consumption of a building based on the information from indicators. In order to represent the energy grade according to the parameters as one measure, a single indicator system was proposed, which assign weights by the number of factors affecting energy consumption. Table 4 shows the differences in energy consumption between the grades according to parameters, obtained from a study by Park.[18] The weights according to parameters show a perfect consistency scale and are assigned. By combining scores according to parameters, buildings were divided into three levels: above 30% as energy efficient, 30%~70% as average and below 30% as energy guzzling.

Table 2. Parameters Related with Energy Consumption

Criteria	Parameters
Basic information	• Orientation • Gross area & building area • Total number of stories • Height
Materials scheme	• Thermal properties of envelope assembly • Window area ratio • Window U-factor & SHGC • Infiltration/ventilation rate • Installation of shadings
Occupancy information	• Occupancy ratio • Schedules and load of occupancy, plugs, lights, thermostat and so on
Mechanical scheme	• Types of HVAC system • HVAC zoning area • Source energy • HVAC system efficiency and capacity • Design temperature • Operating schedule and load

Table 3. Energy Efficiency Potential by Parameters

Criteria	Energy Efficient Level	Average Level	Energy Guzzling Level
Orientation	S/SSE/SSW	SE/SW/ESE/WSW	E/W
Surface area to volume ratio	10%	10~20%	20%~
U-factor: Wall	~0.15 W/m²K	0.15~0.47 W/m²K	0.47 W/m²K~
U-factor: Roof	~0.15 W/m²K	0.15~0.29 W/m²K	0.29 W/m²K~
U-factor: Floor	~0.15 W/m²K	0.15~0.41 W/m²K	0.41 W/m²K~
U-factor: Window	~1.8 W/m²K	1.8~2.3 W/m²K	2.3 W/m²K~
Window ratio	~50%	50%~70%	70%~
Shadings	Installation	-	None
Lights	LED lamp/ dimming control	A fluorescent lamp within ballast stabilizer	Incandescent/ halogen/ fluorescent lamp
Heating & cooling equipment	Ground source heat pump	EHP/GHP /Absorption chiller heater/radiant floor	Steam boiler/Gas furnace/Packaged air conditioner

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Table 4. Weighting Factor of Energy Parameters

Criteria	The difference of energy efficient level and energy guzzling level (kWh/m²yr)	Weighting factor
Heating & cooling equipment	78.3	1
U-factor: window	43.3	0.5
Lights	36.2	0.5
Window wall ratio	21.0	0.25
Orientation	19.5	0.25
U-factor: wall, roof, floor	9.3	0.125
Surface area to volume ratio	5.9	0.125
Shading devices	0.6	0

3. Process of Mobile Applications to the Building Energy Assessment Model

The application is to provide building information and energy performance information for ordinary users, and is developed in the form of the mobile applications available on smart phones. The hardware, software, wireless communication function, etc. required for Augmented Reality (AR) have all been built in the mobile sector, so AR has been actively developing there lately. High-performance information processing chips as well as cameras and GPS communication functions are embedded in smart phones, which provides the best environment for the combination of real information and virtual information. In addition, the expansion of smart phone penetration has enabled users to easily access the information they seek; and the needs of customers seeking real-time information on the 'visible' objects at the site have been enlarged more and more; so applications using mobile technologies are expected to be highly utilized.

It is assumed that the application will address complexes consisting of multiple building groups (e.g. energy village, condominium complex, university campus, etc). Building energy performance assessments are divided into two areas; one is the assessment using the building database, and the other is the assessment from actual energy consumption. Providing this in the

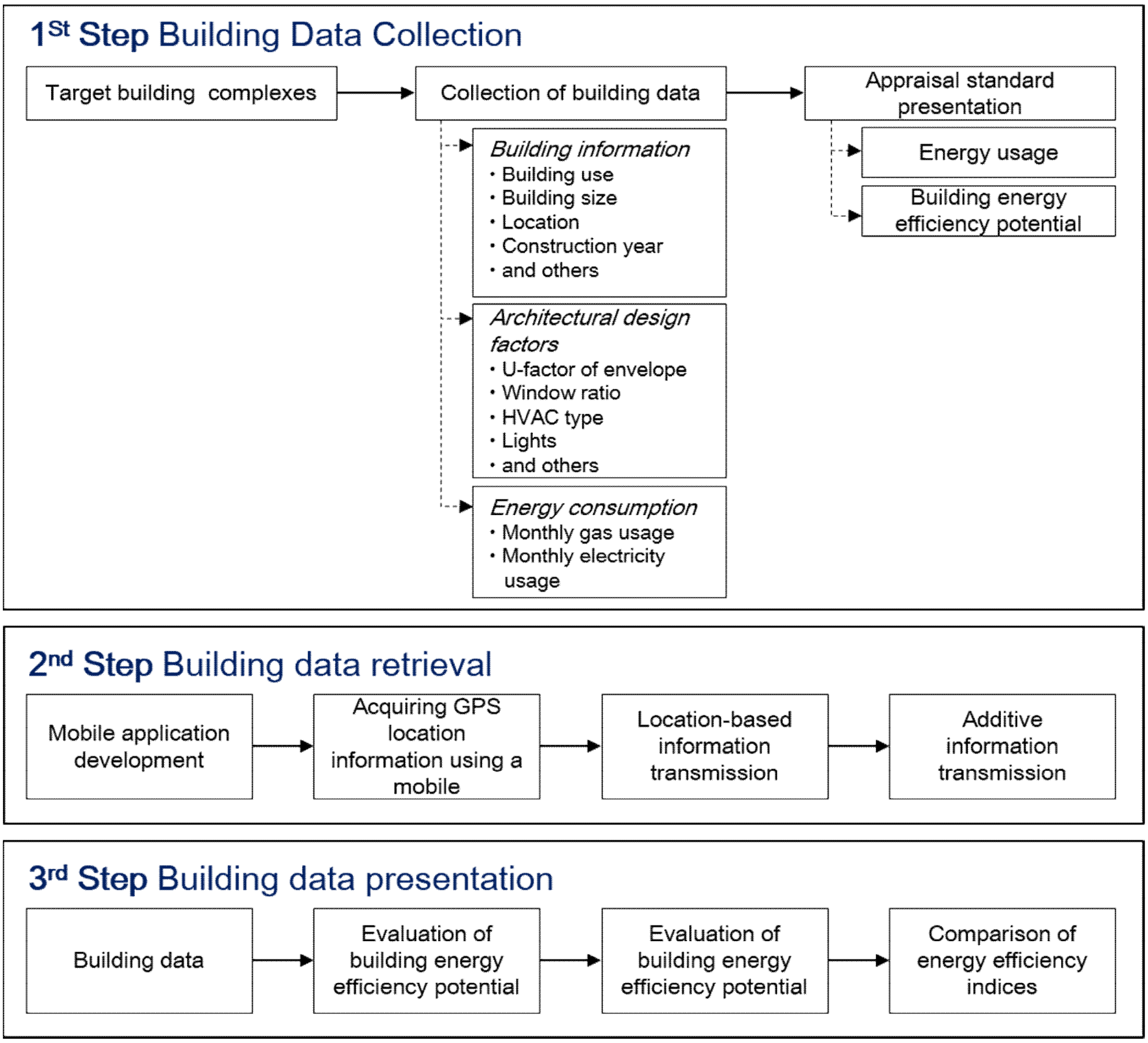

Fig. 1. The Process of Application.

form of an application using mobile technology enables users to easily find the energy level of the building and to determine the energy level of the building through comparison with similar buildings. Fig. 1 shows the process of the application which is proposed in a previous study.[19)]

Fig. 2. Information Access Mode by a Map.

Fig. 4. The Outline of the Building.

Fig. 3. Information Access Mode by a Camera

The application proceeds through the following three stages: first, the building information calling stage; second, the energy consumption assessment stage; and third, the building database evaluation stage. In the building information calling stage, the building or complex under analysis is displayed on the screen of the smart device through maps and cameras (Fig. 2 and 3); when one of the displayed buildings is selected, its basic information will be presented. This can be divided into the building information detail and the energy consumption assessment stage and building database assessment stage. When a screen is called through maps or cameras, the building to be analyzed will be displayed on the screen, and when the icon is selected, the basic information about the building will be displayed (Fig. 4). The building information detail will display usage, location, size (building area, floor area, number of stories, etc.), year of construction, HVAC system (operating control system and equipment), and other information when moving from the basic information screen to the information detail screen. Special features such as the application (or not) of renewable energy systems in the building shall be included with the other information (Fig. 5).

A comparative analysis shall be made through presentation of the annual energy consumption of the building in the energy consumption assessment stage (the second of the three stages) (Fig. 5). Energy analysis is based on the building's consumption of electricity and gas; comparison of its energy consumption shall be made with other buildings by presenting the energy consumption per unit of floor area. The average energy consumptions of the buildings under analysis is presented; based on the data, the energy consumptions are divided into five grades and the monthly energy consumption of the building shall be assessed.

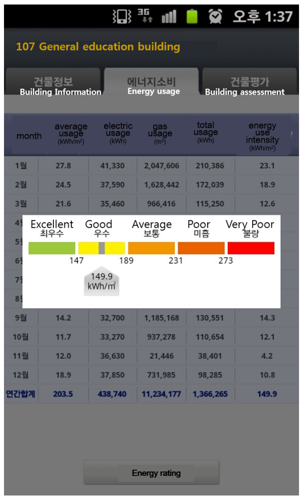

Fig. 5. Monthly Energy Data

Fig. 6. Energy Efficiency Potential Assessment.

The building database assessment stage is an applied technology of the building that can be secured from the drawings and literature of the building and will be used when conducting the comparative analysis of the factors which affect the energy consumption directly and indirectly (Fig. 6). The assessment parameters, consisting of the previously set architectural design elements and equipment elements, will present the grades compared to the properties of each corresponding item. As in the energy consumption assessment, the mean values of the building data (where available) shall be presented to conduct the comparison of the levels between the applied technologies of the buildings.

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4. Case Study

4.1. Overview of the case study

The case study applied the energy assessment model by conducting an energy consumption and building database assessment mainly on complexes consisting multiple building groups. The university campus was selected as the complex on which the case study shall be conducted. The university campus comprises various buildings such as training facilities, dormitories, lecture buildings, research buildings, etc. Most of the large buildings, as heavy consumers of energy, had shown a decrease in energy consumption while the university campus as a whole exhibited an increase. Hence, an assessment of energy consumption and the introduction of energy saving in the university campus were already considered to be required; so it was chosen as the subject of the case study. Excluding the buildings in which energy consumption was measured in conjunction with a neighboring building, 10 university buildings in which energy consumption was individually measured were selected as the subjects of the case study. An overview of those 10 buildings is given in Table 5.

The construction dates of the buildings were found to be diverse, from the 1960s to the 2010s. The average energy use intensity was shown to be 237.5kWh/m^2, which is similar to the average energy consumption of the education buildings, 190 kWh/m^2. Energy consumption according to the building showed large variations, from 101.5 kWh/m^2 to 460.1 kWh/m^2 depending on the purpose of the buildings. It is considered that energy consumption was higher in some buildings due to the use of laboratory equipment in addition to the teaching and administrative duties. Classified according to the five grades system mentioned above, the assessments of the 10 buildings were: 1 excellent, 1 good, 3 average, 1 poor, and 4 very poor results.

Table 5. The Building Characteristics of the Case Study.

Building ID	Building area(m^2)	Gross area(m^2)	Number of floor	The year of construction	HVAC type
01	1,228	7,861	6(B2)	1974	EHP
02	813	3,707	5(B1)	2005	GHP
03	858	9,122	6	1961	Gas furnace, packaged air conditioner
04	641	3,674	5(B1)	1991	EHP
05	3,163	14,258	7(B1)	2009 (remodeling)	EHP
06	2,490	22,145	7(B1)	1969	Gas furnace, EHP
07	1,777	11,894	9(B3)	1999	Absorption chiller heater (F.C.U)
08	767	5,299	5(B3)	1991	GHP
09	3,733	35,119	14(B3)	2007	Steam boiler (F.C.U), GHP
10	2,397	19,164	15(B2)	2010	EHP, Radiant Floor

Table 6. Standard Energy Demand of the Case Study Building Group (unit:kWh/m^2)

Building ID	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
01	11.3	10.1	16.9	13.3	13.3	14.2	17.1	16.9	13.1	12.9	17.2	26.3
02	14.1	21.0	34.7	32.5	34.8	35.8	35.2	34.9	33.5	32.5	34.5	44.3
03	31.0	22.3	14.0	5.9	5.0	6.5	7.9	7.8	5.3	4.6	18.4	25.4
04	35.8	26.1	23.8	15.7	19.6	24.3	26.4	25.6	20.4	15.1	27.7	42.7
05	19.3	15.8	14.1	12.4	11.3	8.9	9.2	8.9	10.6	12.4	14.8	18.9
06	11.6	9.4	17.9	13.5	13.1	14.1	16.9	16.6	13.0	12.9	18.4	29.2
07	14.9	13.1	23.1	17.3	17.3	16.0	18.1	18.1	17.1	17.3	23.1	33.3
08	39.0	29.2	30.6	14.7	14.8	22.9	23.5	25.6	17.8	10.2	18.8	30.9
09	9.9	8.7	12.2	10.9	11.0	11.0	14.7	14.4	10.6	10.8	12.0	15.9
10	19.9	14.0	14.8	11.5	11.7	12.1	12.5	12.3	10.6	10.2	16.6	23.3

Table 7. Comparison between Energy Consumption and Simple Assessment

Building ID	Actual consumption		Standard energy demand		Energy efficiency potential	
	Energy consumption (kwh/m^2)	Grade	Energy demand (kwh/m^2)	Grade	Weighted total score	Grade
01	181.7	Average	182.5	Average	81	High Energy
02	460.1	Very Poor	387.9	Very Poor	73	High Energy
03	101.5	Excellent	154.1	Good	65	High Energy
04	338.0	Very Poor	303.2	Very Poor	85	Average
05	157.4	Good	156.6	Good	73	High Energy
06	279.2	Very Poor	186.7	Average	90	Average
07	229.6	Poor	229.0	Poor	89	Average
08	278.5	Very Poor	278.0	Very Poor	98	Average
09	171.7	Average	142.2	Good	90	Average
10	176.9	Average	169.6	Good	95	Average

4.2. Standard Energy Demand Analysis

Since the actual energy consumption reflects both the occupants' characteristics and building characteristics, it is very difficult to predict accurately the energy consumption of a building linking to the building characteristics through the actual energy consumption. In this context, the study analyzed the standard energy demand of buildings using e-QUEST to assess the energy consumption implicit in the buildings themselves. The annual energy demand of target buildings in the simulation(shown in Table 6) was shown to be 219.0 kWh/m^2,which was less than the actual consumption, 237.5kWh/m^2.

It is expected that the variations in energy consumption between the buildings are due to the varied functions of the rooms in the buildings. The buildings with the longest hours of operation and greater internal heat gain, such as laboratories and computer rooms, showed the greatest differences. This is considered to be because a standard occupancy schedule was applied in the simulation, whereas buildings have variable actual operating schedules and variable occupancy patterns.

4.3. Comparative Analysis of Building Energy Efficiency Potential Assessments by a Simple Assessment

A comparison was made between actual energy consumption and standard energy demand in order to assess the energy efficiency potential of the buildings, using a comprehensive evaluation index of a simple assessment. The standard energy demand reflected standard schedules rather than the actual schedules of the occupants and their usage of the rooms. Therefore, the buildings having higher proportions of rooms with longer occupancy schedules and greater energy loads of internal equipment, such as labs and computer rooms and graduate labs, exhibited higher actual energy consumption compared to the standard energy demand.

Building-05 was constructed with a curtain wall structure and the heat transmission coefficient of the skin facade was low, so it was shown to be lower in the simple assessment grading. In addition, most of the buildings displayed lower grades in the comparison between the simple assessment and the standard energy demand. This revealed that there were little buildings satisfying the excessively high requirements of the lower energy grade, and there was the limitation that the design of the external wall affects the energy requirements, but the simple assessment could not reflect it.

5. Conclusions

As interest in building energy has been growing lately, the demand for information about energy consumption and energy saving in buildings is increasing among ordinary users as well as construction professionals. Thus, the study attempted to present an energy assessment model for development of a building energy assessment program, using mobile applications to facilitate easy access to information on building energy.

The energy assessment model is intended to assess the energy level through the energy consumption and to assess the energy level by reference to the building information. The assessment of the energy level using the building information (that is, the building drawings and the equipment status) is intended to predict and evaluate the energy consumption of buildings by considering the factors affecting the energy loads. Apart from this, actual energy consumption linked to the building operation was assessed. The building information-based energy assessment model and the energy consumption-based assessment model have a close relationship, but even if the building information-based energy assessments are similar, energy consumption might vary depending on the actual usage patterns of the buildings and their users. Therefore, studies on the correlation will be required with regard to the assessment of future energy consumption and the securing or not of the building information.

In addition, from the assessment conducted, applying a simplified energy assessment model to the actual buildings, the prior availability or unavailability of building information is considered to be of importance in the energy assessment in the building information-based energy efficiency potential assessment. However, it was difficult to conduct an accurate assessment of any building long after it was built, due to the difficulty in securing the building information. The reliability of the building energy assessment will be considered to be higher if good quality data on the building can be secured through drawing analysis and actual measurements at the construction stage. The application enables users to find the energy consumption status of buildings by providing them with information on the energy consumption levels of buildings. Future works will propose the energy-saving strategies and guidelines for bad performance buildings and present energy saving effect. The energy saving measures will be proposed with a stage-by-stage. The application will enable users to choose which component technologies to apply, and subsequently displays the scope and effects of such applications. It can be expected to be used in the information transport about buildings and education of energy savings through this.

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