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Development of Mobile Application for Energy Consumption Assessment of University Buildings

M. H. Chung, B. Y. Lee, Y. Kim, E. K. Rhee

Abstract**—**With an increase in the interest in the energy conservation for buildings, and the emergence of many methods and easily-understandable approaches to it, energy conservation has now become the public's main interest, as compared to in the past when it was only focused upon by experts. This study aims to help the occupants of a building to understand the energy efficiency and consumption of the building by providing them information on the building's energy efficiency through a mobile application. The energy performance assessment models are proposed on the basis of the actual energy usage and building characteristics such as the architectural scheme and the building equipment. The university buildings in Korea are used as a case to demonstrate the mobile application.

Keywords**—**Energy consumption, energy performance assessment, mobile application, university buildings.

I. Introduction

As the paradigm of energy use has changed because of the high oil prices and climate change, the interest in the reduction of energy consumption in buildings has increased. The energy consumption of buildings is steadily increasing depending on consumption factors such as expansion of residential area, supply expansion and scale expansion of appliances, and high technological application in buildings [1]. In particular, according to the survey report of the total energy consumption [2], the energy consumption of buildings that consumed a significant amount of energy, such as offices, apartment housing, and public facilities has reduced, but the energy consumption of buildings in universities has increased. Buildings in a university consist of building groups with multiple purposes such as classrooms, laboratories, facilities, and dormitories. The occupancy patterns of users also vary in this case. Because a large number of users simultaneously use the buildings in a university, it is difficult to manage the energy in the buildings [3]. Therefore, in order to increase the number of low-energy-consumption buildings, general users who are non-professionals with respect to building energy should be able to easily understand this concept and have access to relevant information [4]-[6]. The purpose of this study is to help general users to understand the energy efficiency and consumption of a building by providing them information on the building's energy efficiency through a mobile application. In order to achieve this goal, in this study, we have developed a mobile application process to apply the building energy assessment model. Further, in this paper, we propose an assessment model based on the amount of energy consumption and another assessment model based on the planning elements of a building as the building energy assessment models. Further, the applicability of developed application is assessed by implementing the energy assessment model through a mobile application and conducting a case study targeting a university campus.

M. H. Chung is with the School of Architecture, Soongsil University, Seoul156743, S. Korea (corresponding author; phone: 82-2-820-0845; fax: 82-2-816-3354; e-mail: mhchung@ssu.ac.kr).

B. Y. Lee, Y. Kim, and E. K. Rhee are with the School of Architecture, Chung-AngUniversity, Seoul, 156756, S. Korea (e-mail: juin10@hanmail.net, kyuri90@gmail.com, ekrhee@cau.ac.kr).

II. Process of Mobile Application for Energy Performance Assessment

Mobile infrastructure includes hardware, software, and a wireless communication system. With the increase in the number of smartphone users, relevant information can be easily accessed by the users. In the past, the energy-related information of buildings was provided to building owners and some facility managers. Of late, however, with considerable importance placed on energy saving in buildings, the need for providing information related to energy consumption to building occupants has increased. In light of this trend, we attempted to use a smartphone to provide information on the energy consumption and energy efficiency potential of buildings. In order to apply the energy assessment to a real building, we chose buildings in a university campus used for similar purposes. In future studies, the target buildings may be expanded to a multiple-building complex or a set of same-purpose buildings.

The construction of and the process followed by the application are depicted in Fig. 1. The application consists of three stages: information processing, information retrieval, and information presentation. In the procession stage, relevant data of the targeted building are collected and an energy consumption-based reference standard is presented. The building data include basic information, such as purpose, size, location, and construction year; monthly energy consumption; and architectural planning components influencing energy consumption such as the window-to-wall ratio, heat transfer coefficients of the windows and envelopes, the heating, ventilating, and air-conditioning (HVAC) system, and light fixtures. The energy consumption reference standards are presented as the average amount of energy consumed within the building, wherein the total energy consumption except for the energy required for cooking is calculated as the amount of energy consumed per unit area of gas and electricity. In the information retrieval stage, basic information is retrieved by a map or camera using the already stored location information of the target building. In this stage, all lists related to the assessment target buildings appear, and upon choosing one building, the energy information of this building is displayed. The energy grade of the selected building is presented by assessing the energy efficiency potential computed from the monthly energy consumption and architectural planning components. By juxtaposing the values of the energy efficiency potential of the building and the actual consumption, we attempted to induce energy-saving behaviors and to use them as base data in presenting an energy consumption reduction method for the considered building.

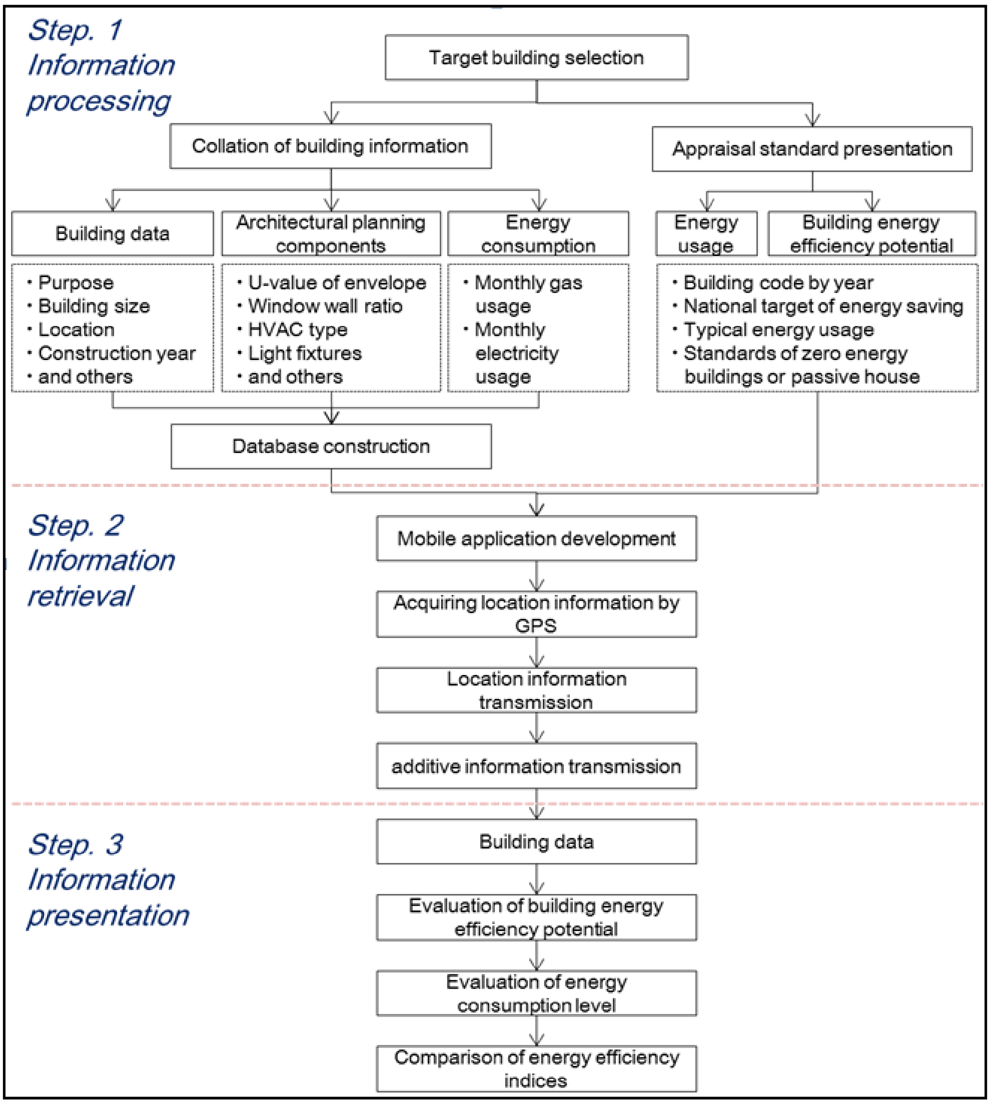

Fig. 1 Process of mobile application development

III. Energy Performance Assessment Model

The energy consumption data are an indicator of an energy assessment reflecting all climate conditions, building characteristics, and occupant characteristics. They are also an indicator of an assessment that general users can easily understand. We know the amount of energy consumed monthly through the energy bill, but the amount of energy consumed in the buildings of a university is disclosed only to some people who manage the buildings and not disclosed to general users. Even if this information were disclosed to general users, it would be difficult for them to estimate the current level of energy consumption of the building on the basis of this information. In order to save energy, first, one needs to understand the current situation of the energy consumption of the building. Thus, we present the level of energy consumption of the considered building by comparing it with and analyzing the buildings in other universities or those within the same campus. Since the buildings of universities are operated on the basis of a schedule, the standards for general office cannot be applied to them. Thus, the actual average amount of energy consumption presented by a report of a total energy consumption survey was used as the standard to compare the level of energy consumption of the considered building with that of various other buildings. If it was within ±10% of the average consumption of 210kWh/m^{2}yr taken as the standard [2], the building was categorized as an average grade. If it was within the range of -10~-30%, -30% or less, +10~30%, and +30% or more, it was categorized as good grade, excellent grade, poor grade, and very poor grade, respectively (Table I).

TABLE I
CLASSIFICATION BY ENERGY USAGE

Grade	Range	Energy Use Intensity (kWh/m²yr)
Excellent	Below -30%	Below 147
Good	-10~-30%	147~189
Average	-10~+10%	189~231
Poor	+10~+30%	231~273
Very Poor	Up to 30%	Up to 273

TABLE II
VARIABLES RELATED WITH ENERGY CONSUMPTION

Criteria	Variables
General Information	Building geometry
	Orientation
	Building area
	Number of floor
	Height
	Plenum height
Materials Scheme	Envelope assembly properties
	Fenestration area
	Fenestration U-value & SHGC
	Infiltration rate
	Shading devices
Occupancy information	Occupancy density
	Schedule of occupancy, equipment, lighting, thermostat and so on
Mechanical scheme	HVAC zoning area
	Source energy
	Capacity
	Efficiency of system
	Design temperature
	Operating schedule

TABLE III
ENERGY EFFICIENCY POTENTIAL BY VARIABLES

Criteria	Low Energy Level	Average Level	Energy Guzzling Level
Orientation	S/SSE/SSW	SE/SW/ESE/WSW	E/W
SVR	10%	10~20%	20%~
U-value : Wall	~0.15 W m²K	0.15~0.47 W/m²K	0.47 W/m²K ~
U-value: Roof	~0.15 W/m²K	0.15~0.29 W/m²K	0.29 W/m²K ~
U-value: Floor	~0.15 W/m²K	0.15~0.41 W/m²K	0.41 W/m²K ~
U-value: Window	~1.8W/m²K	1.8~2.3W/m²K	2.3 W/m²K~
Window wall ratio	~50%	50~70%	70%~
Shading devices	Installation	-	None
Light fixtures	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

The characteristics of a building include architectural planning elements such as orientation, window area, heat transmission coefficient of windows, and heat transmission coefficient of envelopes; and equipment elements such as the type of air-conditioning system, capacity, efficiency, and lighting density [7]. These characteristics also represent the potential of the energy consumption of a building. Energy consumption is collectively affected by a variety of factors such as the characteristics of the envelope of the building itself, the purpose of use of each room and the schedule of use, and the air-conditioning system required to maintain a comfortable environment. It is very difficult for general users who are not professionals who understand the energy consumption mechanism of a building, to understand the energy consumption of a building by looking at the detailed building information. The potential for the energy consumption of a building is assessed by presenting information in brief on the essential elements to general users. In order to do this, the input data of an energy simulation tool is investigated and simplified in order to develop the energy assessment model [8]-[10]. Table II represents the input data of the main energy interpretation program being used in an energy simulation tool such as e-Quest, EnergyPlus, and TRANSYS; these data are simplified by using only the main variables. These variables represent a total of three grades of a building, namely energy guzzling, average, and low energy, on the basis of the effect of each variable on the amount of energy consumed. The reason for this is that the energy consumption of a building is not caused by only one variable but is affected by the complex actions of various factors. According to a previous study [11], the energy efficiency potential grades by variables are presented in Table III. The energy efficiency potential by variables is not a single indicator unlike the amount of energy consumed. Thus, it is difficult for general users to estimate the level of energy consumption of a building and categorize the building into one of the considered grades on the basis of these variables. Thus, in order to have the energy grade by variables as one measure, a single indicator is proposed by assigning weights to the other variables in the order of the extent to which these factors affected the energy consumption. According to a study by Park [12], the impact on the energy consumption of a building of certain variables is shown in Table IV. The weights are applied to the variables by using a perfect consistency scale and are assigned as shown in Table IV. By combining the given scores by variables, the top 30%, middle 30~70%, and the bottom30% were classified as the buildings of low, average, and high energy consumption, respectively.

TABLE IV
WEIGHTING FACTOR OF ENERGY VARIABLES

Criteria	The energy use intensity difference of energy level (kWh/m^{2}yr)	Weighting factor by variables(A)	Energy efficiency potential score by energy level(B)			The score of energy efficiency potential (C=A×B)
			Low Energy Level	Average Level	Energy Guzzling Level	
			4	2	1	
Heating & cooling equipment	78.3	16		*1*		*32*
U-value: Window	43.3	8			*1*	*8*
Light fixtures	36.2	8		*1*		*16*
Window wall ratio	21.0	4	*1*			*16*
Orientation	19.5	4		*1*		*4*
U-value: wall, roof, floor	9.3	2			*1*	*2*
SVR	5.9	2			*1*	*2*
Shading devices	0.6	1			*1*	*1*
Total energy efficiency potential score (D= sum(C))						*81*

* The italics are the example of weighting factor

IV. ASSESSMENT OF APPLICABILITY OF PILOT MOBILE APPLICATION

Android is used as a platform for mobile applications as it is an open platform that supports the development of various applications [13]. The database manages location information, energy consumption, and building information using SQLite. The application was developed as a standalone application to simplify the operations, and the database is updated when the annual energy consumption of the evaluation factors change.

For a real-life application, we conducted a case study in a complex consisting of various building groups. We performed the energy consumption and building DB assessments, and applied the energy assessment model. The target complex was a university campus consisting of multiple building blocks with diverse purposes of use such as basic educational facilities, residence halls, lecture halls, and laboratory blocks. Excluding the building blocks whose separate energy consumption could not be calculated because they shared measuring gauges with neighboring buildings, we chose 10 building blocks with separate measuring gauges. Table V lists the basic assessment values of the 10 targeted buildings.

TABLE V
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
A	1,228	7,861	6(B2)	1974	EHP
B	813	3,707	5(B1)	2005	GHP
C	858	9,122	6	1961	Gas furnace, packaged air conditioner
D	641	3,674	5(B1)	1991	EHP
E	3,598	39,295	11(B4)	2011	EHP, Absorption chiller heater (F.C.U)
F	2,490	22,145	7(B1)	1969	Gas furnace, EHP
G	1,777	11,894	9(B3)	1999	Absorption chiller heater (F.C.U)
H	767	5,299	5(B3)	1991	GHP
I	3,733	35,119	14(B3)	2007	Steam boiler (F.C.U), GHP
J	2,397	19,164	15(B2)	2010	EHP, Radiant Floor

The screen configuration of the developed application consists of the calling information of evaluated buildings, building basic information, energy consumption data, and assessment of the architectural planning component. With respect to the stage calling information, information entered in the database is checked and called through a GPS sensor and a camera sensor mounted on a smartphone (Figs. 2~3). The corresponding information calls the information on the target building in close proximity through the coordinate information stored in the database (Fig. 4). The method of calling the information is divided into two: one is to call the required information through the map, and the other is to call it by using an augmented reality technique. If you click on the target building on a map or a camera screen, the basic information of the building appears and you can move to the screen evaluating the energy efficiency potential or the energy consumption of the building. In the energy consumption tab, the data of the monthly gas and electricity consumption are displayed and the energy grade of the corresponding building is represented as a bar chart (Figs. 5~6). The assessment of the energy efficiency potential of the building provides the grade of the building on the basis of the total scores by corresponding items and weight by factors (Figs. 7~8).

For the validation of the value index of the energy efficiency potential, a quantitative assessment of the energy efficiency potential of the building was carried out through a simulation targeting the building using the information on the building characteristics. The estimated standard energy consumption of the buildings was used; further, e-Quest and the occupancy schedule, not the actual occupancy schedule but the standard occupancy schedule, were used. A comparison of the standard energy consumption with the value index of the energy efficiency potential is presented in Table VI. The cooling and heating system is the variable that has the biggest impact on energy consumption. Since the energy consumption varies depending on the system's capacity and efficiency, even if it is the same system, it is thought to consider the assessment on it.

The 10 buildings included in the case study were built between the 1960s and the 2010s. The average total energy consumption per unit area was 237.5 kwh/m^2, which was closest to the average energy consumption of the educational building blocks, 210.5 kwh/m^2. Out of the 10 building blocks, our assessment resulted in 1 excellent, 1 good, 3 average, 2 poor, and 3 very poor grade buildings. The amount of energy consumption by building ranged from 101.5 kwh/m^2 to 460.1

kwh/m^2, showing a large deviation depending on the use status. Some of the multi-purpose buildings showed particularly high amounts of energy consumption because of the power demand for lectures, administrative works, and experimental devices.

Fig. 2 Calling information by camera

Fig. 3 Information by map

Fig. 4 Building information

기간	캠퍼스 평균에너지 소비량 (kWh/㎡)	전력 소비량 (kwh)	가스 소비량 (㎥)	총 에너지 소비량 (kwh)	단위면적당 총 에너지 소비량 (kwh/㎡)
1월	27.8	548,740	1,889,495	704,742	17.9
2월	24.5	555,950	1,442,820	675,073	17.2
3월	21.6	428,240	2,190,927	609,129	15.5
4월	17.0	317,190	1,950,432	478,223	12.2
5월	12.0	405,520	132,671	416,474	10.6
6월	14.2	496,270	0	496,270	12.6
7월	13.7	469,180	0	469,180	11.9
8월	15.9	529,140	0	529,140	13.5
9월	14.2	396,760	0	396,760	10.1
10월	11.7	406,300	0	406,300	10.3
11월	12.0	418,430	38,456	421,605	10.7
12월	18.9	515,580	825,462	583,732	14.9
연간합계	203.5	5,487,300	8,470,263	6,186,628	157.4

Fig. 5 Monthly energy consumption

Fig. 6 Energy performance level by energy consumption

Fig. 7 Energy efficiency potential Assessment (Simplified mode)

Fig. 8 Energy efficiency potential Assessment (Detail mode)

TABLE VI
COMPARISON OF VARIOUS ENERGY EFFICIENCY INDICES

Building ID	Actual energy consumption (kWh/m^2yr)	Energy consumption level	Energy efficiency potential	Standard energy consumption (kwh/m^2yr)
A	181.7	Average	81	182.5
B	460.1	Very poor	73	378.9
C	101.5	Excellent	65	154.1
D	338.0	Poor	85	303.2
E	157.4	Good	73	156.6
F	279.2	Very poor	90	186.7
G	229.6	Poor	89	229.0
H	278.5	VeryPoor	98	278.0
I	171.7	Average	80	142.2
J	176.9	Average	95	169.6

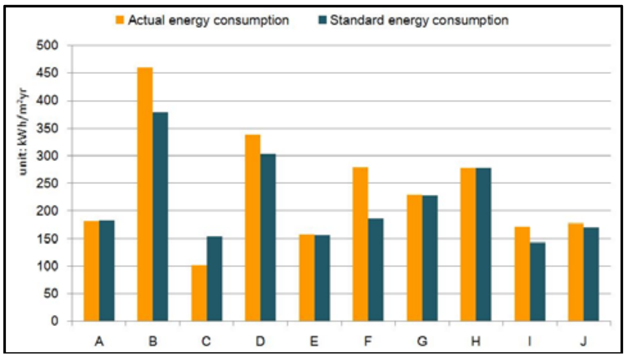

Fig. 9 Comparison actual and standard energy consumption

The standard energy demand was analyzed using e-Quest. The average total energy demand of all target building blocks estimated by simulation was 219.0 kwh/m^2, which is smaller than the actually consumed amount (237.46 kwh/m^2). The reason for different levels of energy consumption among the buildings was assumed to be the different purposes of use of the individual rooms. Buildings, which contained a large number of rooms having long occupancy hours or internal loads such as laboratories and computer rooms, showed large deviations. A simulation analysis was performed on the basis of the standard room occupancy schedules, and it was assumed that there were differences between the building operation schedules and the actual occupancy patterns of building users according to the nature of the buildings.

In order to assess the energy efficiency potential of the buildings, the actual energy consumption and the standard energy demand were compared. The latter was estimated on the basis of the standard schedule without taking into account the actual schedule of the room occupants depending on the purpose of use of the considered room. Consequently, the actual energy consumption was measured to be higher than the standard energy demand in the buildings with a high proportion of rooms that have a long occupancy schedule and a considerable load of installed devices, such as laboratories, computer rooms, and graduate school research rooms. Further, building E, which had a curtain-wall structure, was categorized as a low-grade building by the simplified energy assessment model because of the low heat transfer coefficients of the envelopes. Moreover, when the simplified assessment and the standard energy demand were compared and analyzed, a majority of the buildings showed the average grade. This could be attributed to the significantly high requirement standards for the low-energy grade, which could not be met by almost all buildings, and the limitation of the simplified assessment that could not reflect the types of envelopes that influenced the energy demand.

V. CONCLUSION

In this study, we developed an application as the basic step for the development of a building-user-centered energy assessment model. As a result of the assessment carried out by applying a simplified energy assessment model for building users, we concluded that securing the building information in advance had a significant impact on the assessment of the energy efficiency potential of a building. However, since it was difficult to obtain DB related to the building information of an existing building that was built a long time ago, it was difficult to conduct an accurate assessment. If high-quality building information could be obtained through a drawing analysis and an actual measurement in the building DB step of the application, we could increase the reliability of the assessment. This application is expected to recognize the current energy consumption status and induce energy savings by providing general users with information on the energy consumption level of the building.

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