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A Study on the Performance Evaluation of User Awareness Technology based Smart Lighting Control System for Energy Saving

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Abstract

The energy consumption in buildings accounts for 38% of total energy consumption, and the lighting energy consumption in Korea shows a high ratio as 22%. Therefore, the purpose of this study is to propose a more effective energy saving method based on Smart Lighting Control System using User Awareness Technology for reduce the consumption of lighting energy in buildings. A basic model of Smart Lighting Control System is proposed in this study, and its effectiveness is proven through the performance evaluation. The performance evaluation was carried out in the way of comparing power consumption between On/Off lighting control method and Smart Lighting Control System according to the user illumination requirement. The analysis result shows that the power consumption of User Awareness Technology based Smart Lighting Control System is lower than the power consumption of On/Off lighting control method at Type 1 in summer and Types 1 and 2 in spring equinox and autumn equinox. The energy saving performance is shown from User C in summer and Users B, C and BC in spring equinox and autumn equinox.

Keywords: *Smart Lighting Control System, User Awareness Technology, Energy Saving*

1. Introduction

The urban area expansion due to industrial developments has created an issue of excessive energy consumption. The energy consumption in buildings accounts for 38% of total energy consumption, and the lighting energy consumption in Korea shows a high ratio as 22%. Since the issue of excessive lighting energy consumption in buildings continues to increase over time, so efforts to solve this issue have been made in various fields these days. Among them, Smart Lighting Control System using IT such as location awareness technology is receiving attention as a new area of study in reducing indoor lighting energy. For efficient lighting control of indoor space, various contexts must be considered in applying to the integrated system[10].

Therefore, the purpose of this study is to propose a more effective energy saving method based on Smart Lighting Control System using User Awareness Technology for reduce the consumption of lighting energy in buildings. A basic model of Smart Lighting Control System is proposed in this study, and its effectiveness is proven through the performance evaluation.

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2. Energy Saving Lighting Control System

2.1. Consideration of Lighting Control System

Indoor lighting is an essential element for securing interior illumination not fulfilled due to temporal and spatial reasons in the lighting performance of building. Indoor lighting is used as a secondary light source for illumination in the daytime and it is used as the main light source at night, so it is necessary to control indoor lighting reasonably depending on the circumstances. The lighting control in on/off mode which is commonly used now can be controlled through manual operation of the space user, so energy loss is inevitable.

A study on the lighting control system for the purpose of energy saving can be carried out from two steps. The first step is to develop the lighting control system using the newest technologies such as Sensor Technology for supplementing previous drawbacks. This depends on the technology-intensive performance, and this is also the tendency toward automation which minimizes user intervention. The second step is to draw effective lighting control system plans based on the internal characteristics of each building structure. Since indoor lighting is managed according to the users' demands, it is possible to draw energy saving measures through the analysis of user behavior or specific elements which cause user behavior. In this context, the basic research for developing the Smart Lighting Control System which responds to technology-intensive characteristics and spatial characteristics is carried out in this study.

2.2. Characteristics of Smart Lighting Control System

Smart Lighting Control System applies an intelligent system through convergence with IT, breaking away from the lighting control method. Smart Lighting Control System has the following two purposes [10].

First is the lighting energy reduction effect. Activity space of humans requires appropriate illumination. The source of sunlight flowing indoors has a limited securement of illumination, and thus artificial lighting is used, which consumes energy in management. To reduce energy consumption, a paradigm shift in the control system is required, and the intelligent system accedes to that demand.

Second is the provision of pleasant light environment. Environmental comfort is determined by the degree of light, temperature, humidity and noise, and among them, light environment has a great influence in visual environment which accounts for more than 80% of sense. The light environment beyond a proper level of illumination may give a direct effect on human behavior, and human behavior can be also affected by color temperature, uniformity ratio of illumination and glare. Smart Lighting Control System provides a pleasant light environment to meet such demands on a real-time basis, improving the quality of the use of space.

In this way, Smart Lighting Control System has an advantage to draw the energy saving performance as well as occupants' satisfaction. There is a wide variety of IT technologies that could apply to Smart Lighting Control System, and those technologies may underline different performance to each other according to the composition. Therefore, it is most important to bring the maximum performance stably by combining various technologies effectively for Smart Lighting Control System. This study is carried out based on User Awareness Technology which is one of intelligent technologies among the applicable technologies on Smart Lighting Control System.

2.3. Implementation of Smart Lighting Control System [10]

The key to Smart Lighting Control System is in intelligent integrated system. The differentiation factors of intellectualization are automation in which it is not controlled directly by people, ability to judge the situation real-time, and performance that maintains the optimum space environment. The intelligent system began from the intelligent building system (IBS) and has since continued to evolve in order to improve performance along with the advanced IT.

The key mechanism of Smart Lighting Control System includes collection of spatial data, judgment by control algorithm, and correspondence to maintain the optimum environment. In the spatial data collection process, various sensor technologies that meet the required conditions are used. Data collected from this process are analyzed by the algorithm of the control logic of Smart Lighting Control System, producing the optimum value. The ultimately produced value is printed as the physical performance of the lighting control, resulting in effective lighting energy consumption and providing the optimum light environment.

2.4. Ways to Improve Performance of Smart Lighting Control System [10]

To improve performance of Smart Lighting Control System, it is necessary to analyze factors that influence performance and establish an integrated system to determine and collect types of valid data.

Table 1. Factors that Influence Performance of Smart Lighting Control System

Factors that influence energy saving performance	Whether there are occupants within the space
	Location of user within the space
	Users' lighting requirements
Factors that influence performance in providing a pleasant light environment	Type of spatial programs
	Users' lighting requirements

This study is carried out based on the illumination demanded by users among the factors shown in Table 1. Users using the space have various lighting requirements. However, the general lighting control method that has been implemented thus far had limitations in that it could not meet such diverse lighting requirements. The simple ON/OFF lighting control method provides a uniform illumination, thereby failing to increase the qualitative level of the light environment and also causing the issue of wasting unnecessary lighting energy. Therefore, this study aims to propose a basic model of Smart Lighting Control System based on user awareness, and verify its energy saving performance through an experiment on the test-bed.

3. User Awareness Technology based Smart Lighting Control System Basic Model

3.1. User Awareness Technology

User Awareness Technology means the acquisition of various information regarding users such as name, age, gender, health condition and requirements, and the user state or required services are searched and analyzed based on such information to provide user-oriented service. User Awareness Technology may be classified into the method of

using communication and method of using biometric information according to the recognition method.

Table 2. Type and Characteristics of Communication Methods Used in the User Recognition System [1]

Classification	Communication technology	Characteristics
Active Badge	Infrared-ray communication	A high possibility of crash occurrence as the number of users increases
Active Bat	Ultrasound	Too much signal interference due to surrounding environments high system configuration cost
RFID	UHF method	Less error problem but short communication distance
Zigbee	IEEE 802.15.4	Low installation cost but seriously affected by obstacles such as wall

The user recognition method using communication is the method to collect user information by identifying unique ID of user stored in the tag or card. Various technologies regarding communication can be used for this method, and those technologies can be classified as shown in Table 2. The user recognition system using the communication method has an advantage to have high recognition rate without any effect from the surrounding environment of user such as brightness. However, users should always carry a sensor such as tag or card on the body.

The recognition method using biometric information is the method of extracting and using unique biometric information of human being such as fingerprints, iris, face and voice of users for recognition. Since the recognition rate with only one biometric information is low, the multi-biometric recognition method which improves the recognition rate by combining various number of biometric information is used, and the multi-biometric system can be classified as shown in Table 3.

Table 3. Type and Characteristics of Multi-biometric System [1]

Classification	Characteristics
Multi-biometric	Recognize by collecting and judging information such as fingerprints, face, iris, vein and voice comprehensively
Multi-module	Recognize all ten fingers during the fingerprint verification process
Multi-acquisition	Recognize biometric information repeatedly for a number of times
Multi-sensor	Recognize using a semiconductor, optical instrument or ultrasonic sensor

Since it is difficult to reproduce biometric information of human being, high reliability can be secured, but there are also inconveniences such as the probability of recognition and procedures. Due to these characteristics, the multi-biometric system is suitable for the environment where security is required, but it may be difficult to apply this system in normal environments.

3.2. User Awareness Technology Application in Smart Lighting Control System

Indoor comfort exists diversely according to the preference or conditions of occupants. The level of individual demand on environmental comfort is affected by purpose of space use, age group and preference. Most environmental control methods intend to maintain the environments closely to the recommended value so that it is

possible to secure stable average value but there are limitations on the guarantee of detailed satisfaction. Therefore, studies on the environmental control system which satisfies both comfort and efficiency are necessary. In this context, securement of both energy saving performance and user satisfaction is set as an important condition for the study on the on Lighting Control System for reducing indoor lighting energy in this study.

In order to satisfy the set conditions, a basic model of User Awareness Technology based Smart Lighting Control System is proposed. The application of User Awareness Technology can lead the establishment of effective control system in response to various user needs and improvement of energy saving and the quality of spatial environments. In order to apply User Awareness Technology effectively, it is necessary to make efforts to minimize users' inconvenience created from the system development process. It's because it is difficult to secure energy saving performance if excessive inconvenience is imposed to users. Smart technology should provide useful services without being exposed. Therefore, Zigbee based wireless communication is considered to be suitable for the User Awareness Technology method in the Smart Lighting Control System study, and the basic model based on such communication method is proposed in this study.

The performance of basic model of User Awareness Technology based Smart Lighting Control System is secured through the following procedures. First, different levels of illumination according to various space users are set to the system. Second, the user recognition in the space is received through the tag carried by the user. The required level of illumination determined through the recognized user information is provided to the space to satisfy the user satisfaction. Here, if illumination flowing indoors from the outside is measured and applied to the lighting control system, energy can be saved more effectively.

4. Performance Evaluation

The energy saving performance of proposed basic model is verified through the experiment on the test-bed. The experiment is carried out through the comparison of power usage between the case of User Awareness Technology based Smart Lighting Control System application and the case of no application. The experiment environment setting and scenario for performance evaluation are as follows.

4.1 Test-bed Environments

In order to evaluate the performance of proposed basic model, the experiment is carried out on the test-bed of real life environment. The main configuration of test-bed is as shown in Table 4 and its actual conditions are as shown in Figure 1. The test-bed consists of the interior space and the chamber space for simulating light environment. The interior space is equipped with the illumination sensor for recognizing the environment information so that various experiment environment settings are possible. A window is installed on one side of the wall which is connected to the chamber, and the high power artificial light source is installed inside of the chamber so that the simulation of natural lighting is available. The artificial light source consists of 00 lamps and the simulation of lighting environment for each season can be carried out through the adjustment of brightness, height and angle.

Table 4. Main Configuration of Test-bed

Test-bed	Window	Camber
4.9m(W)×6.6m(D)×2.5m(H) wall: reflexibility 46%, ceiling: reflexibility 86%	2,200mm(W) × 1.800mm(H) pair glass 12mm(3mm+6mm+3mm)	4.5m(W)×2.7m(D)×4.6m(H) wall: reflexibility 46%, ceiling: reflexibility 86%

Figure 1. Actual Conditions of Test-bed

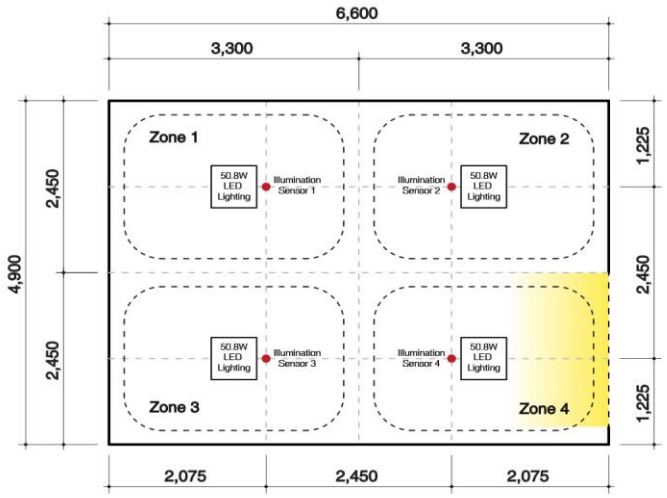

Figure 2. Environment Setting for Experiment

The environment setting for experiment is as follows. The inside of test-bed is divided into 4 zones and an artificial light source in On/Off lighting control method which provides proper level of illumination is installed on the ceiling of each zone. The sensors for measuring the level of illumination are arranged at intervals of 2450mm at the center of each zone as shown in Figure 2. The illumination sensors are installed at 800mm from the floor surface based on the height of user operation.

4.2 User Illumination Requirement Setting and Lighting Simulation

The user illumination requirement setting of User Awareness Technology based Smart Lighting Control System is as shown in Table 5. Space users are set as family member A, B and C, the space users are classified by age, and 600 lx, 400 lx and 300 lx are set respectively for the user illumination requirement of 60s, 40s and 20s. This setting is based on the fact that a higher age requires higher illumination requirement.

500 lx is set as the illumination requirement setting of On/Off lighting control system which is the comparison target based on the relevant studies for all illumination requirements.

Table 5. Illumination Requirement Setting for Experiment

	A (60s)	B (40s)	C (20s)
Smart Lighting Control System User Illumination Requirement	600 lx	400 lx	300 lx
On/Off lighting control System User Illumination Requirement	500 lx		

The time range to be applied in the experiment is between 12 PM to 1 PM with lighting toward the south. The result of measuring incoming illumination to the indoor in the lighting simulation for each season using the test-bed chamber is as shown in Table 6. The measurement result showed that the illumination in winter season exceeded 600 lx which was the maximum user illumination requirement in all zones, so it was excluded from the experiment range. Therefore, the experiment range is limited to summer, spring equinox and autumn equinox.

Table 6. Results of the Measurement of Luminance Brought into the Indoors at Noon from Full South

Seasons	Zone 1	Zone 2	Zone 3	Zone 4
Summer Solstice	329.92	1310.41	389.85	2599.82
Spring and Autumnal Equinoxes	472.74	1325.28	577.89	2736.34
Summer Solstice	910.33	1787.03	1351.19	13433.27

4.3 Method of Experiment

When a user enters into the test-bed, User Awareness Technology based Smart Lighting Control System figures out the user illumination requirement through the tag. For any zone which does not satisfy the user illumination requirement in the space, the indoor light source is used to secure the level of illumination. The number of entering into the space according to the personnel organization of users is a total of 7 times, and the relevant hierarchy of illumination requirement is as shown in Table 7. In case two or more users enter into the space, lighting is controlled by giving priority to the user with higher illumination requirement. Finally, the energy saving performance is examined through the comparison of power usage between the case of On/Off lighting control and the case of User Awareness Technology based Smart Lighting Control System.

Table 7. Hierarchy of Illumination Requirement According to the User Configuration in the Space

	Illumination requirement	Type 1	Type 2	Type 3
A (60age)	600 lx	A	A,B / A,C	A, B, C
B (40age)	400 lx	B	B, C	-
C (20age)	300 lx	C	-	-

4.4 Performance Evaluation

In order to verify the performance of User Awareness Technology based Smart Lighting Control System basic model proposed in this study, the comparative experiment with On/Off lighting control system is carried out. The details of experiment carried out according to the method setting are as shown in Table 8.

Table 8. Experimental Measurement Result

System	Season	Type	User / Illumination requirement	Zone 1 Lighting / Lux	Zone 2 Lighting / Lux	Zone 3 Lighting / Lux	Zone 4 Lighting / Lux	Electronic Consumption (kWh)
On/Off Lighting Control System	Summer	Type 1	A / 500	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			B / 500	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			C / 500	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
		Type 2	AB / 500	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			AC / 500	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			BC / 500	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
		Type 3	ABC / 500	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
	Spring And Autumn	Type 1	A / 500	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
			B / 500	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
			C / 500	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
		Type 2	AB / 500	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
			AC / 500	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
			BC / 500	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
		Type 3	ABC / 500	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
Smart Lighting Control System	Summer	Type 1	A / 600	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			B / 400	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			C / 300	Off / 329.92	Off / 1310.41	Off / 561.44	Off / 2637.55	0
		Type 2	AB / 600	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			AC / 600	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
			BC / 400	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
		Type 3	ABC / 600	On / 817.31	Off / 1341.09	Off / 561.44	Off / 2637.55	0.0513
Smart Lighting Control System	Spring And Autumn	Type 1	A / 600	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
			B / 400	Off / 472.74	Off / 1325.28	Off / 577.89	Off / 2736.34	0
			C / 300	Off / 472.74	Off / 1325.28	Off / 577.89	Off / 2736.34	0
		Type 2	AB / 600	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513
			AC / 600	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513

			BC / 400	Off / 472.74	Off / 1325.28	Off / 577.89	Off / 2736.34	0
		Type 3	ABC / 600	On / 960.13	Off / 1355.96	Off / 749.48	Off / 2774.07	0.0513

The experiment result is as follows.

First, according to the experiment result of On/Off lighting control, the illumination requirement of Zone 1 was inadequate at all types including summer, spring equinox and autumn equinox. Therefore, a total of 7 artificial lightings were used to satisfy the illumination requirement.

Second, according to the experiment result of Smart Lighting Control System, the number of artificial lighting used due to insufficient illumination requirement at the summer setting is a total of 6 artificial lightings. The artificial lightings used for each type include two Type 1 artificial lightings, three Type 2 artificial lightings and one Type 3 artificial lighting.

Third, according to the experiment result of Smart Lighting Control System, the number of artificial lighting used due to insufficient illumination requirement at the spring equinox and autumn equinox setting is a total of 5 artificial lightings. The artificial lightings used for each type include one Type 1 artificial lighting, two Type 2 artificial lightings and one Type 3 artificial lighting.

4.5 Result of Performance Evaluation

The analysis result shows that the power consumption of User Awareness Technology based Smart Lighting Control System is lower than the power consumption of On/Off lighting control method at Type 1 in summer and Types 1 and 2 in spring equinox and autumn equinox. The energy saving performance is shown from User C in summer and Users B, C and BC in spring equinox and autumn equinox.

5. Conclusion

The main result of this study can be summarized as follows.

First, On/Off lighting control method can be done only through manual operation, so it is difficult to achieve thorough lighting energy saving. Smart Lighting Control System is the automation system with IT technology applied in order to make up for the disadvantages of On/Off lighting control, and it provides lighting energy saving and pleasant light environment.

Second, there is a wide variety of IT technologies that could apply to Smart Lighting Control System, and those technologies may underline different performance to each other according to the composition. Therefore, it is most important to bring the maximum performance stably by combining various technologies effectively for Smart Lighting Control System.

Third, the primary mechanism of Smart Lighting Control System is carried out in sequence of collection of spatial data, judgment according to the control algorithm and response for maintaining the optimal environment. Various sensor technologies to respond to required conditions are used in the process of collecting spatial data.

Fourth, factors that influence the energy saving performance of Smart Lighting Control System include the occupation in the space, user position, and user illumination requirement, and factors that influence the performance to provide pleasant light environment include the type of spatial program and user illumination requirement.

Fifth, User Awareness Technology is divided into the method of using communication and the method of using biometric information, and for the Smart Lighting Control System application, the method of using communication which minimizes inconvenience of users is more suitable.

Sixth, the performance evaluation result of basic model of Smart Lighting Control System proposed in this study proved that it had higher energy saving performance than On/Off lighting control method. The energy saving performance is confirmed from User C in summer and Users B, C and BC in spring equinox and autumn equinox.

In this study, the basic model of User Awareness Technology based Smart Lighting Control System was proposed for lighting energy saving and its validity was verified through the performance evaluation on the test-bed. Studies with regard to energy saving according to spatial program among the factors that influence the performance of Smart Lighting Control System will be necessary in future.

References

[1] H. W. Lee, H. D. Jeong and Y. S. Kim, "A Basic Study on Application of User and Location Awareness for the Green Home IT", Journal of Architectural Institute of Korea, vol. 28, no. 1, **(2012).**
[2] S. O. Cho, "A Study on the Development of Building Control and management System : Focusing on the Lighting Control and Monitoring system", Journal of Korean Institute of Interior Design, vol. 16, no. 4, **(2007).**
[3] H. M. Lee and H. S. Kim, "An Experimental Study on the Lighting Control System for Appling for Home Network", The Society of Living Environment system, Korea, vol. 16, no. 5, **(2009).**
[4] A. S. Choi, J. E. Lee and B. C. Park, "Development and Application of Health Lighting Plan in Residential Areas", Journal of Architectural Institute of Korea, vol. 20, no. 10, **(2004).**
[5] A. S. Choi and J. E. Lee, "A Study of Luminous Environment for Standard Illuminance in Residential Areas", Journal of Korean Institute of Illuminating and Electrical Installation Engineers, vol. 19, no. 3, **(2005).**
[6] S. P. Han, "A Study on Lighting Control Method for Harmonization of Daylighting and Artificial Lighting - Development of Visual Model for Harmony and Comfort in Interior Space", Journal of Architectural Institute of Korea, vol. 26, no. 8, **(2010).**
[7] S. R. Ryu, K. N. Lee, M. S. Yeo and K. W. Kim, "A Study on the Home Network Systems for the Integrated Control of the Indoor Environment", Journal of Architectural Institute of Korea, vol. 25, no. 1, **(2005).**
[8] S. Cho, "The Technical Development Status of Energy Convergence Building", Journal of Architectural Institute of Korea, vol. 53, no. 2, **(2009).**
[9] Samoo Architects and Engineers, Editor, NET ZERO : Sustainable Design Process of Zero Energy House, Korea, **(2010).**
[10] K. H. Choi, H. W. Lee and Y. S. Kim, "A Study on the Basic Model of Smart Lighting Control System Using User Awareness Technology", Architecture and Civil Engineering 2014, vol. 47, **(2014).**

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