Implementation of a Scenario-based Energy Saving Mechanism in Smart Lighting Systems

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***Abstract*—A smart lighting system solution that optimizes the energy is required for energy saving. It should control lighting based on time and space, and it should be context-aware. In this study, we propose a scenario-based energy-saving mechanism based on the user's behavior patterns and situations in order to reduce significantly the energy consumption compared to the conventional Light Emitting Diode (LED) lighting in buildings. In addition, we built 10 test bed unit spaces for our test bed that were controlled automatically. Through evaluation, the scenario-based smart lighting system test bed presented in this study proved to be about 54% better than conventional LED lighting in terms of energy saving.**

Keywords- smart lighting system; energy saving; internet of things; LED.

I. Introduction

The proportion of energy consumption by lighting in Korea reaches 20% [1]. In particular, the amount of energy consumed in buildings accounts for more than 30% of total energy consumption. As the national government prohibits the use of incandescent lamps, replacement of incandescent lamps and fluorescent lamps with LED lighting is increasing [2]. By replacing the existing fluorescent lamp with LED lighting, it is possible to reduce the energy by 30%, and when using dimmable LED lighting, energy savings of about 50% are possible [1]. However, in order to save energy, a smart lighting solution can be developed and popularized to optimize energy consumption through lighting control based on time, situation, and space to enhance user satisfaction by supporting customized service, and suitable for the situation instead of simply replacing with LED lighting [3]. In this study, we propose a scenario-based energy saving mechanism suitable for user 's behavior pattern and situation in order to reduce energy consumption much more than conventional LED lighting in the unit space of a building.

The remainder of this paper is organized as follows. Section II describes the smart lighting system architecture. In Section III, scenarios appropriate to the behavioral patterns of each unit space are described. In Section IV shows energy saving performance measured in each unit space. Finally, conclusions are discussed in Section V.

II. Design of Smart Lighting System Architecture

The purpose of this study is to utilize a smart lighting system to provide users with functional, human conformity, emotional satisfaction and realize energy savings. For this purpose, ten unit spaces, such as an office, a conference room, a restroom, a hallway, parking lots, a staff lounge, stairwells, a lobby, a cafe, and a development room (lab) are selected, and user behavior patterns are defined for each unit space. We constructed a test bed to control the lighting according to each unit space and environment. The test bed in the unit space is designed to allow the user to directly control the lighting using the smart pad. It can also be controlled automatically without user intervention for 24 hours based on scenarios such as environmental events, schedule, and user behavior patterns.

Figure 1 shows a network configuration of a smart lighting system. The management server can control the lighting through the gateway, and the sensors transmit the event to the management server through the gateway when the event occurs. In addition, power consumption is measured by Current Transformer (CT) sensor in each unit space, and it is transmitted to the management server or service servers through the metering gateway so that the amount of power consumed in real time in each unit space can be monitored.

III. Scenario Design Appropriate to Behavior Patterns in Unit Space

In this study, the scenarios of 10 unit spaces for user convenience and energy saving were defined for behaviors and events. The behavior of each space was derived through the survey of major act patterns by space and empirical test subjects [4]-[6]. Table 1 shows the behavioral scenarios for the three unit spaces, such as office, restroom, and stairwells among 10 unit spaces. In Table 1, the main activities in the office were defined as weekly work, lunch, and night work, and the scenarios were designed so that the lighting of the office could be appropriately controlled according to the main activity. The main behaviors in the restroom were defined as the activities, such as entrance, toilet, washing and color temperature control according to the season. In the stairwells, scenarios for the entrance, movement, and fire occurrences were designed.

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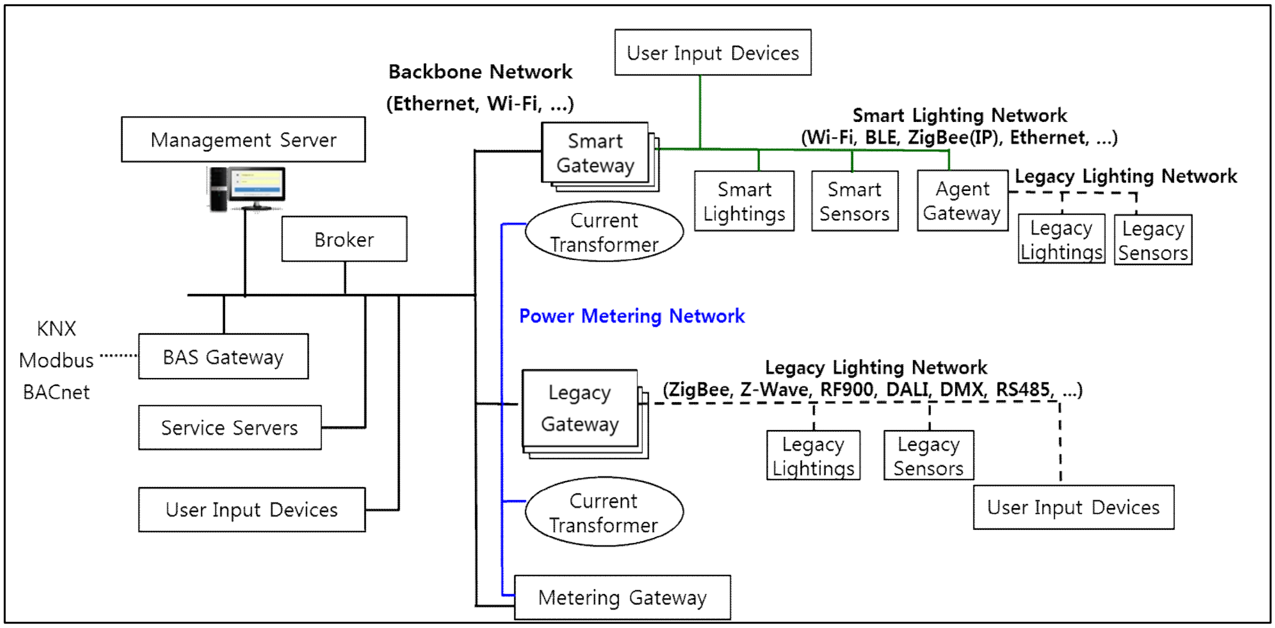

Figure 1. Configuration of smart lighting system

TABLE I. DESIGN OF SCENARIOS IN ACCORDING TO ACTIVITIES

Space	Behavior/ Event	Scenario
Office	Day work	Turn on all lights if there are occupants. Automatically adjusts the brightness of lights according to the amount of daylight. Turn off all lights if there is no occupant.
	Lunch	If there are occupants, dimming to 20-25% of working time brightness.
	Night work	Illuminates above occupant seat by human body detection. (3 ~ 5m from user's spot keeps 20 ~ 25% illumination, Turn off if it is more than 5m away from the user' s spot) Turn off the corresponding lights if there is no occupant.
Restroom	Entrance	Lights are illuminated by each zone through human body detection. Lights are turned off for each zone when no human body is detected.
	Toile	Lighting in individual partition by human body detection when entering individual partition.
	Wash/Mirror	The ceiling lights and indirect lights are turned on when washing hands or approaching the vanity unit to see the mirror.
	Four seasons	Spring/Autumn 4000K, Summer 5000K, Winter 3000K
Stairwells	Entrance	When a person opens the door of a stairway, the light upstairs and downstairs including that floor are turned on. (The brightness of the lighting on the floor where the person is located is 150 lux, Upper/lower floors apply 50%)
	Movement	Identify the person's position and direction of movement so that the floor in the direction in which the person is moving gradually becomes bright. In this case, the lighting brightness is the same as the entrance
	Fire occurrence	If a fire is detected by a sensor, a fire alarm is sent to the management server through the gateway. Detects the human body and informs the management server through the gateway of the position of the evacuator. The escapable floors connected to the outside are brightly lit at 150 lux and the other floors lit at 30 lux. Illuminates the current number of floors on the wall and illuminates the arrow lights to induce evacuation.

IV. ENERGY SAVING EVALUATION

In order to investigate the real -time power consumption in each unit space, we measured the power consumption by attaching CT sensors to the switchboard of the test bed.

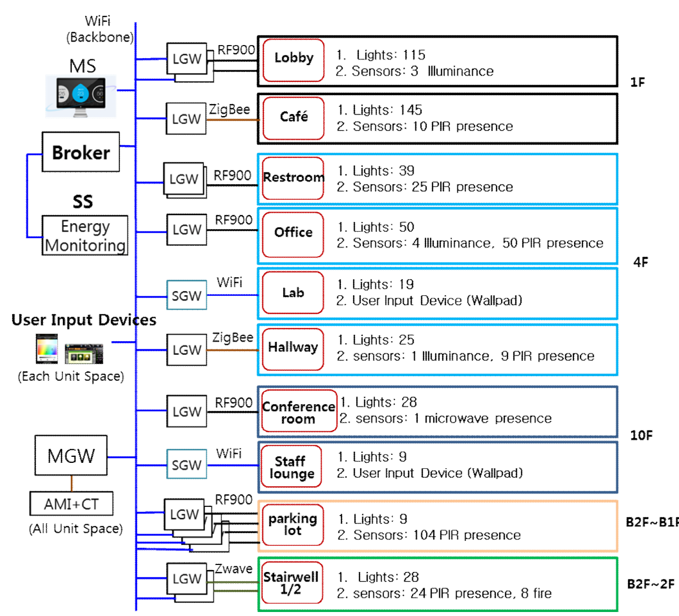

Figure 2. Test bed configuration for evaluation.

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We implemented the system so that the physical quantities (target illuminance, use time, dimming) of each behavior can be matched as much as possible. Also, we evaluated the energy saving rate compared to LED lighting by measuring the energy amount satisfying the illuminance value for each unit space. Figure 2 shows the test bed configuration for energy saving evaluation.

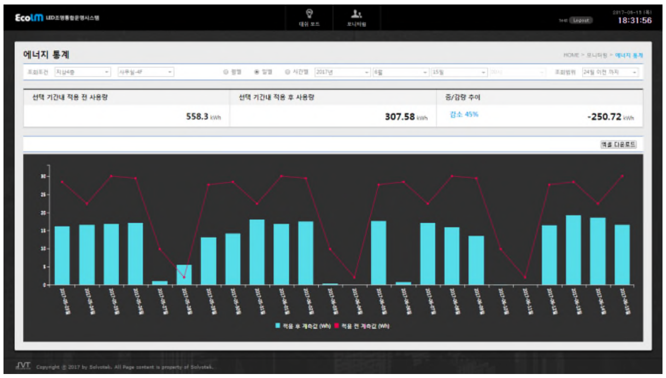

Figure 3. Real-time energy consumption monitoring in the office room.

Figure 3 shows how the management server monitors the energy consumption measured in the office every one minute. The dotted line represents the power consumption for the conventional LED lighting, and the bar represents the power consumption when controlling the LED lighting based on behavioral scenarios using the smart lighting system. Compared with real-time power consumption data of about 25 minutes, it shows 45% energy saving rate compared to LED lighting.

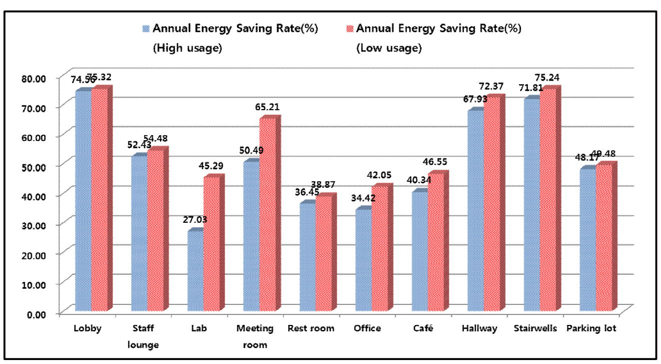

Figure 4. Anuual energy saving rate of proposed mechanism.

Figure 4 shows the annual energy saving rate for each unit space when applying the scenario-based mechanism presented in this study against existing LED lighting. For each unit space, the bar graph on the left shows annual energy saving rate when the behavior frequency is high, and the right bar graph shows annual energy saving rate when the behavior frequency is low.

V. CONCLUSION

In this study, a smart lighting system test bed is constructed for 10 unit spaces of a building to provide users with functional, human conformity, emotional satisfaction and realize energy savings. We defined behavior patterns suitable for each unit space. The smart lighting recognizes each behavior pattern, and controls lighting to suit each unit space and environment. Each test bed has a higher energy saving rate than the conventional LED lighting because the lighting is systematically controlled according to each defined pattern behavior. In particular, lobby, hallway, and stairwells showed energy savings of more than 70% compared to LED lighting, and on average, energy savings of more than 54% (see Figure 4). The scenario based energy saving mechanism in the smart lighting system suggested in this study has high utility for energy saving while providing user convenience.

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REFERENCES

[1] J. U. Shin, “The Efficiency of LED lighting using Intelligent Control,” The Proceedings of he Korean Institute of IIluminating and Electrical Installation Engineers (KIIEE), vol. 29, no. 1, pp. 4-8, Jan. 2015.

[2] P. Waide, “Phase out of Incandescent lamps,” International Energy Agency, Apr. 2010.

[3] J. C. Lee and H. J. Jang, “LED Light Source and Control and Management Lighting System IT Convergence Technology for Energy-saving,” The Proceedings of he Korean Institute of IIluminating and Electrical Installation Engineers (KIIEE), vol. 26, no. 1, pp. 15-20, Jan. 2012.

[4] J. Y. Park, J. S. Lee, C. U. Jeong, and E. J. Seo, “A Study on the Visual Point and Preferred Lighting System by Activity in the bedroom,” Korean Society for Emotion and Sensibility Fall Conference, pp. 43-44, Nov. 2013.

[5] M. J. Lee, “A Study on the Comparison of the Emotional Experiment from Fluorescent Lamp and LED Lighting” Journal of the Korean Institute of IIluminating and Electrical Installation Engineers, vol.26, no. 8, pp. 8-17, Aug. 2012.

[6] J. H. Kim, J. K. Ko, and M. R. Cho, “A Study of Integrated Evaluation of System Lighting and User Centered Guideline Development-Focused on the Lighting Design Method for Office Space-.” Journal of the Korean Institute of Interior Design, vol.23, no. 6, pp. 78-86, Dec. 2014.