

Automated demand response system in lighting for optimization of electricity cost

Kyoung-Mi Im

Received: 27 June 2015 / Accepted: 3 April 2017 / Published online: 5 May 2017
© Springer Science+Business Media Dordrecht 2017

Abstract Daylighting is an important factor in improving visual comfort and energy efficiency. Lighting control using daylighting can reduce energy consumption in buildings. This thesis proposes an automatic demand response system for lighting based on wireless sensor networks (WSN) in order to reduce the peak electricity demand according to the stage of electricity rate with real-time pricing (RTP), time of use pricing (TOUP), and critical peak pricing (CPP). The proposed system automatically controls the slat angle of the venetian blind with a cut-off angle according to the altitude of the sun, automatically executing light dimming according to measured current luminance to remove an unpleasant glare caused by daylighting. The target illuminance of area at this time is set at a minimum illuminance required for the work execution in the office during the time zone where the electricity load is high to save the lighting energy cost, while a maximum illuminance is set during the time zone where the electricity load is low according to the real-time electricity pricing stages obtained through the advanced metering infrastructure (AMI) in order to improve the work efficiency of the occupants. In this study, two testbeds having the same environments, as well as a control system targeting a fixed illuminance per price system, were established. The illuminance energy consumption

and cost were then measured and the effect of the proposed illuminance system was evaluated.

Keywords Demand response · Lighting control system · Energy saving · Wireless sensor networks

Introduction

A smart grid, which is a technology that maximizes energy efficiency by fusing information and communication technology (ICT) in the existing grid, provides various demand response (DR) programs which maintain the stability of the grid with an intelligent grid that can exchange the data with a bidirectional mode between the power provider and customers at real time (Javald et al. 2013; Khajavi et al. 2011; Kim and Kim 2012). This demand response is a mechanism that induces customers to respond to the real-time electricity price sent through the grid and to change the electricity consumption pattern by themselves. This mechanism displays a demand response either by load shedding during maximum power load or by shifting the load to the minimum load time zone (Lujano-Rojas et al. 2012; Piette et al. 2013). However, with current demand response programs, it is difficult to expect an effective response without persistent human intervention by customers since customers have to control energy consumption by directly monitoring the electricity price which keeps on changing at real time. Consequently, interest about an automated demand response, a mechanism that controls power consumption by

K.-M. Im (✉)
Department of Digital Contents, Korea Nazarene University, 48,
Wolbong Ro, Seobuk-gu, Cheonan-si 31172
Chungcheongnam-do, Republic of Korea
e-mail: ikm9260@komu.ac.kr

automatically responding to the power supply status, peak load rate, power production, and supply price, is abruptly increased. ADR, in particular, dynamically schedules a power price according to the time-varying electricity rates for various power consuming devices such as heating, ventilation, and air conditioning (HVAC), thereby operating with a normal mode during the time zone when electricity rate is low, while converting itself to a low power mode during such time when electricity price is high (Piette et al. 2013; Asano et al. 2011; Li et al. 2012; Lee and Bahn 2013; Taheri et al. 2013; Shahgoshtasbi and Jamshidi 2014; Dong et al. 2012).

In Korea, around 24% of the total energy consumption is used in the building section. Among this, around 30% of the office buildings and around 40% of the commercial buildings use energy for lighting (Kim and Kim 2014; Ihm et al. 2012; Yun and Kim 2013). Daylighting is a cost-effective way to save energy for lighting, although it brings risk of glare. Therefore, in the preceding researches, a daylight dimming system was suggested, which can save lighting energy by blocking direct solar glare by blind systems, utilizing an inflow of daylight (Koo et al. 2010; Soori and Vishwas 2013; Ihm et al. 2009; Parise et al. 2014). Traditional daylight dimming control systems maintain a constant task illuminance, but they do not consider variable electricity rates.

This paper proposes an automatic demand response system for the lighting in order to reduce lighting energy by using real-time pricing (RTP), time of use pricing (TOUP), and critical peak pricing (CPP) which are the electricity pricing systems of the smart grid. The proposed system collects the illuminance data and real-time electricity pricing data from the illuminance sensors and from the smart meter located in the area through a gateway, calculates the dimming stage of the lighting per the target illuminance matching to the electricity rate at present, and sends control signals to the lighting controller. At this time, different target illuminances are applied according to the three electricity pricing stages, i.e., peak, mid-peak, and off-peak of each pricing system. The standard is set per the minimum, standard, and maximum illuminances recommended by the illuminance standard in Korea, KS A 3011 (Yang and Nam 2010). A system is designed to provide visual comfort to the occupants by applying a target illuminance during the time zone when energy cost is relatively low, while it provides a minimum

illuminance necessary for the work execution as a target illuminance during the time zone when electricity rate is high in order to save the lighting energy cost. Also, the system calculates a profile angle to block the glare from direct sunlight to the workplane and sends a control signal to the blind controller to control the venetian blind with a cut-off angle. This study compares and evaluates the system which controls lighting to variable target illuminance according to each electricity pricing system of the smart grid with the system which controls the lighting with a fixed target illuminance by establishing a testbed having the same condition to assess the lighting energy consumption and cost based on the electricity pricing systems. This paper is constructed as follows: in the “Literature review” section, we discuss various electricity pricing systems. In the “Methodology” section, we discuss the operation procedure of the proposed system. In the “Results” section, the simulation and evaluation results with the proposed system are discussed. The effect and comparison of the proposed system with the existing electricity pricing system is discussed in the “Discussions and conclusions” section as a conclusion of the study.

Literature review

Electric rates

Electricity pricing system in Korea at present is operated with two types, i.e., a flat rate which imposes the same price throughout a year regardless of the electricity consumption, and a dynamic pricing which imposes a different price per time zone. A flat rate system based on the average cost causes an over-consumption when the power production cost is higher than the average price, while it causes a low consumption phenomenon that restricts the power consumption which could be economically effective when power production cost is lower than the average price. Meanwhile, a dynamic pricing system is a pricing system designed to shift the energy consumption of the time zone where electricity price change is high to the time zone where energy consumption is less. In the dynamic pricing system, there are various types of pricing like TOUP, CPP, and RTP as shown in Fig. 1 (Mohsenian-Rad and Leon-Garcia 2010; Yu et al. 2012; Widergren et al. 2012; Faria and Vale 2011; Ahmad 2010).

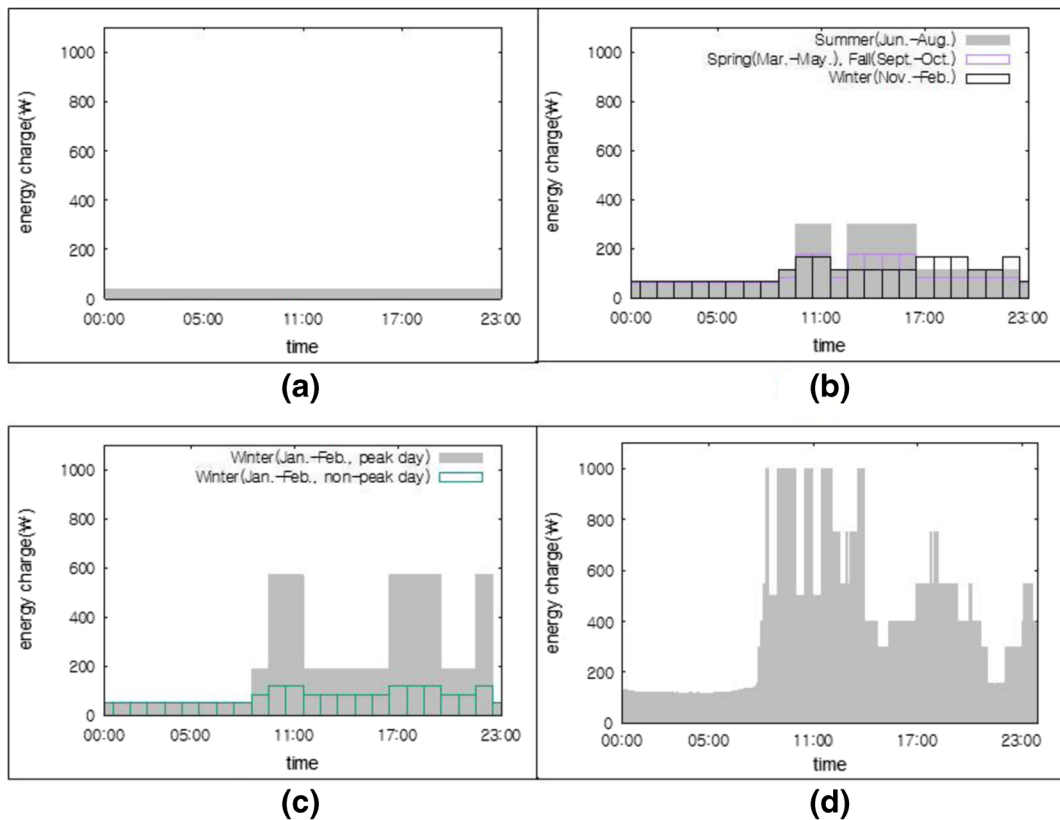


Fig. 1 Electricity rates in Korea. **a** Flat rate. **b** TOUP. **c** CPP. **d** RTP

TOUP

TOUP is an electricity pricing system wherein the time zone wise average power generation and transportation cost during 24 h a day is differently applied according to the seasons and time zones. It is not a system which reflects the electricity market situation at real time but approaches in a statistical manner.

CPP

CPP is the electricity pricing system wherein utility providers notify the electricity rate during peak time when electricity demand is high to the customers in advance before supplying the electricity. The price during off-peak is more or less lower than that with TOUP. However, an extremely high price is imposed during peak time with CPP. In Korea at present, CPP is operated for around 121 days from the first of July till the 31st of August and from the first of January till the end of February. The electricity rate with a maximum load

during the peak day is imposed around 3.3 times of that with TOUP (KEPCO 2014).

RTP

RTP is a pricing system wherein electricity rate imposed on the customer keeps on changing according to time zone just as in TOUP. However, while a flat rate is imposed within seasons and time zones set in the TOUP system, RTP variable rates are imposed according to electric power system and demand and supply status. Therefore, the variability of the electricity rate by RTP could be high. Still, the benefit for both the supplier and customer sides can be increased when a customer consumes electricity in an economical way. Figure 1d shows a graph showing the electricity rate which is changed at a 5-min interval imposed on the 26th of December in 2012. The electricity consumption was calculated at a minimum of SMP at ₩ 123.20 and a maximum of ₩ 276.42. Therefore, RTP was recorded as a minimum of ₩ 117.98 and a maximum of ₩ 1000. In

the USA, RTP is operated by around 100 power suppliers at present according to LBNL in 2004. Additionally, Georgia Power operated two types of RTP of Day Ahead RTP and Hour Ahead RTP. The price difference by the time zone was 81.2 times at maximum (0.08–6.5\$/kWh) while customers saved on an average of 17% of load (LBNL 2004). In Korea, RTP was operated as a model case for the 200 families by the smart grid field test unit established in the Jeju Island (Daphne et al. 2012). It is planned to be expanded to a national level after analyzing the demand response.

This paper proposes an automated demand response system for lighting based on a pricing scheme that can optimize power cost. Target illumination as a reference was set at a minimum at a higher stage of the pricing scheme, whereas at a lower stage of the pricing scheme, maximum illumination was set as a reference.

Blind control

Daylight which flows into a building not only provides many benefits like visual comfort, psychological comfort, health, and workplace productivity but also reduces electricity consumption used for lighting and cooling/heating (Koo et al. 2010; Kang et al. 2012). However, excessive inflow of daylight causes impaired work performance and visual discomfort and can increase cooling energy consumption during summer (Kim et al. 2007). Therefore, shading devices are used to improve the visual environment for the occupants and to reduce energy consumption (Tzempelikos and Athienitis 2007). Venetian blind is one of the shading devices that can control solar radiation by controlling the slat angle and is used the most to regulate daylight in office buildings or commercial buildings. However, according to previous researches, occupants almost did not control the blinds once they were opened or closed until they felt discomfort by the glare (Kim et al. 2007, b, c). The average frequency of blind movement was just zero to one time a day (Koo et al. 2010; Kim et al. 2007, b, c). This is a drawback of the manual blind which is controlled by the users. Therefore, there is a limit in meeting the visual requirement of the occupants and in reducing the energy consumption. Accordingly, an automated blind that can control the slat angle of the blind by the external solar conditions at real time is used as an alternative solution for the manual blind.

The automated control strategy of the automated blind is a profile that controls blinds with a cut-off angle

from the profile angle, considering the position of the sun as shown in Fig. 2. It is a control method to remove the glare while maximizing daylight, as well as inflow of the solar radiation. The calculation equations for the profile angle and cut-off angle are the same as (1) and (2), where β is solar altitude angle, Φ is solar azimuth angle, and γ is azimuthal angle (Soori and Vishwas 2013).

$$\theta = \arctan\left(\frac{\tan\beta}{\cos(\Phi-\gamma)}\right) \quad (1)$$

$$\beta_{cutoff} = \arcsin\left(\frac{d\cos(\theta)}{w}\right) - \theta \quad (2)$$

Methodology

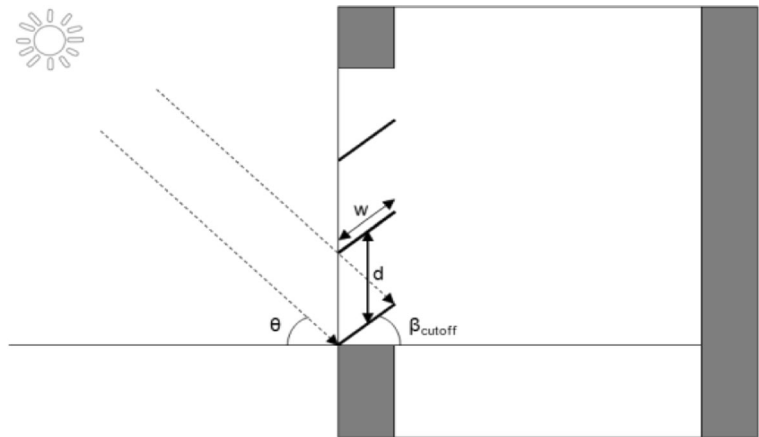
System architecture

The automated demand response system proposed in this paper is designed to collect data and control devices based on ZigBee wireless communication. It is comprised of three layers as shown in Fig. 3.

1. Sensing layer

The sensing layer receives the raw data from each sensor which is installed in the system. The types of sensors installed are light sensors that sense illumination of the workspace and a smart meter that can receive current power cost information from the power service provider. The light sensor that senses the current illuminance was installed at a work platform 850 mm from the ground and it sent data to the gateway of the system at 1-sec intervals. The real-time electricity charge which the utility provider sends to the smart meter of each consumer is collected in the gateway at 5-min intervals. The information collected from each sensor is stored in the database as raw data to be sent to the Middleware Layer. During this time, solar altitude angle, solar azimuth angle, and azimuthal angle are directly collected from the data stored in the system according to concerned date and time to calculate cut-off angle of the blind. In addition, basic data such as distances between two slats and width of the slats were also directly obtained from the pre-stored data.

Fig. 2 Cut-off shading control strategy



2. Middleware layer

In the middleware layer, raw data stored in the database of the system through gateway are abstracted as a high-level context of the lower as well as the higher level by the context rules. A present context is reasoned. The received raw data are defined as a low-level context such as an illuminance at present, electricity rate per

time zone, and time according to the abstraction level. These low-level contexts are abstracted as high-level context like target illuminance and cut-off angle per the pricing stage. The pricing stage of RTP used in the context rules is abstracted into three stages of peak, mid-peak, and off-peak. The RTP formed in the power market in Korea was a minimum ₩ 100 up to a maximum of ₩ 1000. Accordingly, the price less than ₩ 400 was

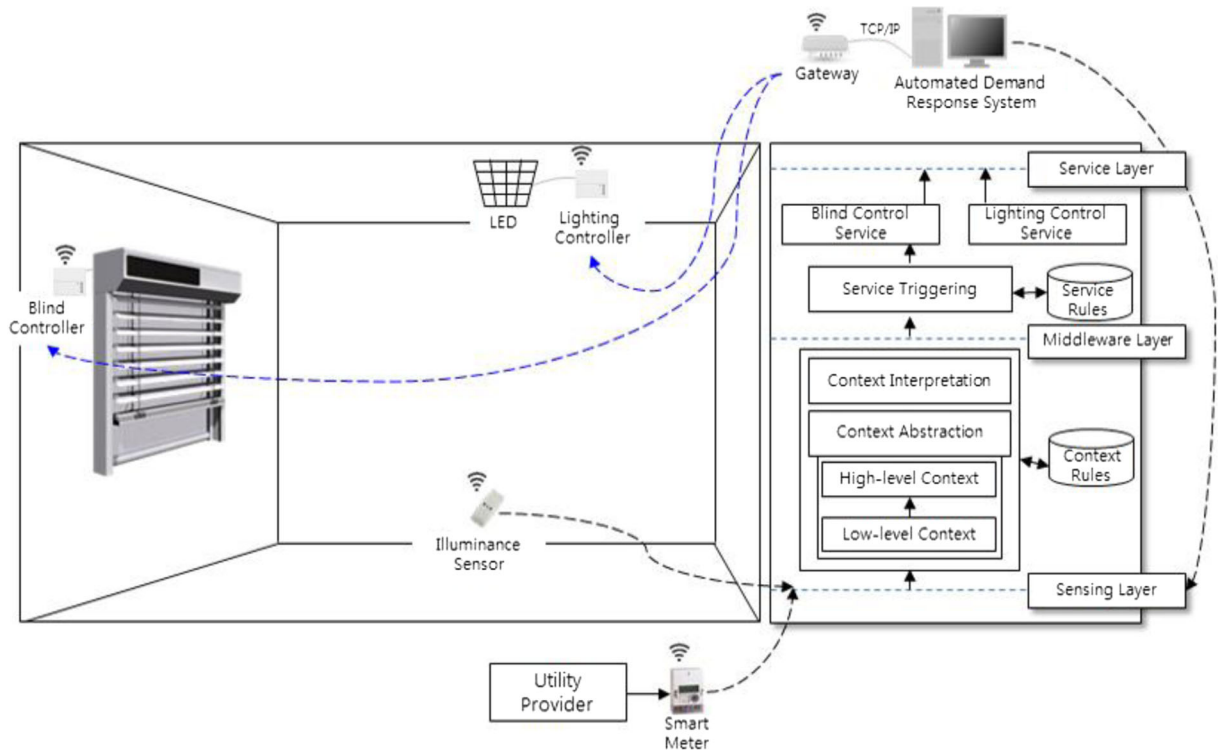


Fig. 3 System architecture of automated demand response system of lighting

Table 1 Design illumination level of an office space

IESNA (lux)	Min. of health, labor, and welfare—Japan (lux)	KS A 3011 (lux)
500–750–1000	300–1000	300–400–600

abstracted as an off-peak, the price between \ 401 and \ 700 was abstracted as a mid-peak, and the price between \ 701 and \ 1000 was abstracted as a peak.

The pricing stages in the TOUP and CPP were also abstracted as off-peak for a minimum pricing stage, a mid-peak for medium pricing stage, and a peak for the maximum pricing stage, respectively, with the same fashion as in the existing structure. The target illuminance used in the context rules is abstracted into three types: level 1, level 2, and level 3. The target illuminance for the office area was categorized as referring to the KS A 3011 which is a standard illuminance table. The illuminance standard in Korea and foreign countries are differently proposed according to the standards from each organization as shown in Table 1 (Yang and Nam 2010). KS A 3011 defines the illuminance as three types, i.e., a minimum illuminance, a standard illuminance, and a maximum illuminance according to the

space and activity type. The recommended illuminances are 300, 400, and 600 lx, respectively. The final target illuminance was abstracted by matched minimum illuminance during time zone of higher price while the maximum illuminance was matched during time zone of lower price according to the pricing stage of the system. Further, cut-off angle was calculated by using the basic data obtained from the system.

The low-level context and high-level context calculated during the abstraction process were utilized as data to interpret the contexts. The brightness of the space and blind control angles by the cut-off angle were determined by comparing the current illuminance to the target illuminance.

3. Service layer

The system checks if illuminance or blinds can be controlled from the data calculated in the Middleware Layer. Once they find the context which does not match with the service rules, it executes the defined service. If the target illuminance in the space is either higher or lower than the illuminance at present, it sends the respective packet to the lighting controller so that

Fig. 4 Implementation of the lighting controller. **a** Hardware block diagram. **b** Layout. **c** Installation. **d** Control packet

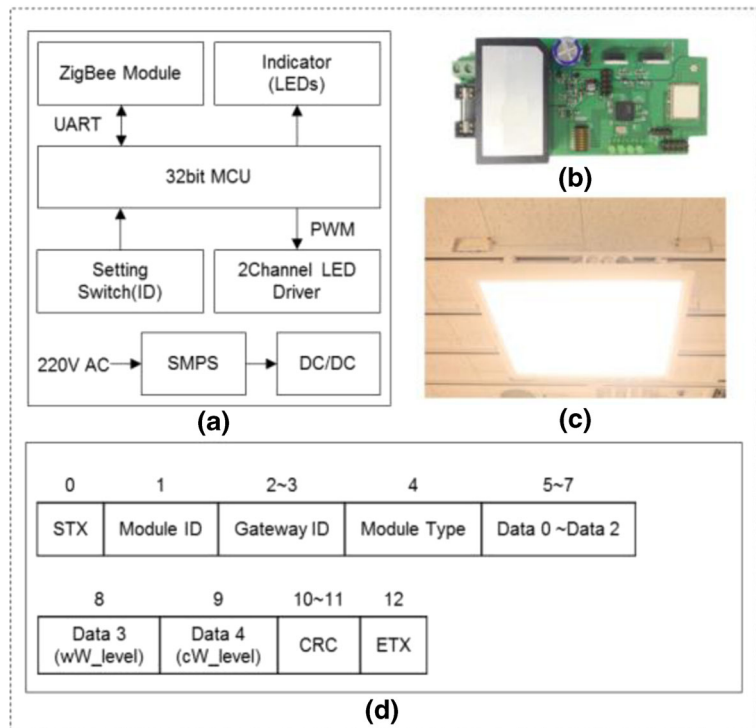
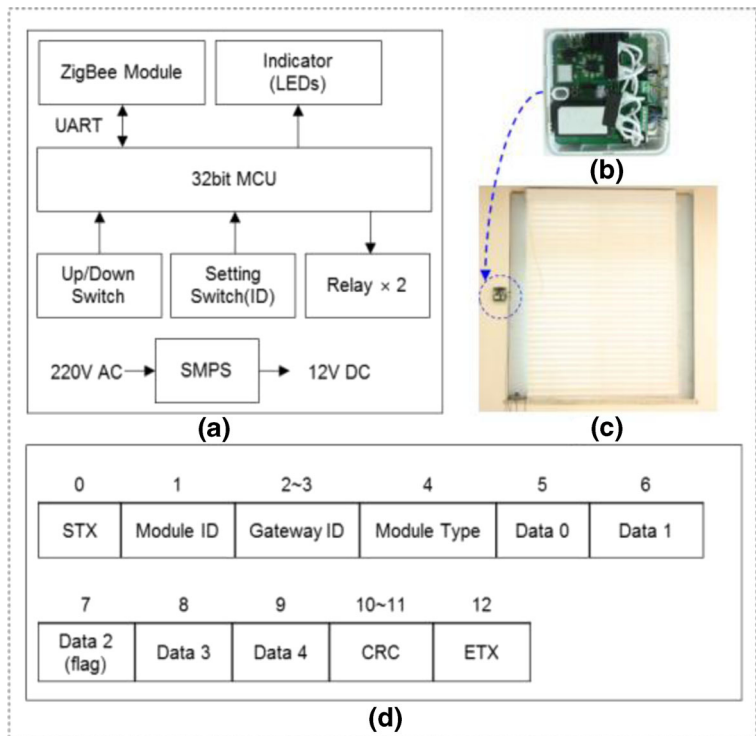


Fig. 5 Implementation of the blind controller. (a) Hardware block diagram. (b) Layout. (c) Installation. (d) Control packet



illumination is either gradually reduced or increased. Further, if a present slat angle is higher or lower after comparing it with cut-off angle, it sends the control packet to the blind controller to achieve the target angle.

System components

The system sends control packets with a wireless mode to the lighting controller and blind controller, respectively, to control the illumination of the lighting and the slat angle of the blind according to the context. The lighting used in the proposed system was a flat type LED lighting. It can execute PWM control from zero till level 255 by the two channels as in Fig. 4.

PWM is a frequency control method that controls the width of the pulse. The LED used in this system divides a duty cycle of 0~100% into 255 stages and sends them to the packet. Figure 4d shows the packet for the lighting control. The PWM control for warm white LED and cool white LED is sent by data no. 8 and no. 9.

Control of illuminance in the system is executed once in 1 min, but if there is no change as compared with the value just before comparison, the previous condition is maintained. However, if the change is large in the lighting due to the sky conditions or abrupt changes in the

pricing stage at the moment of the lighting control, occupants would feel a visual discomfort after recognizing the brightness changes. Therefore, in this study, if illuminance changes by more than 20% from the previously measured level, the change is limited to within 20% so that dimming is performed more than twice in 1 min instead of a one-time action. It does not correct all at once but is made to be dimmed more than twice in 1 min during illumination control. Figure 5 shows the

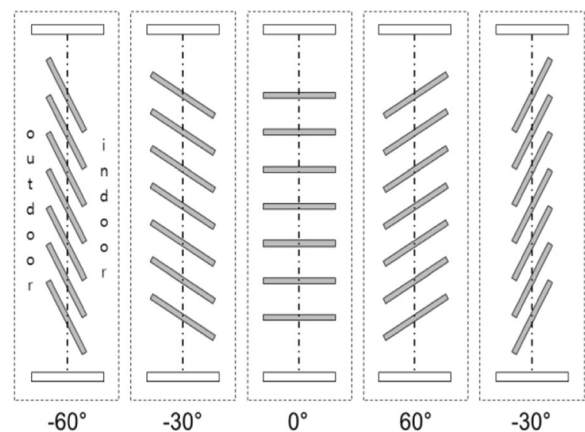
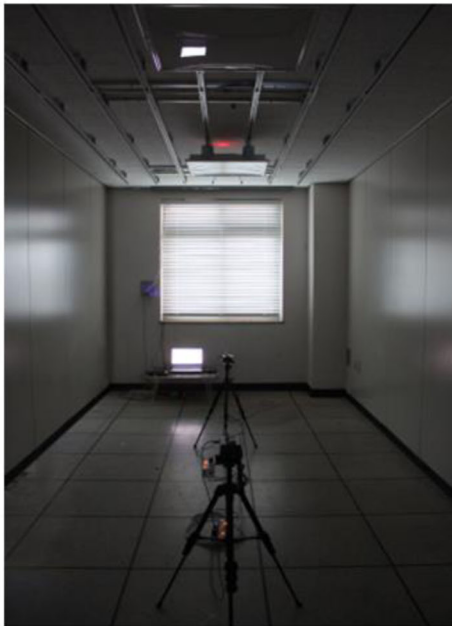
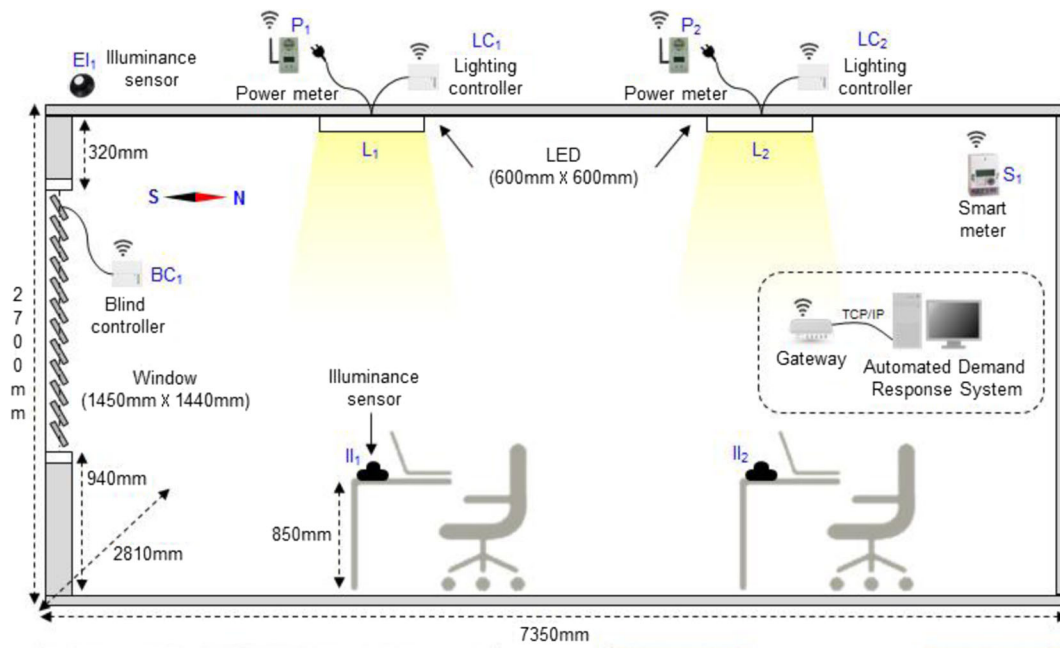


Fig. 6 Blind slat angle



(a)



(b)

Fig. 7 Testbed for simulation. a Testbed. b Testbed for the comparison

Table 2 Material property of venetian blind

Length of blind	Width of the slats	The distance between two slats
1.45 m	0.05 m	0.045 m

implementation of the blind controller. Figure 5d shows the packet to control the up, down, and slat angle of the blind. When packet no. 7 flag is 0×00 , the packet no. 5 and packet no. 6 are set as blind up (0×0100) and blind down (0×0001). Meanwhile, when flag is 0×01 , the packet no. 5 and packet no. 6 are used as signs of the slat angles. The packet no. 8 and packet no. 9 are used as slat

Table 3 Experimental environment

Date of experiment	Electric rates	Target illuminance	
		Test group	Control group
Dec. 28, 2014	TOUP	Off-peak 600 lx Mid-peak 400 lx Peak 300 lx	500 lx
Dec. 29, 2014	CPP	Off-peak 600 lx Mid-peak 400 lx Peak 300 lx	500 lx
Dec. 30, 2014	RTP	Off-peak 600 lx Mid-peak 400 lx Peak 300 lx	500 lx

angles. If the packet no. 5 and packet no. 6 are 0×0001 when flag is 0×01 , the slat angle of the blind has a negative sign; if the packet is 0×0000 , it has zero, and if the packet number is 0×0100 , it has a positive sign.

The slat angle of the blind is controlled to the five angles of -60° , -30° , 0° , 30° , and 60° as shown in Fig. 6 and is controlled as a larger value than the cut-off angle calculated in the system.

Results

Testbed which is south-facing located on the fourth floor of latitude 36.850483 and longitude 127.150056 was set up as in Fig. 7 to carry out simulation and assessment for the proposed system.

Fig. 8 Electricity rate for simulation

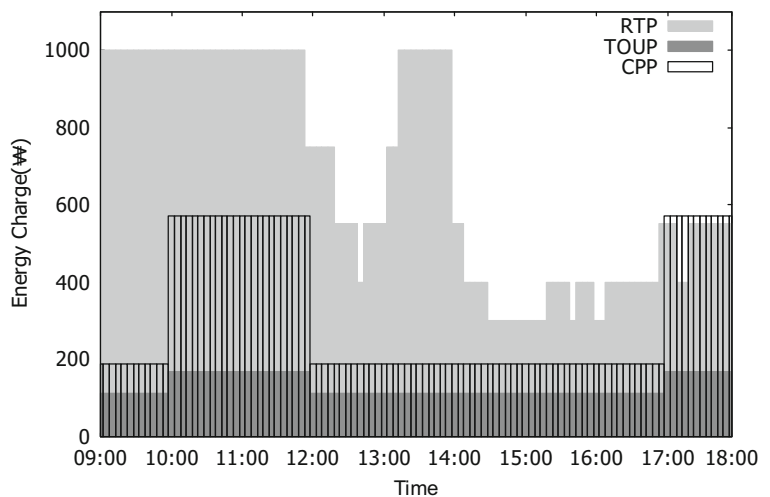


Table 4 Slat angle on December 28, 2014

Time	Profile angle	Cut-off angle	Slat angle
09:00	17.4528165	41.70334127	60
10:00	24.4320341	30.5934717	60
11:00	28.04512651	24.54593007	30
12:00	29.63450332	21.83508167	30
13:00	29.7018	21.71955734	30
14:00	28.267018	24.16919346	30
15:00	24.88075195	29.85190958	30
16:00	18.30590084	40.39354676	60
17:00	5.617585103	57.97802144	60

The lighting energy consumption and electricity cost were calculated according to the pricing systems of RTP, TOUP, and CPP. The target illuminance per pricing system was provided as a minimum of 300 lx, a standard of 400 lx, and a maximum of 600 lx according to the pricing stage. Further, the experiment was conducted by establishing one more testbed having the same environment to compare with the proposed system. The target illuminance of the testbed for comparison was set at 500 lx in the illumination system of the traditional office space. The experiment was then performed in two testbeds simultaneously. That was because illumination energy consumption and electricity cost had to be measured under the same environment and at the same time.

Two sets of LED lightings, two illuminance sensors that could measure the present illuminance at the workplane, one illuminance sensor that measured the outdoor global horizontal illuminance, two power

meters to measure the electricity consumption, and one venetian blind were installed in each testbed. The control ratio of warm white LED and cool white LED was set as same for the illumination and electricity consumption for the test. When the 255 level that is the maximum during PWM control of the lighting was given, illuminance was measured at 1000 lx and power consumption was 84 W. The geometrical properties of the venetian blind installed in the testbed are tabulated in Table 2.

The test lasted for 3 days from December 28, 2014 to December 30, 2014, for the two testbeds per electricity pricing system only during working hours from 9:00 till 18:00 as shown in Table 3. During the experiment, the On/Off status of the lighting should be considered as per the presence of people. However, for the evaluation of the proposed system, motion control was excluded to calculate energy and power cost used at maximum for a limited time according to external illumination and pricing schemes. Figure 8 shows the electricity rate per time zone under each electricity pricing system used on the day of testing. In case of RTP, the time which was consumed during peak where the rate was the highest was 2 h and 25 min. The time consumed in mid-peak was 1 h and 35 min, while the time consumed in off-peak was 5 h and 0 min. Under the TOUP and CPP systems, the time consumed under peak was 3 h and 0 min, under mid-peak 6 h and 0 min, and under off-peak 0 h and 0 min.

Table 4 is a profile angle, cut-off angle, and blind slat angle according to time zone on December 28, 2014. The proposed system transmits a packet for controlling the slat angle of the blind to the blind controller of the system by 1 h.

Figure 9 depicts external illuminance by time measured for 3 days, illuminances L1 (test group) and L2 (test group) of the two lighting types that were dimmed by the proposed method and two types of illuminances—L1 (control group), L2 (control group)—controlled by the existing illuminance method. L1 (test group) and L1 (control group) represent the data measured from the illuminance sensors that were located at the window side. These sensed high illuminance because the quantum inflow from outside was more than L2 (test group) and L2 (control group). The reason why sensed internal illuminance was high was because quantum from outside was higher than the target illuminance. In this case, the lighting at that location was not turned on. Figure 10 shows power measured by time when two lighting systems were dimmed for each test to maintain illuminance as in Fig. 9.

The total electricity consumption and electricity price used for two lightings on the testing date were calculated as in Table 5. With RTP system, the electricity consumption and cost were reduced by 20.86 and 40.85%, respectively, in the proposed system compared with those in the control. The electricity consumption was reduced

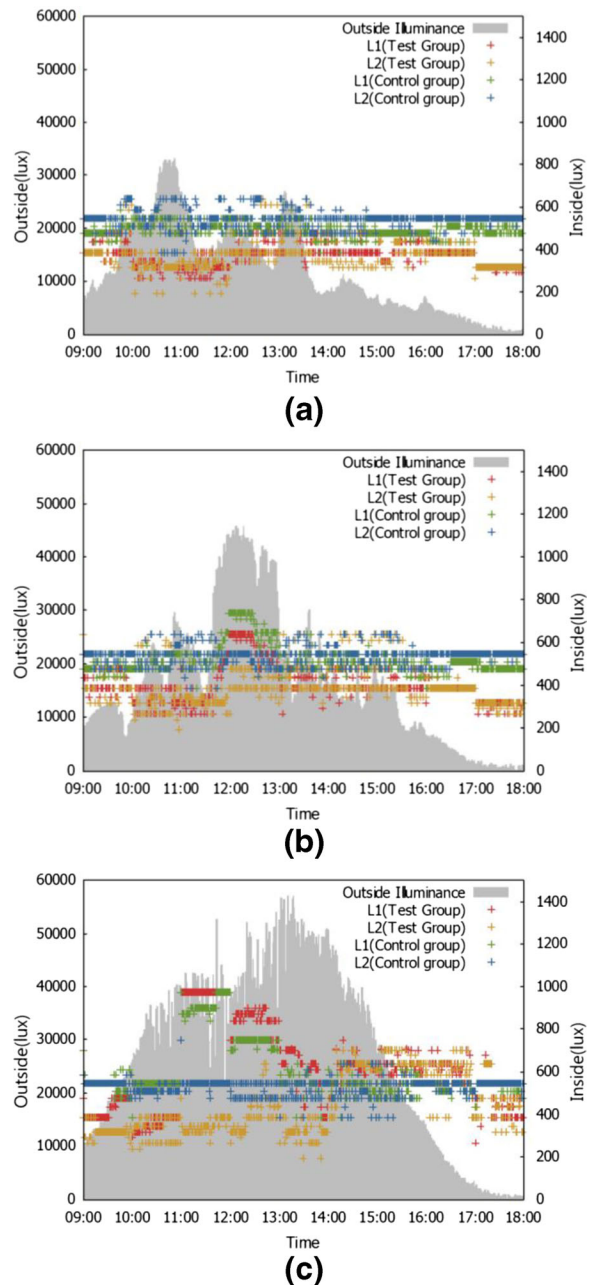


Fig. 9 Illuminance from each illuminance sensor according to electricity pricing system. **a** TOUP. **b** CPP. **c** RTP

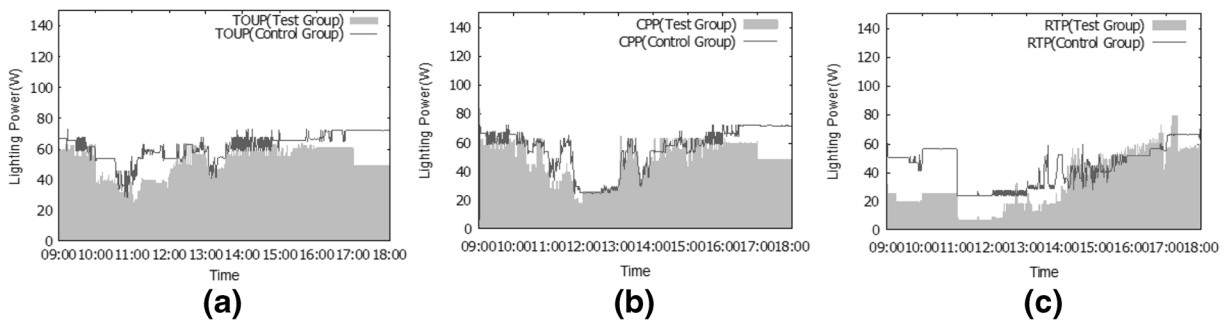


Fig. 10 Electricity consumption according to electricity rates. **a** TOUP. **b** CPP. **c** RTP

by 18.69% and cost was saved by 20.47% using the proposed system compared with those by the control employing the TOUP system. The electric consumption and cost were decreased by 17.61% and 20.07%, respectively, in the proposed system under the CPP scheme.

Discussions and conclusions

In this paper, an automated demand response system, which automatically responds according to the pricing systems based on the price-based demand response programs RTP, TOUP, and CPP of smart grid and reduces the load of lighting, is proposed. The pricing stage was categorized into the three stages, i.e., off-peak, mid-peak, and peak according to the pricing system. The target illuminance according to the pricing stage was set at a minimum of 300 lx, a standard of 400 lx, and a maximum of 600 lx per the recommendation by the KS A 3011 which is a standard illuminance table in Korea. The proposed system recognizes the current pricing stage which is transmitted through the smart meter, automatically executing light dimming matching the pricing stage per the target illuminance suited to the pricing stage. The illuminance change was operated at a 1-min interval. The control frequency of the

illuminance was tuned to reach the target illuminance smoothly if the illuminance change exceeds 20% as against current illuminance. Further, the slat angles of the blind were automatically adjusted with the cut-off angle according to the solar altitude angle and solar azimuth to improve the energy efficiency inside the office area while removing the unpleasant glare.

The testbeds were set to evaluate the performance of the proposed system. The energy consumption and lighting cost by the proposed system were compared with the traditional lighting system which provided the service with the fixed target illuminance (500 lx). However, experiment was conducted excluding the presence of the person and activities of the person in the experimental space.

The energy consumption and cost for the lighting were calculated during 9:00–18:00. The lighting energy consumptions under RTP, TOUP, and CPP systems were 31.43, 50.12, and 45.76 Wh, respectively, while the energy costs were calculated as ₩ 157.15, ₩ 57.35, and ₩ 123.38. The energy consumptions of the control system were, on the other hand, calculated as 44.02, 61.64, and 55.54 Wh. The electricity costs of the control system were ₩ 265.7, ₩ 72.11, and ₩ 160.37, respectively. The RTP, TOUP, and CPP systems could achieve the lighting energy savings by 28.60, 18.69, and 17.61%, as well as lighting cost savings by 40.85,

Table 5 Total electricity consumption and electricity rate

Electricity rates	Proposed system		Control system	
	Electricity consumption (Wh)	Electricity rate (₩)	Electricity consumption (Wh)	Electricity rate (₩)
TOUP	50.12	57.35	61.64	72.11
CPP	45.76	123.38	55.54	160.37
RTP	31.43	157.15	44.02	265.70

20.47, and 23.07%, compared with those using conventional lighting systems. The reason why the different energy consumptions and costs were obtained was because TOUP and CPP were the pricing systems imposed based on the statistical calculation unlike the RTP which imposes variable rates according to operation and supply conditions.

In the future, an integrated demand response system needs to be developed by analyzing the relationship between lighting energy and air conditioning energy according to the blind's slat angle control by setting up the control strategy of optimum blind control accordingly in order to minimize the lighting and air conditioning cost per the pricing system of smart grid that is changed at real time.

Compliance with ethical standards

Conflict of interest The author declares that he has no conflict of interest.

References

- Ahmad, F. (2010). The ethics of dynamic pricing. *The Electricity Journal*, 23(6), 13–27. doi:10.1016/j.tej.2010.05.013.
- Asano, H., Takahashi, M., & Yamaguchi, N. (2011). Market potential and development of automated demand response system. 2011 I.E. Power and Energy Society General Meeting, 24–29 July 2011, San Diego, CA.
- Daphne, N., Johanners, M., Jasper, C., & Peter, R. (2012). Governing the transition of socio-technical systems: a case study of the development of smart grids in Korea. *Energy Policy*, 45, 133–141.
- Dong, M., Meira, P. C. M., Xu, W., & Freitas, W. (2012). An event window based load monitoring technique for smart meters. *IEEE Transactions on Smart Grid*, 3(2), 787–796.
- Faria, P., & Vale, Z. (2011). Demand response in electrical energy supply: an optimal real time pricing approach. *Energy*, 36(8), 5374–5384.
- Ihm, P., Nemri, A., & Krarti, M. (2009). Estimation of lighting energy savings from daylighting. *Building and Environment*, 44(3), 509–514.
- Ihm, P., Park, L., Krarti, M., & Seo, K. (2012). Impact of window selection on the energy performance of residential buildings in South Korea. *Energy Policy*, 44, 1–9.
- Javaiid, N., Khan, I., Ullah, M. N., Mahmood, A., & Farooq, M. U. (2013). A survey of home energy management systems in future smart grid communications. Presented at 2013 8th International Conference on Broadband and Wireless Computing, Communication and Applications (BWCCA), 28–30 Oct. 2013, Compiegne, France.
- Kang, M., Chang, J. D., Yoon Y., and Kim S. (2012). Determining occupant-friendly lighting environments for improvement of visual perception. International Conference on Sustainable Design, Engineering, and Construction (ICSDEC) 2012.
- Khajavi, P., Abniki, H., & Arani, A. B. (2011). The role of incentive based demand response programs in smart grid. Presented at 2011 10th International Conference on Environment and Electrical Engineering (EEEIC), 8–11 May 2011, Rome, Italy.
- Kim, D. M., & Kim, J. O. (2012). Design of emergency demand response program using analytic hierarchy process. *IEEE Transactions on Smart Grid*, 3(2), 635–644.
- Kim, G. G., & Kim, K. J. (2014). Implementation of a cost-effective home lighting control system on embedded Linux with OpenWrt. *Personal and Ubiquitous Computing*, 18(3), 535–542.
- Kim, J. H., Yang, K. W., Park, Y. J., Lee, K. H., Yeo, M. S., & Kim, K. W. (2007). An experimental study for the evaluation of the environmental performance by the application of the automated venetian blind. In Proceedings of Clima 2007 WellBeing Indoors, Helsinki, 10–14 June 2007
- Koo, S. Y., Yeo, M. S., & Kim, K. W. (2010). Automated blind control to maximize the benefits of daylight in buildings. *Building and Environment*, 45(6), 1508–1520.
- Korea Electronic Power Corporation (KEPCO). (2014). Electric rates table. <http://cyber.kepco.co.kr/ckepco/front/jsp/CY/E/E/CYEEHP00201.jsp?menuCd=FN02010602>.
- Lee, E., & Bahn, H. (2013). Electricity usage scheduling in smart building environments using smart devices. *The Scientific World Journal*. doi:10.1155/2013/468097.
- Li, Y., Ng, B. L., Trayer, M., & Liu, L. (2012). Automated residential demand response: algorithmic implications of pricing models. *IEEE Transactions on Smart Grid*, 3(4), 1712–1721.
- Lujano-Rojas, J. M., Monteiro, C., Dufó-López, R., & Bernal-Aguistin, J. L. (2012). Optimum residential load management strategy for real time pricing (RTP) demand response programs. *Energy Policy*, 45, 671–684.
- Mohsenian-Rad, A. H., & Leon-Garcia, A. (2010). Optimal residential load control with price prediction in real-time electricity pricing environments. *IEEE Transactions on Smart Grid*, 1(2), 120–133.
- Parise, G., Martirano, L., & Cecchini, G. (2014). Design and energetic analysis of an advanced control upgrading existing lighting systems. *IEEE Transactions on Industry Applications*, 50(2), 1338–1347.
- Piette, M. A., Kiliccote, S., & Dudley, J. H. (2013). Field demonstration of automated demand response for both winter and summer events in large buildings in the Pacific Northwest. *Energy Efficiency*, 6(4), 671–684.
- Shahgoshtasbi, D., & Jamshidi, M. M. (2014). A new intelligent neuro-fuzzy paradigm for energy-efficient homes. *IEEE Systems Journal*, 8(2), 664–673.
- Soori, P. K., & Vishwas, M. (2013). Lighting control strategy for energy efficient office lighting system design. *Energy and Buildings*, 66, 329–337.
- Taheri, N., Entriken, R., & Ye, Y. (2013). A dynamic algorithm for facilitated charging of plug-in electric vehicles. *IEEE Transactions on Smart Grid*, 4(4), 1772–1779.

- Tzempelikos, A., & Athienitis, A. K. (2007). The impact of shading design and control on building cooling and lighting demand. *Solar Energy*, *81*(3), 369–382.
- Widergren, S., Marinovici, C., Berliner, T., & Graves, A. (2012). Real-time pricing demand response in operations. 2012 I.E. Power and Energy Society General Meeting, 22–26 July 2012, San Diego, CA.
- Yang, I. H., & Nam, E. J. (2010). Economic analysis of the daylight-linked lighting control system in office buildings. *Solar Energy*, *84*(8), 1513–1525.
- Yu, R., Yang, W., & Rahardja, S. (2012). A statistical demand-price model with its application in optimal real-time price. *IEEE Transactions on Smart Grid*, *3*(4), 1734–1742.
- Yun, G., & Kim, K. S. (2013). An empirical validation of lighting energy consumption using the integrated simulation method. *Energy and Buildings*, *57*, 144–154.