Comparison of Power Consumption Reduce Effect of Intelligent Lighting System and Lighting Control System Using Motion Sensors

Katsunori Onobayashi[1], Yuki Sakakibara[1], Hiromitsu Nakabayashi[1], Mitsunori Miki[2] and Hiroto Aida[2]

[1]*Graduate School of Engineering, Doshisha University , Kyoto, Japan*

[2]*Department of Science and Engineering, Doshisha University, Kyoto, Japan*

Keywords: Motion Sensor, Power Consumption, Simulation.

Abstract: Designed in accordance with conventional uniform lighting systems, lighting control systems that use motion sensors allow lighting control per area because they only switch on the lights linked to the motion sensors. However, further power consumption reductions can be possible using a dimmer control for individual lights to supply the level of brightness desired by each worker (hereafter referred to as target illuminance) instead of the per-area method. In the present study, we therefore conducted a comparative experiment with regard to the power consumption of a lighting control system that uses motion sensors and a system that controls the lighting for each worker (hereafter referred to as intelligent lighting system). The validity of the power consumption reduction in offices where intelligent lighting system was introduced was determined using a comparative simulation. A simulation was performed for various worker patterns in a mock-up of an actual office environment to verify the validity of the proposed system. The simulation results showed the effectiveness of the proposed method under all work patterns and thus indicated that the intelligent lighting system saves more energy than the lighting control system that uses motion sensors.

1 INTRODUCTION

On March 11, 2011, Japan experienced the Great East Japan Earthquake. As direct aftermath of the said earthquake, many power plants shut down, and power transmission facilities were damaged. Taking the Great East Japan Earthquake as an opportunity, the insufficiency of electricity supply has been highlighted in recent years. Japanese enterprises have therefore been requested to implement wide-ranging power-saving measures, and saving energy in office buildings has become an important issue.

Energy consumed by lighting accounts for approximately 40% of the total power consumed in offices in Japan(The Enegry Conservation Center,). Switching off lights that workers do not need or implementation of energy savings by reducing illumination levels are believed to lead to reduction in the overall power consumption in offices. For this reason, an annually increasing number of offices have introduced lighting control systems that use motion sensors to control the switching off of lights not needed by workers. In the same manner, we are currently researching and developing a lighting control system that provides the desired luminance of a worker at any desired location and switches off or dims unnecessary lights (hereafter, intelligent lighting system)(Miki, 2007). By setting the luminous intensity required by workers (hereafter, target illuminance) in the illuminance sensors depending on the type of work or their preference, obtaining the information from the control PC, and performing dimming control, the target illuminance can be achieved with minimum power consumption. Moreover, by providing a lighting environment that matches the respective worker environments, comfort and intellectual productivity are expected to improve(F. Obayashi, 2006). Data from a field test that introduced the intelligent lighting system in an actual office showed that many workers require a target illuminance that is lower than the illuminance specified in the Japan Industrial Standard(M. Miki, 2012). Results were obtained that indicated that high levels of energy savings can be achieved by introducing an intelligent system that can provide the necessary illuminance at the desired locations(K. Ono, 2012),(Doshisha University, 2011).

The present study considers the energy savings of a conventional uniform lighting as a benchmark and

Onobayashi K., Sakakibara Y., Nakabayashi H., Miki M. and Aida H..
Comparison of Power Consumption Reduce Effect of Intelligent Lighting System and Lighting Control System Using Motion Sensors.
DOI: 10.5220/0005191403340340
In *Proceedings of the International Conference on Agents and Artificial Intelligence* (ICAART-2015), pages 334-340
ISBN: 978-989-758-074-1

examines the power consumption reduction achieved from a widely used lighting control system that uses motion sensors. It then examines the power consumption reduction achieved from our researched and developed intelligent lighting system using the same benchmark. In these two studies, we compare the effectiveness in reducing power consumption by the lighting control system that uses motion sensors and by the intelligent lighting system. The validity of the intelligent lighting system is verified by simulation. We performed a test in a simulation environment by employing various usage patterns because we assume a variety of work patterns in an office.

2 LIGHTING CONTROL SYSTEMS USING MOTION SENSORS

2.1 Motion Sensor Overview

Motion sensors are devices that detect movement of people and send signals when movement of people or objects in the sensing area is detected.Using technologies such as infrared light, ultrasonic waves, or visible light, these sensors detect motions. When someone or something with a temperature different from the temperature of the surroundings enters the detection range, the detection method uses the temperature difference for the detection. Generally, most systems use infrared light to detect people; thus, we performed our simulation based on infrared light motion sensors. Motion sensors used in the Sumitomo Corporation buildings or by Toshiba were arranged at a ratio of one sensor for every 3.6 m2 with a detection range of 0.9-m high from the floor and 3.0-m radius, as shown in Fig. 1. When workers sit, the desk surface is lit with luminance (750 cd) that provides the minimum illuminance (750 lx).

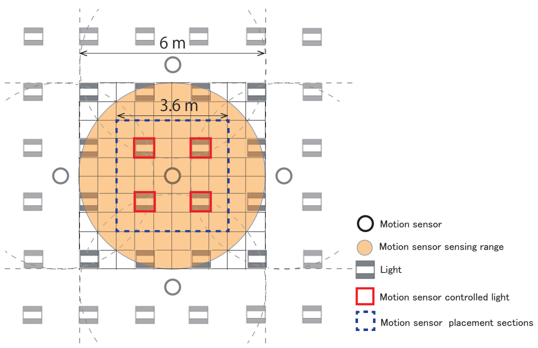

Figure 1: Motion sensor diagram.

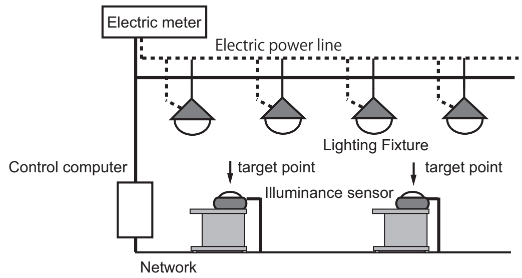

Figure 2: Configuration of Intelligent Lighting System.

3 INTELLIGENT LIGHTING SYSTEM

3.1 Configuration of Intelligent Lighting System

The intelligent lighting system, as indicated in Fig.2, is composed of lights equipped with microprocessors, portable illuminance sensors, and electrical power meters, with each element connected via a network.

Individual users set the illuminance constraint on the illuminance sensors. At this time, each light repeats autonomous changes in luminance to converge to an optimum lighting pattern. Also, with the intelligent lighting system, positional information for the lights and illuminance sensors is unnecessary. This is because the lights learn the factor of influence to the illuminance sensors, based on illuminance data sent from illuminance sensors. In this fashion, each user's target illuminance can be provided rapidly.

The most significant feature of the intelligent lighting system is that no component exists for integrated control of the whole system; each light is controlled autonomously. For this reason, the system has a high degree of fault tolerance, making it highly reliable even for large-scale offices.

3.2 Adaptive Neighborhood Algorithm using Regression Coefficient (ANA/RC)

The control algorithm is a critical element for the control of an intelligent lighting system. The speed of convergence to the target illuminance as well as its accuracy depends largely on the lighting control algorithm. As the best algorithm presently available for lighting control, we have proposed an Adaptive Neighborhood Algorithm using Regression Coefficient (ANA/RC)(S. Tanaka and M.Yoshikata, 2009), which was developed by adapting the Stochastic Hill

Climbing method (SHC) specifically for lighting control purposes.

In ANA/RC, the design variable is the luminous intensity of each lighting: the algorithm aims to minimize the power consumption while keeping the illuminance at the target level or above. It further enables the control system to learn the effect of each lighting on each illuminance sensor by regression analysis and, by changing the luminous intensity in response, enables a quick transition to the optimum intensity.

The following is the flow of control by ANA/RC:

1. Each lighting lights up by initial luminance.
2. Each illuminance sensor transmits illuminance information (current illuminance, target illuminance) to the network. The electrical power meter transmits power consumption information to the network.
3. Each lighting acquires the information from step 2, and conducts evaluation of objective function for current luminance.
4. Neighborhood is determined, which is the range of change in luminance based on factor of influence and illuminance information.
5. The next luminance within the neighborhood is randomly generated, and the lighting lights up by that luminance.
6. Each illuminance sensor transmits illuminance information to the network. The electrical power meter transmits power consumption information to the network.
7. Each light acquires the information from step 6, and conducts evaluation of objective function for next luminance.
8. A regression analysis is conducted and the level of influence is estimated.
9. If the objective function value is improved, the next luminance is accepted. If this is not the case, the lighting returns to the original luminance.
10. Steps 2‘9 are one search operation of the luminance value, which is repeated.

A search operation process (requiring about 2 seconds) consists of steps 2) through 9) above: by iterating this process, the system continues to learn how the lighting affects the illuminance sensor measurement until it realizes the target illuminance with minimum power consumption. Furthermore, by using the influence level found in step 8) as a basis for the evaluation and generation of the next illuminance value, the system can quickly optimize illuminance.

Next, we will see the objective function used in this algorithm. The purpose of the intelligent lighting system is to achieve each user's desired illuminance, and to minimize energy consumption. Thus, it can be understood as an optimization problem in which each light optimizes its own luminance. Following from this, the luminance of each light is considered a design variable, under the constraint of the user's target illuminance, in resolving the problem of optimization to minimize energy consumption. For this reason, the objective function is set as in Eq. (1).

$$f = P + w \sum_{i=1}^{n} g_i \tag{1}$$

$$g_i = \begin{cases} (It_i - Ic_i)^2 & I^* \leq |It_i - Ic_i| \\ 0 & otherwise \end{cases} \tag{2}$$

P: Power consumption, w: Weight, Ic: Current illuminance It: Target illuminance, n: Number of target points
I^*: Threshold on illuminance difference

The objective function was derived from amount of electric power P and illuminance constraint g_j. Also, changing weighting factor w enables changes in the order of priority for electrical energy and illuminance constraint. The illuminance constraint is decided so that a difference between current illuminance and target illuminance within a threshold, as indicated by Eq. (2)(N. Miyazaki, 2012).

4 POWER CONSUMPTION CALCULATION METHOD

To calculate the objective function shown in Eq. (1), power consumption is used. To calculate the objective function shown in Eq. (1), power consumption is used. For this purpose, we used a Sharp Corporation LED light in performing a preliminary experiment. In the preliminary experiment, we confirmed that a relational expression between the power consumption and luminance exists, as shown in Fig. 3.

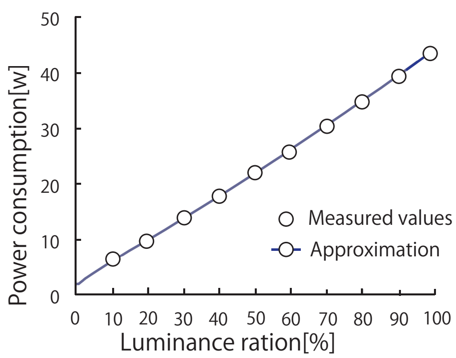

Figure 3: Relationship between luminance and electricity.

This relational expression is linear, and we used it to calculate the power consumption.
The desk surfaces were illuminated at a uniform lighting luminance of 750 lx or higher, and we considered the power consumption for this condition as the benchmark.

5 EXPERIMENT THAT COMPARES THE POWER CONSUMPTION OF A LIGHTING SYSTEM USING MOTION SENSORS WITH THAT OF THE INTELLIGENT LIGHTING SYSTEM

5.1 Simulation Overview

We verified the effectiveness of power consumption reduction for a lighting system using motion sensors and the intelligent lighting system through a simulation. To model the fluctuation in the number of workers for a certain day, we created time periods when people arrive at the office (arrival period), when people are at work (working period), and when people leave the office (departure period). We then assumed a variety of work patterns for these periods. Three work patterns were envisaged for the respective periods, and we performed verification experiments for 27 work patterns. If no one is present in the sensing area of a particular sensor, the dimmer control is set at 25% for that area so as not to cause visual stress for any people present in the neighboring area. When this situation continues for 5 min, the lights are switched off.

5.2 Simulation Environment

Verification that compares the power consumption of a lighting system using motion sensors with that of the intelligent lighting system by simulation. We created a simulation environment representing an actual office with 32 workers, as shown in Fig. 4. The present simulation was based on an actual office with a space of 10.8 m 10.8 m and used 36 white fluorescent lights, which can be dimmed. For the system that uses motion sensors, nine sensors were installed, and for the intelligent lighting system, the work environment was modeled using 32 illuminance sensors.

Furthermore, a variety of work patterns were considered because fluctuations in the number of workers throughout the day affect the lighting control, and the power consumption will likely vary. Fig. refpeople shows a schematic diagram of the work patterns throughout the day. The period from T_M to T_A indicates the period when workers arrive at the office, that from T_A to T_L represents the working hours, and that from T_L to T_N is the period when workers leave the office. Fig. 5 shows that three patterns were considered for the arrival and departure rates in the periods when workers arrive and leave the office, respectively, namely, inverted-U-shaped, linear, and U-shaped patterns.

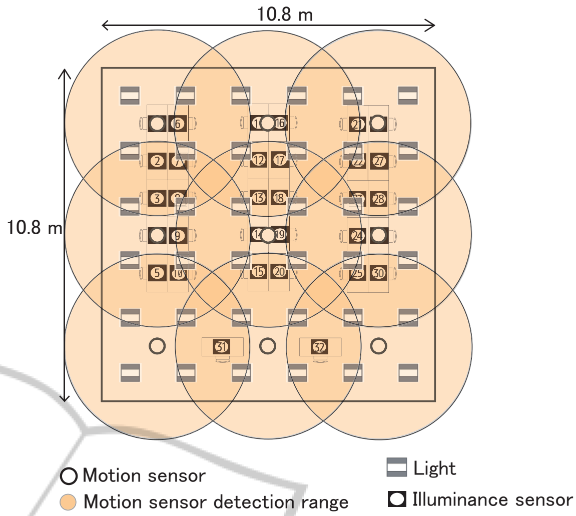

Figure 4: Experimental environment.

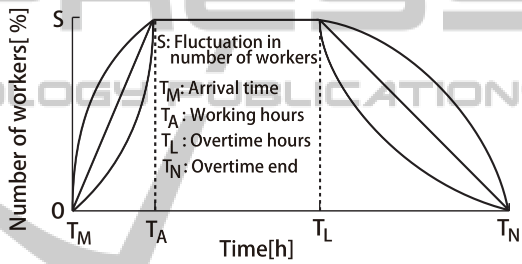

Figure 5: Work patterns.

With regard to the varying presence rates during the working period, we considered the three patterns listed in Table. 1 The hour from 12:00 noon to 1:00 PM was considered to be lunch hour, and the lights were assumed to be turned off.

A verification experiment was performed for 27 work patterns based on the above conditions.

5.3 Simulation Results

According to the working patterns shown in Fig. 5, which was conducted continuously for a month excluding weekends, we performed a 20-day simulation.For the working pattern throughout the day, we

Table 1: Work patterns per period.

Arrival period(T_M-T_A)	Working period(T_A-T_L)	Departure period(T_L-T_N)
Inverted-U-shaped arrival rate Linear arrival rate U-shaped arrival rate	Presence rate: 30% Presence rate: 60% Presence rate: 90%	Inverted-U-shaped departure rate Linear departure rate U-shaped departure rate

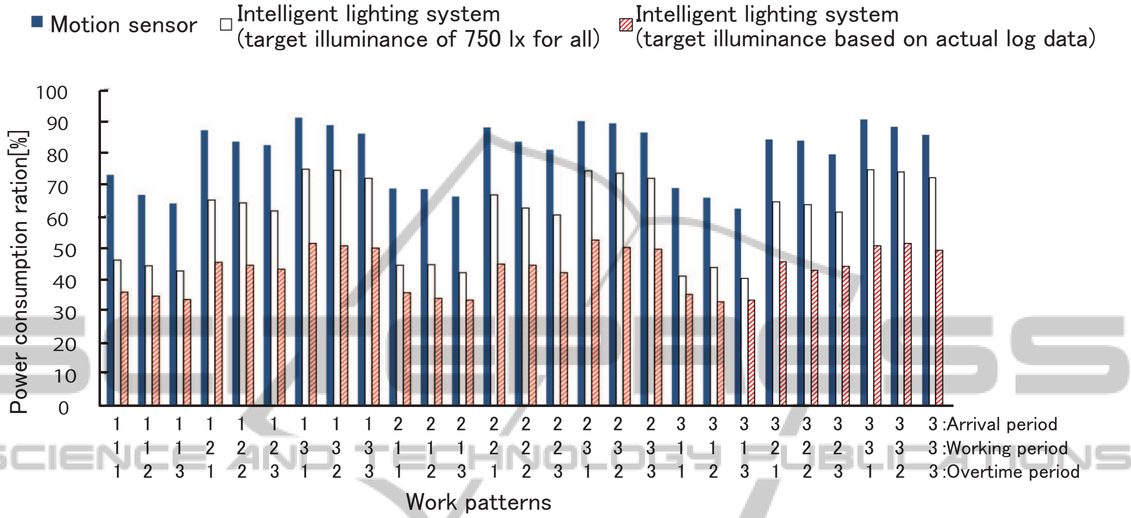

Figure 6: Average power consumption ration over 20 days.

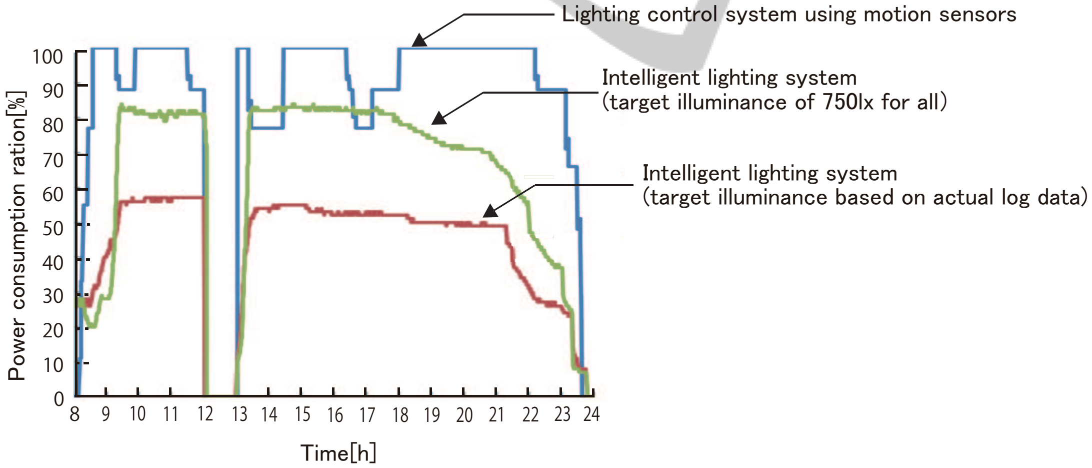

Figure 7: Example of varying power consumption ration for one day.

considered the following: T_M as 8:00 AM, T_A as 9:00 AM, T_L as 6:00 PM, and T_N as12:00 midnight. Fig. 6 shows the average power consumption over 20 days for this one-day work pattern both for the lighting control system that uses motion sensors and for the intelligent lighting system. On the other hand, Fig. 7 shows the power consumption under the same condition for both control systems. Fig. 7 shows that the work patterns in the arrival and departure periods were linear, and the presence rate was 60It shows the changes in the power consumption ratio for a particular day for this work pattern.

Furthermore, the overall average power consumption in the experimental results for both control systems shown in Fig. 5 and the power consumption for the uniform lighting are shown in Fig. 8.

Fig. 6 shows that the intelligent lighting system was more effective in reducing power consumption than the lighting control system that uses motion sensors under all work patterns. Moreover, comparison of each individual work pattern showed the highest power consumption reduction of approximately

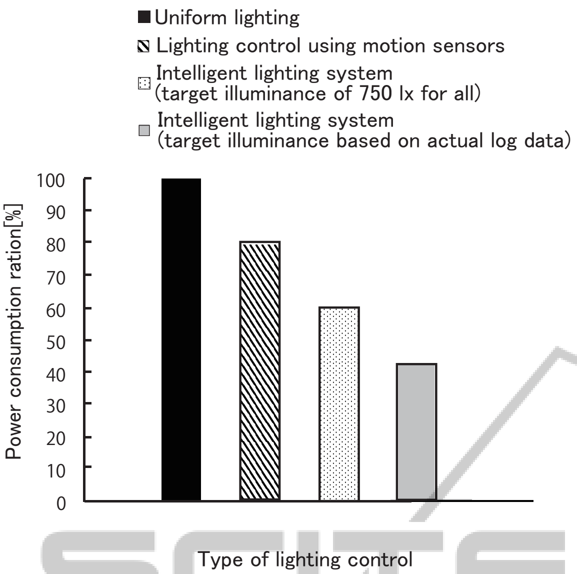

Figure 8: Average power consumption ration of the data in Fig. 6.

42.3%, which was higher than that of the lighting control system that uses motion sensors.It was still 29.0% higher at its lowest power consumption reduction. At its highest, the work pattern was linear in the arrival period, the presence rate during the working period was 60%, and the pattern during the overtime period had an inverted-U shape. At its lowest, the work pattern had an inverted-U shape in the arrival period, the presence rate during the working period was 90%, and the pattern in the overtime period had an inverted-U shape.

Fig.8 shows that the lighting control system that uses motion sensors achieved a 21% power consumption reduction compared with the 100% power consumption in the conventional lighting. The reduction by the intelligent lighting system was 41%, which delivered similar target illuminance as the system that uses motion sensors. A 58% reduction in power consumption was realized in the actual log data by the intelligent lighting system that delivered the target illuminance.

6 DISCUSSION

Fig. 7 shows that even after the departure period, the lighting control system that uses motion sensors did not reduce the power consumption until all workers have left because it controls the lighting on a per-area basis. On the other hand, the intelligent lighting system gradually decreased the power consumption after the departure period. We can therefore conclude that the intelligent lighting system, which controls the individual lights, is effective in reducing the power consumption. With regard to the power consumption ratio for a certain day, the intelligent lighting system, which provides the same illuminance as the lighting control system that uses motion sensors, consumes less power than the lighting control system that uses motion sensors.

Fig.6 also shows that the intelligent lighting system saves more electricity under all work patterns than the lighting control system that uses motion sensors. Specifically, with a minimum number of workers, its effectiveness in reducing power consumption was markedly high compared with that of the lighting control system that uses motion sensors where all office lights were lit.

The main cause for such difference in the power consumption ratios depending on the lighting control can be considered the difference in the average illuminance, as shown in Fig. 8 The main cause for such difference in the power consumption ratios depending on the lighting control can be considered the difference in the average illuminance, as shown in We can therefore state that in uniform lighting, many sensors obtain an illuminance of 750 lx or higher. On the other hand, we can state that to realize the target illuminance required by each worker in the intelligent lighting system using the actual log data, the target illuminance is realized by the minimum required number of lights and the minimum required luminance from these corresponding lights. On the other hand, we can state that to realize the target illuminance required by each worker in the intelligent lighting system using the actual log data, the target illuminance is realized by the minimum required number of lights and the minimum required luminance from these corresponding lights. The power consumption rate of the intelligent lighting system has been shown to be less than half that of the conventional uniform lighting.

7 CONCLUSION

The intelligent lighting system is more effective in reducing power consumption under all work patterns than the lighting control system that uses motion sensors. The intelligent lighting system is therefore shown to operate at reduced power consumption levels compared with the lighting control system that uses motion sensors.

REFERENCES

Doshisha University, M. G. S. S. I. (2011). Research and development of energy efficient lighting system by using autonomous distributed optimization algorithms (fy2008-fy2010) final report. Number 20110000000875. New Energy and Industrial Technology Development Organizeation.

F. Obayashi, K. tomita, Y. H. M. K. H. S. H. I. M. T. H. Y. (2006). A study on environmental control method to improve productivity of office workers - development of productivity evaluation method, cptop -. volume 53, pages 447–450. Human Interface Symposium.

K. Ono, M. Miki, S. T. A. N. K. S. M. F. (2012). Construction of intelligent lighting system using in-office frames. volume 95, pages 549–588. The Institute of Electronics, Information and Communication Engineers.

M. Miki, H. K. H. Y. T. T. N. (2012). Construction of intelligent lighting system providing desired illuminance distributions in actual office environment. volume 94, pages 637–645. The Institute of Electronics, Information and Communication Engineers.

Miki, M. (2007). The consortium for smart office environment. volume 22, pages 399–410. The Japanese Society for Artificial Intelligence.

N. Miyazaki, M. Miki, M. Y. Y. Z. (2012). Estimation using mathematical programming of the illuminance sensor position in the intelligent distributed control system. volume 5, pages 481–482. Proceedings of the 74th National Convention of Information Processing Society of Japan.

S. Tanaka, M. Miki, T. and M.Yoshikata (2009). An evolutional optimization algorithm to provide individual illuminance in workplaces. pages 941–947. 2009. SMC 2009. IEEE International Conference on, Proc:Systems Man and Cybernetics.

The Enegry Conservation Center, J. Characteristics of energy consumption of office.