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An Energy-Saving Control System of Lighting and Air-Conditioning Linked to Employee's Entry/Exist in the Zone of the Office

Yosuke Kaneko[1], Masahito Matsushita[1], Shinji Kitagami[2], Jun Sawamoto[3,*], Tetsuo Shiotsuki[4], Tatsuji Munaka[5]

[1]Information Technology R&D Center, Mitsubishi Electric Corporation, Kanagawa, Japan
[2]Mitsubishi Electric Building Techno-Service Co. Ltd., Tokyo, Japan
[3]Department of Software and Information Science, Iwate Prefectural University, Iwate, Japan
[4]Department of Robotics and Mechatronics, Tokyo Denki University, Tokyo, Japan
[5]School of Information and Telecommunication, Tokai University, Tokyo, Japan

Abstract We have developed an energy-saving control system that controls lighting and air-conditioning considering desk allocation in the office. This lighting control system makes the desk area that a person uses brighter, but makes the lighting gradually dimmer with distance from the person at a desk. In addition, the air-conditioning system controls temperatures only for areas where someone is at the desk, which can be done by controlling the on and off time of the thermostat in the air-conditioning system. We evaluated this control system by actual measurement and simulations and validated its effectiveness for the reduction of electrical power consumption.

Keywords Lighting, Air-Conditioning, Energy-Saving, Office

1. Introduction

Energy consumption in office buildings is increasing. Lighting and air-conditioning account for the majority of power consumption in the office. Therefore, energy conservation methods of these facilities are important. To achieve energy-saving of the lighting without impairing comfort in the office, it is effective approach to turn off the lighting in the unnecessary area, and to keep appropriately illuminance. Therefore, conventional studies have proposed control systems that turn off lighting automatically in the unoccupied area using a motion sensor and control brightness using illumination sensors for the occupied area [1-3]. In addition, other conventional studies have decided brightness of the area where persons are detected by optimizing method [4] [5]. Regarding the energy saving of the air-conditioning, a conventional method detects a change in occupancy by motion sensors and control to turn on or off of the air-conditioning [6]. In addition, another study has been done to divide the office floor and control only those zones for which someone is at a desk to satisfy the target room temperature [7]. As discussed, in conventional studies, energy conservation is achieved by controlling lighting and air-conditioning only in the area of the office floor where someone is at the desk and only when someone is there.

As described in this paper, we propose an energy-saving system that can reduce the area in which brightness and temperature should be satisfied while keeping the target brightness and the target temperature. This proposed system pinpoints locations where brightness and temperature should be satisfied. At this time, the proposed system detects a person in the floor in cooperation with an access control system without using motion sensors. Furthermore, the proposed algorithm controls lighting and air-conditioning to maintain the brightness and the temperature of the locations. We evaluated the proposed system with a simulation and an experimental evaluation. As the results, we verified that the proposed system can reduce power consumption compared with the conventional means while maintaining the brightness and the temperature where someone is there.

2. Background

2.1. Features of Office Lighting

The lighting power consumption accounts for about 19% of the total of the commercial sector in the US [8]. And, its

* Corresponding author:
sawamoto@iwate-pu.ac.jp (Jun Sawamoto)
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usage pattern remains almost constant throughout the year. Therefore, it is possible to obtain a large energy-saving effect throughout the year by applying the energy-saving methods for office lighting. While, in an office building, employee are constantly entering and leaving a floor, so lighting systems may turn on the zone where there is not a person. So, it is an effective approach for reducing the waste to control equipment using the entering and leaving information such as the number of employee in a floor, and the presence or absence.

Meanwhile, with the increase in the security consciousness in company, more access control systems are installed into office buildings. While the primary function of the access control system is to control the entry and exit of persons, it can also be utilized as a means to grasp the entry or exit information such as the presence or absence of persons in the rooms.

2.2. Features of Air-Conditioning

The air-conditioning exhausts about 65% of the total power consumption consumed by a building in the US [9]. In general, an air-conditioning system controls room temperature at a certain level by its autonomous control. However, control methods in the general air-conditioning system do not consider whether someone is at the desk or not. Therefore, it sometimes maintains temperatures wastefully even in areas that no person is using. Another control method aside from the autonomous control of the system is rotation control. The rotation control divides an office floor into N number of groups, each with indoor unit. The system achieves energy conservation by switching the thermostat on and off. By application of this control method, we can achieve energy conservation by switching the thermostat on and off depending on whether someone is at a desk or not. However, even in the same office floor, the room temperature might vary depending on the distance from ducts and windows. Therefore, in this rotation control, it is necessary to determine the time interval between the thermostat switching on and off by consideration of the variation of the room temperature in the office, which is crucial also from the perspective of maintaining the target room temperature.

3. Proposed Method

This paper describes the "energy-saving control system of lighting and air-conditioning linked to employee's Entry/Exist", which uses entry and exit information obtained from the access control system and the seat position information of each person. And, the system controls automatically lighting and air-conditioning so that each equipment are turned on only in the required area and for the required time ensuring a certain amount of illuminance only on and around desks people are sitting.

3.1. Structure of a Proposed System

Figure 1 illustrates the structure of a proposed system. This system consists of the access control system (ACS), the lighting control system, the air-conditioner control system, and the energy-saving control server. These systems and the server are linked over the network.

The ACS consists of an authentication device and some card readers. The ACS is equipped with two types of card readers for entry and exit at each door on a floor. When employee passes a door, he passes IC Card over the card reader. Thereby, the information of the employee who has passed a door is sent to the energy-saving control server through the authentication device.

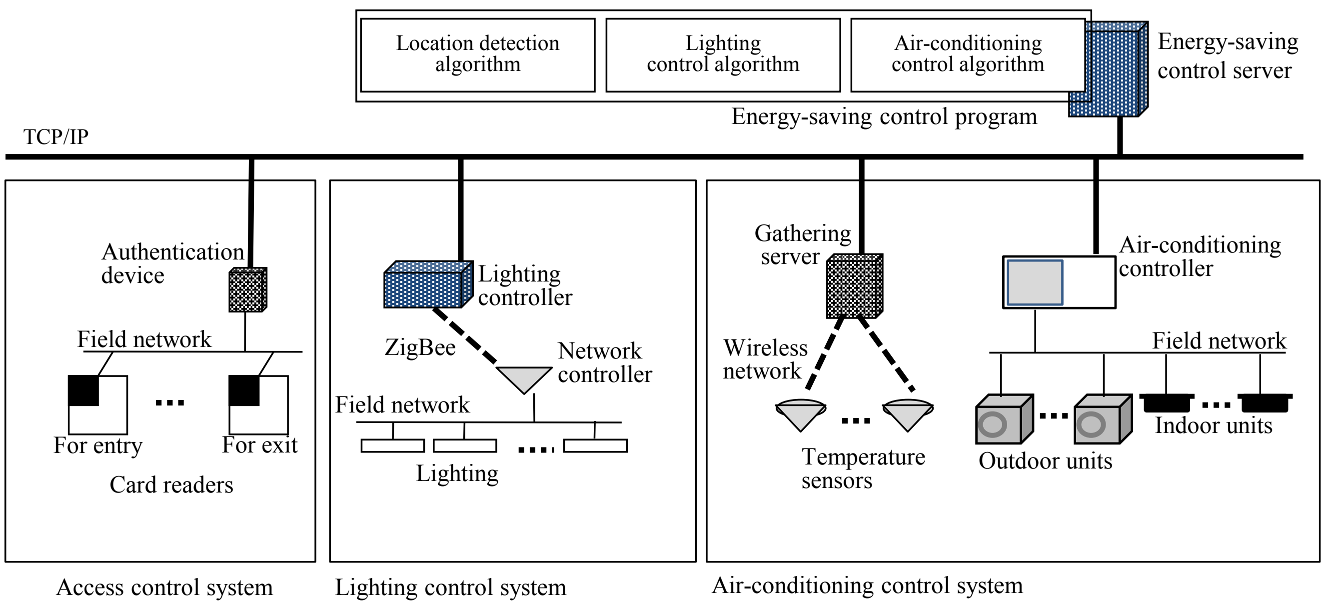


Figure 1. Structure of the proposed system

The lighting control system consists of a lighting controller, a network controller, and lighting fixtures. This system is able to turn on/off and adjust the dimming rate for each lighting fixture. The energy-saving server, connected to the lighting controller through the TCP/IP network, is able to send control instructions to control lighting fixtures by the BACnet protocol [10]. Lighting fixtures which have received the control instructions adjust brightness with inverter control.

The air-conditioning control system consists of a room temperature gathering subsystem and an air-conditioning control subsystem. The room temperature gathering subsystem is composed of a gathering server and temperature sensors. This server is connected to these sensors through the wireless network and receives room temperature data from these sensors at fixed intervals. The air-conditioning control subsystem is composed of an air-conditioning controller, outdoor units, and indoor units. This controller is able to control temperature setting, air flow direction, air flow strength, thermostats' on and off, and so on. The energy-saving control server is connected to this controller through the TCP/IP network and is able to send control instructions to this controller. Thereby, this server is able to control indoor units and outdoor units.

The energy-saving control server is installed with a energy-saving control program. This program has implemented a location detection algorithm, a lighting control algorithm and an air-conditioning algorithm. The location detection algorithm specifies the position of the person in the floor. The lighting control algorithm and the air-conditioning control algorithm control illumination and room temperature so that the zones where person is in are satisfied to keep target illuminance and target temperature.

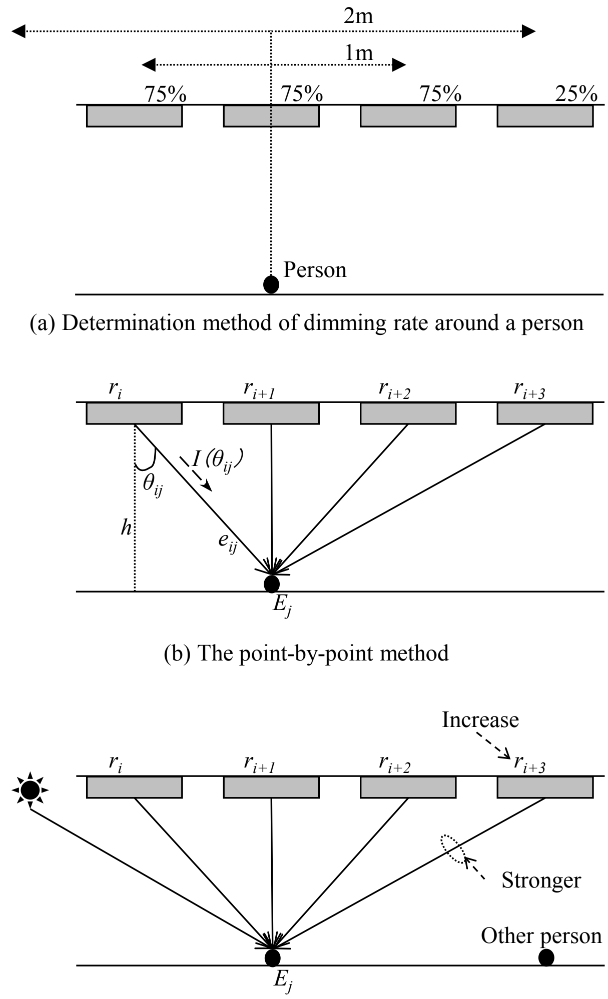
3.2. Detection Method of the Person's Location in the Floor

The location detection algorithm detects the presence or absence of employees in the floor with data sent by the ACS. When employee is out of the office floor, he passes IC Card over the card reader for exit. As a result, the door opens. On the other situation, when employee goes into the office floor, he passes IC Card over the card reader for enter. By these actions of employees, the location detection algorithm is able to identify employees entering and leaving a room. The data to identify each employee are included in each IC Card. These data are sent to the location detection algorithm when employee passes IC Card. Thus, this algorithm is able to detect presence or absence of employees in the floor. In addition, the proposed system grasps seat position information of each employee. The proposed system detects positions where employees are at.

3.3. Lighting Control Algorithm

The lighting control algorithm controls lighting fixtures by the two phases. We describe these phases in detail below.

(1) 1st phase. The energy-saving control server detects employee within a floor. And then, it specifies the zone that should be illuminated, using seat position information.



(a) Determination method of dimming rate around a person

(b) The point-by-point method

(c) Influence of other person and sunlight

Figure 2. Lighting control algorithm 1st phase

The lighting fixtures are turned on and the dimming rates are controlled only around the zones where persons are in. As the distance from the zones increases, brightness will decrease. For example, as shown in Figure 2 (a), the dimming rate of a lighting fixture within one meter from each person are set to 75%, and the lighting fixtures within two meters are set to 25%. Through this dimming control, zones near the persons are kept bright, and a sharp decrease in brightness is prevented. In addition, the lighting fixtures near persons who have gone home or who are away from their desk for a meeting are automatically turned off.

Here, the value 75% and 25% are an example. In fact, these values are adjusted so as to satisfy the target illuminance of the person. Therefore, the proposed system calculates the illuminance for a presence person in the floor using the point-by-point method. As shown in Figure 2 (b), the system calculates the illuminance e_{ij} which the lighting equipment i give the point j by Equation (1). Here, C_{ij} is an influence that the lighting fixture i gives the point j, r_i is a dimming rate of the lighting fixture i, θ is an angle between the lighting fixture i and the point j, I is the intensity of the lighting fixture i, h is the floor height, and M is a parameter to explain maintenance frequency for lighting fixture. Further, since the point j is influenced from the several lighting fixtures, the illuminance E_j which is brightness of the point j can be calculated by Equation (2).

$$e_{ij} = C_{ij} * r_i$$
$$C_{ij} = I(\theta_{ij}) * \cos^3(\theta_{ij}) * M / h^2 \quad (1)$$

$$E_j = \sum_{i=1}^{N} C_{ij} * r_i \quad (2)$$

The brightness of the point j is changed by changing the dimming rate. The proposed system changes the dimming rates gradually until the calculated dimming rates, to not change the brightness rapidly.

(2) 2nd phase. When the 1st phase was executed, it assumed that there is only one sitting employee in a floor. Therefore, the illuminance of the sitting person's zone is optimized under the situation in which the influence of the lightings for neighbors is not received. But, as shown in Figure 2 (c), when its influence is received, it becomes the overmuch illuminance. In addition, since the window seat is affected by the sunlight, it becomes the factor of the overmuch illuminance. To solve these problems, the proposed method corrects the dimming rates to negate the influence of the illuminance that received from the lighting fixtures for neighbors and the sunlight according to the following procedure.

Figure 3 shows an image of illuminance correction control. In the situation of Figure 3 where the control of the 1st phase was finished, the dimming rates was controlled r_i%, r_{i+1}%, r_{i+2}%, r_{i+3}%, · · · , r_N%. Here, when we defined corrected dimming rates as r'_i%, r'_{i+1}%, r'_{i+2}%, r'_{i+3}%, · · · , r'_N%, the sunlight influences for point j as e_sun_j lx, the gap of the present illuminace and the target illuminance for the point j as ΔE_j, this relationship is shown in Equation (3).

$$\begin{cases} E_1 = \sum_{i=1}^{n} C_{i1} * r_i - \sum_{i=1}^{n} C_{i1} * r'_i - e\_sun_1 \\ E_2 = \sum_{i=1}^{n} C_{i2} * r_i - \sum_{i=1}^{n} C_{i2} * r'_i - e\_sun_2 \\ \quad \cdots \\ E_j = \sum_{i=1}^{n} C_{ij} * r_i - \sum_{i=1}^{n} C_{ij} * r'_i - e\_sun_j \\ \quad \cdots \\ E_n = \sum_{i=1}^{n} C_{in} * r_i - \sum_{i=1}^{n} C_{in} * r'_i - e\_sun_n \end{cases} \quad (3)$$

Here, C_{ij} is an influence that the lighting fixture i gives the point j, it is same value that is shown Equation (1). The proposed method solves equation (3), and it determines r'_i%, r'_{i+1}%, r'_{i+2}%, r'_{i+3}%, · · · , r'_N.

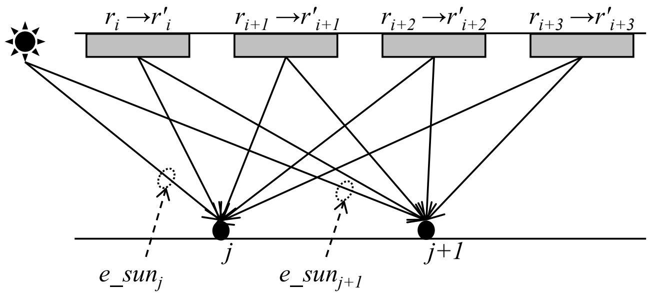


Figure 3. Lighting control algorithm 2nd phase

3.4. Air-Conditionings Control Algorithm

In this proposed method, by considering the fact that heat transfers to each location unevenly, it controls the thermostat on and off to maintain the target room temperature where someone is in the zone.

(1) Structure of air-conditioning control function and operation outline. Figure 4 shows a structure and operation outline of the air-conditioning control function. Figure 4 (a) shows the ground plan of the floor, and also the figure shows the positions of the air-conditioners, the positions of the persons, and the positions of the thermo-sensors. As portrayed in Figure 4 (a), the proposed method divides N number of zones in the whole office floor. Dotted lines shows zones. Moreover, in the proposed method, a movable thermo-sensor is to be installed in each zone.

(2) Method of switching a thermostat on and off

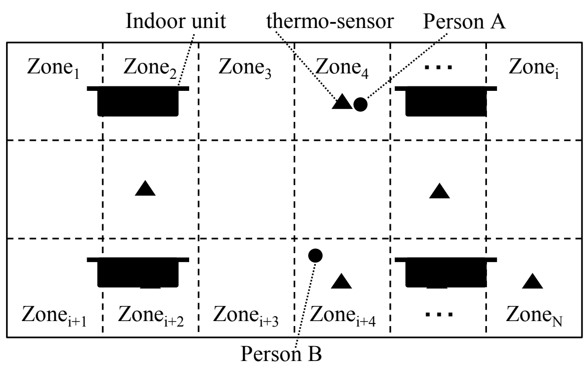
It determines the timing of turning the thermostat on and off at each group, which is done by the variation of the reading value at the thermo-sensor that is installed in the zone. The determination method in the case of heating is shown below.

1) Figure 4 (a) shows that Person A is at $Zone_4$ and Person B is at $Zone_{i+4}$. This proposed method sets the target temperature as T_{target} and the tolerance of the target temperature as w. In short, it controls the thermostat on and off to maintain the temperature, $T_{target} \pm w$ in the zone being used by someone.

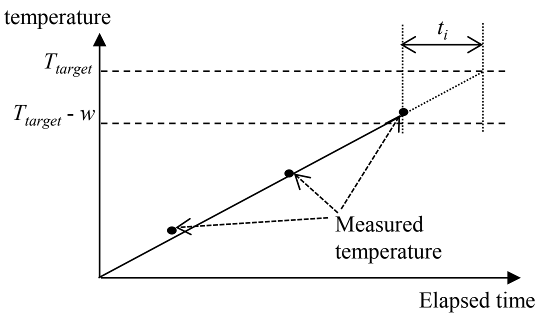
2) This proposed method turns the thermostat on in the air-conditioning until the room temperature for the zone i reaches T_{target}. Figure 4 (b) shows the time necessary to turn the thermostat on to reach T_{target}. In this Figure, the X-axis shows elapsed time after the air-conditioning has turned into thermostat on, the Y-axis shows the measured value of the thermo-sensor. First, measure the room temperature until it exceeds $T_{target} - w$ when turning the thermostat on. When the room temperature exceeds $T_{target} - w$, set the thermostat on time t_i that requires the room temperature to reach T_{target}.

This proposed method enables zone i to reach the target temperature by turning the thermostat on during time t_i toward the zone to which person i belongs. Subsequently, turn the thermostat off at each zone.

3) This proposed method controls air-conditionings to maintain room temperature of zone i in the range of $T_{target} \pm w$. The method monitors a temperature sensor that installed in the zone i continuously and switches the thermostat off when room temperature T_{i_b} which the method measured this time decreases than the value T_{i_a} which the method measured last time. Conversely, the method switches the thermostat on when T_{i_b} rises than T_{i_a}. In addition, when T_{i_b} is lower than T_{target} - w, the method assumes thermostat on. And the method switches the thermostat off when T_{i_b} is higher than $T_{target} - w$.



a) Structure of air-conditioner and zone



b) Determination method of the thermostat on time

Figure 4. Air-conditioner control method

4. Evaluations and Considerations of the Proposed Method

In order to evaluate an effectiveness of the developed technology, we built a simulator and a prototype system.

4.1. Lighting Control Method

We evaluate the proposed lighting control algorithm by the simulator. Figure 5 shows an evaluation condition. The size of the room is 20 by 7.5 meters, and 48 lighting fixtures are installed. A window is installed in the south side of the room, and the sunlight pours into the room. As this evaluation condition, we assume that right under lighting fixtures of the southernmost line are affected by 100lx by the sunlight. And, we assume that there are six persons in the room.

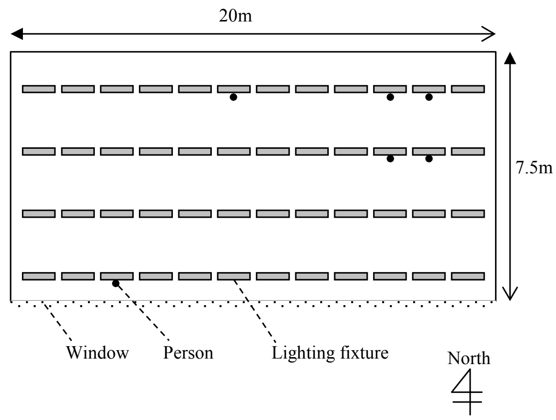
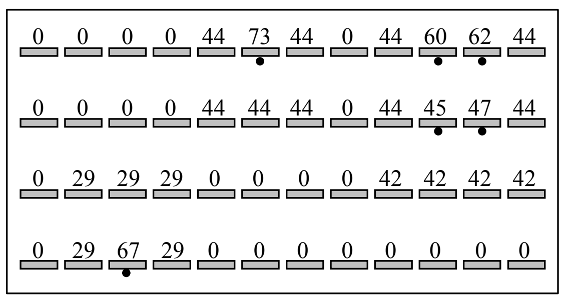
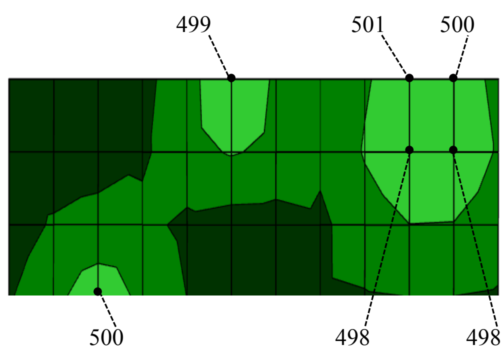


Figure 5. Evaluation condition of the lighting control

Figure 6 shows dimming rates that the proposed method determined and the calculated illuminance on the desk surface by the point-by-point method. Here, the target illuminance of the presence zone is 500lx, and the presence zones are shown by black point in Figure 6. In addition, the illuminance level is expressed by gradation. In the case of Figure 6, the calculated illuminance is 498lx ~ 500lx, we were confirmed that there was little error about the target illuminance 500lx. Further, we were confirmed that the illuminance can be controlled so as to be lower with increasing distance from the presence person.



a) Dimming Rate [%]



a) Calculated illuminance [lx]

Figure 6. Simulation result of the lighting control

Figure 7 illustrates a result of the average dimming rate. In Figure 7, the proposed method is 22%, the general lighting is 53%. Here, the general lighting control the lighting fixtures with uniform dimming rate. In this case, we simulated while changing dimming rate until illuminance of the zones where six person are in become 500lx. Because the power consumption shows a proportion tendency for strength of dimming, we can consider that the proposed method can reduce an amount of power consumption than the general lighting. The proposed method detects the person, and controls to narrow the area where brightness is necessary. So, we can get high effectiveness of the energy-saving.

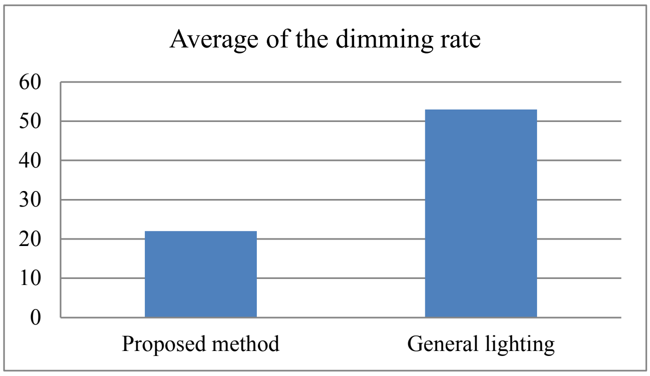


Figure 7. Average of dimming rate

4.2. Air-Conditioner Control Method

We measure room temperature change of the zone where someone is in and the power consumption to evaluate the proposed method. We evaluate it based on a comparison with automatically control of the air-conditioner. Figure 8 shows an evaluation condition. The size of the room is 14 by 8.5 meters, and 4 indoor units are installed. And, the room is divided in the several zones as shown in dotted lines. We assume that there is one person in the Zone1, and we operate the proposed method and automatically control. In addition, the target temperature in the zone where someone is there is 22.0 degrees Celsius.

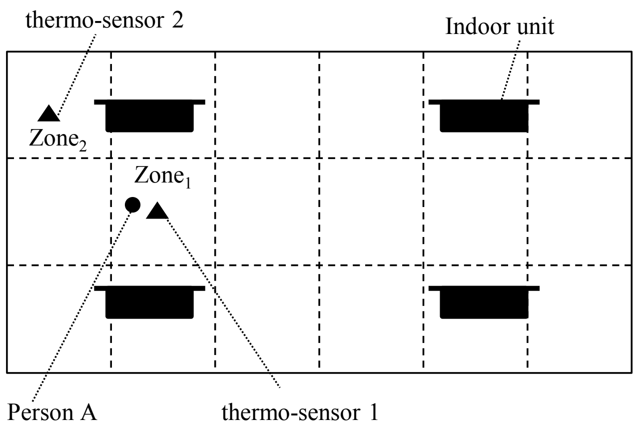
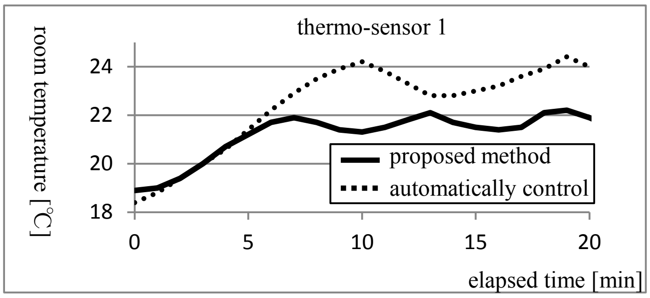
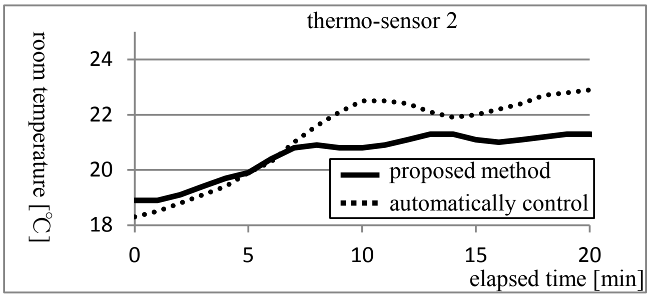


Figure 8. Evaluation condition of the air-conditioner control

Figure 9 (a) shows a room temperature change of Zone1, and Figure 9 (b) shows one of Zone2. Moreover, in Figure 9, the proposed method is shown by solid lines, and, the automatically control is shown by dotted lines. In Figure 9 (a), the room temperature of the proposed method rises until the lapse of 7 minutes from the start of the experimental evaluation. And, the average temperature that is from the lapse of 7 minutes to the lapse of 20 minutes is 21.7 degrees Celsius. On the other hand, the room temperature of the automatically control rises until the lapse of 10 minutes from the start of the experimental evaluation. And, the average temperature that is from the lapse of 10 minutes to the lapse of 20 minutes is 23.5 degrees Celsius. Also, as shown in Figure 9 (b), the average temperature of the proposed method until the lapse of 20 minutes from the lapse of 7 minutes is 21.0 degrees Celsius. This temperature is lower 1 degree Celsius than a target temperature. On the other hand, the average temperature of the automatically control until the lapse of 20 minutes from the lapse of 10 minutes is 22.4 degrees Celsius. Based on these results, we confirmed that the proposed method can control the temperature of the only specific zone to close to the target temperature.



a) Zone1



b) Zone2

Figure 9. Room temperature changes on zone1/zone2

Figure 10 shows the power consumption of the air-conditioner. The abscissa of the graph is the time axis, and the ordinate represents the evaluation value. Both results of the proposed method and the automatically control are shown for comparison. The total power consumption values for 25 minutes are shown in the far right-hand side of the graph. As shown in graph form, the proposed method is 0.9 kWh, and the automatically control is 1.3 kWh. From this result, we confirmed that the proposed method could reduce power consumption than automatically control.

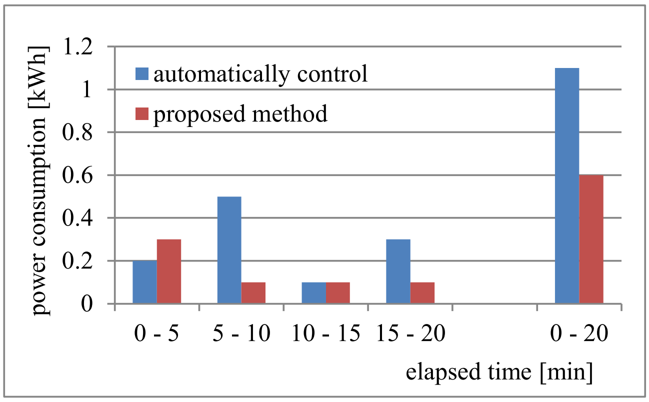


Figure 10. Power consumption of air-conditioner

5. Conclusions

In this article, we mentioned to control the lighting system and the air-conditioning system for the only zone where someone is in. We evaluated the proposed lighting control algorithm by simulation and confirmed that the proposed algorithm got the energy saving effect while keeping the target illuminance of the zone where person is in. In addition, we evaluated the proposed air-conditioning control algorithm by the experimental evaluation and confirmed that the proposed algorithm got energy saving effect while keeping the target room temperature of the zone where person is in. By the above, we confirmed that the proposed method is effective for the energy saving of office buildings.

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