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Real-Time Occupant Based Plug-in Device Control Using ICT in Office Buildings

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Abstract: The purpose of this study is to reduce the unnecessary plug loads used by computers, monitors, and computer peripheral devices, all of which account for more than 95% of the entire plug loads of an office building. To this end, an occupant-based plug-in device control (OBC-P) software was developed. The OBC-P software collects real-time information about the presence or absence of occupants who are connected to the access point through the Wifi and controls the power of monitors or computers, while a standby power off device controls computer peripheral devices. To measure the plug load saving of the occupant-based plug-in device control, an experiment was conducted, targeting 10 occupants of three research labs of the graduate school, for two weeks. The experiment results showed that it could save the plug loads of monitors and computer peripheral devices by 15% in the Awake mode, and by 26% in the Sleep mode.

Keywords: occupancy detection; occupant based control; plug-in device control; real-time occupant information collection; Wifi

1. Introduction

According to the U.S. Department of Energy (DOE), about 33% of the entire energy consumption of an office building is consumed by plug loads, which are expected to surge to 49% by 2030 [1,2]. In case of an office building, 95% of plug loads are consumed by computers (69%), monitors (9%), and computer peripheral devices (17%), except for severs and air handling units [3].

In the past, the reduction of plug loads in office buildings was heavily dependent on the improvement of the behaviors of occupants, by raising their awareness about the importance of energy saving [1,3–5]. However, as the dependence on occupants' behaviors inevitably caused inconvenience to occupants, it was difficult to expect continuous plug load saving effects. In recent years, the standby power off device has been widely used to reduce the unnecessary plug loads of computer peripheral devices of an office building [1,3].

However, the standby power off devices can save the plug loads of computer peripheral devices only when occupants turn off the computer; otherwise, it cannot reduce the plug loads. Therefore, the plug load saving effect using the existing standby power off devices was still dependent on occupants' behaviors, for instance, their awareness to turn off computers. However, office building occupants usually do not pay for energy consumption, and the act of pulling off plugs is often perceived as inconvenience. As a result, unnecessary plug loads are wasted by the current office buildings. Against this backdrop, it is necessary to develop a way of reducing unnecessary plug loads of computers, monitors and computer peripheral devices without being dependent on behavioral tendencies.

2. Limitation of the Conventional Plug Load Saving Strategies

The existing plug load saving measures can be divided into the education-based method (namely, the improvement of the energy saving behavior of occupants), the software-based measures, and the hardware-based method [3].

The education-based method aims at improving the energy saving behavior of the occupants, and has its own advantages; it does not incur any additional costs and can be applied to most of the plug-in devices. It involves turning off the unnecessary devices or pulling out the plugs whenever an occupant moves to another place. However, this inevitably causes inconvenience to the occupants, and energy saving is too much dependent on the behaviors of occupants to expect a continuous energy saving effect.

Although the software-based method that can be remotely controlled by a building superintendent does not incur additional costs, it cannot control computer peripheral devices, and a remote-control software needs to be installed to enable users to remotely control computers and monitors from a personal computer. Also, as it can terminate the operation of a computer or a monitor, it is likely to cause inconvenience to occupants.

The hardware-based method is to use a standby power off device or to replace the existing plug-in device with a highly efficient one. The mechanisms of standby power off devices can be divided into the scheduling-based method and the standby power detection and cut-off method.

The scheduling-based method is to connect plug-in devices with schedulers to a standby power off device, and to adjust the scheduler setting of the standby power off device to allow the plug-in devices to automatically go off. The method is effective in reducing the plug loads of the plug-in devices with built-in schedulers. However, it cannot respond to the irregular use of plug-in devices by the occupants.

The power detection & standby power-off method is to connect the power cable of a computer to the master outlet of the standby power-off device and computer peripheral devices to the controlled outlets. After the standby power-off device is installed, if an occupant turns off the computer, the standby power of the computer peripheral devices is automatically discontinued, or when an occupant turns on the computer, the power is supplied to computer peripheral devices. This method is effective in cutting off standby power. However, the reduction of plug loads is dependent on the occupant's act of turning off the power of the computer.

The replacement method is to preplace a low efficient device with a high efficient device to save plug loads. This method is expected to achieve a higher energy saving efficiency than any other method, but the replacement method is not cost-efficient in most cases.

To make up for the shortcoming of the existing plug load reduction methods which are overly dependent on behavioral tendencies, the development of occupant-based plug-in controls is in a great demand in recent years [1,4,6]. The occupant-based plugin device control is to collect real-time information about the presence or absence of occupants and, based on the occupant information, to control the plug-in devices.

Harris *et al.* [7] proposed a method of controlling computers and monitors through the bluetooth of smartphones after installing an occupant-based plugin device control software in a computer. However, as bluetooth consumes a greater amount of battery than Wifi, it is not widely used. Also, the study by Harris did not include the controlling of computer peripheral devices.

In a study by Ken Christensen *et al.* [8], computers, monitors, and computer peripheral devices were connected to the standby power-off device, a control software was installed in a computer, while a control application was installed in a smartphone. Subsequently, the computers, monitors, and computer peripheral devices were controlled through the Wifi of the smartphone. When an occupant left the office room for a short period of time, the monitor would go off and the standby power of computer peripheral devices would be cut off. Also, the monitors and computer peripheral devices are turned off right before the occupant enters the office room. Therefore, a plug load saving effect can be achieved while minimizing the inconvenience of the occupant. However, in the study by Ken Christensen *et al.*, the computer was always turned on even when the occupant was absent for a short period, and an analysis on plug in saving quantities was not conducted. Also, another disadvantage is that the occupant, who was not obliged to pay for energy consumption, had to experience the inconvenience of installing an application in the smartphone.

The purpose of the study is to develop a new mechanism to control computers, monitors, and computer peripheral devices according to information about the presence or absence of occupants, using the Wifi and a standby power cutoff device, and installing a control software in a computer, but without the installation of an application in a smartphone. To this end, this study developed an occupant-based plug-in control software and analyzed plug load saving rates through an experiment.

3. Occupant Based Plug-in Device Control

3.1. Development of Software

Figure 1 shows the role of OBC-P software (version 1.0) and standby power cut-off device for the plug-in device control. The Occupant Based Control-Plugged in Device (OBC-P) software was developed for the control of occupant-based plug-in devices. The OBC-P software was developed by Matlab and has a graphical user interface (GUI) as seen in Figure 2. The OBC-P software collects real-time occupant information through Wifi, and plays a role to control the main monitor or computers.

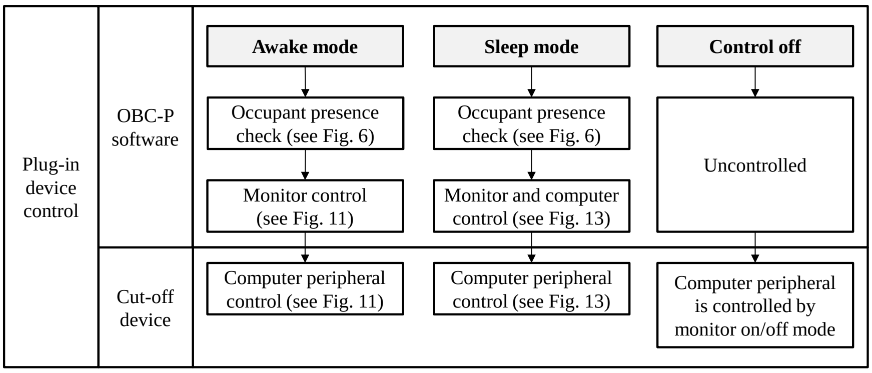

Figure 1. Role of OBC-P software and cutoff device for plug-in device control.

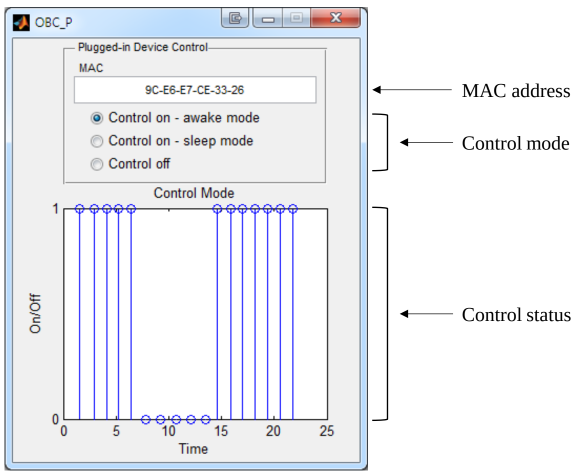

Figure 2. OBC-P software.

The GUI of the OBC-P software consists of three sections. The first section is where the Media Access Control (MAC) address is entered. Every smartphone has its unique MAC address, and when an occupant is connected through the Wifi of a smartphone, the MAC address is displayed on the AP (Access Point) administration page, as seen in Figure 3. The absence and presence of an occupant is determined by comparing the MAC address that is entered into the OBC-P software with the one stored in the AP administration page. The second section is where a control model is selected. The plug-in device control has been developed into two types: Awake mode to control monitors and computer peripheral devices, and Sleep mode to control monitor, computer peripheral devices, and computers. The third section indicates the controlling status, which shows the ON/Off status of plug-in devices in a real-time basis; "ON" is expressed in "1", while "OFF" is expressed in "0".

	MAC address	Network name	Signal strength	Connect hours
1	D0-9D-AB-09-1C-9C	Room3	90%	04:04:54
2	F8-0C-F3-FB-49-D3	Room3	98%	03:57:20
3	9C-E6-E7-CE-33-26	Room3	96%	01:20:50

Figure 3. Access point administration page.

3.1.1. Real-Time Occupant Information Acquisition

Figure 4 shows how the occupant information is collected in a real-time basis by the OBC-P software through Wifi. (1) When an occupant is connected to the access point through the Wifi of a smartphone (the connection to the Wifi of the smartphone is induced by synchronizing the ON/OFF status of computers, monitors, and computer peripheral devices with the connection and disconnection to the Wifi); (2) the OBC-P software gains access to the AP administration phase to collect the MAC address, the Wifi network name, and signal intensity information; (3) Based on the collected information, the OBC-P software gathers information about the location of an occupant (Wifi network name, signal intensity), the presence or absence of occupants (MAC addresses), the number of occupants (number of MAC addresses), and the identities of occupants (MAC addresses); (4) The OBC-P software logs in to the AP administration page on a regular basis to collect occupants' information on a real-time basis.

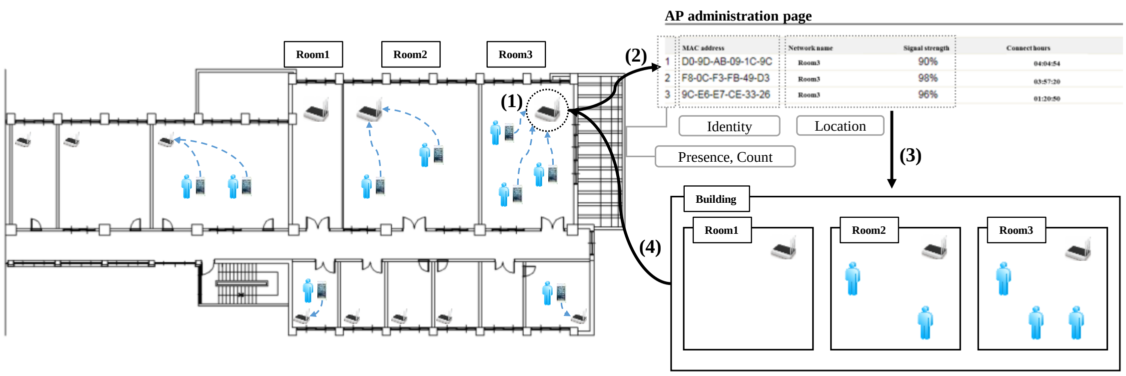

Figure 4. Real-time occupant information collection.

In order to control computers, monitors and computer peripheral devices, it is necessary to compare real-time information to find out whether the occupants are present or absent. Figure 5 shows how to confirm the presence and absence of occupants. (1) The OBC-P software logs in to the AP administration page to collect MAC addresses, Wifi network names, and signal intensity information; (2) Figure 6 displays a flowchart of checking the absence and presence of occupants. First of all, the MAC address of the OBC-P software checks whether an AP administration page exists or not. If the MAC address does not exist in the AP administration page, it is judged that an occupant is out of the accessible range of the Wifi, and it is determined as an unoccupied room. If the MAC address exists in the AP administration page, it will check whether the signal intensity is higher than 80% or not. If the signal intensity is higher than 80%, it will be judged as an occupied room. The time delay is set at one second in order to prevent the overload of computers.

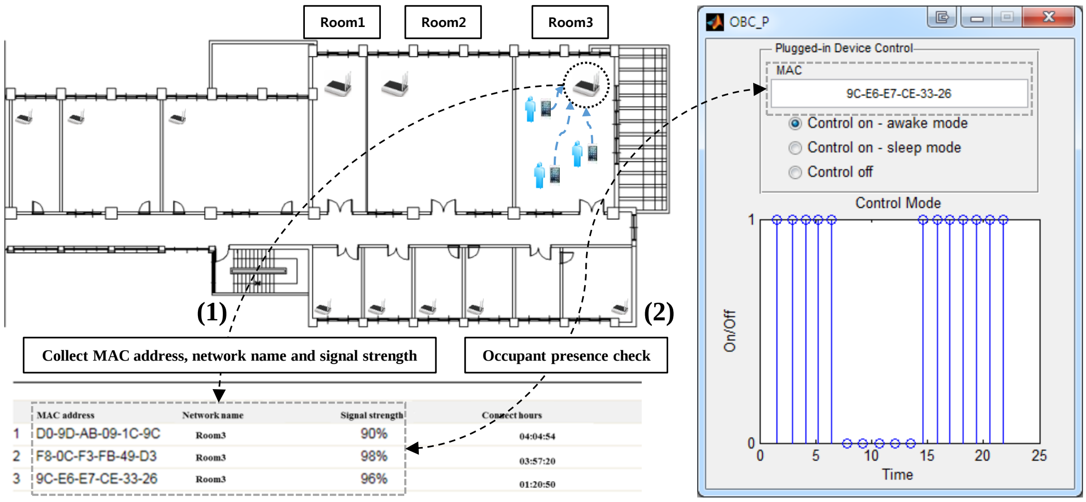

Figure 5. Occupant presence check method.

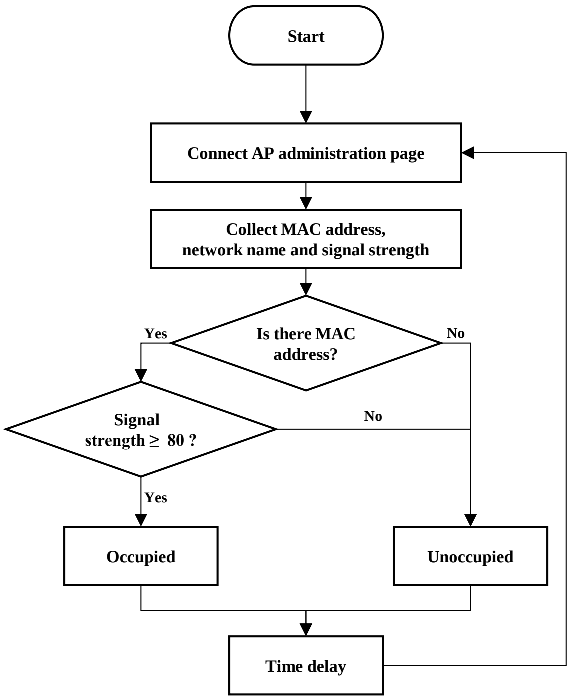

Figure 6. Occupant presence check algorithm.

Figures 7 and 8 show an experiment on the plug-in load saving and explains why the occupancy signal intensity was set at 80%. Two experimental locations on the second floor of the experimental place used the same AP. In cases of AP1 and AP2, the signal intensity was reduced to 80%, when occupants moved 11 m away from the AP with the smartphone in the hand. In case of AP 3 on the fourth floor, the signal intensity was reduced to 80%, when occupants moved 15 m away from the AP with the smartphone. In the case of AP3, the signal intensity of 90% was considered appropriate, but this study set up the signal intensity at 80% in order to simplify the plug-in device control software. Therefore, after the Wifi was activated by occupants, when they moved away by about 11–15 m from the experimental locations, they were determined to be absent in the rooms, but when the occupants moved within 11–15 m from the assess point of the experimental locations, they were determined to be present in the rooms. When applying the methodology of this study to other buildings, signal intensity criteria can vary according to the number and placement of obstacles, the performance of Wifi access point and *etc*.

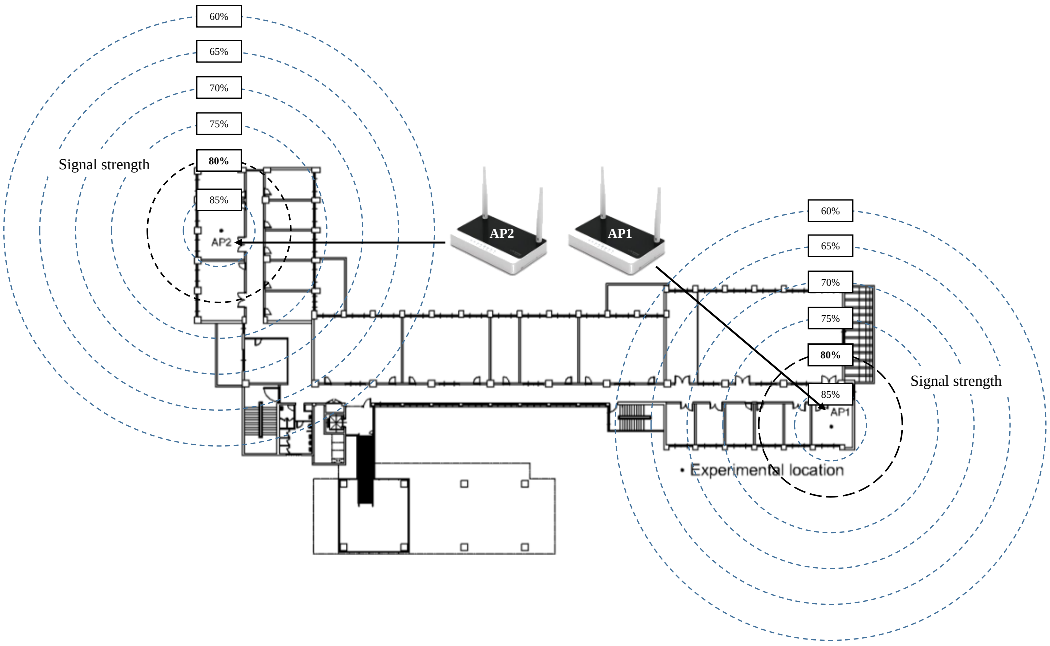

Figure 7. Experimental location (second floor).

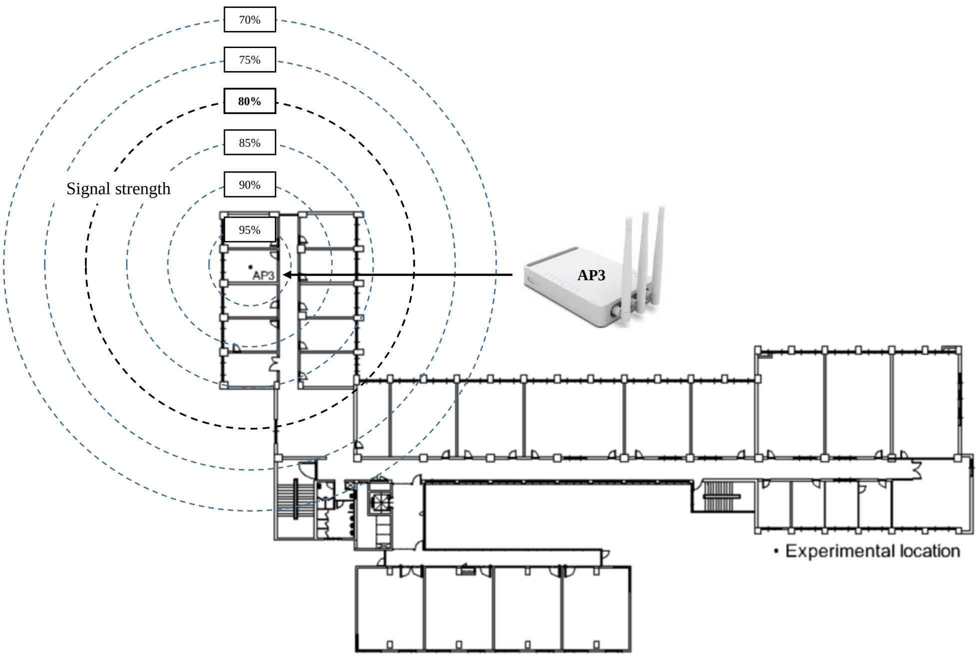

Figure 8. Experimental location (fourth floor).

3.1.2. Plug-in Device Control

For the occupant-based plug-in device control, the OBC-P software and the standby power cut-off device seen in Figure 9 are used. The standby power cut-off device consists of the Always ON outlet, Master outlet, and Controlled outlets.

The Always ON outlet does not have the power cut-off function as ordinary socket outlets. Therefore, if a plug-in device is activated it consumes electricity, but if a plug-in device is not activated, it consumes standby power.

The Master outlet also does not have the power cut-off function as ordinary socket outlets. However, it regulates the controlled outlets, depending on whether a plug-in device connected to the Master outlet is activated or not. In other words, if a plug-in device connected to the Master outlet is activated, it supplies electricity to the Controlled outlets, but if a plug-in device connected to the Master outlet is not activated, it cuts off electricity supplied to the Controlled outlets (standby power cut-off).

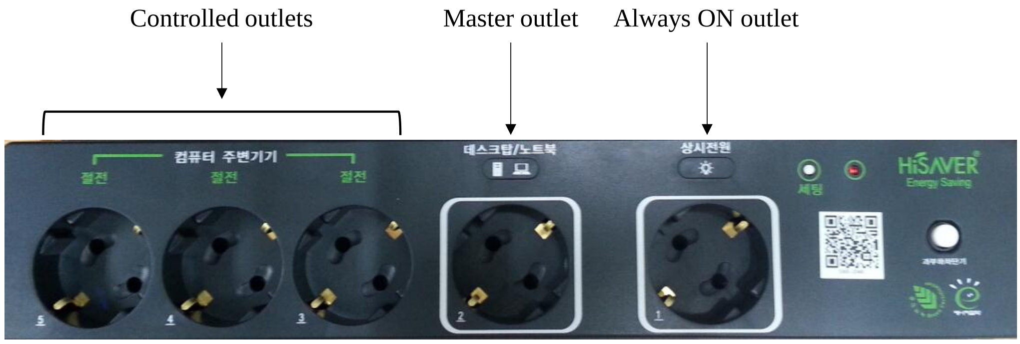

Figure 9. Cutoff device.

The mechanism of ordinary standby power cut-off devices is that a computer is plugged into the Master outlet, while monitors and computer peripheral devices, including personal lighting, are connected into the Controlled outlets. Therefore, if the computer is turned off, the standby power supplied to computer peripheral devices will be cut off. However, this method cannot reduce plug loads, when the computer is turned on.

In order to control unnecessary plug-in devices when occupants are not present, this study connected the computer to the Always ON outlet, the main monitor to the Master outlet, and computer peripheral devices including the sub-monitor, personal lighting, and speakers to the Controlled outlets. Therefore, if the power of the main monitor is turned off, it cuts off the standby power supplied to the computer peripheral devices connected to the Controlled outlets.

In the plug-in control methods of the OBC-P software, this study developed the Awake mode, Sleep mode, and control off. In the Awake mode (as seen in Figure 10), if an occupant leaves the office room for a short period of time, the computer consumes the normal electricity, and the main monitor consumes standby power, while the supply of standby power to computer peripheral devices is cut off. Also, before the occupant enters the office room, the main monitor and computer peripheral devices are activated. Therefore, it can reduce plug loads of the main monitor and computer peripheral devices while reducing the inconvenience of the occupant. Figure 11 shows the algorithm of the Awake mode. When the OBC-P software is set at the Awake mode, it collects real-time occupant information and checks whether an occupant is present or absent in the room; if the occupant is present, the OBC-P software activates the main monitor and the computer peripheral devices by disabling the standby power cut-off device. If the occupant is absent, the OBC-P software turns off the power of the main monitor and cut off the standby power to the computer peripheral devices by enabling the standby power cut-off device.

In the Sleep mode (as seen in Figure 12), when the occupant leaves the office room for a short period of time, the computer switches to the saving mode, and the main monitor consumes standby power, while the electricity supply to computer peripheral devices is cut off. Therefore, it can save more plug loads than the Awake mode. But when the occupant returns to the office room, the occupant must click the mouse or press the keyboard once to reactivate the plug-in devices connected to the independent socket outlet and the dependent socket outlets. Figure 13 shows the algorithm of the Sleep mode.

If it is set in the Sleep mode, the OBC-P software collects real-time occupant information, and if it determines the absence of the occupant, it switches the power of the computer to the saving mode. After that, the standby power cut-off device discontinues the supply of standby power to computer peripheral devices. If an occupant is present, the OBC-P software detects a movement of the mouse or a button click of the keyboard. Only when the mouse moves or the keyboard button is clicked, the OBC-P software activates the monitor and computer.

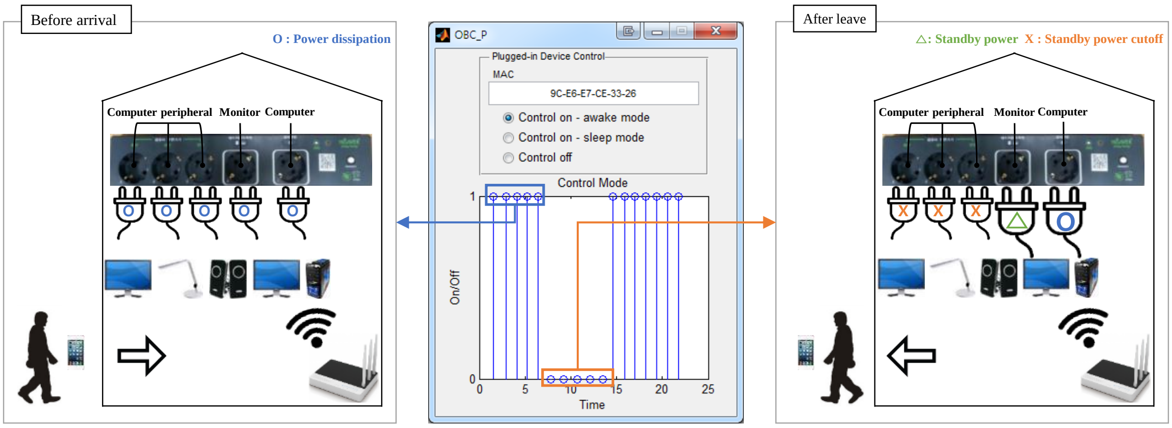

Figure 10. Awake mode.

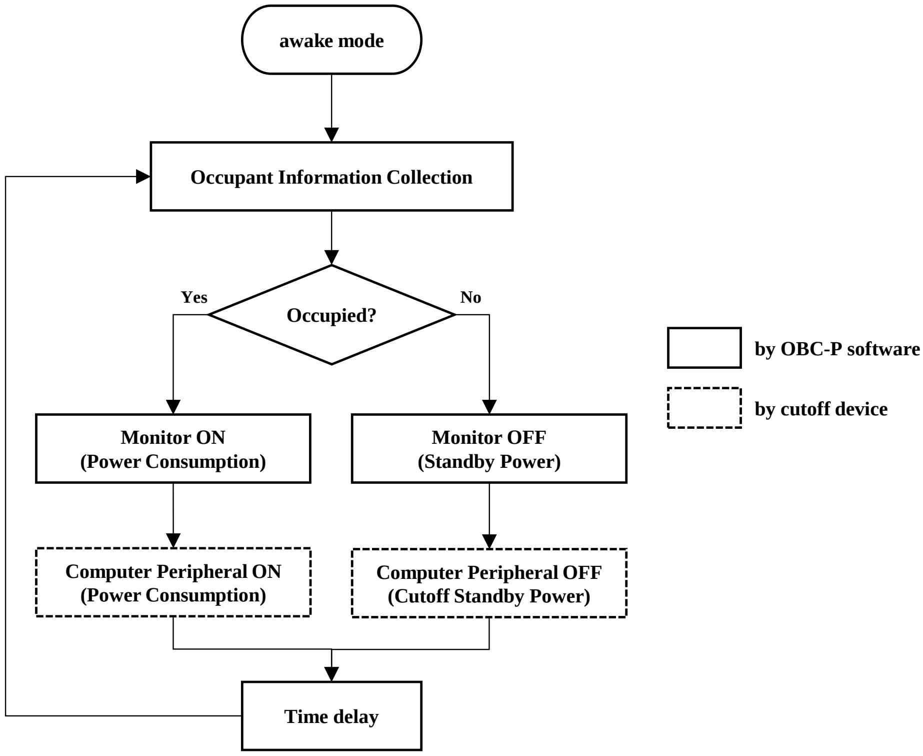

Figure 11. Awake mode algorithm.

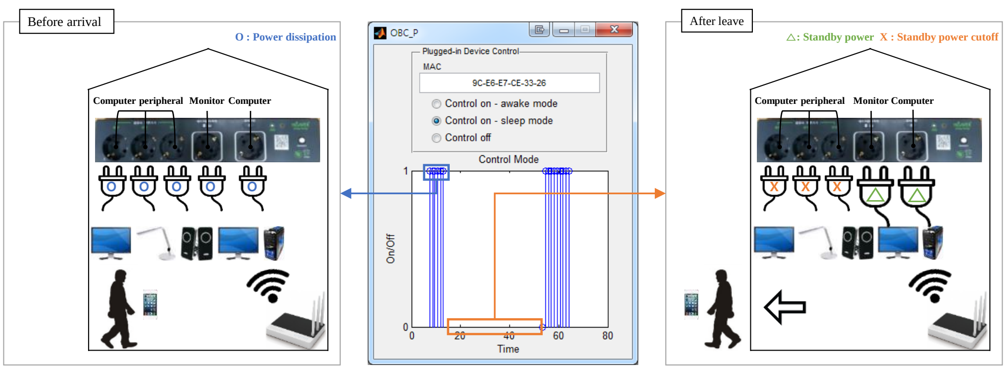

Figure 12. Sleep mode.

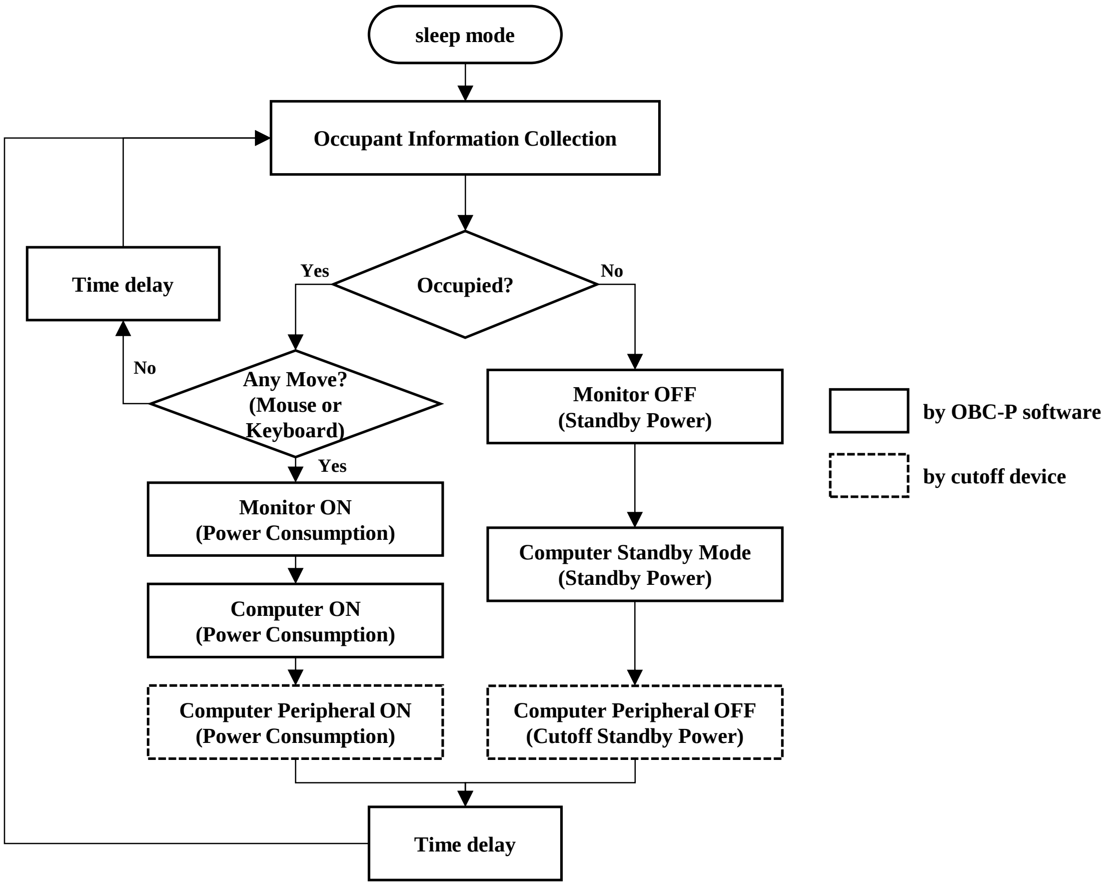

Figure 13. Sleep mode algorithm.

The Control-off mode is a control model that does not regulate plug-in devices regardless of the absence or presence of an occupant.

3.2. Selection of Representative Value

In order to estimate plug load saving quantities of the occupant-based plug-in device control in each control mode, the same occupancy schedule was applied for comparative analysis. Therefore, the electricity consumption of each occupant's plug-in devices in four control modes (when all the plug-in devices are activated, when an occupant leaves the office room for a short period of time after setting the control to Awake mode, an occupant leaves the office room after setting the control to Sleep mode, or when all plug-in devices are deactivated) were measured 500 times before the experiment, and these were selected as the representative values of plug loads.

Figures 14 and 15 show the representative values of plug loads which were measured 500 times at an interval of three seconds, when all the plug devices were activated due to the presence of Occupant A and Occupant B, and when they were absent for short leave after setting the control to the Awake mode. In case of Occupant A, the mean value of plug loads is similar to the median value. Therefore, if either the mean value or the median value is set as the representative value, there was not much difference in the total electricity consumption. However, when Occupant B was present and the plug-in devices were activated, there was a difference by about 10 W between the mean value and the median value. In this case, either the mean value or the median value has to be selected as the representative value. If the mean value is used as the representative value of plug loads, it is likely to overestimate the electricity consumption. The mean value tends to show a greater response to a more distant value from the center [9]. Therefore, this study used the median value as the representative value.

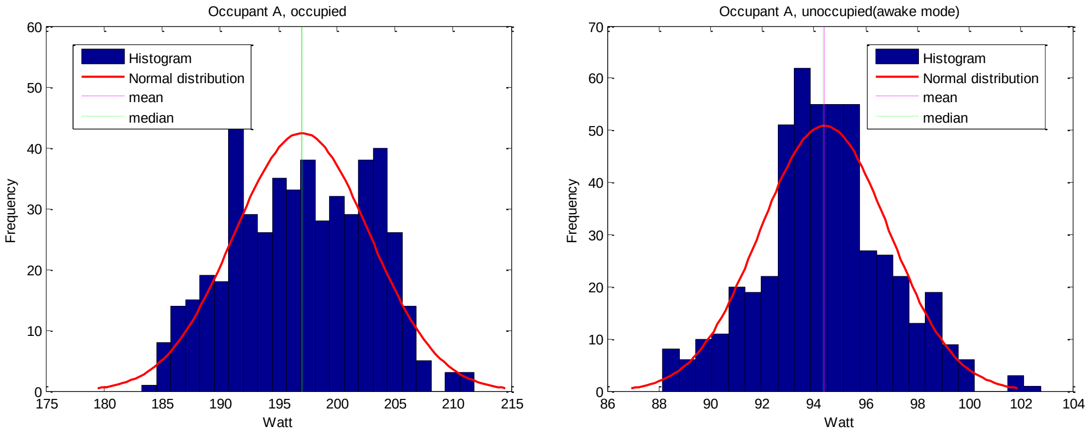

Figure 14. Occupant A, representative value of plug load.

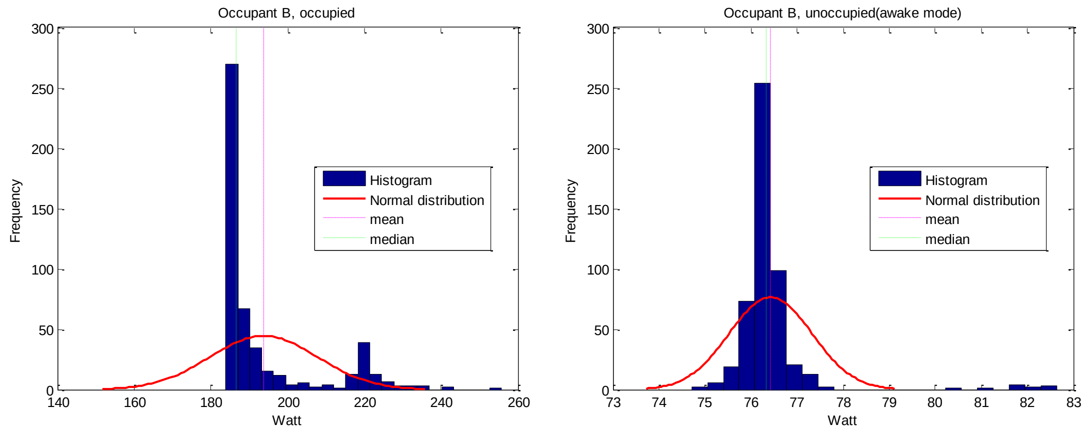

Figure 15. Occupant B, representative value of plug load.

4. Plug Load Saving Experiment

This study conducted an experiment to measure the plug load saving quantities due to plug-in device control. Table 1 shows the occupants who participated in the experiment and the types of the used plug-in devices. Figures 7 and 8 display the experimental places. The experiment was conducted by targeting a total of 10 occupants in three research labs at University of Seoul for two weeks.

Table 1. Occupants and plug-in devices.

Laboratory	Occupant	Computer	Notebook	Monitor	Personal Lighting
1	A	1	-	2	1
	B	1	-	2	1
	C	1	-	2	1
	D	1	-	1	1
2	E	1	-	2	1
	F	1	-	2	1
	G	1	-	2	1
	H	1	-	2	1
3	I	1	1	2	1
	J	-	1	-	1
Total	10	9	2	17	10

The equation to calculate the plug load saving quantity was established in reference to Option A of the IPMVP (International Performance Measurement and Verification Protocol) [10].

$$\text{Plug Load Saving} = \sum_{i=1}^{4} (\text{BRV}_i \times \text{BP}_i - CRV_i \times CP_i) \tag{1}$$

The plug load saving quantity was calculated by multiplying the Baseline Representative Value (BRV_i) with the Baseline Period (BP_i) and then by subtracting the multiplied value of the Representative Value (CRV_i) and the Control Period (CP_i) from it. Herein, "i" is the control mode of plug-in devices (i = 1: when all the plug-in devices are activated, i = 2: when an occupant leaves the office room for a short period of time after setting the control to Awake mode, i = 3: an occupant leaves the office room for a short period of time after setting the control to Sleep mode, and i = 4: when all plug-in devices of an occupant are deactivated).

5. Results and Discussion

To confirm the accuracy of the occupancy OBC-P software, experiments of the case of leaving the room and the case of occupying the room with a smart phone were performed 20 times, respectively. As a result of 100% accuracy, plug-in devices have been activated before the occupants occupy the room and deactivated after the occupants are out.

Figures 16–21 show the results of the experiment on the occupant-based plug-in device control, which was conducted by targeting a total of 10 occupants for two weeks. The baseline system was set as follows: after occupants came to work, they turned on plug-in devices, such as computers, monitors and computer peripheral devices; during the short leave period, they did not control the plug-in devices; when they went to home, they turned off the plug-in devices.

Figure 16 shows the plug load of Occupant A on Wednesday. Occupant A came to work at around 10 A.M. and went to home at around 2 P.M., and there were five short leaves between the clock-in time and the clock-out time. When Occupant A used the occupant-based plug in device control, the plug-in devices were automatically controlled during the short leave period, and as a results, unnecessary plug loads were reduced. When the occupant set the control to the Awake mode, it could reduce the plug loads by 10.2%, compared to the baseline system. In case of the Sleep mode, it can save the plug loads by 18.2%.

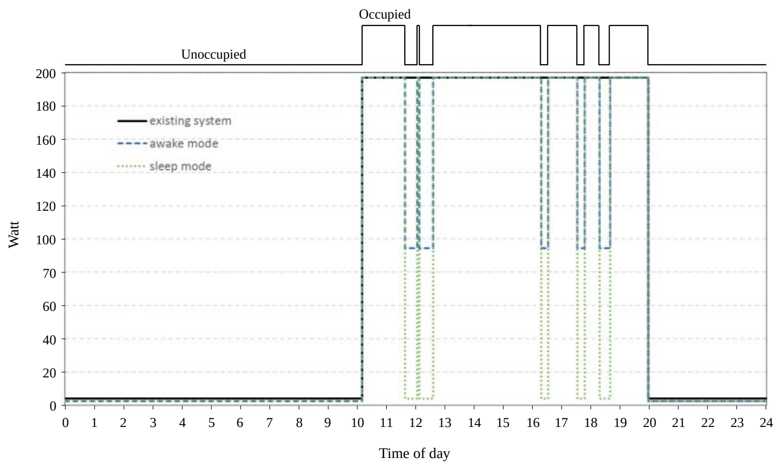

Figure 16. Occupant A, plug load (Wednesday).

Figure 17 shows the total occupied time of Occupant A for two weeks and the plug load quantities. In case of Occupant A, the short leave period and the period from the clock-out time to the next clock-in time varied widely depending on the day of the week, and the plug load quantities changed accordingly. In most cases, a longer unoccupied time means a smaller plug load quantity. However, in cases where the unoccupied time was similar (Tuesday, Wednesday and Thursday of the second week), the plug load quantity in the Awake mode was decreased when the period from the clock-in time to the next clock-out time was increased. In the Sleep mode, when the unoccupied time was increased, the plug load quantity was decreased. These results show the differences in plug load quantities depending on the control mode during the short leave period, as seen in Figure 16.

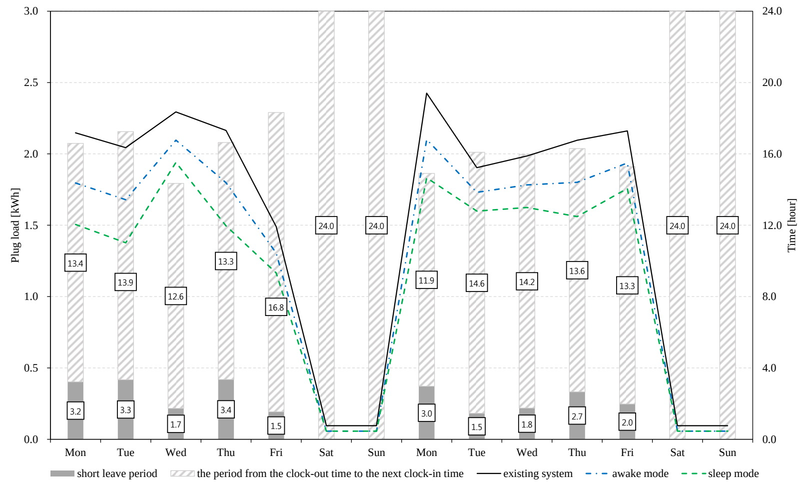

Figure 17. Occupant A, daily unoccupied time and plug load.

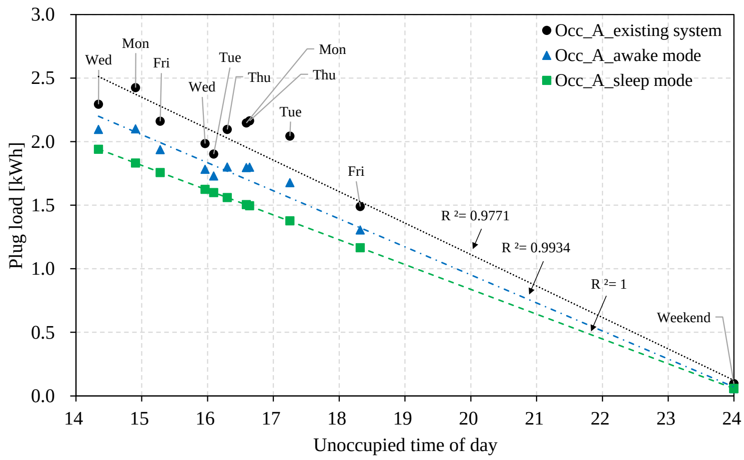

Figure 18. Occupant A, unoccupied time and plug load.

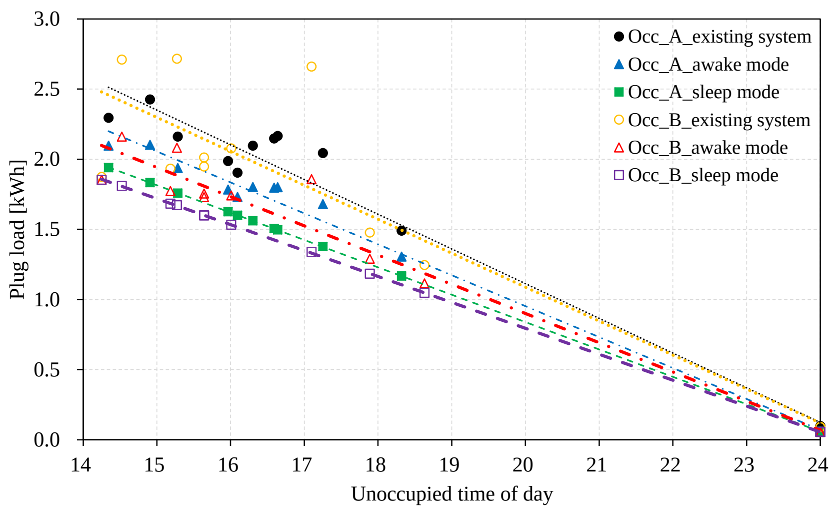

Figure 19. Occupant A, Occupant B, unoccupied time and plug load.

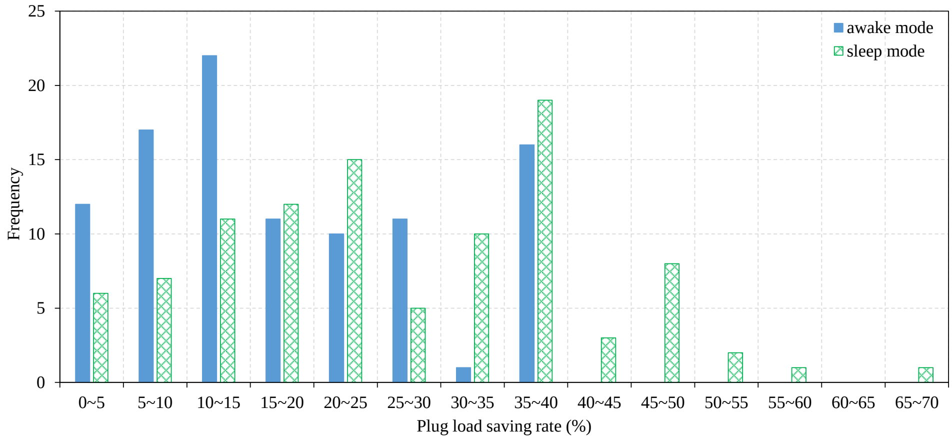

Figure 20. Plug load saving rate.

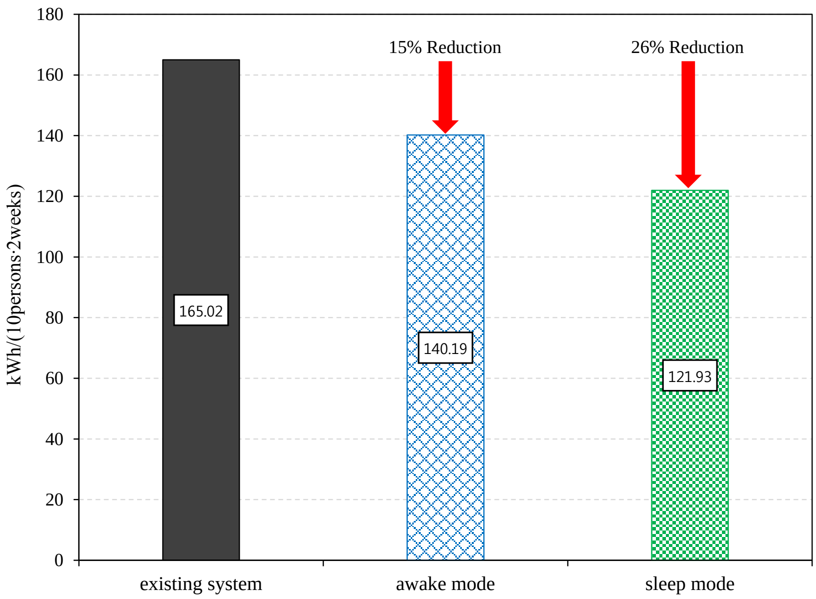

Figure 21. Comparison of plug load.

Figure 18 shows the plug loads of Occupant A by the unoccupied hours for two weeks. On Saturdays and Sundays, the occupant did not come to work, so the plug log quantity was the same. Except for Saturdays and Sundays, the unoccupied time varied depending on the day of the week. When the unoccupied time was increased, the plug load quantity was decreased. Also, in case that the unoccupied time was the same, the Sleep mode had the greatest plug load saving, followed by the Awake mode and the baseline system. In case of the baseline system, the plug load quantity was increased in some cases, even though the unoccupied time was increased ($R^2 = 0.9771$).

In contrast, the Awake mode showed a more remarkable decreasing in the plug load quantity than the baseline system, when the occupied time increased ($R^2 = 0.9934$). In the Sleep mode, an increase in the unoccupied time always led to a decrease in the plug load quantity ($R^2 = 1$). The varying results of the Awake mode and the Sleep mode can be ascribed to differences in the short leave period and the unoccupied period from the clock-out time to the next clock-in time, as seen in Figure 16. In other words, the Awake mode used a plug load of 94.34 W during the short leaves of occupants and a plug load of 2.39 W for an unoccupied period from the clock-out time to the next clock-out time. In contrast, the Sleep mode consumed a plug load of 4.05 W during the short leave of occupants, and used a plug load of 2.39 during a period when all the plug-in devices were deactivated by occupants. Therefore, the use of the Sleep mode enables the reduction of plug loads in proportion to the unoccupied time.

Figure 19 shows the plug load by hour during the unoccupied period of Occupant A and Occupant B. Even though Occupant A and Occupant B had similar unoccupied periods of time, their normal use power consumption and standby power consumption of computers, monitors and computer peripheral devices were different, and their short leave period and their unoccupied period from the clock-out time to the next click-in time were also different, leading to differences in the plug load quantities among occupants.

Figure 20 shows the plug load saving rates of 10 occupants during the weekday depending on the varying control modes. The Awake mode had the daily minimum plug load saving rate of 1.39%, the daily maximum plug load saving rate of 39.80%, and the average plug load saving rate of 18%. The Sleep mode saves a daily minimum plug load of 1.55%, the daily maximum plug load of 65.76%, and the average plug load of 26.93%. The reason why the Sleep mode had a higher average plug load saving rate than the Awake mode was that occupants additionally controlled the computer to the power save mode when they left the rooms for short leave.

Figure 21 shows the comparison of plug load quantities when 10 occupants used the occupant-based plug-in device control for two weeks. The Awake mode had a higher plug load saving rate by about 15% than the baseline system, while the Sleep mode could reduce the plug loads by about 26% compared to the baseline system.

6. Conclusions and Future Directions

This study was conducted to develop a way of reducing unnecessary plug loads while minimizing the inconvenience of occupants by using an occupant-based automatic control of computers, monitors and computer peripheral devices, all of which account for approximately 95% of plug loads of an office building. To this end, the study developed the OBC-P software which uses the Wifi of smartphones and standby power cutoff devices. The OBC-P software collects information about occupants who are connected to the AP administration page through the Wifi, and based on this information, it controls the power on/off of computers and monitors, while a standby power cutoff device is used to control the power of computer peripheral devices. In order to measure the plug load saving rate in case of the use of the occupant-based plug-in device, the experiment was conducted targeting 10 occupants in three research labs of the graduate school for two weeks. The results of the study can be summarized as follows:

(1) When an occupant went out for a short break, the Awake mode automatically switched the main monitor to the standby mode and interrupted the supply of standby power to computer peripheral devices. Also, it reactivated the main monitor and computer peripheral devices right before the occupant returned to the room. The Awake mode could reduce the plug loads of computers, monitors, and computer peripheral devices by 15% compared to the baseline system.

(2) When an occupant left the room for a short period of time, the Sleep mode automatically switched the main monitor to the standby mode and interrupted the supply of standby power to computer peripheral devices. Thus, since it switched the computer to the saving mode, more plug loads could be saved than with the Awake mode. However, the computer, main monitor and computer peripheral devices were reactivated only when the occupant moved the mouse or touched the keyboard button. The Sleep mode could reduce the plug loads of computers, monitors, and computer peripheral devices by 26% compared to the baseline system.

This study has its limitations. Some test subjects likely felt that the computer gets slow when they run OBC-P software for a long time (10 h or more). It is estimated to be associated with the performance of the computer. It was difficult to collect correct information about the presence or absence of occupants, with increasing distance between the occupants and their smartphones. Also, when an occupant was within the range to the wireless access point but had left his or her workspace, the plug-in devices were not controlled. Further studies need to be conducted using a sensor which can locate the position of those occupants who are not connected to the access point through the Wifi. In addition, when the occupant's smart phone is connected to the other Wifi access point in the adjacent area, it will have to be added, the algorithm for determining the occupied or not.

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