

Physiological and Psychological Influence on Office Workers during Demand Response

Megumi Nishida, Naoya Motegi, Takurou Kikuchi, Tomoko Tokumura

Abstract—In recent years, the power system has been changed and a flexible power pricing system such as demand response has been sought in Japan. The demand response system works simply in the household sector and the owner as the decision-maker, can benefit from power saving. On the other hand, the execution of demand response in the office building is more complex than in the household because various people such as owners, building administrators and occupants are involved in the decision-making process. While the owners benefit from demand saving, the occupants are exposed to restricted benefits of a demand-saved environment. One of the reasons is that building systems are usually under centralized management and each occupant cannot choose freely whether to participate in demand response or not. In addition, it is unclear whether incentives give occupants the motivation to participate. However, the recent development of IT and building systems enables the personalized control of the office environment where each occupant can control the lighting level or temperature individually. Therefore, it can be possible to have a system which each occupant can make a decision of whether or not to participate in demand response in the office building.

This study investigates personal responses to demand response requests, under the condition where each occupant can adjust their brightness individually in their workspace. Once workers participate in the demand response, their desk-lights are automatically turned off. The participation rates in the demand response events are compared among four groups, which are divided by different motivation, the presence, or absence of incentives and the method of participation. The result shows that there are significant differences of participation rates in demand response event between four groups. The method of participation has a large effect on the participation rate. The “Opt-out” groups where the occupants are automatically enrolled in a demand response event if they do not express non-participation have the highest participation rate in the four groups. Incentives also have an effect on the participation rate.

This study also reports on the impact of low illumination office environment on the occupants, such as stress or fatigue. The electrocardiogram and the questionnaire are used to investigate the autonomic nervous activity and subjective fatigue symptoms of the occupants. There is no big difference between dim workspace during demand response event and bright workspace in autonomic nervous activity and fatigue.

Keywords—Demand response, illumination, questionnaire, electrocardiograph.

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I. INTRODUCTION

DEMAND RESPONSE (DR) is a system which controls the demand and supply of electricity. One of the DR methods is the payment-based method, which changes the electricity rate depending on time to reduce the peak-time electric consumption. Another way is the incentive-based method, which offers special electricity rates if the suppliers reduce or stop supplying electricity at peak-time [1]. Power system has been changed to be flexible by DR in Japan and the incentive-based method has been demonstrated in household sectors [2]. On the other hand, the experiment in office sectors is assumed difficult and complicated because various kinds of people are involved in the decision-making process of DR, such as owners, building administrators and occupants [3]. Moreover, it is difficult for occupants to benefit from power saving although they endure a less comfortable office by power saving. However IT development enables the “personalized control” of office environment such as lighting and air-conditioning and the direct decision of DR by occupants has become possible [4], [5].

II. RESEARCH OBJECT

This research examines the possibility of personalized DR system of desk lighting quantitatively by comparing the participation differences of four groups, which are divided in terms of participation method and the presence or absence of incentives.

- Demonstrate personalized load shedding when the individual occupants can choose participation enabled by personalized environment control.
- Understand behavioral changes under conditions of Opt-in/Opt-out participation formats, and provision/lack of incentives for participants.
- Identify physical stress caused by the load-shed control, through analyzing cardiac rate monitoring and questionnaire.

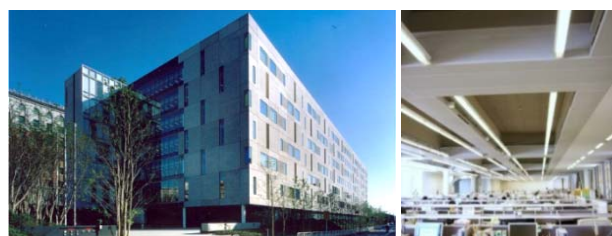


Fig. 1 Image of building and floor

III. EXPERIMENTAL OUTLINE

A. Building

The experiment was held in an office building in Tokyo, Japan. Fig. 1 shows the image of the building and floor area and Table I shows the outline of the building and experiment. About 200 occupants on the 7th floor participated in the experiment from July 14, 2014 to August 1, 2014. DR events were held 6 times in 3 weeks from 13:30 to 15:30.

TABLE I
OUTLINE OF BUILDING AND EXPERIMENT

Building	Takenaka Corporation Tokyo Headquarters
Completion	2004
Use	Office
Area	29,747m ²
No of floors	7-stories
Target floor	7 th floor (800 m ² , 200 seats)
Experimental Period	July 14, 2014 - August 1, 2014
DR Event	July 16, 18, 23, 24, 30, August 1
DR Announcement	8:30 on the day
DR time	13:30 - 15:30 (2 hours)

B. Personal DR System

Fig. 2 shows the personal DR system. Firstly, DR announcement was sent to all occupants at 8:30 by email asking whether they want to participate in the DR event or not. Secondly, they responded to the announcement by 13:30 and then the desk-lights of the occupants who join the DR event were turned off automatically at 13:30 through smart outlet. Finally, the desk light was turned on automatically at 15:30 when DR event ended.

Table II shows the group setting and Fig. 3 shows the group area. Occupants on the 7th floor are divided into four groups in terms of participation and incentive type. There are two participation types: Opt-in and Opt-out. Opt-in occupants who participate in DR event need to apply for it; otherwise, their desk-lights are turned off. On the contrary, Opt-out occupants who participate in DR event do not need to apply for it. There are also two types of incentive category: performance incentive and fixed incentive. Occupants in performance incentive group get a voucher for a cup of coffee each time. On the other hand, occupants in fixed incentive group get a voucher for two cups of coffee regardless of participation. For comparison, occupants on the 5th floor are followed for the rate of utilization of desk-lights.

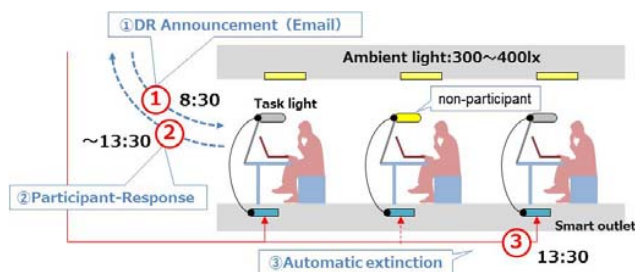


Fig. 2 Personal DR system

TABLE II
GROUP SETTING

Group	Ctrl Group	Treatment Group			
		Group1	Group2	Group3	Group4
Participation	-	Opt-in	Opt-in	Opt-out	Opt-out
Incentive	-	Performance	Fixed	Performance	Fixed
Participants	66	48	51	58	54
Seating %	42.7	40.8	40.4	46.8	42.4

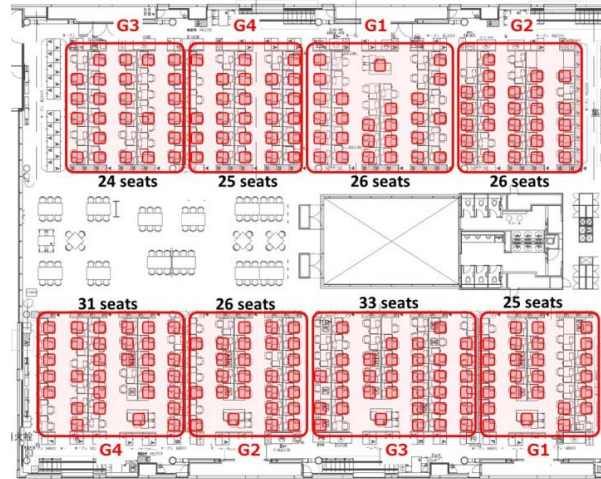


Fig. 3 Group area

C. Physiological & Psychological Measurement

There was concern that the dim light environment during DR event has negative effects on occupants, such as stress, fatigue or unpleasantness so 12 occupants are asked for physiological & psychological effects of temporal dim working space.

Table III shows 12 subjective attribute data, group, age, sex, and eyesight. Table IV shows physiological and psychological measurement items, cardiograph, and questionnaire. Cardiograph is used to analyze the autonomic nerve activity, which is useful as indicator of stress or fatigue. The autonomic nerve activity can be calculated by frequency analysis of the interval of electrocardiographic R-wave and R-wave. LF, which is the indicator of stress or fatigue, is obtained by integrating the power spectrum density from 0.05Hz to 0.15Hz. HF is similarly calculated from 0.15Hz to 0.40Hz and used as relax index.

TABLE III
SUBJECTIVE ATTRIBUTE DATA

Subject	Group	Age	Sex	Eye sight
1	G1	40s	M	1.5
2		30s	M	1.2
3		-	M	-
4		-	M	-
5	G2	30s	M	1.5
6		50s	F	1.5
7		50s	F	0.8
8		40s	M	1.5
9	G3	50s	M	1.0
10		40s	M	1.5
11		40s	M	1.5
12		40s	F	1.0

TABLE IV
MEASUREMENT ITEMS

Instrument	Measurement	Interval
Cardiograph	Autonomic nerve activity	24 hours (except for bath)
Questionnaire	Fatigue	9times/3weeks

Subjects required wearing cardiograph on their left chest for 24 hours except during bath time

Questionnaire named “Subjective symptom check” consists of 25 questions about sleepiness, unstableness, unpleasantness, fatigue, blurry vision. The questionnaire is sent by email 3 times a week including two times during DR event.

IV. RESULT

A. Participation Rate of DR

Fig. 4 shows the participation rate of DR event. 43.8 percent of Opt-in group, group 1 and 2, participated in DR event. On the other hand, the participation rate of Opt-out group goes up to more than twice that of Opt-in group. Considering Opt-in group, the participation rate of performance incentive group is 51.4 percent and that in fixed incentive group is 36.3 percent. Participation type has a large influence on DR participation rate and it indicates that occupants tend to have a passive attitude to the application for DR event. When participation rate is not high, incentive type also influences the participation rate and performance incentive is more effective than fixed incentive.

B. Ratio of Turned-Off Desk-Light and Power-Saving Effect

Fig. 5 shows the ratio of turned-off desk-light before/during DR. The ratio of extinction in group 1 is the highest, 1.6, which means occupants in performance incentive group join DR more than fixed incentive group. Fig. 6 shows the power consumption of desk-light per person before/during DR event, which is converted by the ratio of, turned-off desk-light. Treatment effect is adjusted by the difference of desk-light power per person in control group. Opt-out group has more than 90 percent of power-saving effects. In Opt-in group, performance incentive group has 81 percent and fixed incentive group has 47%.

C. “Subjective Symptom Check”

Fig. 7 shows the average score of questionnaire “Subjective symptom check”. Sleepiness and Unstableness of normal day is higher than DR day but there is less difference in unpleasantness, fatigue and blurry vision when comparing DR and normal day. Fig. 8 shows the Average score of sleepiness within- subjects. 7 subjects, 1, 5, 6, 7, 9, 10 and 12, feel less sleepy during DR event. It implicates that occupants were wakeful in dim lighting environment.

D. Autonomic Nerve Activity

Fig. 9 shows LF/HF, autonomic nerve activity index. If LF/HF is more than 1.0, it indicates sympathetic dominance and subject might feel tense or stressed. LF/HF of 5 subjects, 5, 8, 10, 11 and 12, significantly increased during DR event.

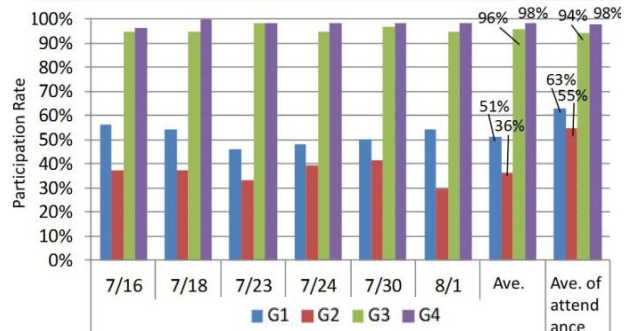


Fig. 4 Participation rate of DR

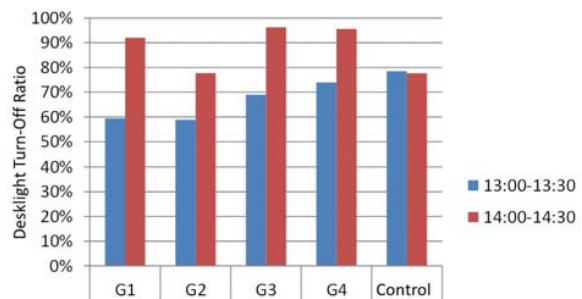


Fig. 5 Ratio of turned-off desk-light, before/during DR

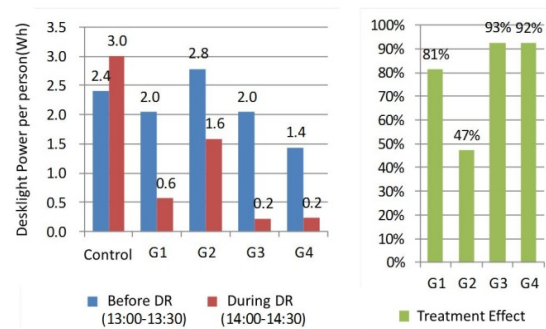


Fig. 6 Power Consumption of Desk-light per Person before/during DR

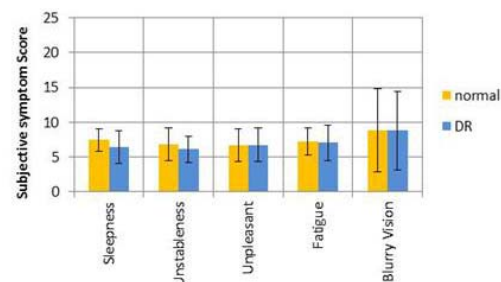


Fig. 7 Average score of “Subjective symptom check”

DR event or dim lighting environment enhanced tenseness or stress. Fig. 10 shows the Average of DR ratio within-group. DR ratio is defined below.

$$\text{DR ratio} = \frac{(\text{Average of LF/HF during DR})}{(\text{Average of LF/HF on other days})} \quad (1)$$

DR ratios of groups 2 and 4 are more than 1 and that of group 4 is the highest. It means the fixed group tends to feel tenser or stressed during DR. Fig. 11 shows the correlation between DR ratio of LF/HF and that of “Subjective symptom check”, sleepiness, and unpleasantness. DR ratio of LF/HF and that of Sleepiness have a weak negative correlation, which means occupants who feel sleepy tend to be relaxed. Similarly, DR ratio of LF/HF and that of unpleasantness also have a weak negative correlation. It implies that the increase of LF/HF during DR might not be affected by negative feeling, such as stress, but positive motivation.

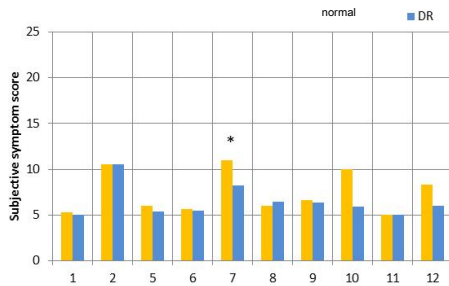


Fig. 8 Average score of Sleepiness within- subjects (*: $p < 0.05$)

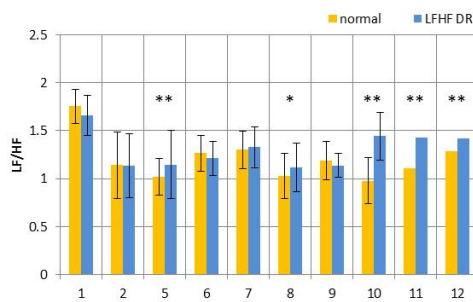


Fig. 9 LF/HF (**: $p < 0.01$, *: $p < 0.05$)

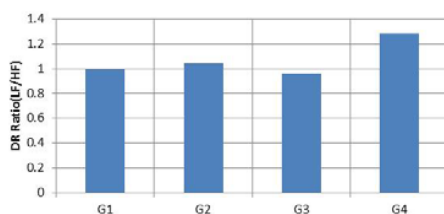


Fig. 10 Average of DR ratio within group

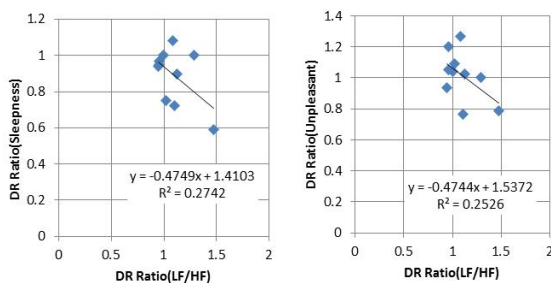


Fig. 11 Correlation between DR ratio of LF/HF and that of “Subjective symptom check”

V. CONCLUSION

- DR participation was higher in Opt-out than Opt-in.
- For Opt-out, over 90% of occupants participated. For Opt-in, approx. 45% of occupants participated.
- DR participation is higher with performance incentive than fixed incentive.
- Participation with fixed incentive is 30% lower than performance incentive, under Opt-in method.
- Sleepiness and unpleasant feeling decrease during DR
- LF/HF increase during DR
- Dim environment during DR does not significantly cause fatigue or sleepiness for occupants.

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