Building and Environment 88 (2015) 10–19

Contents lists available at ScienceDirect

Building and Environment

journal homepage: www.elsevier.com/locate/buildenv

Workers' awareness and indoor environmental quality in electricity-saving offices

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ARTICLE INFO

Article history:
Received 29 July 2014
Received in revised form
21 September 2014
Accepted 22 September 2014
Available online 2 October 2014

Keywords:
Earthquake
Energy saving
Workers' awareness
Indoor environment
Productivity

ABSTRACT

Owing to the enormous damage caused by the Great East Japan Earthquake of 2011, a 15% reduction in peak power consumption was required to address the gap between demand and supply capabilities in the summer of 2011. Electricity-saving measures are promoted in offices today for both environmental and safety reasons, and indoor office environments have changed greatly. This paper aims to reveal to what extent workers' awareness of electricity-saving has changed since the earthquake disaster had an impact on energy consumption and productivity. The authors have conducted continuous fieldwork and questionnaire surveys in seven electricity-saving office buildings in the summers of 2011–2013. Additionally, our laboratory's past research data were collected together and analyzed. The results show that excessive indoor air temperatures, such as 28 °C, were avoided, and the desk level illuminance greatly decreased, from 750 lux to around 400 lux, after the earthquake. People learned to implement electricity saving in a proper way that does not spoil workers' comfort, and workers' acceptability zone for the indoor environment was extended by the experience of electricity-saving. Moreover, when we compared individual differences in the way environmental information is perceived, it was shown that differences in the workers' awareness of electricity-saving had a more profound effect on their satisfaction with the indoor environmental quality than those in their gender or age. Mechanical power-saving is definitely important; however, building devices that induce the occupants' energy-saving actions are vital. Our results will be considerably useful to other countries, whether or not they experience a natural disaster.

1. Introduction

1.1. Towards a focus on worker-centered concerns

A boost in environmental-friendly and moderate economic activities is needed in order to maintain a sustainable society in Japan and the quality of life for future generations. This research focuses on how much the change in workers' awareness of saving electricity affects energy saving, workers' comfort, and productivity in the context of the changes caused by the 2011 Great East Japan Earthquake.

People spend about 80–90% of their time indoors, and scientific studies have determined various comfort and health effects associated with the characteristics of buildings, ventilation and air conditioning systems, and the indoor environment [1]. Therefore, the aspects of not only energy savings, but also “workers,” are critical in evaluating office space in buildings. There has actually been a shift in the direction of scientific research from a focus on the energy use and environmental performance of buildings towards a focus on human-centered concerns (in this research: worker-centered concerns), as outlined in the paper by Steemers [2]. What is more, in the past, most thermal comfort questions about buildings and building designs were addressed by applying instrumental observations or simulations of indoor climate parameters to predictive models of human thermal comfort. However, in the last few decades, field studies involving large samples of actual occupants in real buildings have highlighted the shortcomings of such models [3].

Still, it is said that if the workers' satisfaction with the indoor environment decreases, then their productivity will also decrease, as discussed in more detail below. Parsons defines productivity as the extent to which activities result in the achievement of system goals [4], and this is related to office economy. Seppänen and Fisk [5] studied the relationship between air temperature and productivity, and showed that maximum performance was observed at 21.6 °C. Tanabe et al. [6] reported that raising the indoor air

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http://dx.doi.org/10.1016/j.buildenv.2014.09.022
0360-1323/

temperature by 1.0 °C, from 25.0 °C to 26.0 °C, would lead to a reduction in performance of 1.9%, from a regression model of the indoor air temperature and call response rate. In addition, our group reported that the cost of maintaining performance, namely avoiding fatigue, is important in evaluating and predicting productivity [7]. That is to say, we acknowledge that the thermal environment affects physiological and psychological processes, which may in turn affect performance and overall productivity. Moreover, Haneda et al. [8] reported that the percentage of workers dissatisfied with air quality was higher in higher temperatures and in lower ventilation, and a vote about the relationships between task performance, satisfaction with the indoor environment, and the level of fatigue was obtained. In contrast, de Dear and Brager [9] suggest with their adaptive comfort theory that optimum productivity can be attained over a wider range of indoor temperatures.

However, no conclusive studies have been conducted about how the change in workers' awareness of saving energy affects their productivity or energy saving practices. Additionally, previous studies generally have been conducted under normal conditions, and few field surveys have been conducted under special conditions, like after a large disaster. Actually, workers' levels of satisfaction and their behaviors may change in response to large disasters, such as the Great East Japan Earthquake, and little study has been conducted about such adaptive behavior in the workplace.

1.2. Change of office environment in Japan caused by the 2011 Great East Japan Earthquake

The Great East Japan Earthquake occurred on March 11th, 2011, which was the most powerful earthquake ever to hit Japan, with a magnitude of 9.0 on the Richter scale. The earthquake caused widespread damage to infrastructure and led to a 15% peak-power reduction in and around Tokyo, the capital city [10]. Electricity-saving measures are promoted in offices on environmental and safety grounds today [11], and office indoor environments have changed greatly. In the summer of 2011, just after the Great East Japan Earthquake, we conducted field surveys to investigate the effects of electricity-saving in five office buildings in Tokyo. This study varied indoor environmental parameters (luminance, room temperature, and outdoor air supply rate) in target floors to investigate these parameters' effects on comfort and productivity. Lowering illuminance was found to be a more effective strategy for electricity-saving than increasing the set-point of the temperature, without having a negative effect on satisfaction. Also, it was found that most workers were positive about saving electricity, but self-estimated productivity was 6.6% lower than in the summer of 2010 [12].

About three summer semesters have passed since the earthquake. We surveyed electricity-saving offices from 2011 to 2013 in order to investigate how these offices may have changed; in particular, we investigated how the indoor environment and workers' awareness have changed.

This paper aims to reveal to what extent workers' awareness of saving electricity has been changed by the Great East Japan Earthquake and its impact on energy consumption and productivity. In addition to our three years of surveyed data, we also collected our laboratory's past research data and analyzed it in conjunction with our field data. The results of this study will be considerably useful for other countries, whether or not they experience such a natural disaster.

2. Methods

We conducted continuous field and questionnaire surveys in seven electricity-saving office buildings in the summers of 2011–2013. Also, we collected our laboratory's past research data (15 buildings, 17 cases: 2003–2012), and analyzed it together with our field data. We have not continuously measured all buildings for many years. This means that the measured buildings and measurement period of the data are almost all different, and, of course, respondents are different, too. However, the measurements, questionnaire items, and survey methods were almost the same throughout all investigations. We only used the data to investigate the indoor environmental quality (IEQ) and workers' feelings toward the IEQ at that time, and to compare that data to the other measurement period.

2.1. Outline of buildings

Table 1 lists the characteristics of these buildings. All cases were studied in the Kanto area comprised of seven adjacent prefectures, including Tokyo, which plays a key role in the politics and economy of Japan. This area is 32,423.90 km^2 in total, and about one-third of the total population of Japan (42,598,300 people) is concentrated there. The GDP in the Kanto area was 199,993,380 million yen in 2011 [13], making it a huge economic zone. All buildings we surveyed are located in this area, where a 15% peak-power reduction was carried out in the summer of 2011. All buildings had functioning air conditioning systems (HVAC), as the studies were carried out during the hot and humid summer season. The surveyed periods are from 2003 to 2013, and each study case is numbered, from No. 1 to No. 60, in chronological order.

The seven electricity-saving office buildings surveyed are labeled as follows: Building L, M, N, O, P, Q, and R. In the 2011 study of case Nos. 16–19, 20–23, 24–27, 28–31, and 32–35, as mentioned above, we varied the temperature, illuminance, and ventilation rate of the target office floors in order to find relationships between each environmental parameter and workers' awareness of saving electricity. We counted each environmental condition as one case. In case Nos. 52 and 60, we conducted the questionnaire survey only and asked the occupants for their overall feelings about saving electricity without taking any physical measurements or carrying out satisfaction assessments. Further, we analyzed the energy data of Building N, which is equipped with the Building Energy Management System (BEMS).

2.2. Physical measurements and representative days

Physical conditions were recorded over long and short time periods. Table 2 shows the variables measured over long time periods and the representative days. For analysis, we selected representative days depending on the number of questionnaire respondents and outdoor air temperature. Data from Tokyo meteorological stations close to these buildings were used to represent outdoor conditions. Air temperature and relative humidity were recorded at several points on each floor of the buildings depending on the size of the floor. Average values for these variables during office hours (namely 9:00–17:00) were calculated for analysis. Detailed measurements of vertical temperature distribution, air velocity, noise level, occupancy rate, and occupants' behavior were also conducted on the representative day as a part of these cases. The percentage of occupants participating was high in almost all cases.

2.3. Questionnaires

Questionnaire surveys for office workers were conducted to investigate the workers' comfort and productivity. In the studies of Buildings L–R, which were surveyed from 2011 to 2013, we also asked workers about means and awareness of saving electricity.