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Analysis of the impact of regional temperature pattern on the energy consumption in the commercial sector in Japan

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ABSTRACT

We conducted this study to clarify the impact of regional climatic conditions on the energy consumption in the commercial sector, in Japan. For this research, we utilized the Database for the Energy Consumption of Commercial Buildings (DECC), which provided data on the individual buildings. The existing energy consumption pattern derived from the individual building data seems to have large variations depending on climatic conditions. Therefore, in this research, connections were made between the seasonal fluctuations in energy consumption as well as the seasonal temperature changes, in order to extract the components of variation due to temperature, and make a regional comparison. In addition, we prepared estimating equations for the energy consumption based on temperature. By applying the regional temperature data to these equations, the impact of temperature alone was extracted for comparison. The results showed that, for the types of buildings addressed in this research, even though there is a regionality to the ratio of increments during summer and winter with regard to heating and cooling, it is offset by summing them up. In this research, we were able to roughly determine the level of fluctuations in the energy consumption as an impact of temperature.

1. Introduction

In recent years, it has become clear that there is an urgent need to develop a low-carbon society as a countermeasure to global warming [1]. Then, with regard to medium- and long-term measures to address global warming in Japan, it is important to understand the trends in fossil fuel consumption and CO_2 emissions. There have been an increasing number of situations where local government policy-makers have been called to ascertain CO_2 emissions and formulate reduction plans for their regions. For this reason there is a need to further improve the basic data and estimation methods. Since the majority of CO_2 emissions in Japan originate from energy consumption [2], it is essential to conduct a factor analysis, and forecast the energy demands, in order to design and evaluate a low-carbon society. In particular, CO_2 emissions due to the energy consumption in the building sector are closely connected with the urban activities of human beings, and hence, an accurate grasp of the current situation is crucial for studying the low-carbon society [3,4].

Moreover, since the Great East Japan Earthquake, topics such as a stable supply of energy and energy conservation during power peaks have become important policy issues at the district level. To achieve these goals together with the reduction of CO_2 emissions, thorough efforts will have to be made to make the energy supply and use, more efficient. In addition, liberalization of low-voltage retail power in Japan began in 2016, and many new power producers and suppliers are entering the power market alongside existing electric companies. Incremental implementation of the Building Energy Efficiency Act began in 2016, and local energy demand forecast and assessment of local conditions are becoming increasingly important. As statistical information on energy consumption has been considered as basic information in the industrial sector, long-term statistical information has been prepared for the sector through the Current Survey of Oil Consumption in Commerce,

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Mining and Manufacturing [5]. However, in the building sector, the preparation of public statistical information has not kept pace with the growing importance of the sector.

The building sector is divided into the commercial sector and the residential sector. The forms of energy usage in the residential sector are comparatively homogeneous and multiple large-scale studies have been conducted in this sector [6–9]. Therefore the actual energy consumption situation is fairly clear. In the commercial sector, however, the energy use and the types of buildings are more diverse than in the residential sector [10]. Hence, it is more difficult to understand the actual situation. For this reason, the need for a detailed field survey and database has been mentioned, for the commercial sector. In response to this need to understand the energy consumption of commercial sectors in detail, we have collected documents on existing surveys of the energy consumption of commercial buildings in Japan [11]. It was found that, although many surveys have been conducted in the commercial sector, there is a large variation among the documents. A number of other problems were also found; for example, many surveys are fragmentary and have not been systematically organized; there is no adequate comparison among the documents, or an adequate analysis of the factors that lead to variations; and many documents do not provide information on accuracy, reliability or validity.

We then analyzed the factors contributing to the variation among the documents [12]. We examined many factors affecting the specific energy consumption, such as secular changes, methods to calculate the heating and cooling in a district, primary energy conversion factor for electricity, and survey sample size. We then roughly clarified the degree to which the specific energy consumption can vary due to these factors. However, the actual variation in the documents was too large to be explained by these general factors.

In the building sector, the energy consumption due to air conditioning is high and is easily influenced by the ambient temperature. Therefore, it is extremely important to study the temperature fluctuations and regional climatic conditions when examining the energy demand forecast and formulating countermeasures. In addition, when using the energy consumption data, analyses are performed only for a limited study period, due to the restrictions of the data. To obtain more stable results from the analyses, the number of samples may be increased by integrating data from multiple years. In such cases, the impact of annual variations in the temperature must be clarified. Therefore, we examined methods to evaluate the impact of temperature fluctuations on the energy consumption in residences and office buildings [13,14]. Although we obtained satisfactory results for the residences in this study, a full examination could not be conducted for the office buildings, due to insufficient data. The existing data does contain some instances that present specific energy consumption, which can be used for comparison between the corresponding regions (e.g., Hayakawa and Komine [15,16]). However, these data show a large variation, due to the differences in the survey methods and the differences in the climatic conditions among survey years. Thus, clear trends in the climatic conditions could not be identified. In reality, the specific energy consumption for each area is influenced by various regional conditions, such as the size of the cities and the urban density, in addition to the climatic conditions. Hence, to gain a comprehensive understanding, these factors should be examined separately. In Japan, since large cities are concentrated in relatively warm areas, indirect correlations can occur. Hence, a simple comparison of the energy consumption data among areas cannot, on its own, differentiate the effects of climate from those of urbanization. In particular, there have been some cases in which the specific energy consumption was utilized to obtain an estimation of energy consumption at the municipality level. The different factors should be understood completely, and the specific energy consumption data should then be established for each area.

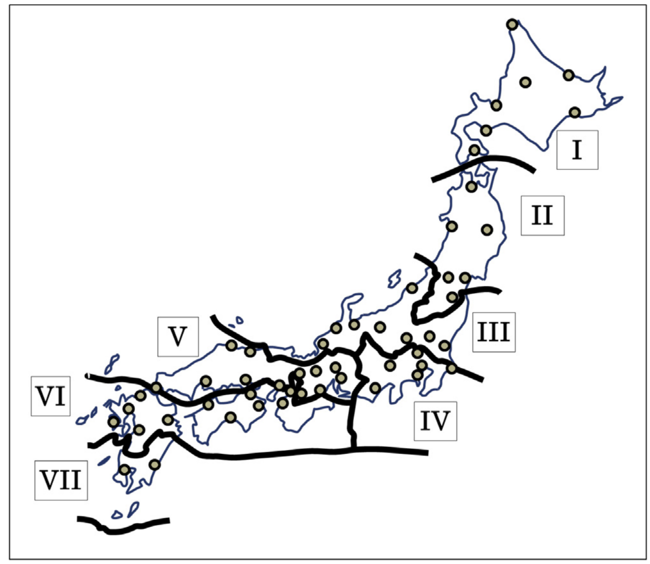

Fig. 1. The distribution of the regions for the study. Solid circles indicate the sites for the observation of air temperature.

Given this background, we examined the impact of regional temperature conditions on the energy consumption of commercial buildings. For target building types, we selected buildings used as offices, mercantile department stores, lodges, and healthcare facilities. In this research, in order to compare the electrical power and gas/kerosene equivalently for fossil fuel consumption, an analysis of the primary energy consumption was conducted. The conversion coefficient for the electric power at daytime was taken as 9.97 MJ/kWh, while for the electric power at midnight, it was taken as 9.28 MJ/kWh. For this research, the specific energy consumption is defined as the amount of energy consumed per standard unit of the floor area.

2. Materials and methods

2.1. Data sources and the target area

In this research, we used the energy consumption data from the Database for the Energy Consumption of Commercial buildings (DECC) by the Japan Sustainable Building Consortium [17]. This database has been used in many research projects in Japan recently [18–23]. In our previous research for office buildings [14], we had used the completed facility data (ELPAC data) by the Japanese Association of Building Mechanical and Electrical Engineers [24]. However, since the ELPAC data mainly concentrate on large cities, for the other cold and warm regions where the climate differs significantly from the cities, a sufficient number of samples could not be obtained for the analysis. Besides, the survey for ELPAC does not include buildings with a total floor area of less than 2000 m^2, leading to some bias. Therefore, in order to avoid these problems, we selected the DECC data for the analysis in this study. This database is not only different from the summarized specific energy consumption data, it can also be used in conjunction with data from individual building samples; thus, allowing detailed analyses based on the regional conditions and building attributes.

The distribution of the regions in this research is shown in Fig. 1. Although the landscape of Japan was divided into 12 regions (A – L) in the original DECC data, we integrated them into 7 regions for this research.