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Energy planning of university campus building complex: Energy usage and coincidental analysis of individual buildings with a case study

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ABSTRACT

As the demonstration of eco-communities, energy planning becomes more and more important for university campus. However, insufficient energy use data accumulation has been a significant barrier against fully understanding of energy use characteristics, and demand load features of campus buildings, which usually provide the basic support for energy planning from the demand side. A methodology to reveal the features of demand load and energy use of campus building was developed for this purpose. As a case study, both the long-term and real-time data of the electricity, heating, and water usage of a Norwegian university campus were analyzed by the descriptive statistics. On this base, coincidence characteristics of energy and water usage of the entire campus were analyzed, and individual coincidental rates to the campus were also quantified accordingly. The coincidence factors were calculated to be at high levels, which implied that the campus buildings' usage of energy was quite similar to that of water. Finally, the individual coincidental contribution to total campus energy use was analyzed by the cluster analysis, to identify those buildings with the large potential of operation optimization. The results from this study could be used for the energy planning of cities and other urban energy systems.

1. Introduction

In recent decades, there has been a growing interest in reducing energy use and related greenhouse gas emissions in the building sector. Playing an important role in learning about the efficient energy planning of future urban energy systems and smart cities, many university campus buildings aroused various increased concerns about policy, education, the technologies of environment and energy conservation, and other related issues, as in [1–4]. Remarkably, the significant increased interest in the energy sustainability of university campuses has arisen since the release of the European Directive on Energy Performance of Buildings (EPBD) [5].

Understanding the energy use of university campuses other than individual educational or research buildings is an important precondition of understanding how to improve the energy efficiency and make a good energy planning of campus building complexes [2,6]. Bonnet et al., developed a tool allowing the diversity of activities and end-uses of electricity and water to be addressed when analyzing energy demand and the environmental impact on a campus [7]. Through a case study, Ó Gallachóir et al., explored the use of simple performance indicators, energy trends and in particular the assessment of building energy performance [8]. Agarwal et al., presented data collected from four selected diverse buildings from residence halls to data centers, and indicated that 'mixed-use' buildings with the energy use of IT equipment accounted for more than a quarter of the total energy use [9]. Hong et al., selected the sixth largest energy consuming university in Korea and analyzed its energy use pattern. An optimized limitation of future energy use by forecasting the trend of growing use was established after examining the kinds and quantities of energy installations being utilized in campus buildings [10]. Hawkins et al., used an artificial neural network (ANN) method for analyzing a wider range of energy use determinants on London university buildings. The electricity use was found to be generally high and heating fuel use was low relative to the Chartered Institution of Building Services Engineers (CIBSE) TM46 benchmarks for the university campus category for University Occupied Buildings (UOB) [11]. Deshko et al., demonstrated the possibilities and problems of using certification to determine the university campuses' (UCs) energy efficiency measures [12]. Zhou et al., carried out a detailed investigation in the form of questionnaire for the energy use of colleges and universities in Guangdong Province of China, including electricity, water, gas, and cooling energy use over six years. The

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survey indicated that there is a great difference in per unit energy use between different types of universities classified by schools' discipline, nature, and level [13]. Escobedo et al., estimated energy use and related GHG emissions for the buildings and facilities of the main university campus at the National Autonomous University of Mexico (UNAM). A scenario analysis for 2020 was also developed, estimating baseline and mitigation scenarios that included energy efficiency technologies and solar water heating [14]. Chung et al., conducted an on-site survey of existing university buildings to determine their current energy use patterns and energy saving strategies for improving their energy efficiencies [15].

Although these studies have been useful to understand the energy use characteristics of actual campuses and individual buildings, a systematic analysis to reveal the energy use features of the campus communities from the demand side, so as to support the energy planning, has not been established yet, including the methodology and case studies. Both long-term and real-time energy use data of the campus buildings are too insufficient in current research to analyze the saving potentials under actual conditions (e.g. building stock size, building floor area, single or multi-function individual buildings, and occupancy level) from the perspective of the energy planning of the entire campus. The important features of energy planning of the entire campus, such as coincidence factor were not investigated in depth, which need to be taken into considerations accordingly. More importantly, for the purpose of optimizing the energy planning strategies of the entire university campus, some key indices, such as the contributions of individual buildings to the energy peak load of the entire campus need to be figured out to build proper evaluation and prediction models based on the abundant monitoring data.

For this purpose, this study intends to focus on as following:

A methodology is developed to reveal the energy use characteristics of university campus buildings stocks from the perspective of energy planning. In this methodology, some indices are developed and the descriptive statistics are used to reflect the campus building characteristics and the energy use features of both entire campus and individual buildings. Coincidental factor is developed to explore the hourly load profile to the total peak of campus building stocks, and cluster analysis is used to figure out the load feature of different building groups and hence provide data support for energy supply and optimal operation of this campus community.

One university campus in Norway is selected as the case study, and the energy use characteristics of this campus building are analyzed by this methodology, to verify the feasibility of this methodology.

2. The methodology

The energy use characteristics of campus buildings are the fundamental information, for a good campus energy planning. In order to make a comprehensive understanding of energy use of campus buildings from the demand side, a research methodology is developed in the following three main steps, in order to elaborate the features of energy use and demand load of campus buildings, as shown in Fig. 1.

Step 1: the basic building information, such as the building stock size, building function, construction year, floor area, and the thermal performance of envelopes, should be collected. Besides that, in order to fully master the actual energy use situation of entire campus and individual buildings, the energy use indices, such as the hourly/daily/monthly/yearly energy use amount and energy use intensity are developed, and both the long-term and real-time energy use data of entire campus and each type of campus buildings should be collected and analyzed. Descriptive statistics and comparative analysis are the useful approaches to achieve this.

Step 2: to provide a good evidence for a reasonable design of the capacity of electric network and the optimal operation of the energy supply system, two main indices, including coincidence factor for the entire campus and coincidental rate of each individual building to the campus peak loads are calculated to reveal the campus load characteristics from the perspective of energy planning.

Step 3: to identify those buildings with the large potential of operation optimization, cluster analysis is used in terms of their actual building energy use characteristics, and coincidental contributions to the campus' energy usage.

Based on the analysis in the above three steps, a comprehensive understanding of the characteristics of both energy use and demand load can be achieved, which provides a good support for the energy planning. In this study, we took one Norwegian university campus as a case study. This methodology is used to analyze the key features of energy use of the campus building stocks.

3. Energy and water usage characteristics of campus buildings

Following Step 1 of the methodology in Fig. 1, the characteristics of campus buildings, energy use characteristics of entire campus and energy use characteristics of individual buildings are analyzed in this part.

3.1. Basic information of the targeted campus

The campus consists of 35 buildings, with a total area of approximately 300 000 m^2. Within the university the following main building types were included: office, education, laboratory, and sport facilities. Most of them are multi-functional buildings. Among them, these research buildings could be categorized into two subtypes by discipline: Engineering & Technology (E&T) buildings and Art & Science (A&S) buildings. Table 1 shows the basic information of the 24 targeted buildings, including building number, construction age, main function, and gross area. It can be noted that most of the buildings have laboratories, which might indicate possible high energy use [7]. Most buildings were built before the year 2000, and the buildings built in 1960 and 1970 occupy the large part, as shown in Fig. 2(a). Fig. 2(b) shows the U-values of the exterior walls are mainly in the range of 0.4–0.6 W/(m^2*K), which are provided from the energy certificates for the buildings. This fact might indicate that many of these buildings fail to comply with current building energy use regulation, which requires 0.18 W/(m^2*K) for exterior wall in TEK10 standard.

The campus is supplied with three main resources: (1) heating for space heating and domestic hot water, (2) electricity, and (3) fresh water. In this study, the first two parts were discussed as the main energy resources on this campus. In the meantime, as the third part, fresh water use, mostly supplied for domestic water (such as sanitary cold and hot water demand), could be one possible indicator of occupants' activities and analyzed as a contrast of potential energy use characteristics.

Building Energy Management System (BEMS) and a web-based Energy Monitoring System (Schneider Electric, Germany) were utilized for collection of the data on the building system and operation. Besides the total energy and water usage of the entire campus, the real-time data of electricity, heating and fresh water of 24 buildings were intensively monitored in this study. Forty-six heating meters, 79 electricity meters and 43 water meters were installed on the campus. Hourly data of electricity, heating and water usage could be collected online via a web-based Energy Monitoring System. Six-year data from the years of 2008–2013 were collected for the analysis in this paper.