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3 **Energy planning of university campus building complex: energy**
4 **usage and coincidental analysis of individual buildings with a case**
5 **study**

6 Jun Guan^a, Natasa Nord^b, Shuqin Chen^{c,*}

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8 ^a School of Energy and Power Engineering, Nanjing University of Science &
9 Technology, Nanjing, 210094, China

10 ^b Department of Energy and Process Engineering, Norwegian University of Science
11 and Technology, NO-7491 Trondheim, Norway

12 ^c College of Civil Engineering and Architecture, Zhejiang University, Hangzhou
13 310012, China

14

15 * Corresponding author. Tel.: +86-13750862640; E-mail addresses: hn_csq@126.com
16 (S. Chen), guanjun@njust.edu.cn (J. Guan), natasa.nord@ntnu.no (N. Nord).

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

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.

Keywords: University campus; building complex; energy use; coincidence factor; energy plan; case study

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. (2002) 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. (2007) explored the use of simple performance indicators, energy trends and in particular the assessment of building energy performance [8]. Agarwal et al. (2009) 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. (2011) 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. (2012) 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. (2013) demonstrated the possibilities and problems of using certification to determine the university campuses’ (UCs) energy efficiency measures [12]. Zhou et al. (2013) 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 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. (2014) 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. (2014) 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:

- 1) 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.

2) 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 m². 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 sub-types 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/(m²*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 0.18W/(m²*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 primary energy supply 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 analysis in this paper.

3.2 Energy and water usage of the entire campus

Table 2 illustrates the total annual specific energy and water usage of the entire campus in six recent years (2008-2013). The average values of annual energy use were 30 343 MWh for heating, 60 070 MWh for electricity, and 120 129 m³ for fresh water. Consequently, annual energy use per building area was calculated to be 99±14 kWh/(m² a) for heating, 197±9 kWh/(m² a) for electricity and 0.39±0.03 m³/(m² a). The total annual electricity and water usage were at slightly elevated levels over time, potentially due to occupants' increasing demand. In contrast, the total annual heating use evidently decreased since the district heating network had been retrofitted in 2011.

Fig. 3 shows the monthly variation of the campus energy and water usage in six recent years (2008-2013). It indicates that electricity, heating and water usage was significantly lower in the summer (e.g. July and August) than in other seasons. However, the distinct decrease of energy and water usage in July might be attributed to lower occupancy, because there were no courses and few laboratory activities took place during these two months. Note that there was distinctly low heating use needed at this period due to seasonal factors. In contrast, the peak values of heating use only occurred in winter, especially in December and January. It seems mostly due to the seasonal impact on heating use.

Fig. 4 further shows the comparison of the campus total daily energy and water usage on weekdays and at weekends in a typical month. A logarithmic coordinate was introduced for the Y axis to present electricity, heating, and water usage in the same plot. All daily data sets for electricity, heating, and water usage in the observed month were collected, respectively. The results in Fig. 4 indicate that there were more evident differences between weekdays and weekends for water usage due to the largest relative differences of the values and the least deviations compared to electricity and heating usage. It could be inferred that high occupancy in weekdays might contribute to the high water usage rates of the campus. For electricity use, lower relative deviation between weekdays and weekends indicated similar operation patterns for electric facilities between weekdays and weekends, which might be attributed to most of the laboratory-type of facilities being operated continuously in general. Furthermore, notice that facilities in public areas such as lights, coffee machines and other service devices, which were always kept under operation, also contributed to the small difference between weekdays and weekends. In contrast, heating use both on weekdays and at weekends varied distinctly, while the difference between total daily heating use on weekdays and weekends was found to be less, compared with the usages of electricity and water. Further continuous operation patterns of heating facilities on weekdays and at weekends might contribute mostly to the less difference of the total daily heating use for the demands of laboratories and indoor thermal comfort.

For more details, Fig. 5 shows the comparison of the hourly profiles of energy and water usage for the entire campus, including average values and deviation within one typical month. The hourly data sets for electricity, heating, and water usage in November 2013 were selected in this example as always one typical month of each year. It indicates that higher electricity and water usage commonly occurred in working hours (from 8:00 am to 6:00 pm) than those in non-working hours (from 6:00 pm to 8:00 am). Notice that there was remarkable variation of heating use both in working days and hours in Figs. 4 and 5. This indicates that the campus' heating use varied within one month and even one day, which might largely be attributed to the

dispersive occupancy of laboratory facilities and the occupants' demand for heat all the time on weekdays and at weekends. In contrast, Fig. 5 also illustrates that electricity and water usage consistently showed fewer changes (RSD (relative standard deviation) $\leq 25\%$) in the lesser occupancy during the non-working hours of workdays and weekends. Accordingly, it can be inferred that the baseline of electricity and water usage at lesser occupancy could be obtained so as to maintain the basic operation of this campus.

3.3 Energy and water usage of individual buildings

Fig. 6 shows the main frequency contribution of energy and water usage of all the targeted individual buildings. The heating, electricity, and water usage of those buildings (N=24) were included during the years of 2011-2013. The main distribution commonly varied at levels of 100-150 kWh/(m² a) for electricity, 50-100 kWh/(m² a) for heating, and 0-0.5 m³/(m² a) for fresh water. Fig. 7 further shows the specific electricity, heating, and water usages of all the targeted campus buildings by floor area. The majority of the buildings had an area under 20 000 m², and the specific heating and electricity usage was lower than 300 kWh/m² with the exception of a few buildings with laboratories, such as Buildings 8# and 10#; see Table 1. In contrast, the specific water usage was commonly below 2 m³/(m² a), except for Building 4# (2 215 m²), which, for education and research in the metallurgy discipline, was served by some high water-use laboratory facilities. It seems that above specific buildings with high energy or water usage could be considered to have considerable potential for energy or water savings. Higher energy or water usage might be attributed to increased capacities for ventilation, sanitary water or other specific demands, typically for laboratory facilities. Furthermore, for a few buildings with abnormally large area, such as Building 24# (52 773 m², See Table 1), as a natural science building, the energy and water usage was not significantly higher (200 kWh/m² and 279 kWh/m², and 0.36 m³/(m² a) for averaged annual electricity, heating use and water use, respectively). It seems that large floor area did not greatly contribute to the energy and water usage of individual buildings. Instead, some specific buildings, especially for the buildings with E&T or A&S laboratories (such as 8# and 16#, also see in Fig.

7), could be more related to higher energy and water usages in this study.

For further impact analysis on the energy and water usage of building function four buildings (1#, 8#, 16# and 19#, as shown in Table 1) were chosen as typical buildings in this campus, including an office and education building (1#), two office and laboratory buildings (8# and 16#, chosen as one E&T and one A&S building, respectively), and a sports building (19#). These four buildings presented high energy and water usage levels likewise. Fig. 8 shows the monthly energy and water usages of these buildings in the years from 2011 to 2013. The results indicated that, similar to the entire campus, the electricity and water usage of these individual buildings was present both at the highest level in winter and the lowest level in summer. It was evident that there was more significant variation in the heating usage than in the electricity and water usage. In contrast, the energy and water usage consistently remained at lower levels in July. It was inferred that there was significant seasonal impact on heating use, but much less occupancy in summer period might contribute to the lower levels of electricity and water usage of individual buildings. Furthermore, in opposition to these buildings, it could be found that the building with the highest electricity and heating usage was 8#, which was an office building with laboratories, and the lowest one was 19#, which was a sports building. As for water use, the highest was 8#, but the lowest was 1#, which was an office building for administration affairs. It was inferred that much of the difference in energy and water usage among these four buildings might be attributed to the characteristics of the building type.

In addition, the above four individual buildings were chosen for further contrast analysis of daily electricity, heating, and water usage at working time and non-working time, respectively, shown in Figures. 9, 10 and 11. The energy and water usage of these buildings in one typical month was compared on weekdays and at weekends, respectively. The results indicated that the values of energy and water usage on weekdays were slightly larger than those at weekends, especially for electricity and water usage during working hours (8:00-18:00), as shown in Figures. 9 and 11. It indicated that occupancy had a significant impact on electricity and water

usage. In contrast, the heating use might remain little changed over a 24-hour period, mostly due to the steady demand supplied by the district heating system, as shown in Fig. 10. Furthermore, the building with the highest values of daily energy and water usage was 8#, the lowest one for energy use was 19#, but the lowest one for water use was 1#; these results were similar to those of the monthly data for these individual buildings. However, notice that there was a larger fluctuation of heating use, especially at working hours of weekdays. It indicates much different heating use at the same period of different days.

A look at the standard deviations shows a large variation, and it should be possible to cluster toward the “good” individual building. This information on the standard deviation in the energy and water usage among different individual buildings was utilized to estimate the energy savings potential. For example, the difference between the average worst third energy or water usage and the total average value could be a qualitative indicator for estimating the potential tendency of individual energy or water usage in a building of the same type. In this discussion, special attention is paid to the energy and water usage of research buildings, with that sector being the most significant in terms of resource use and annual growth [7]. Table 3 shows the potential for energy efficiency improvement in the individual research buildings (N=21) except other building types of Buildings 1#, 17#, and 19#, as shown in Table 1, including E&T buildings (e.g. Building 8#) and A&S buildings (e.g. Building 16#), which comprised the main energy and water usages of the campus. The average better half, average best third, average middle third, average worst third of energy, and water usage of individual buildings were calculated. The bolded values in Table 3 showing the difference between the worst third and the total average indicate the energy savings potential in the third worst part of the campus buildings. The results indicated that the average energy and water usage for the worst third was very high and definitely needed to be reduced. The difference between the averages of the middle and the best third was not that large. Therefore, it was inferred that that there could be reasonability and potential if trying to decrease the energy and water usage of the worst third to the level of the middle third. Furthermore, notice that there might

be evidence that the worst third of E&T buildings, such as Building 8# have a different potential tendency due to their higher absolute values of difference than those of A&S buildings, such as Building 16#, as also seen in Table 3. However, more detailed information of laboratory facilities in the individual buildings needed to be involved if the quantitative potential of energy and water usage of these individual buildings was to be analyzed. Overall, potential analysis of the individual buildings in the campus was an insight of the energy use characteristics of the building complex with different functions, which could be a reference of further cluster analysis of the individual buildings on the campus.

4. Coincidental analysis of campus buildings

Based on the Step 2 shown in Fig.1, both coincidence factor of the entire campus, and coincidental contribution of individuals are used to describe the coincidental characteristics of entire campus as follows.

4.1 Coincidence factor of the entire campus

For further analysis of the usage of electricity, heating, and water, the coincidence factors of the campus were calculated by the following equation:

$$S = \frac{P_{tot,max}}{\sum_{i=1}^n P_{i,max}} \quad (1)$$

where

S - the coincidence factor of total campus energy or water use at observed years

$P_{i,max}$ - the maximum electricity load, heating load, or water use load of building i

$P_{tot,max}$ - the maximum electrical load, heating load, or water use load of the total campus use

n - the number of targeted buildings

From the above equation, this parameter reflects the conformance of energy and water usage of all individual buildings to the campus. Coincidence factors which are below 1.0 indicate that the individual maximum power, heat rate, or water flow rate do not appear at the same time. Based on hourly data of all the individual buildings in three recent years (2011-2013), the maximums of annual coincidence factors were

347 averaged to be 78.8% for electricity, 79.4% for heating, and 40.3% for fresh water
348 usage. The higher coincidence factors of electricity and heating usage indicated the
349 energy usage of individual buildings had a larger conformance to the entire campus
350 because most of buildings were research buildings on the campus. However, it also
351 implied that higher total energy use peak might be aroused accordingly, which was
352 adverse for energy planning of the campus. For water use, the lower coincidence
353 factor indicated the comparatively dispersive water use of individual buildings on this
354 campus.

355 Fig. 12 shows the calculations of daily coincidence factors of the campus energy
356 and water usage. To calculate daily coincidence factors, the hourly data within a
357 month when maximums of energy and water usage for each year occurred were used.
358 The minimum, 25% (lower quartile), 50%, average, 75% (upper quartile) and
359 maximum of coincidence factors were presented by ordination analysis, respectively.
360 The results indicated that the daily average values were 96% for electricity use, 88%
361 for heating use and 79% for water use. It could be concluded that the buildings on the
362 campus were quite similar in use, due to the high daily coincidence factors of energy
363 and water usage in this month with energy and water use peaks. Furthermore, the
364 maximums of coincidence factors for electricity, heating and water usage were 98.8%,
365 95.9% and 90.4%, respectively. However, most of the time, coincidence factors
366 commonly varied, ranging mainly from 25% (lower quartile) to 75% (upper quartile)
367 in sorted order, namely 95%-97% for electricity, 85%-91% for heating and 76%-83%
368 for fresh water. Furthermore, the values on weekdays and at weekends were
369 calculated to be 0.98 and 0.97 for electricity, 0.95 and 0.91 for heating, and 0.89 and
370 0.82 for water, respectively, which shows a very small reduction of the peak load on
371 weekends. These data can reveal the energy and water use features of the peak load of
372 the whole campus, as well as the relationship between the peak load of the campus
373 and the sum of the peak load of individual buildings. These data can support the
374 optimal operation of the existing campus, because the corresponding countermeasures
375 of demand response can be taken at the appropriate period during the operation, based
376 on these data of coincidence factor.

4.2 Coincidental contribution of individual buildings

To analyze any building's proportional contribution to the entire campus peak, the coincidental rate of the individual building to the total energy use of the entire campus peak can be defined by the following equation [16]:

$$S_i = \frac{P_i}{P_{i,max}} \quad (2)$$

where

P_i - a building's electricity load, heating load, or water use load at the time of the campus peak

S_i - coincidental rate of Building i to the campus peak at observed years. Higher coincidental rate of one building implies larger conformance of energy use to the entire campus.

Table 4 shows the calculation of the coincidental rates of each building by Equation (2). The results imply that these buildings with higher coincidental rate had larger consistency with the campus peak. However, notice that some individual buildings with higher coincidental rate alone, such as Building 1# (office building), instead contribute less to the campus peak due to the lower energy use. Likewise, some individual buildings with lower coincidental rate alone, such as Building 2# (research building) contribute more to the campus peak due to the higher energy use. Thus, it can be concluded that the coincidental contribution of individual buildings to the entire campus peak depends on two aspects including coincidental rate and energy usage amount according to the definition.

5. Identification of individual coincidental contribution to total campus energy use

5.1 Description of cluster model

To provide more detailed support for the energy planning of the entire campus building complex, the individual buildings with high coincidental contribution to the total electricity, heating, and water usage of the campus needed to be identified in a more concise way.

In that case, following the Step 3 in Fig. 1, a cluster model was applied to classify the existing similarities of each individual coincidental contribution. The cluster variables used in this analytic model refer to building floor area of the individual buildings, annual energy / water use per building floor area, and individual coincidental rate. K-means cluster method was used for the building classification. ANOVA analysis was made to check whether there is significant distinction between different groups, and the significance of the contribution of each variable to the cluster results. The values of each variable for all the building samples were standardized. The software, Statistical Program for Social Sciences (SPSS, IBM Inc.), was used for the calculation.

5.2 Cluster analysis of individual buildings

Table 5 shows the classification of all the 24 individual buildings processed by the cluster model, which were categorized into four building groups with similar individual coincidental contribution to total campus energy use for electricity use, heating use and water use respectively. Table 6 shows the ANOVA test results of the cluster models, which shows all these classifications passed the ANOVA tests.

Regarding the electricity use, Cluster I consists of 13 buildings, which occupies the main part of the targeted buildings. In Cluster I, the floor area of the buildings ranges from 2 476 m² to 17936 m², while the average electricity use amount is small and the individual coincidental rate is as high as 0.825. This indicates these buildings also have large electricity load rate when the whole campus reaches the peak of its electricity load. Buildings in Cluster III have the small values in floor area, electricity use amount, and as well as individual coincidental rate, which shows these buildings contribute to the shift of peak load of the whole campus. Buildings in Cluster II and IV have both the relatively large electricity use of 317.75 kWh/(m² a) and 200 kWh/(m² a), and high individual coincidental rates of 0.799 and 0.885, and this indicates these buildings have the large potential to reduce the peak load of the whole campus, if some countermeasures, such as the actions in energy conversation and demand response, are taken.

Likewise, for heating, Clusters I and III have the high contribution to campus peak values, with average values of , 477 and 279 kWh/(m² a) for heating use respectively, and 0,759 and 0.913 for individual coincidental rate, respectively. One individual building (Building 24#) in Cluster III was identified as having the largest potential for peak load shifting of campus heating plan. Instead, the buildings in Custer IV were identified to have smallest potential for peak load shifting of the campus heating load compared with other three groups, due to the small average values of 5961 m² for building floor area, 110.9 kWh/(m² a) for heating use, and 0.634 and 0.61 for individual coincidental rate. Cluster II, consisting of 11 buildings with the large floor area and high individual coincidental rate, becomes the main part contributing to the peak load of the whole campus.

As for water, the building in Cluster IV with the highest contribution to campus peak was categorized with average values of 2 215 m², 9.180 m³/(m² a), and 0.243 for building floor area, water use, and individual coincidental rate, respectively. Notice that this building in Cluster IV had distinctly large water use per floor area and a relatively high individual coincidental rate despite the small floor area. Buildings in Cluster I also have the large potential for the load shift as they have the large water use intensity and a relatively high individual coincidental rate. Followed by Cluster I are the buildings in Cluster II. Buildings in Cluster III have the contribution to shift the water load as they have the small individual coincidental rate of only 0.1.

6. Discussion and conclusions

This study aims to develop a methodology to fully understand the characteristics of energy and water usage of campus building stocks, from the perspective of energy planning, and based on this methodology, one case study of Norwegian campus is conducted. Long-term and real-time electricity, heating, and water in this university campus were monitored online and analyzed by statistical methods. Coincidental characteristics of both the whole campus and the individual buildings to the entire campus were emphasized. The individual buildings with the large coincidental contribution were identified to shift peak load of campus energy and water use.

The case shows that the methodology can be used to comprehensively reveal the energy use characteristics of the whole campus. These indices developed in the methodology, such as floor area, heat transfer coefficient, hourly/daily/monthly/yearly electricity/heating/water use intensity for the whole campus and individual buildings, individual and campus coincidental rate of specific building type (commonly classified by discipline, such as building with E&T laboratories), could be considered as important indicators, which would be a good reference of energy planning of new campus or other similar building stock. On this base, specific heating, electricity, and water use can be multiplied with a planned area to obtain energy and water demand. After that the demand data can be coupled with the coincidental distribution curves to find possible ranges of energy use. In that way reliable energy use data including uncertainty will be obtained. Load profiles together with the information on the standard deviation, and coincidence factors can be combined to obtained sizing parameters for energy and water planning. In that way sizing parameters including uncertainty for the heat, electricity, and water supply will be obtained. Compared with the most of the current sizing methods using only one (maximum) value for sizing, uncertainty in sizing will be easily included in this methodology. The analysis and data presented are valid for an existing university campus.

However, this is also some limitation in this methodology and the case study in this paper. For example, if the campus energy use database is established including enough universities, the possible trends in energy use can be predicted, and then the methodology can also be used for the energy use prediction and planning of new campus, while this part is not included in this methodology. Besides that note that control strategies regarding how to optimize the energy and water usage of the individual buildings were not covered in this study, which will be specially discussed in future work. Furthermore, the coincidental characteristics of entire campus and individual buildings are more related to the occupant behavior (such as occupancy time above mentioned), which are also greatly affected by the energy use management. Therefore, energy use management is also important for the energy planning. Some useful information about the specific buildings, such as the energy

saving technologies applied in the buildings, should be publicized to the occupants in the buildings. Guidelines for energy conservation measures and technologies, and energy saving working style and behavior, should be disseminated to the public. In this way, technological intervention can be realized at the building level and subsequently at the campus level, which has a big influence on urban energy planning and management. In the case study, more information on facility usage features, such as energy usage amount and working time of each facility, needs to be further quantified accordingly. In addition, for the individual buildings, the energy performance of each building could not be discussed in more detail due to the survey limitation. Sub-metering needs to be applied on each facility with high energy and water usage in order to obtain more detailed information; this was not involved in this study.

The following conclusions are drawn from this study:

1) The annual energy and fresh water use of the campus were present at slightly elevated levels over time, with average values of 99 ± 14 kWh/(m² a) for heating, 197 ± 9 kWh/(m² a) for electricity, and 0.39 ± 0.03 m³/(m² a) for water in six recent years.

2) Energy and water usage of all individual buildings mainly varied at the levels of 50-100 kWh/(m² a) for heating, 100-150 kWh/(m² a) for electricity, and 0-0.5 m³/(m² a) for fresh water. Comparison of four typical building types indicates that the difference in energy and water usage among them might be attributed to the characteristics of the building type. Some specific buildings with E&T laboratories, commonly related to higher energy and water usages, could have more potential tendency of energy savings than other buildings.

3) Occupancy had a much higher influence on the electricity and water usage of the campus and the individual buildings than the seasonal factor, but the reverse was the case for the heating use. The baseline of electricity and water usage at lesser occupancy could be obtained so as to maintain the basic operation of this campus.

4) The maximums of annual coincidence factors were averaged to be 78.8% for electricity, 79.4% for heating, and 40.3% for fresh water use. And the high

coincidence factors of this campus's energy usage verified that the campus buildings were quite similar in use.

5) The individual coincidental contribution to total campus energy use, proved to depend on coincidental rate and energy usage amount were discussed in this case. Cluster method was used to identify the building groups with the similar features of the contribution to energy and water loads to the whole campus, and those buildings with the large optimizing potential to shift the peak load of the whole campus. . The results from this study could be used for the energy planning of cities and other urban energy systems.

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Table Captions

- Table 1** The basic information on all targeted campus buildings (N=24)
- Table 2** Total annual specific energy and water usage of all the campus buildings over six years (2008-2013)
- Table 3** Potential for energy efficiency improvement in individual research buildings
- Table 4** Coincidental rate of individual building to the entire campus (N=24)
- Table 5** Classification of all 24 individual buildings by cluster model
- Table 6** ANOVA analysis

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20 **Table 1** The basic information on all targeted campus buildings (N=24)

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NO.	Construction year	Main function [*] (O/E/L/S)	Building area (m ²)	NO.	Construction year	Main function (O/E/L/S)	Building area (m ²)
1#	1910	O/E	17 360	13#	1924	O/E/L	4 116
2#	1962	O/E/L	15 026	14#	1960	O/L	5 028
3#	1965	O/L	3 030	15#	1961	O/L	17 936
4#	1951	O/L	2 215	16#	1968	O/L	12 861
5#	1960	O/E/L	7 598	17#	1910	O	3 375
6#	1966	O/E/L	11 400	18#	1981	O/E/L	3 955
7#	1958	O/E/L	12 600	19#	1966	S	4 046
8#	1954	O/L	10 206	20#	1975	O/E/L	18 175
9#	1967	O/L	5 050	21#	1951	O/E/L	5 053
10#	1965	O/L	4 510	22#	1996	O/E/L	2 476
11#	1957	O/E/L	9 277	23#	2002	E/L	4 312
12#	1965	O/E/L	9 168	24#	2000	O/E/L	52 773

22 * O: office; E: educational room; L: laboratory; S: sports complex.

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Table 2 Total annual specific energy and water usage of all the campus buildings over six years (2008-2013)

Item	2008	2009	2010	2011	2012	2013
Electricity use (kWh/(m ² a))	182	188	199	201	204	206
Heating use (kWh/(m ² a))	106	107	121	90	85	87
Water use (m ³ /(m ² a))	0.37	0.37	0.43	0.42	0.37	0.41

Table 3 Potential for energy efficiency improvement in individual research buildings

Items	E&T Buildings			A&S Buildings		
	Electricity *	Heating *	Water #	Electricity	Heating	Water
Total average	204	209	1.42	128	116	0.32
Average better half	132	107	0.33	87	76	0.26
Difference to total	35.2%	48.9%	76.9%	32.1%	34.3%	20.2%
Average best third	116	83	0.25	78	73	0.15
Difference to total	43.1%	60.0%	82.5%	38.8%	37.5%	51.7%
Average middle third	179	181	0.52	117	91	0.36
Difference to total	12.5%	13.2%	63.1%	8.3%	21.5%	-11.5%
Average worst third	318 (9#, 8#, 18#, 20#)	361 (8#, 10#, 18#, 20#)	4.18 (2#, 4#, 8#)	188 (14#, 16#, 24#)	185 (13#, 15#, 24#)	0.43 (6#, 13#)
Difference to total	-55.5%	-73.2%	-194.1%	-47.1%	-59.0%	-34.4%

* Unit: kWh/(m² a) (energy use); # Unit: m³/(m² a) (water use).

Table 4 Coincidental rate of individual building to the entire campus (N=24)

NO.	Individual coincidental rate (Si)			NO.	Individual coincidental rate (Si)		
	Electricity	Heating	Water		Electricity	Heating	Water
1#	90.2%	92.6%	19.3%	13#	51.7%	83.2%	23.0%
2#	54.7%	83.9%	43.8%	14#	89.2%	67.0%	NA
3#	39.2%	61.0%	4.8%	15#	88.0%	59.3%	11.5%
4#	68.1%	45.6%	24.3%	16#	89.4%	76.7%	40.8%
5#	75.9%	73.3%	7.4%	17#	84.1%	55.6%	9.1%
6#	71.6%	63.4%	11.4%	18#	75.2%	84.2%	16.0%
7#	85.8%	78.8%	19.8%	19#	63.3%	68.9%	15.5%
8#	86.6%	78.9%	28.2%	20#	87.7%	67.4%	60.1%
9#	70.2%	64.8%	NA	21#	56.0%	68.3%	40.3%
10#	74.4%	72.9%	45.3%	22#	77.9%	55.6%	6.1%
11#	92.0%	81.1%	1.7%	23#	81.1%	74.1%	NA
12#	72.4%	85.4%	14.3%	24#	88.5%	91.3%	51.4%

* NA: not available.

Table 5 Classification of all 24 individual buildings by cluster model

Category name	Cluster NO.	Sample size	Variable		
			Building area *	Energy/water use #	Si
Electricity	Cluster I	13	9069.3	126.9	0.825
	Cluster II	4	9346.5	317.75	0.799
	Cluster III	6	5581	127.83	0.555
	Cluster IV	1	52773	200	0.885
Heating	Cluster I	2	7358	477	0.759
	Cluster II	11	10404	147	0.8
	Cluster III	1	52773	279	0.913
	Cluster IV	10	5961	110.9	0.61
Water	Cluster I	6	10971	0.864	0.431
	Cluster II	1	52773	0.358	0.514
	Cluster III	16	7545	0.307	0.1
	Cluster IV	1	2215	9.180	0.243

* Unit: m²; # Unit: kWh/(m² a) (energy use), m³/(m² a) (water use).

Table 6 ANOVA analysis

Category name	Variables	Cluster		Error		F	Sig.
		Mean Square	df	Mean Square	df		
electricity	floor area	6.233	3	0.265	20	23.516	0.000
	electricity	5.766	3	0.335	20	17.208	0.000
	elec. Si	5.652	3	0.352	20	16.049	0.000
heating	floor area	6.388	3	0.242	20	26.42	0.000
	heating	6.349	3	0.248	20	25.641	0.000
	heating Si	5.652	3	0.352	20	16.049	0.000
water	floor area	6.336	3	0.25	20	25.394	0.000
	water	7.557	3	0.066	20	113.649	0.000
	water Si	6.454	3	0.232	20	27.822	0.000

Figure Captions

Fig. 1. The flow chart of methodology

Fig. 2. The construction year and U-values of all targeted campus buildings

Fig. 3. The monthly variation of energy and water usage of the campus in six recent years (2008-2013)

Fig. 4. Comparison of the campus' total daily energy and water usage on weekdays and at weekends

Fig. 5. Hourly profiles for energy and water usage of all campus buildings in one typical month

Fig. 6. Energy and water usage of selected individual buildings (N=24) in the years of 2011-2013

Fig. 7. Specific energy and water usage of targeted individual buildings (N=24)

Fig. 8. Monthly energy and water usage of four individual buildings of different types

Fig. 9. Comparison of daily electricity use profile of four different individual building types in one typical month

Fig. 10. Comparison of daily heating use profile of four different individual building types in one typical month

Fig. 11. Comparison of daily water use profile of the four different individual building types in one typical month

Fig. 12. Calculations of coincidence factors in the month with the peak of campus energy and water usage

Fig. 1. The flow chart of methodology

Fig. 2 (a). Building year frequency at the university campus

Fig. 2 (b). Frequency of the building U-values of the university buildings

Fig. 2. The construction year and U-values of all targeted campus buildings

Fig. 3. The monthly variation of energy and water usage of the campus in six recent years (2008-2013)

Fig. 4. Comparison of the campus total daily energy and water usage on weekdays and at weekends (Note: Logarithmic coordinate was applied on Y-axis)

Fig. 5 (a). Electricity use

Fig. 5 (b). Heating use

Fig. 5 (c). Water use

Fig. 5. Hourly profiles for energy and water usage of all campus buildings in one typical month

Fig. 6(a). Energy uses

Fig. 6(b). Water use

Fig. 6. Energy and water usage of targeted individual buildings (N=24) in the years of 2011-2013

Fig. 7. Energy and water usage of targeted individual buildings (N=24)

Fig. 8 (a). Monthly electricity use

Fig. 8 (b). Monthly heating use

Fig. 8 (c). Monthly water use

Fig. 8. Monthly energy and water usage of four individual buildings of different types

Fig. 9. Comparison of daily electricity use profile of four different individual building types in one typical month

(a). Weekdays

(b). Weekends

Fig. 10. Comparison of daily heating use profile of four different individual building types in one typical month

(a). Weekdays

(b). Weekends

Fig. 11. Comparison of daily water use profile of the four different individual building types in one typical month

Fig. 12. Calculations of coincidence factors in the month with the peak of campus energy and water usage