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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 and hence the full understanding of energy use characteristics and demand load features of campus buildings usually provide the basic support for energy planning. In this research, a methodology is developed to fully reveal the energy use characteristics of campus buildings from the demand side, and a case study of a Norwegian university campus was analyzed based on this methodology. Both the long-term and real-time data of the electricity, heating, and water usage of the campus buildings 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, both long-term and real-time energy use data of the campus buildings are insufficient 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, 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, a preliminary method in this study was developed to analyze energy use of campus buildings to better understand the energy planning of building complexes or even city. A case study of a Norwegian university campus was analyzed based on this methodology.

2. The methodology

The energy use characteristics of campus buildings are the fundamental information and also serve as the base 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 order to elaborate the features of energy use and demand load of campus buildings in the following three main aspects, as shown in Fig.1.

It is the first step to fully master the actual energy use situation of entire campus and individual buildings. In order to realize this, both the long-term and real-time energy use of entire campus and each type of campus buildings should be analyzed, besides the building characteristics. Descriptive statistics and comparative analysis are the useful approach to achieve this.

On this base, coincidental characteristics of entire campus and individuals are the important targets, which can provide a good evidence for a reasonable design of the capacity of electric network, and the optimal operation of the energy supply system as well. Coincidence factors for the entire campus and coincidental rates of individual buildings to the campus peak loads are the main parameters to reveal the campus load characteristics.

Finally, the identification of individual coincidental contribution to total campus energy use is suggested to be conducted, as it is very helpful for the identification of those buildings with the large potential of operation optimization. The cluster analysis is used to identify all the individual buildings in terms of their actual coincidental contributions to the campus' energy usage.

Based on the analysis in the above three aspects, a comprehensive understanding of the characteristics of both energy use and demand load can be achieved in the demand side, which provides a good support for the energy planning.

3. Energy and water usage characteristics of campus buildings

3.1 Basic information of the targeted campus

In this paper, the energy use characteristics of the campus building complex were analyzed by means of a case study on a Norwegian university 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 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. This fact might indicate that many of these buildings fail to comply with current building energy use regulations.

The campus is supplied with three main energy 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 m^3 for fresh water. Consequently, annual energy use per building area was calculated to be 99±14 kWh/(m^2 a) for heating, 197±9 kWh/(m^2 a) for electricity and 0.39±0.03 m^3/(m^2 a). This indicates that 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. 2 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. 3 further shows the comparison of the campus total daily energy and water usage on weekdays and at weekends. The monthly peak values of energy and water usage in 2013 were considered in this example. 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. 3 indicate that there were more evident differences between workdays and weekends for water usage due to the largest relative differences 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, similar operation patterns for electric facilities between weekdays and weekends could be found, 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 negligible. 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. 4 shows the comparison of the hourly profiles of energy and water usage for the entire campus, including variations 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 6:00pm to 8:00 am). Notice that there was remarkable variation of heating use both in working days and hours in Figs. 3 and 4. 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. 4 also illustrates that electricity and water usage consistently showed fewer changes (RSD (relative standard deviation)≤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. 5 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/(m^2 a) for electricity, 50-100 kWh/(m^2 a) for heating, and 0-0.5 m^3/(m^2 a) for fresh water. Fig. 6 further shows the specific electricity, heating, and water usage of all the targeted campus buildings by floor area. The majority of the buildings had an area under 20 000 m^2, and the specific heating and electricity usage was lower than 300 kWh/m^2 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 m^3/(m^2 a), except for Building 4# (2 215 m^2), 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, which is further discussed in this paper. 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 m^2), the energy and water usage was not significantly higher. It seems that large floor area did not greatly contribute to the energy and water usage of individual buildings.

For further impact analysis on the energy and water usage of individual buildings, four buildings (1#, 8#, 16# and 19#) were chosen from the main building types including an office and education building, an office and laboratory building, and a sports building. Of these four buildings, Buildings 8# and 16, as office buildings with laboratories, were categorized into two sub-types by discipline: Engineering and Technology (E&T) buildings and Art and Science (A&S) buildings, respectively. These four buildings presented high energy and water usage levels likewise. Fig. 7 shows the monthly energy and water usage 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 Figs. 8, 9 and 10. 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); see Figs. 8 and 10. 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; see Fig. 9. 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.

The potential in energy savings was estimated for the university campus. For individual buildings, it is hard to estimate the potential in terms of saving energy and water due to the limitation of information for the individual buildings. However, 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. 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) including E&T buildings and A&S buildings, which comprised the main energy and water usage 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 seems reasonable to try to lower the energy and water usage of the worst third to the level of the middle third. Furthermore, notice that there might be evidence that E&T buildings have a different potential tendency due to their higher absolute values of difference than those of A&S buildings. 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

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:

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

where

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

$P_{i,max}$ - the maximum electrical power, heat rate, or water flow rate of building i

$P_{tot,max}$ - the maximum electrical power, heat rate, or water flow rate 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 averaged to be 78.8% for electricity, 79.4% for heating, and 40.3% for fresh water usage. The higher coincidence factors of electricity and heating usage indicated the energy usage of individual buildings had a better conformance to the entire campus because most of the research buildings were located on the campus. However, it also implied that higher total energy use peak might be aroused accordingly, which was adverse for energy planning of the campus. For water use, the lower coincidence factor indicated the comparatively dispersive water use of individual buildings on this campus.

Fig. 11 shows calculations of daily coincidence factors of the campus energy and water usage. The hourly data within a month when monthly maximums of energy and water usage for each year occurred were used for the calculation of daily coincidence factors. The minimum, 25%, 50%, average, 75% and maximum of coincidence factors were presented by ordination analysis, respectively. The results indicated that the daily average values were 96% for electricity use, 88% for heating use and 79% for water use. It could be concluded that the buildings on the campus were quite similar in use, due to the high daily coincidence factors of energy and water usage in this month with energy and water use peaks. Furthermore, the maximums of coincidence factors for electricity, heating and water usage were 98.8%, 95.9% and 90.4%, respectively. However, most of the time, coincidence factors commonly varied, ranging mainly from 25% to 75% in sorted order, namely 95%-97% for electricity, 85%-91% for heating and 76%-83% for fresh water. It was also inferred that there were energy saving potentials for electricity and heating usage for the entire campus peak due to their large coincidence factors, which could be useful for the planning of other similar complexes.

Fig. 12 shows the comparison of daily coincidence factors for campus energy and water usage on weekdays and at weekends within one typical month with peak values of each year from 2011 to 2013. The maximum values on weekdays and at weekends for 2011-2013 were averaged for this comparison. The values on weekdays and at weekends were 0.98 and 0.97 for electricity, 0.95 and 0.91 for heating, and 0.89 and 0.82 for water, respectively. This indicated that, different from the energy and water use levels, the usage patterns of all these individual buildings were quite similar to those of the entire campus both on weekdays and at weekends. Compared to energy use, the water usage rates of all individual buildings on weekdays were relatively higher than those at weekends. This might be due to the fact that most of the research buildings with facilities for high energy use were kept in continuous operation all the time.

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]:

$$S_i = \frac{P_i}{P_{i,max}} \tag{2}$$

where

P_i - a building's energy use 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 better 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 better 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

To better understand the energy planning of the entire campus building complex, some 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, a cluster model was applied to classify the existing similarities of each individual coincidental contribution. The key independent variables used in this analytic model refer to building floor area of the individual buildings, annual energy or water use per building floor area, and individual coincidental rate. The individual coincidental contribution to total energy and water usage of the campus was taken as the dependent variable. Hierarchical Cluster and Wards Method were applied for cluster analysis in this case. Significance difference of above three continuous variables between groups was identified by using ANOVA analysis (Sig.<0.001). The software, Statistical Program for Social Sciences (SPSS, IBM Inc.), was used for the calculation.

Table 5 shows the classification of all the 24 individual buildings, which were categorized into three groups by cluster model. It indicates that, for electricity, four individual buildings (i.e. Buildings 8#, 18#, 20#, 24#) were clustered into Cluster III, with average values of 21 277 m^2 for building floor area, 309 kWh/(m^2 a) for electricity use, and 0.845 for individual coincidental rate, which indicates the highest contribution to campus peak values due to the higher electricity use and individual coincidental rate than the other two clusters. It was also inferred that these four individuals in Cluster III were identified as having the largest potential for peak load shifting of the campus electricity load. Likewise, for heating, Cluster III with the highest contribution to campus peak values, was categorized with average values of

52 773 m^2, 279 kWh/(m^2 a), and 0.913 for building floor area, heating use, and individual coincidental rate, respectively. One individual building (i.e. Building 24#) in Cluster III was identified as having the largest potential for peak load shifting of campus heating plan.

In contrast, for water, Cluster III with the highest contribution to campus peak was categorized with average values of 2 215 m^2, 9.180 m^3/(m^2 a), and 0.243 for building floor area, water use, and individual coincidental rate, respectively. Only one individual building (i.e. Building 4#) in Cluster III was identified as having the largest potential to peak load shifting of campus water plan due to the higher water usage amount and individual coincidental rate compared to other clusters. Notice that this building in Cluster III had distinctly large water use per floor area and a relatively high individual coincidental rate despite the small floor area.

6. Discussion and conclusions

This study aims to understand the characteristics of energy and water usage in one case study for the better energy planning of university campuses and building complexes. Long-term and real-time electricity, heating, and water in one university campus were monitored online and analyzed by statistical methods. Coincidental characteristics of individuals to the entire campus were emphasized from the perspective of energy planning of the campus. The individual buildings with the largest coincidental contribution were identified to shift peak load of campus energy and water plan. These results could also be a reference of energy planning of newly-built university campuses or other similar building stock.

However, control strategies regarding how to optimize the energy and water usage of the individual buildings to facilitate more individual coincidental contribution to the total energy and water usage of the campus were not covered in this study, which will be specially discussed in future work. 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/(m^2 a) for heating, 197±9 kWh/(m^2 a) for electricity, and 0.39±0.03 m^3/(m^2 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/(m^2 a) for heating, 100-150 kWh/(m^2 a) for electricity, and 0-0.5 m^3/(m^2 a) for fresh water.

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.

4) The coincidence characteristics of energy and water usage of the entire campus and the individual coincidental rates to the campus were quantified, 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 was analyzed by the cluster method, 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.

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Figure Captions

Fig. 1. The flow chart of methodology

Fig. 2. The monthly variation of energy and water usage of the campus in six recent years (2008-2013)

Fig. 3. Comparison of the campus' total daily energy and water usage on weekdays and at weekends

Fig. 4. Hourly profiles for energy and water usage of all campus buildings in one typical month

Fig. 5. Energy and water usage of selected individual buildings (N=24) in the years of 2011-2013

Fig. 6. Specific energy and water usage of targeted individual buildings (N=24)

Fig. 7. Monthly energy and water usage of four individual buildings of different types

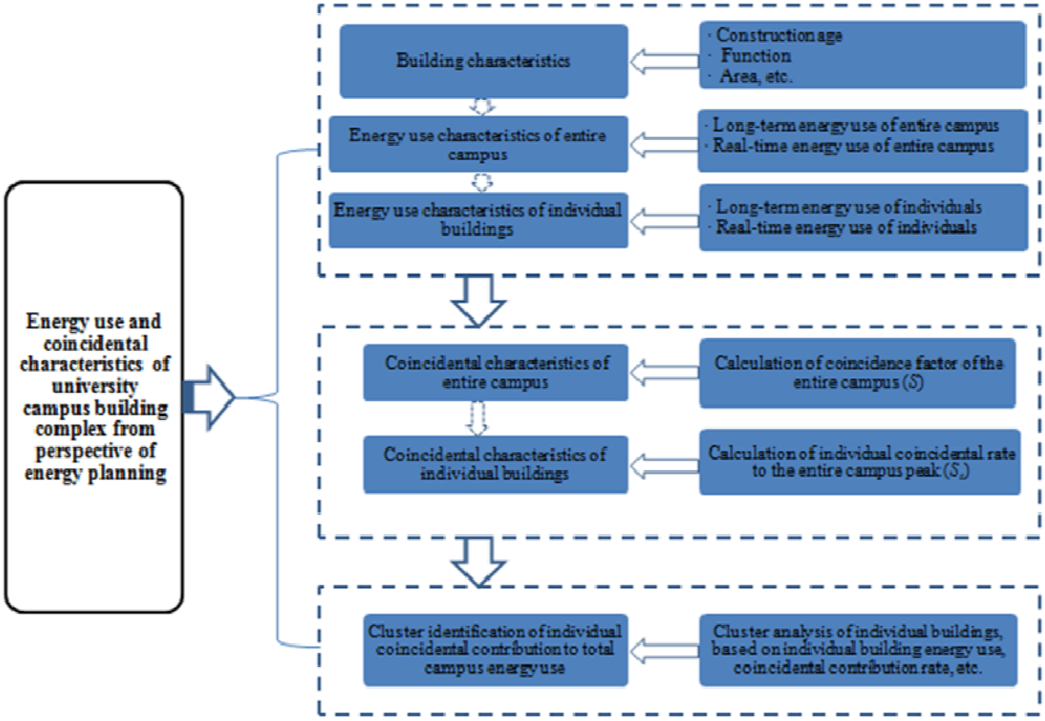
Fig. 8. Comparison of daily electricity use profile of four different individual building types in one typical month

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

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

Fig. 11. Calculations of coincidence factors in the month with the peak of campus energy and water usage

Fig. 12. Comparison of coincidence factors of campus energy and water usage between weekdays and weekends



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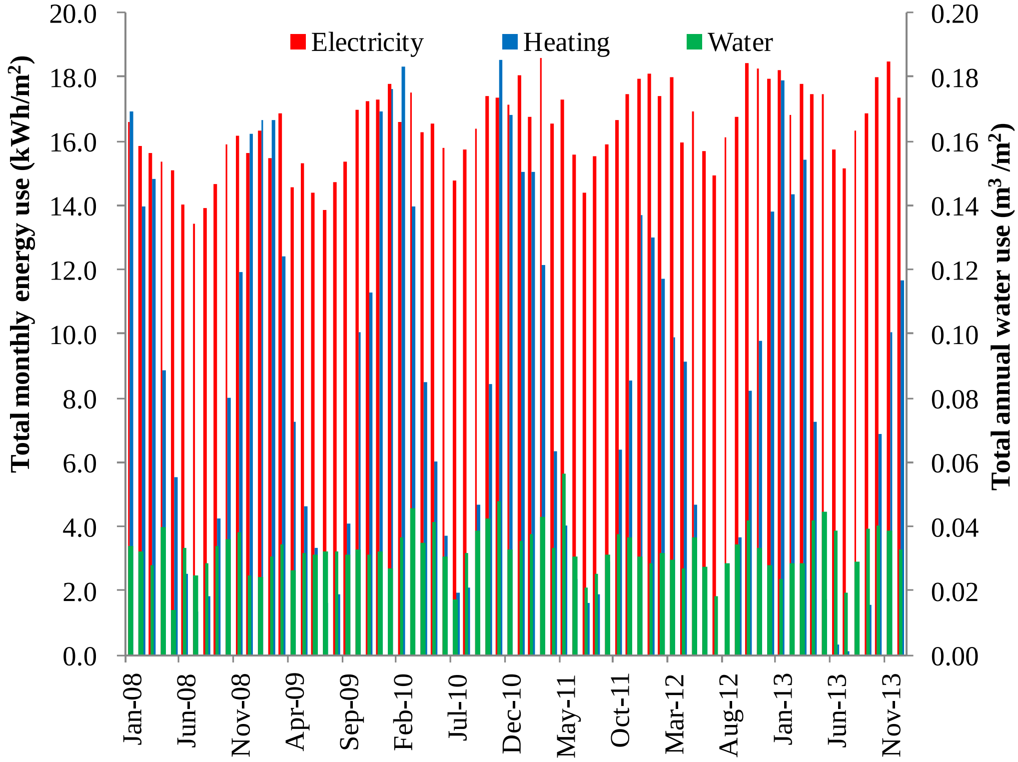


Fig. 2. The monthly variation of energy and water usage of the campus in six recent years (2008-2013)

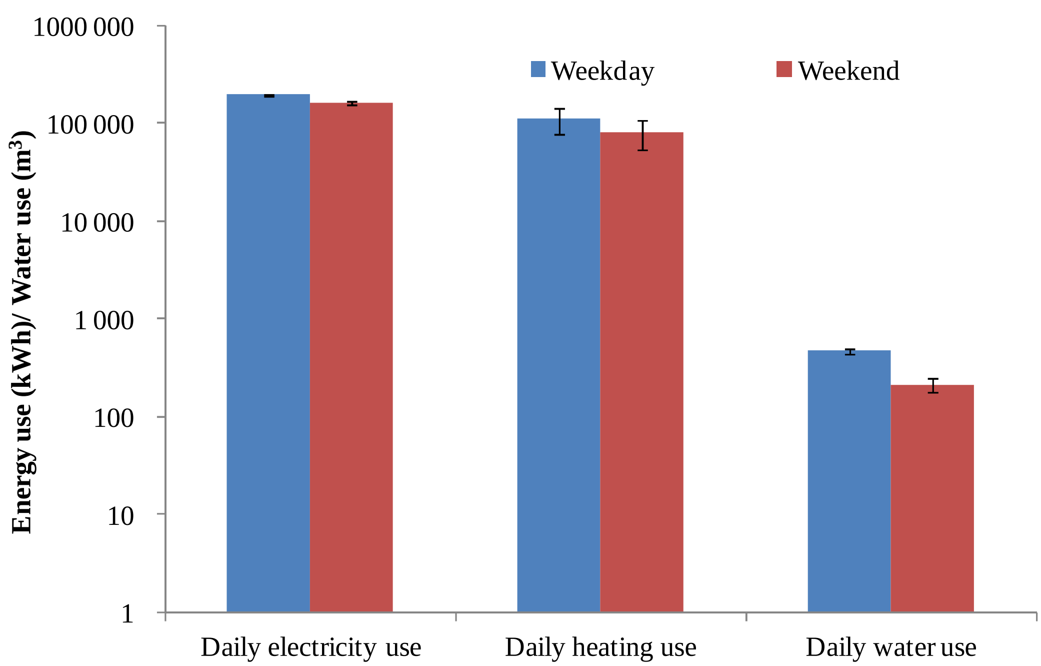


Fig. 3. Comparison of the campus total daily energy and water usage on weekdays and at weekends (Note: Logarithmic coordinate was applied on Y-axis)

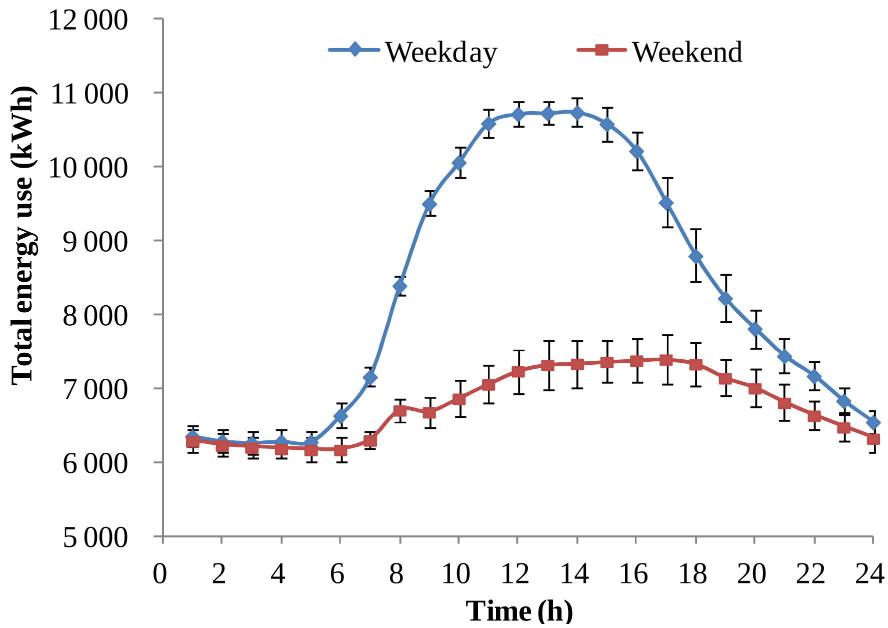


Fig. 4 (a). Electricity use

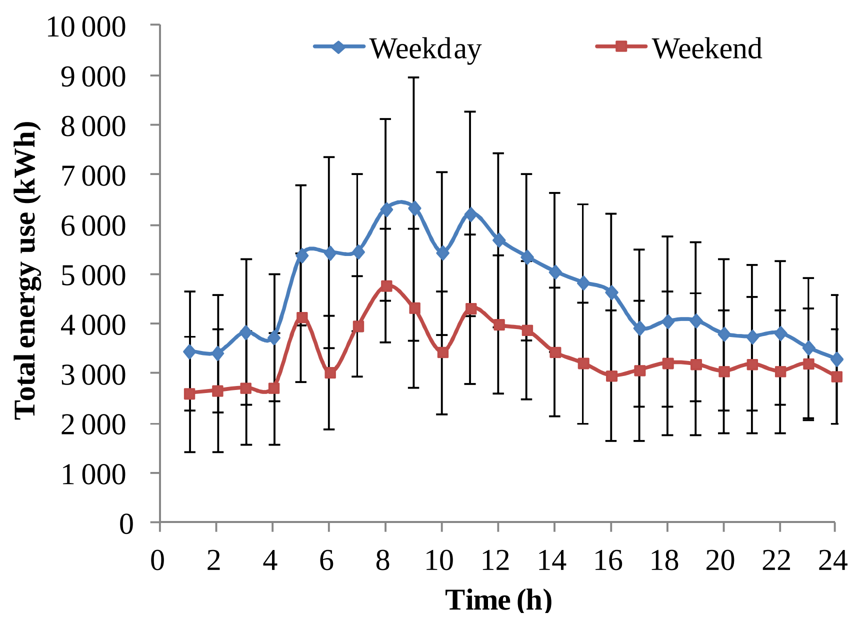


Fig. 4 (b). Heating use

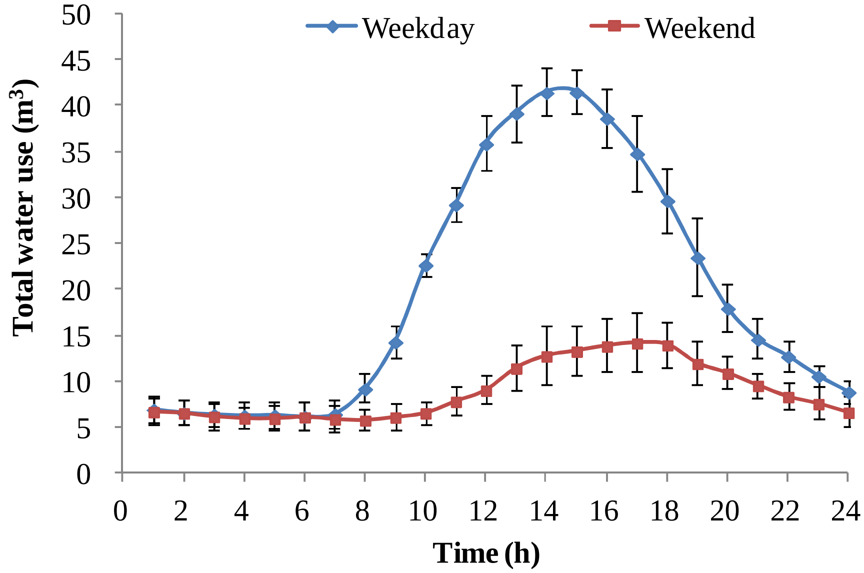


Fig. 4 (c). Water use

Fig. 4. Hourly profiles for energy and water usage of all campus buildings in one typical month

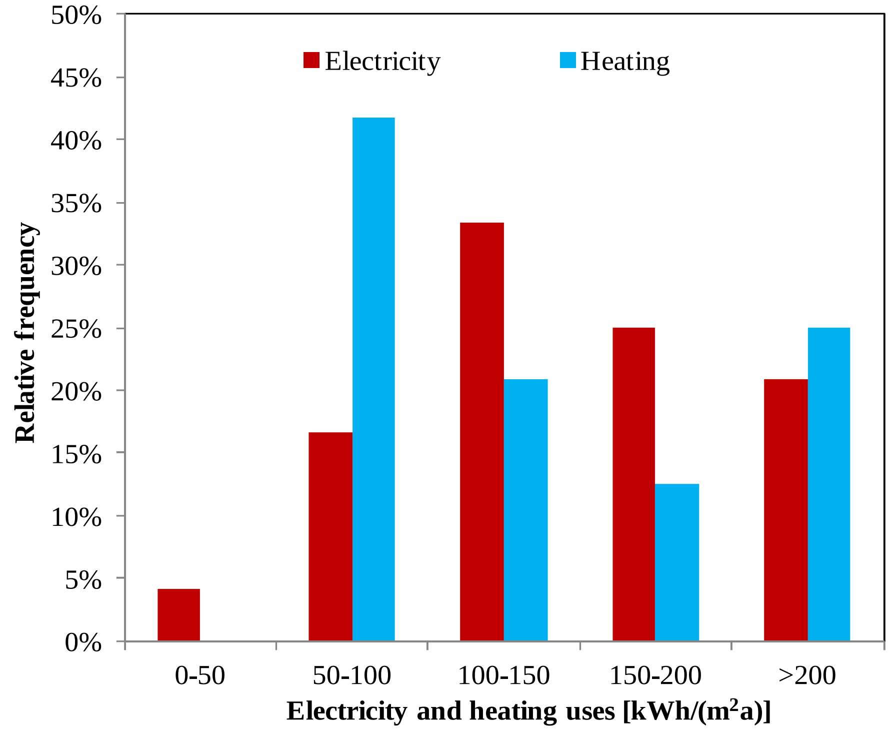


Fig. 5(a). Energy uses

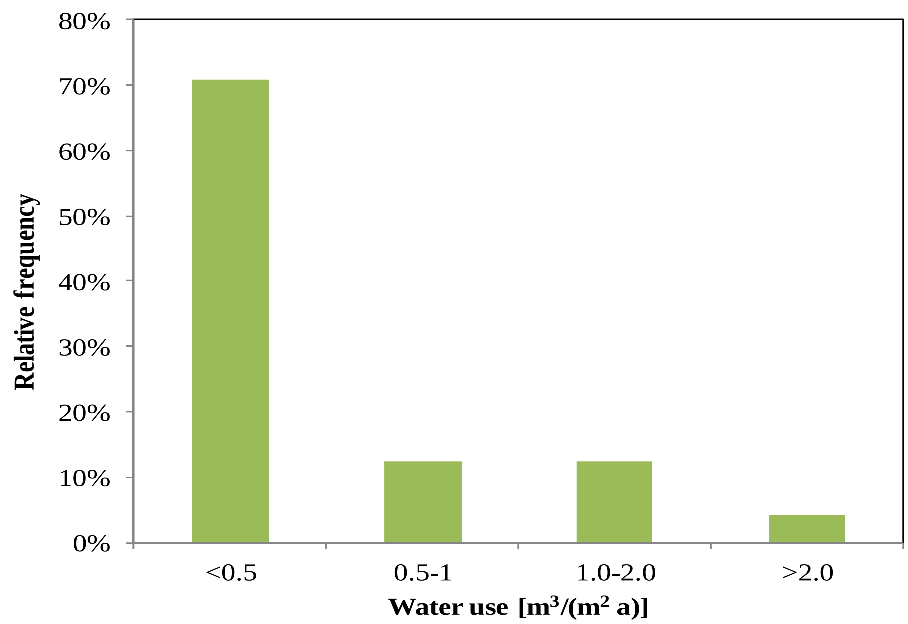


Fig. 5(b). Water use

Fig. 5. Energy and water usage of targeted individual buildings (N=24) in the years of 2011-2013

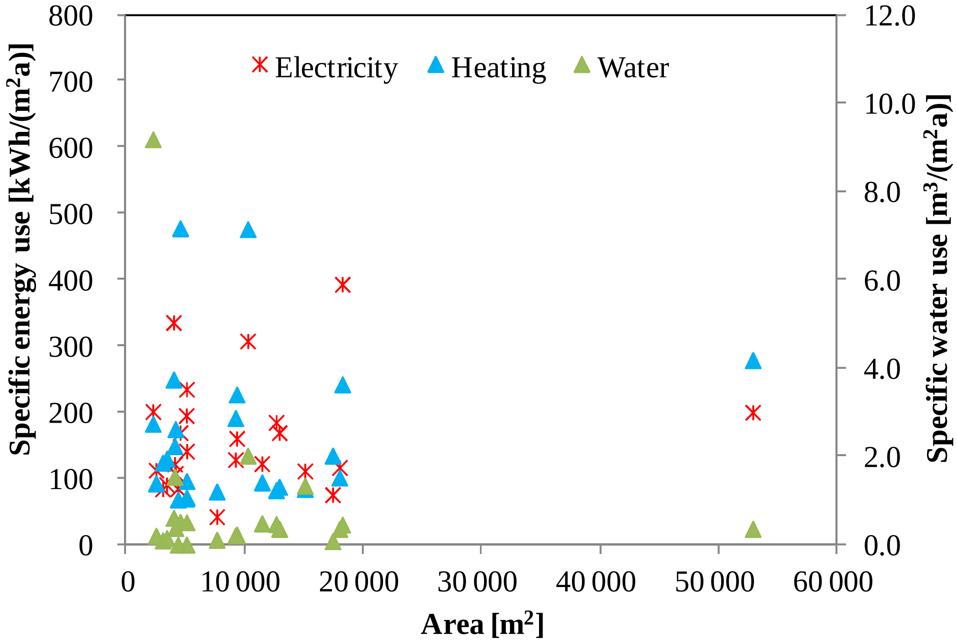


Fig. 6. Specific energy and water usage of targeted individual buildings (N=24)

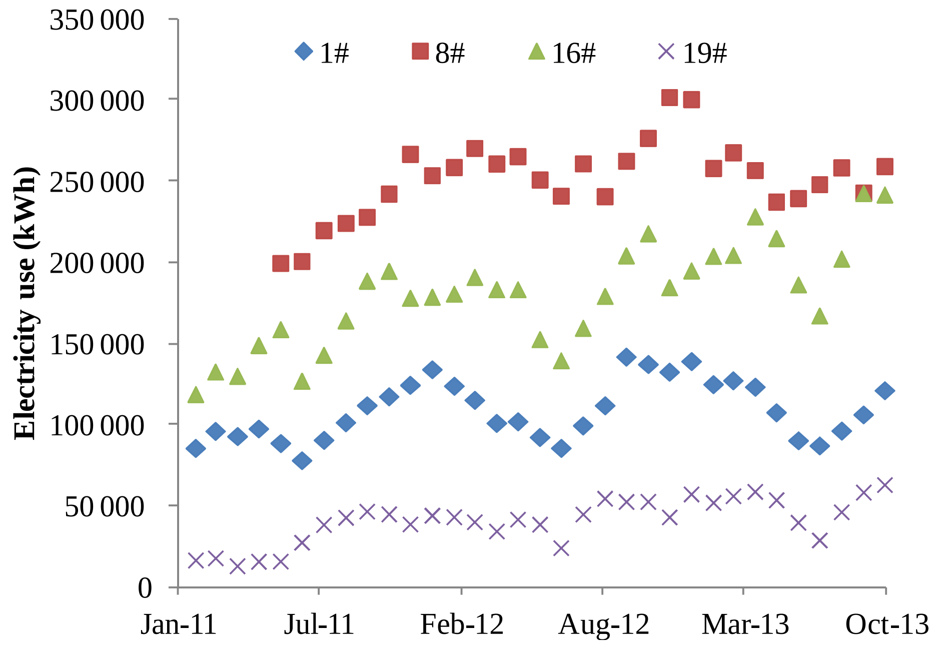


Fig. 7 (a). Monthly electricity use

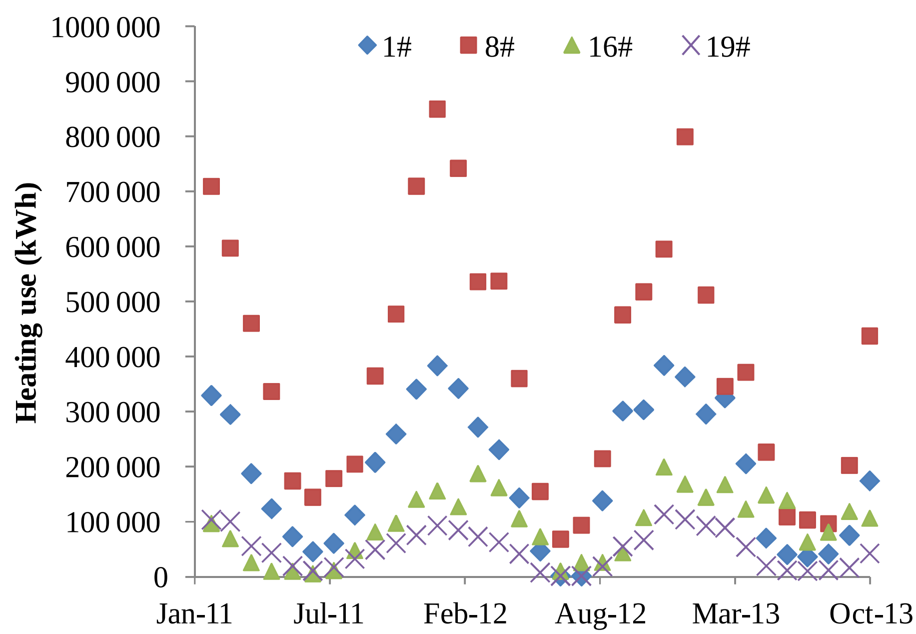


Fig. 7 (b). Monthly heating use

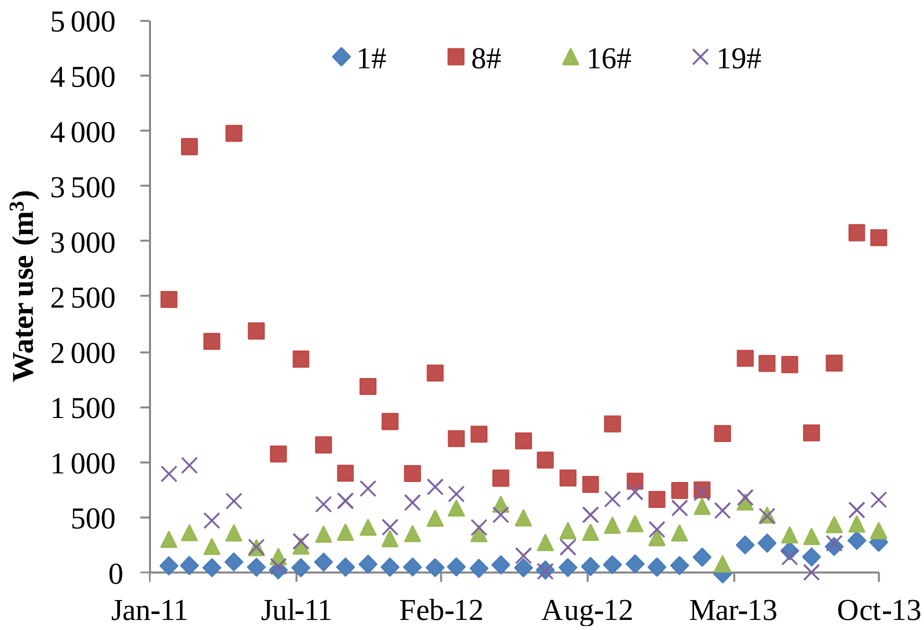
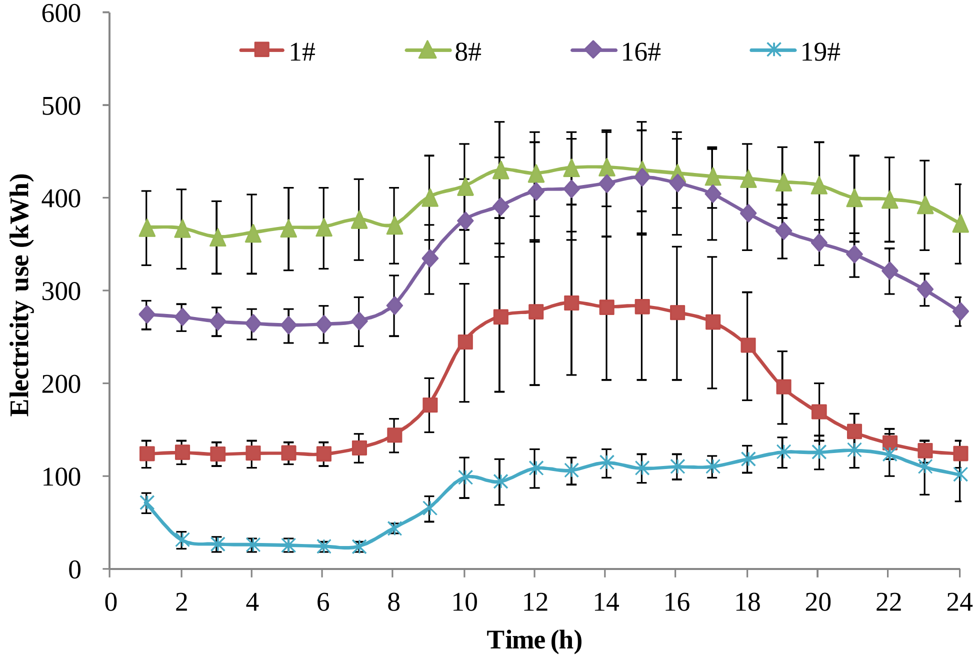
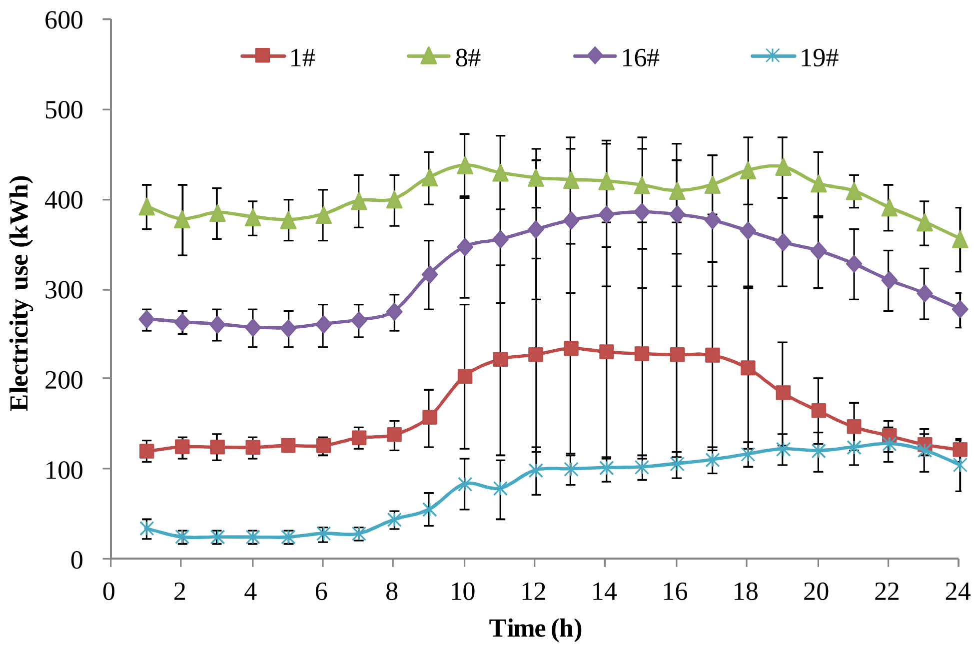


Fig. 7 (c). Monthly water use

Fig. 7. Monthly energy and water usage of four individual buildings of different types

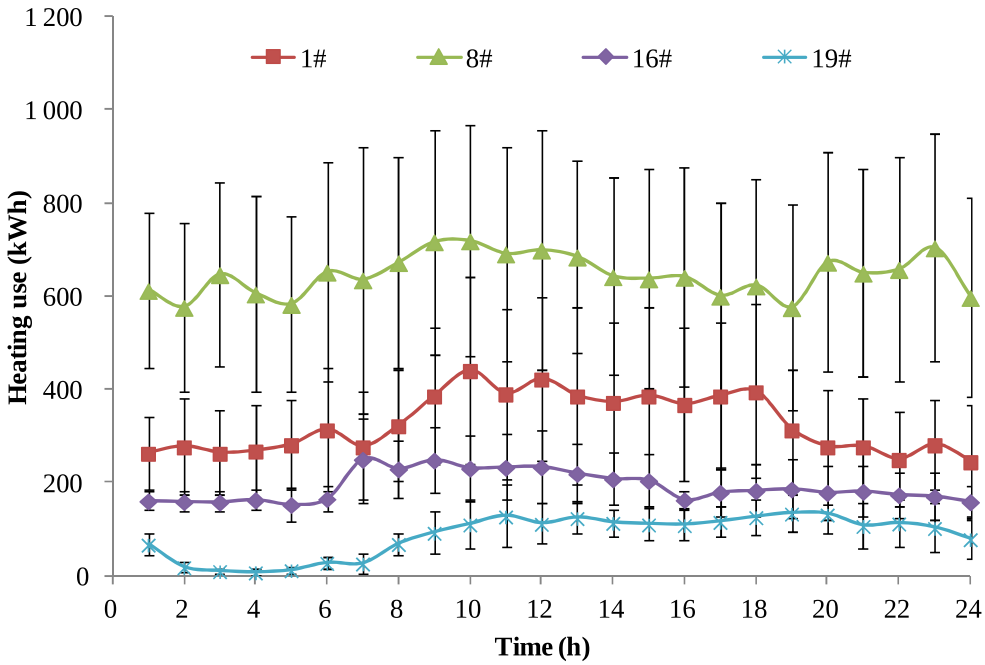


(a). Weekdays

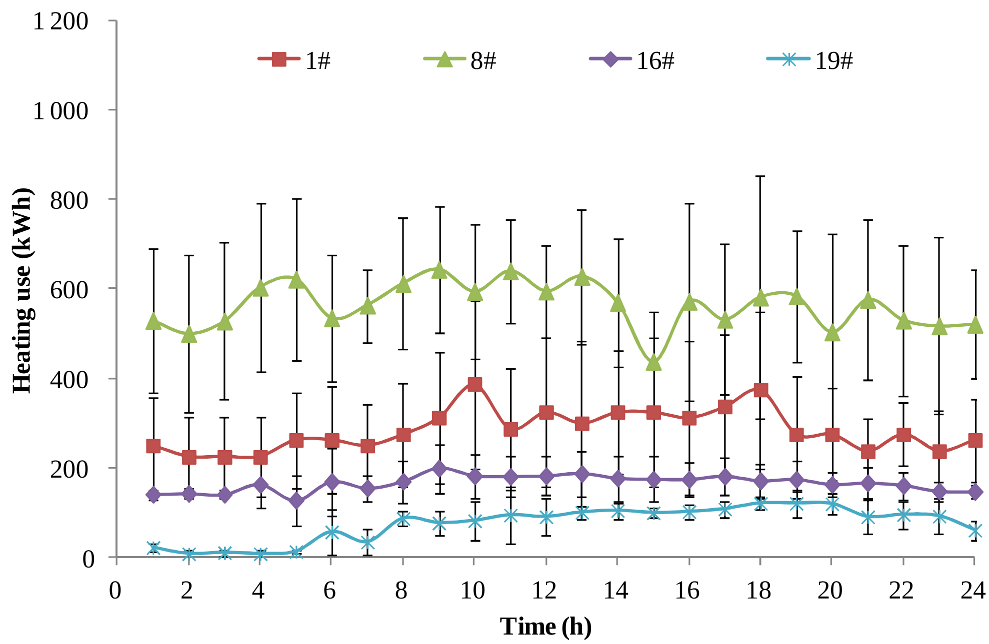


(b). Weekends

Fig. 8. Comparison of daily electricity use profile of four different individual building types in one typical month

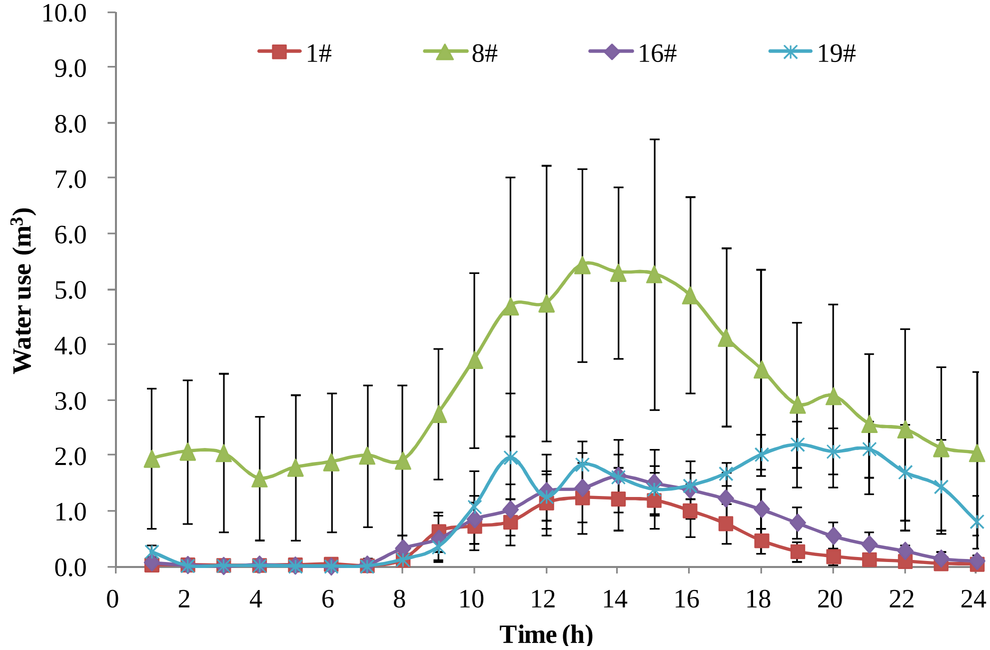


(a). Weekdays

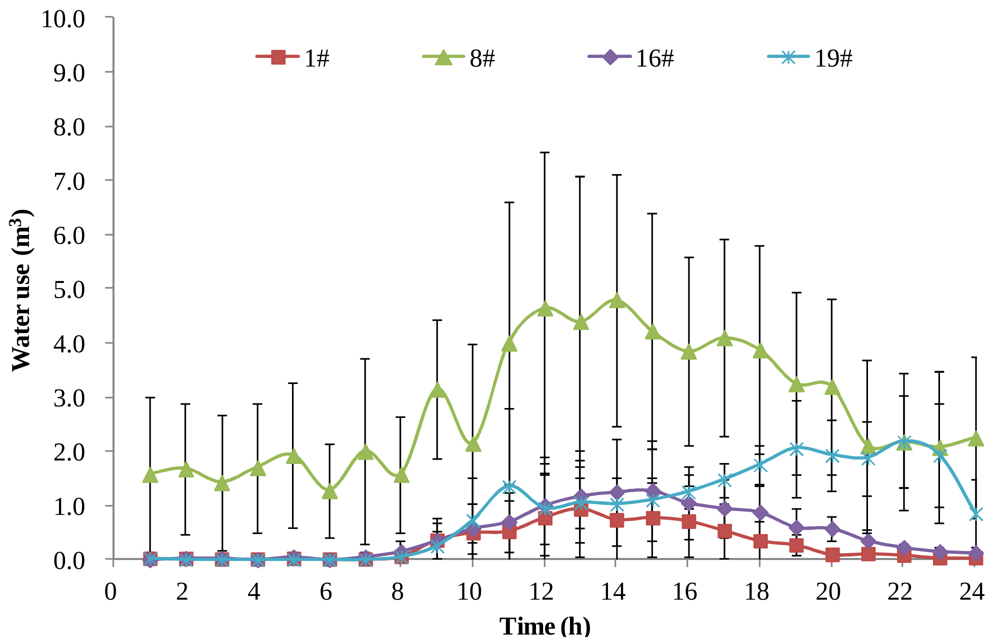


(b). Weekends

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



(a). Weekdays



(b). Weekends

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

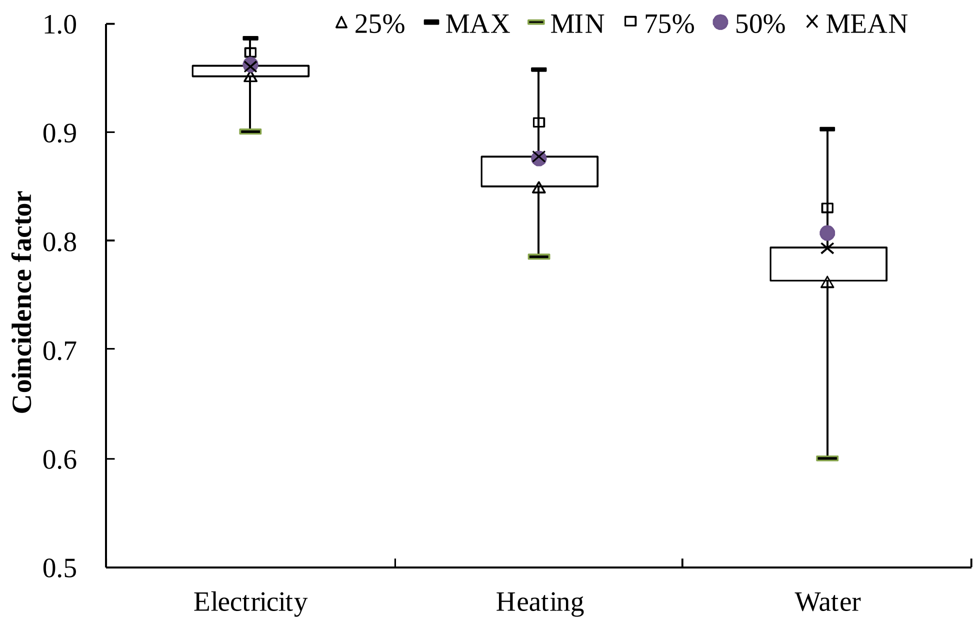


Fig. 11. Calculations of coincidence factors in the month with the peak of campus energy and water usage

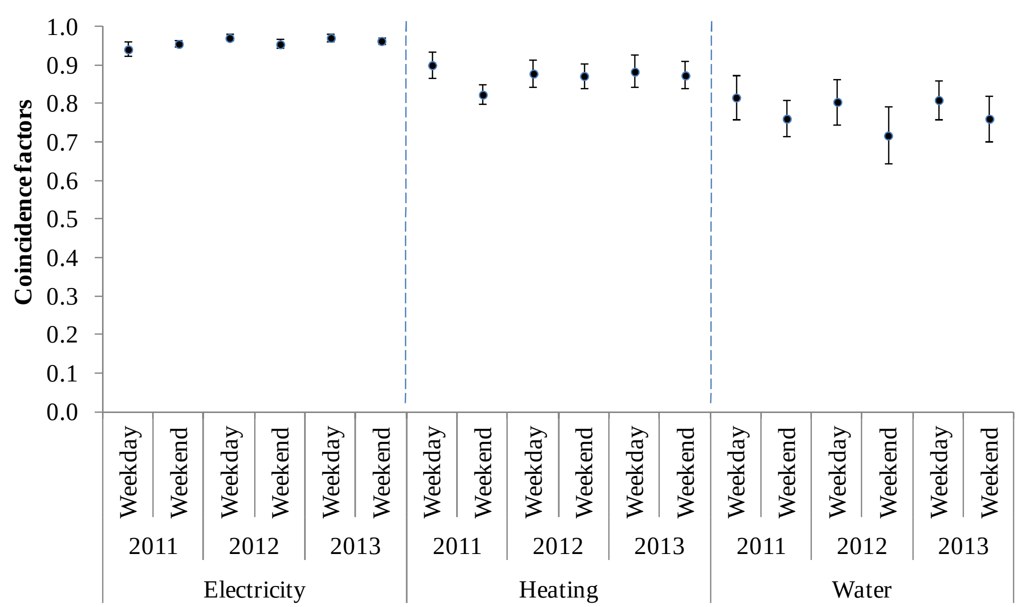


Fig. 12. Comparison of coincidence factors of campus energy and water usage between weekdays and weekends

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

NO.	Construction age	Main function* (O/E/L/S)	Building area (m^2)	NO.	Construction age	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

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

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	361	4.18	188	185	0.43
Difference to total	**-55.5%**	**-73.2%**	**-194.1%**	**-47.1%**	**-59.0%**	**-34.4%**

* Unit: kWh/(m^2 a) (energy use); # Unit: m^3/(m^2 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	5	6 254	113	0.530
	Cluster II	15	8 344	139	0.807
	Cluster III	4	21 277	309	0.845
Heating	Cluster I	13	6 900	115	0.634
	Cluster II	10	9 908	218	0.818
	Cluster III	1	52 773	279	0.913
Water	Cluster I	14	8 325	0.494	0.134
	Cluster II	7	16 943	0.792	0.443
	Cluster III	1	2 215	9.180	0.243

* Unit: m^2; # Unit: kWh/(m^2 a) (energy use), m^3/(m^2 a) (water use).