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The Application of Building Energy Consumption Index in Campus Energy Efficiency Management Platform

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Abstract

Categorized, itemized energy consumption model of buildings is established using energy consumption data of campus energy efficiency management platform; existing categorized, itemized energy consumption evaluation indices of buildings are summarized; and a mathematical model of building energy consumption indices is established, providing the basis for the quantitative evaluation of building energy consumption. The scope of application of each index is summed up; and the methods and steps for evaluation of building energy consumption using categorized, itemized energy consumption indices of buildings are elaborated through case study. The results show that the categorized energy consumption indices of buildings can be used to analyze the whereabouts and proportion of various energy consumptions of buildings, grasp the energy structure of buildings, and help analyze the power consumption trends of buildings and the proportion of various sub items, providing the basis for the formulation of energy efficiency management plan.

Keywords: *Building energy saving, Index of energy consumption evaluation, Case analysis*

1. Introduction

Campus is an important part of society, and a major social energy client as well. As of 2010, there has been 2,600 general and adult institutions of high education in China, with the number of enrollments reaching up to 32.8 million [1], accounting for 5.3% of national urban population, and with the total energy consumption accounting for 10% of the total national energy consumption of the society. Per capita energy and water consumption of universities are 4 times and 2 times those of national average, respectively [2]. Establishment of energy efficient campus energy efficiency management platform provides reliable data basis for conducting energy audit and analysis of existing buildings on campus, and exploring the optimal campus energy structure; it also provides a data sharing platform for scientific research of campus building energy conversation [3-5] .

The Figure 1 shows the number of campuses that have implemented energy efficient campus construction at home and abroad. As can be seen, the United States has been in the forefront in this respect. In 1997, C2E2 (The Campus Consortium for Environmental Excellence) organization was founded; Harvard and many other well-known U.S. universities actively joined it [6]. In December 2006, U.S. Green Building Council announced Green School Rating System. In 2007, presidents of more than 200 U.S.

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universities actively participated in it and reached a consensus to build low-carbon campuses, in order to address the problem of rapidly growing greenhouse gas emissions [7]. In early June, 2009, ISCN (International Sustainable Campus Network) conference was held in Switzerland, which explored and expanded the advanced concepts of sustainable campus construction standards, financial and decision-making mechanisms for sustainable campus design, and management of sustainable development in colleges and universities [8]. In [9], Jorge et al. built a reduced cost platform, which can not only collect energy consumption data from campus departments, but also produce load diagrams and send mail to the users for verification. In 2006, Nagata proposed an electric power energy consumption monitoring system by using the Intranet in a Japanese university. The real-time energy consumption data are displayed at the "Large-size Display Panel", which is the resource for further energy saving [10].

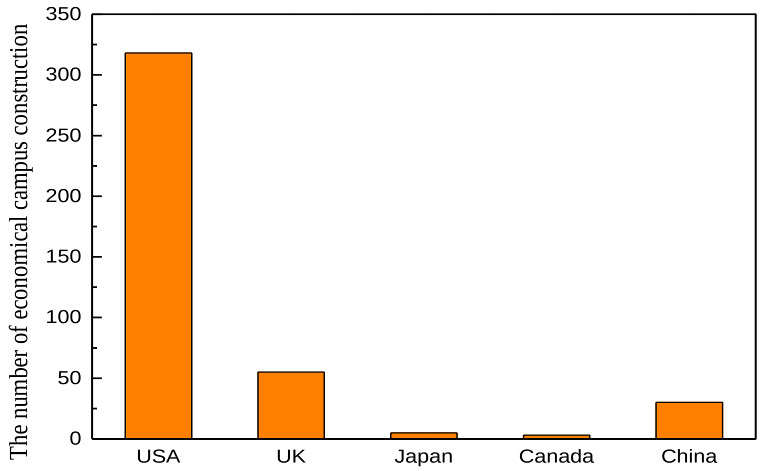

Figure 1. The Number of Economical Campus at Home and Abroad

In China, some progress has been made in construction of energy-efficient campuses after several years of promotion. Now energy-efficient campus construction has been completed in first batch of 12 and second batch of 18 colleges and universities, and the energy-efficient campus construction for third batch of 42 colleges and universities are under implementation. Despite large differences in energy consumption among various schools in China, energy consumption is improved significantly for schools that have implemented energy efficient campus.

In this paper, long-term evaluation index system for categorized, itemized energy consumption of buildings is established by using the building energy consumption data of energy efficiency management platform; and the usable range of each index is summed up; then the usage of evaluation of categorized, itemized energy consumption indices of buildings is analyzed combined with engineering case; which is of important guiding significance to the campus building energy conservation works.

2. The Establishment of Energy Consumption Evaluation Index Model

2.1. Building Energy Consumption Index

Total energy consumption indices include total building energy consumption, total unit building area energy consumption and total per capita energy consumption [11]. Total building energy consumption is the sum total of power, heat, centralized heat supply and the like of various sub items actually consumed by a single building energy system within a certain period of time after converted to coal equivalent; its calculation formula is shown in (1). According to the cycles in energy consumption statistics, total energy consumption indices can be divided into annual, seasonal and monthly energy consumption indices.

$$E = \sum_{i=1}^{n} E_i C_i \tag{1}$$

Where E is the total energy consumption of building, its unit is kg coal equivalent; E_i is the consumption of sub item energy consumption i of building, such as power consumption and heat consumption; C_i is the conversion coefficient for converting subitem energy consumption i to coal equivalent, see Appendix A; i is the energy consumed by building; and n is the number of energy types consumed within building.

Total unit building area energy consumption is the ratio of total building energy consumption to building area, which is calculated as shown in (2).

$$E_{Area} = \frac{E}{A} \tag{2}$$

Where E_{Area} is the total energy consumption of unit building area, kgce/m^2; and A is the total building area, m^2.

Total per capita energy consumption is the ratio of total building energy consumption to the number of people using energies within the building; its calculation formula is shown in Equation (3).

$$E_S = \frac{E}{N} \tag{3}$$

Where E_S is the total per capita energy consumption of building, kgce/people; and N is the number of people using energies within the building.

2.2. Construction of Water Consumption Index

Water consumption indices include total building water consumption, unit building area water consumption and per capita water consumption, as shown in Table 1.

Table 1. Index of Building Water Consumption

Index	Unit	Sign	Model
Total water consumption	t	W	—
Water consumption of Per unit area	t/m^2	W_A	$W_A = \frac{W}{A}$
Per capita water consumption	t/person	W_S	$W_S = \frac{W}{N}$

2.3. Construction of Power Consumption Index

Evaluation indices for building power consumption mainly include total building power consumption indices, mean indices and proportional indices of power consumption of various sub items.

(1) Total power consumption indices

Total building power consumption indices consist of total building power consumption, power consumption of sub items like lighting & sockets, HAVC, power systems and special power consumption, as well as power consumption at peak time, valley time and ordinary times, as shown in Table 2.

Table 2. Index of the Total Building Electricity Consumption

Index	Unit	Sign
Total electricity consumption	kWh	E_{01000}
Total electricity consumption of lighting socket	kWh	E_{01A00}
Total electricity consumption of HAVC	kWh	E_{01B00}
Total electricity consumption of power	kWh	E_{01C00}
Total electricity consumption of special	kWh	E_{01D00}
Total electricity consumption in peak	kWh	E_{peak}
Total electricity consumption in valley	kWh	E_{valley}
Total electricity consumption in flat	kWh	E_{flat}

(2) Mean power consumption indices

Mean building power consumption indices are divided into unit building area power consumption indices and per capita power consumption indices. Unit building area power consumption is the ratio of total power consumption of various subcategories to building area, while per capita power consumption is the ratio of total power consumption of various subcategories to the number of people using electricity within the building. List of indices are shown in Table 3.

Table 3. Average Class Index of Building Electricity Consumption

Index	Unit	Sign	Model
Total electricity consumption of Per unit area	kWh/m^2	E_{01000A}	$E_{01000A} = \frac{E_{01000}}{A}$
Total electricity consumption of Per unit area of lighting socket	kWh/m^2	E_{01A00A}	$E_{01A00A} = \frac{E_{01A00}}{A}$
Total electricity consumption of Per unit area of HAVC	kWh/m^2	E_{01B00A}	$E_{01B00A} = \frac{E_{01B00}}{A}$
Total electricity consumption of Per unit area of power	kWh/m^2	E_{01C00A}	$E_{01C00A} = \frac{E_{01C00}}{A}$
Total electricity consumption of Per unit area of special	kWh/m^2	E_{01D00A}	$E_{01D00A} = \frac{E_{01D00}}{A}$
Total electricity consumption of Per unit area in peak	kWh/m^2	E_{peakA}	$E_{peakA} = \frac{E_{peak}}{A}$

Total electricity consumption of Per unit area in valley	kWh/m^2	$E_{valleyA}$	$E_{valleyA} = \frac{E_{valley}}{A}$
Total electricity consumption of Per unit area in flat	kWh/m^2	E_{flat}	$E_{flatA} = \frac{E_{flat}}{A}$
Per capita total electricity consumption	kWh/person	E_{01000S}	$E_{01000S} = \frac{E_{01000}}{N}$
Per capita total electricity consumption of lighting socket	kWh/person	E_{01A00S}	$E_{01A00S} = \frac{E_{01A00}}{N}$
Per capita total electricity consumption of HAVC	kWh/person	E_{01B00S}	$E_{01B00S} = \frac{E_{01B00}}{N}$
Per capita total electricity consumption of power	kWh/person	E_{01B00S}	$E_{01D00S} = \frac{E_{01D00}}{N}$
Per capita total electricity consumption of special	kWh/person	E_{01D00S}	$E_{01D00S} = \frac{E_{01D00}}{N}$

(3) Proportional power consumption indices

Proportional building power consumption indices refer to the proportion of power consumption of various subcategories to total power consumption, including the proportional power consumption indices of various sub items and proportional power consumption indices of peak, valley and ordinary times; see Table 4.

Table 4. Ratio Class Index of Building Electricity Consumption

Index	Sign	Model
The ratio of lighting socket to total electricity consumption	E_{01A00P}	$E_{01A00P} = \frac{E_{01A00}}{E_{01000}}$
The ratio of HAVC to total electricity consumption	E_{01B00P}	$E_{01B00P} = \frac{E_{01B00}}{E_{01000}}$
The ratio of power to total electricity consumption	E_{01C00P}	$E_{01C00P} = \frac{E_{01C00}}{E_{01000}}$
The ratio of special to total electricity consumption	E_{01D00P}	$E_{01D00P} = \frac{E_{01D00}}{E_{01000}}$
The ratio of freezing pump to total HAVC electricity consumption	E_{01B1AP}	$E_{01B1AP} = \frac{E_{01B1A}}{E_{01B00}}$

The ratio of Cooling pump to total HAVC electricity consumption	E_{01B1BP}	$E_{01B1BP} = \frac{E_{01B1B}}{E_{01B00}}$
The ratio of Cold and heat source to total HAVC electricity consumption	E_{01B1CP}	$E_{01B1CP} = \frac{E_{01B1C}}{E_{01B00}}$
The ratio of Cooling tower to total HAVC electricity consumption	E_{01B1DP}	$E_{01B1DP} = \frac{E_{01B1D}}{E_{01B00}}$
The ratio of consumption in peak total electricity consumption	E_{peakP}	$E_{paekP} = \frac{E_{peak}}{E_{01000}}$
The ratio of consumption in valley total electricity consumption	$E_{valleyP}$	$E_{valleyP} = \frac{E_{valley}}{E_{01000}}$
The ratio of consumption in flat total electricity consumption	E_{flatP}	$E_{flatP} = \frac{E_{flat}}{E_{01000}}$

3. Analysis Case of Energy Consumption Evaluation

3.1. Case Description

Object of this case study is the campus of a certain University located in Taiyuan. The university is a comprehensive science and engineering university, its campus contains a total of 66 single public buildings covering a total area of 650,000 square meters, and there are about 25,800 teachers and students currently within the university. Buildings are mainly public facilities such as office buildings, teaching buildings, research buildings, student dormitories, dining halls, gymnasiums, laboratories and hospitals. Winter heating is provided to the buildings by the central heating system, and summer cooling mainly relies on ventilation through windows supplemented by electric fans.

Campus building energy consumption monitoring system is established, and some buildings achieve the online metering and sub-metering of energy consumption.

(1) Overview of buildings

Table 5 shows the number and building area of administrative office building, libraries, teaching buildings, research buildings, general buildings, stadium gymnasium, dining halls, bathroom, student dormitories, research laboratories, hospitals, exchange center and other buildings within the campus.

Table 5. Basic Information of Public Buildings of a Certain Campus

Building type	Abbreviation	Quantity	Area/m^2
Administrative office	Ao	4	16174
Library	Li	2	21514
Teaching building	Tb	7	47459
Scientific research buildings	Sr	7	69852

Comprehensive buildings	Cb	7	58828
Venue construction	Vc	3	10451
Dinning buildings	Db	4	23013
Bathroom buildings	Bb	2	1000
Dormitory	Do	19	133296
Laboratory	La	5	11774
Hospital	Ho	1	2750
Exchange center	Ec	2	16386
Other function buildings	Of	5	15835

(2) Energy consumption of various subcategories

Table 6 shows the power and water consumption, unit area power and water consumption, and per capita power and water consumption of the campus in the past five years. It can be seen from the total power consumption column that the power consumption increases every year. From the column of unit area power consumption, it can be seen that the annual mean unit area power consumption of the campus is about 31.4kWh/m^2·a.

Table 6. Energy Consumption of Different Sorts of A Certain Campus between 2006 and 2010

Index	Year				
	2006	2007	2008	2009	2010
Total electricity consumption (Million kWh)	1860	1990	1947	2189	2208
The electricity consumption of per unit area (kWh/m^2·a)	28.62	30.62	29.95	33.68	33.97
Per capita electricity consumption (kWh/peason·a)	664.52	710.97	695.61	782.07	788.85
Total water consumption (Million m^3)	276	258	247	246	218
The water consumption of per unit area (m^3/m^2·a)	4.25	3.97	3.80	3.78	3.35
Per capita water consumption (m^3/person·a)	98.61	92.18	88.25	87.89	77.88

3.2. Classification Building Energy Consumption Analysis

In this paper, 66 public buildings in the campus are used as the cases to analysis the energy consumption characteristics of subcategory buildings such as office buildings, libraries, teaching buildings, research buildings, general buildings, stadium and gymnasium, dining halls, student dormitories, laboratories, hospitals and exchange center. Table 7 shows the categorized energy consumption of the campus, such as power, water, central heating, gas and coal consumption. As can be seen from the table, unit building energy consumption (coal equivalent) of the campus is higher than that of China's 2008 urban mean of 18.1 kgce/m^2·a. The university has a high energy consumption level; moreover, the level showed an increasing tendency before 2009 when the energy efficient campus was constructed. However, since 2009, after the construction of energy efficient campus, the level has been declining every year.

Table 7. Statistical Energy Consumption of Different Sorts of A Certain Campus

Year	2008	2009	2010
Electricity (Million kWh·a)	1947	2189	2208
Water(Million m^3·a)	247	246	218
Heat(GJ)	38814	46654	53917
Gas(Million m^3·a)	80	78	69
Coal(Million t·a)	5100	4980	4840
Standard coal (t·a)	41725	41139	40043
Standard coal of per unit area (kgce/m^2·a)	25.73	26.15	26.00
Per capita standard coal (kgce/person·a)	597.60	607.27	603.83

The energy structure of the campus in 2010, for example, is shown in Figure2. The major energy consumption of the campus is power consumption, accounting for about 58.94% of total energy consumption, which is mainly used for lighting, office equipment, elevators, laboratory equipment and so on. Gas consumption accounts for 6.06% of total energy consumption, which is mainly used for dining halls, bathroom and boiler room. Central heating consumption accounts for 12.15% of total energy consumption. And other energies account for 22.84% of total energy consumption of the campus.

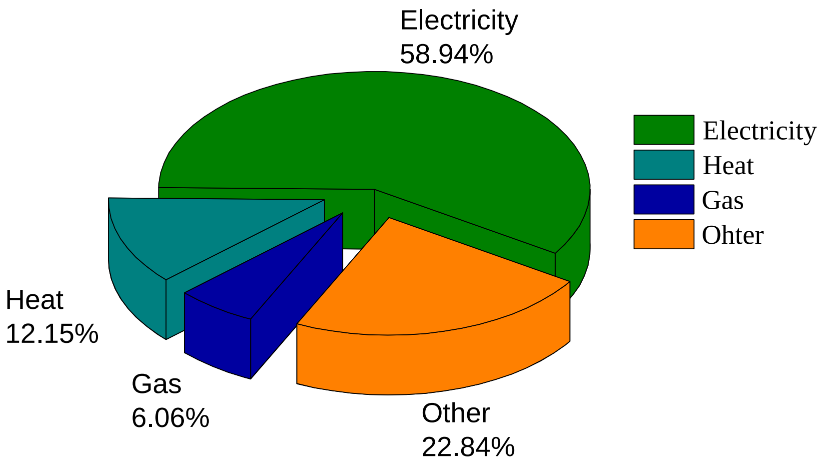

Figure 2. Energy Consumption Structure of a Certain Campus

Figure 3 shows the monthly power consumption of the campus between 2009 and 2010. It can be seen from the figure that the power consumption trends are basically the same every year and monthly power consumption does not fluctuate significantly with the seasons. As winter vacation is from late January to the end of February, and summer vacation is mid-July to the end of August, electricity use reduces obviously during the vacations.

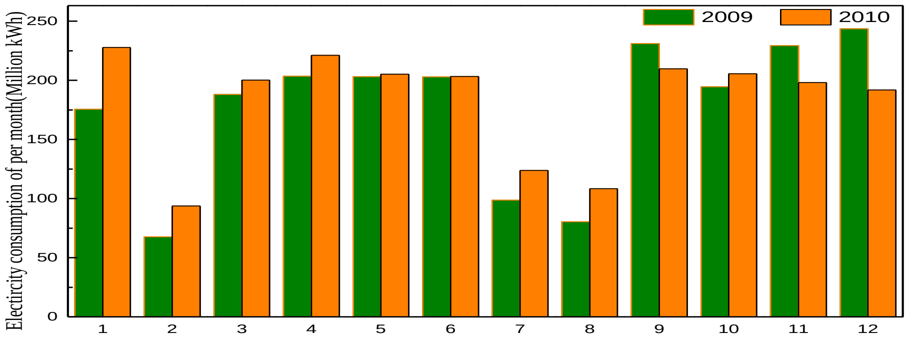

Figure 3. Monthly Energy Consumption of a Certain Campus

Statistics of power consumption of 66 public buildings on campus in 2010 are worked out using the energy consumption statistical function of the established campus energy efficiency management platform; see Figure 4. The annual mean unit area power consumption of the public buildings on campus is 31.4 kWh/(m^2·a). The campus adopts centralized heating in winter, and open window or electric fan cooling in summer, so the annual unit area power consumption is relatively low. The analysis finds that power consumption of public buildings on campus is greatly related to building functions, thus power consumption of various public buildings on campus is rearranged according to different building functions, as shown in Figure 5.

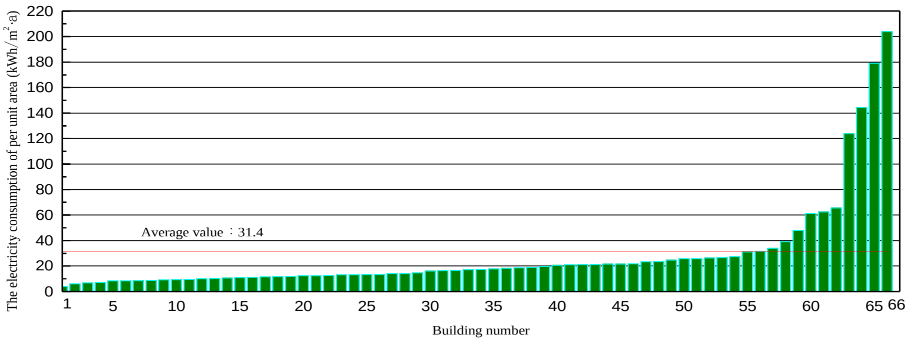

Figure 4. Unit Construction Area Electricity Consumption of a Certain Campus

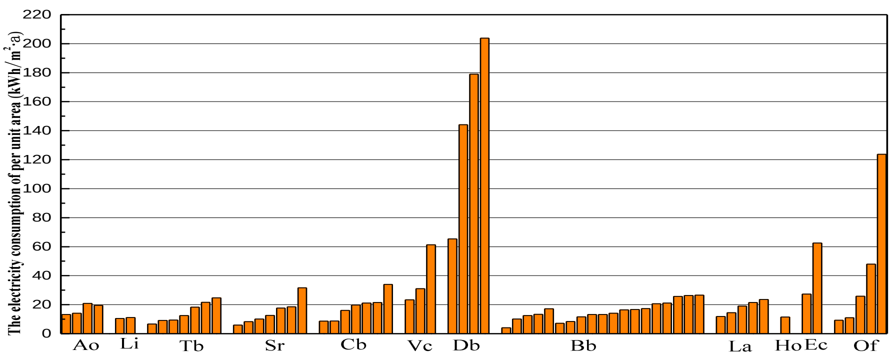

Figure 5. Unit Construction Area Electricity Consumption of a Certain Campus, Group by Building

As can be seen from Figure 5, overall energy consumption level varies widely among various buildings. The mean unit building area power consumption of office buildings, libraries, teaching buildings, research buildings, general buildings, stadium and gymnasium, dining halls, student dormitories, laboratories, hospitals and exchange center are.

Teaching buildings have the smallest unit area energy consumption, *i.e.*, 10.8 kWh/m^2, whereas dining halls have the largest unit area energy consumption, *i.e.*, 148.1 kWh/m^2. It can be seen that high energy consuming buildings on campus are stadium and gymnasium, dining halls and exchange center, especially the dining halls, which has a mean unit building area power consumption of 148 $kWh/m^2 \cdot a$, a value 5~10 times that of office buildings of the campus, reaching the level of power consumption of large public buildings.

4. Conclusion

Through the analysis of categorized, itemized energy consumption indices of various buildings within the campus, the following conclusions can be drawn.

(1) Overall energy consumption of campus buildings is larger than residential buildings. Major energy consumption for campus buildings is power consumption. Energy consumption of buildings fluctuates rather greatly with the seasons and vacations.

(2) Unit area and per capita energy consumption of public campus buildings are both higher than the average levels of urban residential buildings and per capita energy consumption of urban residents. With the construction of energy efficient campus in colleges and universities nationwide, power- and water-saving effects have been remarkable in campuses. However, buildings of some colleges and universities still have great power, water consumption, where there is large energy-saving space.

(3) Due to the diversity of campus building types, energy consumption level varies greatly among various buildings. Research buildings, general buildings, stadium and gymnasium, dining halls and exchange center on campus are high energy consuming buildings, which are the focus of campus building energy conservation, with great water- and power-saving space.

Acknowledgments

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