DEVELOPMENT OF A DATA MODEL FOR ENERGY CONSUMPTION ANALYSIS AND PREDICTION OF LARGE-SCALE COMMERCIAL BUILDINGS

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ABSTRACT

This paper presents a new methodology for large-scale commercial buildings energy consumption data analysis. This methodology relies on a unified energy consumption classification structure and on a set of index models and estimating models. All these elements have been combined into a data model that is presented in this article.

This new methodology has been applied successfully to 4 office buildings, two of them being Chinese and two of them being French.

KEYWORDS

Data model, Energy Consumption, Energy Efficiency, unified Classification, Index model, Large-scale commercial buildings

INTRODUCTION

Energy consumption (EC) data is a key issue for building energy efficiency (EE) analysis. Whether it concerns diagnosis, retrofit and management of existing buildings or design and associated design optimization of new buildings, EC data is always the basis for building EE analysis.

Building science litterature has not yet provided an international method for analysing EC data of buildings. Different authors use different energy conversion factors, different EC classifications and different energy use indexes, making building EC comparisons between different countries a very complex and subtle exercise. Confusions in conversion of one type of energy into another for instance make EC data from different investigators difficult to compare and lead to confused conclusion.

This paper presents a new methodology for EC data analysis for large-scale commercial buildings (LCB). This methodology relies on a unified EC classification structure and on a set of index models and estimating models(ASHRAE, 2001). All these elements have been combined into an international data model that can be used for large scale commercial buildings EC analysis and prediction, no matter the country in which the building is located.

Analyzing the EE of large-scale commercial buildings only on the basis of the entire building EC data, is a difficult task. Because these buildings are very complex, it is often necessary and profitable to use sub-EC data.

For existing buildings, the most reliable and straight forward way to get sub-EC data is sub-metering. Because sub-metering is most of the time very costly and because there exist many different wiring situations in LCBs, it is impossible to get all of the required sub-EC data by relying only on sub-metering. It is necessary to disaggregate sub-metering data in accordance with the appropriate classification of EC data (as defined by the unified EC classification structure and the characteristics of the building). To do so a dissagregation method has been developed, which will be presented in another paper. This paper focuses on the unified EC classification structure and on the set of index models used for LCB EC analysis.

This paper is divided into two parts. The first part presents an overview of the general methodology and explains on what basis the unified classification structure for buildings EC was created. Some explanations on the index models of the data model are also given. The second part of this paper presents 4 case studies and shows how the unified classification structure can be used in all 4 buildings and on how the index models can be used to characterize and compare EC data of different buildings.

DESCRIPTION OF THE LCB EC ANALYSIS METHODOLOGY

Preliminary remark

A unified classification structure for building EC data has been created. It is presented in Fig 1 (see the end of this paper). Every branch and box in this tree structure represents a specific category of end use.

This structure was made to be used for any commercial building.

Overview of the methodology

The EC analysis of a given commercial building should be carried in several steps as shown in Fig 2.

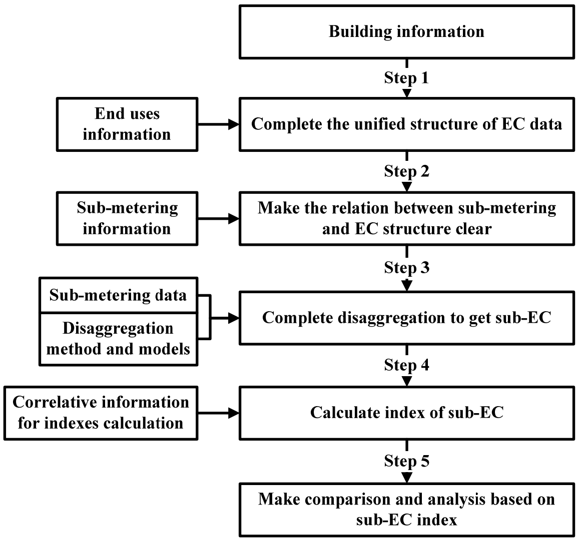

Figure 2 Building EC analysis methodology

Step 1: the EC data structure of the building should be determined in accordance with the unified EC classification structure and the characteristics of the building (see below for the detailed description of the unified EC classification structure and see figure 4 to 7 for examples of how this unified EC data structure can be used for different buildings).

Step2: to ensure that the disaggregation of the EC data is made in accordance with the building EC data structure, it is necessary to relate the data measured by sub-metering to all end uses included in the building EC data structure (see below for the detailed description and see figure 8 for an example).

Step3: sub-metering data must be dissagregated to get sets of end use EC data in accordance with the building EC data structure. The dissagregation method is based on sets of estimating models for different end use EC.

Step4: the indexes for the building end uses will be calculated using the index models and the correlative information that need to be gathered for this purpose.

Step5: The analysis of the sub-EC data and indexes can be done. The rationality and EE of sub-EC can be estimated clearly and conveniently.

The unified classification structure for building EC data

The unified EC classification structure has been created on the basis of several principles, which are presented below.

Many surveys were carried for large-scale commercial buildings in China. These surveys have highlighted the fact that there exist different “special loads” in LCB. “Special loads” include computer room/information center, washhouse(mostly in hotels), indoor park ventilation, cookroom(in hotels, office buildings, shopping malls, etc.), special indoor environment systems for storerooms, telephone exchange and stand-by power. The EC intensity levels of all these special loads are much higher than that of those usual loads such as office room load. Because of the differences in nature and scale of such special loads, it is necessary to separate these loads from other loads. This will ease the comparison of EC data between buildings.

In large-scale commercial buildings, it is very common that a given requirement is satisfied at the same time by individual equipments and by complex centralised systems. This can be the case for cooling for instance, when individual air-conditioning devices (split units) and central air-conditioning system are used at the same time. Since the influencing factors for the EC of complex centralised systems and of individual devices are very different and are much complex in the case of centralised systems, it is better to separate all the individual devices from the corresponding centralised system in the classification structure.

Individual devices for hot water, ventilation, space heating and cooling appear in the tree structure in the “Indoor Wiring” branch. This branch also provides an “others” end use box, which refers to different devices such as, for instance, computers, copy machines and other miscellaneous equipments for office work in office building.

Lighting EC and heating and cooling EC (which includes space heating and hot water heating) are the most important end uses for energy efficiency analysis and for energy conservation retrofit. Therefore EC data for these end uses should be analysed with great attention.

The lighting EC is divided into three categories: outdoor lighting, emergency lighting and indoor lighting, to take into account different lighting functions and operating modes.

As for heating and cooling EC, special attention should be devoted to the “source” category. The unified EC classification structure provides a source category for air-conditioning systems, heating systems and hot water systems. The concept of source includes all devices that supply heating and cooling energy. For example, the “air-cooled source” includes the chiller, the “hydrocooling source” includes the chiller and all devices working for cooling water. Since the chilled water pumps are used for heat transportation, they are not included in the source category.

Every source in a building produces heat. Because of the same mechanism, it is possible to use the same source device to meet the requirements of space heating, space cooling and hot water heating, simultaneously or not. The overall energy efficiency of the source working for heating and cooling simultaneously will be better than the energy efficiency of the source working in a single operating mode (i.e. for heating only or for cooling only). In fact, the EC for heating and the EC for cooling of a source working in a combined mode (for heating and cooling simultaneously) can't be separated exactly. In such a situation, the analysis should focus on combined systems and should not try to separate different operating functions. This is the reason why the unified EC structure provides the following two EC categories : "H&AC system and hot water system" and "H&AC system".

The detailed structure and classification of air conditionning (AC) systems is shown in Fig 3. Where the boxes under the hemicycles refer to different types of equipment that won't always be used together and belong to the same category. Whereas the boxes under the triangles refer to all equipments that are to be used together and belong to the same category.

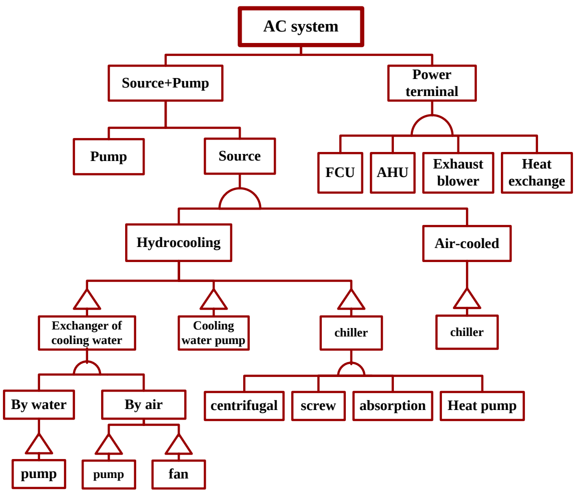

Figure 3 AC system structure

The commonly used power terminals for H&AC system include fan coil unit(FCU), air handling unit(AHU), exhaust blower for fresh air supplement and heat exchanger for heat recovery. They all appear under the hemicycle of the "Power terminal" category.

The index models

A set of index models have been created in order to characterize the different energy end uses in buildings. Each end use of the unified EC classification structure can be characterized by one or several indexes. Every index has a unique unit, which allows comparisons between buildings.

Considering the characteristics of sub-EC data, all the end uses in the unified EC classification structure can be divided into three types as presented in Table 1. Type 1 end uses are related to the building thermal environment control, whose requirements depend on many complex factors like weather, systems characteristics, the building heat gains, etc. Type 2 end uses relate to various services to the building occupants and their EC is very sensitive to the number of occupants. Type 3 end uses include all the other end uses.

Table 1 Three types of end uses

TYPE	END USES
1	AC/heating system source; Pumps (AC/heating system); Terminals (AC/heating system); Heating heaters; Split units;
2	Drinking water heaters; Hot water heaters; Others;
3	Indoor lighting; Emergency lighting; Supply/drainage pumps; Hot water pumps; Elevators; Ventilation; Fans on sockets; Powered enclosure; Outdoor lighting; Keep watch load;

The types 1, 2 and 3 end uses are highlighted in figure 1 with different colors.

The methodology introduced in this paper uses a set of indexes, each index being characterized by a special unit. The indexes for type 1 and type 2 end uses along with their units are presented in the following two tables (see the nomenclature section at the end of the text for the description of all the main symbols used in this paper). Most of the time, the unit that is used for buildings EC comparisons is kWh per unit of floor area. In the following tables, two units are presented : the one that is usually used for comparisons (characterized by *) and a new one. Most of these "new" units do not take into account the building floor area.

Table 2 Definition and unit of several type 1 sub-EC indexes

END USE	INDEX	
	UNIT	DEFINITION
AC/heating system	kWh/kWh	$I_{AC/H1} = \dfrac{EC_{AC/H}}{Q_{AC/H}}$

	*kWh/m^2	$I_{AC/H2} = \frac{EC_{AC/H}}{A_{AC/H}}$
	kWh/kWh	$I_{AC/H3} = \frac{EC_{AC/H\_S} + EC_{AC/H\_P}}{Q_{AC/H}}$
AC/heating system source	kWh/kWh	$I_{AC/H\_S1} = \frac{EC_{AC/H\_S}}{Q_{AC/H}}$
	*kWh/m^2	$I_{AC/H\_S2} = \frac{EC_{AC/H\_S}}{A_{AC/H}}$
AC/heating system pump	kWh/kWh	$I_{AC/H\_P1} = \frac{EC_{AC/H\_P}}{Q_{AC/H}}$
	*kWh/m^2	$I_{AC/H\_P2} = \frac{EC_{AC/H\_P}}{A_{AC/H}}$
AC/heating system terminal	kWh/kWh	$I_{AC/H\_T1} = \frac{EC_{AC/H\_T}}{Q_{AC/H}}$
	*kWh/m^2	$I_{AC/H\_T2} = \frac{EC_{AC/H\_T}}{A_{AC/H}}$
Heating heater	kWh/kWh	$I_{H1} = EC_H / Q_H$
	*kWh/m^2	$I_{H2} = EC_H / A_H$
Split unit	kWh/kWh	$I_{SU1} = EC_{SU} / Q_{AC}$
	*kWh/m^2	$I_{SU2} = EC_{SU} / A_{AC}$

For type 1 end uses, because of the complexity of the building thermal environment control processes, EC comparisons based on the building floor area usually result in confused conclusion. The main purpose of an AC/heating system is to meet the cooling and heating requirements of a given building, so its energy efficiency can be analyzed through the relation between the requirements of the building and its EC. The cooling and heating requirements of a large-scale commercial building depends on many complex factors such as climate and internal heat gains and is therefore difficult to estimate. The EC unit per floor area reflects the level of requirement to some extent, but it does not reflect the influence of climate and internal heat gains. To improve the comparison of AC/heating systems EC, the data model provides a new unit using the cooling and heating requirement(load) $Q_{AC/H}$ as the basis for comparison.

The building load is calculated by an estimating model (see later for details).

Table 3 Unit and definition of sub-EC index for several type 2 end uses

END USE	INDEX	
	UNIT	DEFINITION
Others	kWh/capita	$I_{O1} = EC_O / N_O$
	*kWh/m^2	$I_{O2} = EC_O / A_{floor}$
Drinking water heater	kWh/capita	$I_{DW1} = EC_{DW} / N_{DW}$
	*kWh/m^2	$I_{DW2} = EC_{DW} / A_{floor}$
Hot water heater	kWh/capita	$I_{HW1} = EC_{HW} / N_{HW}$
	*kWh/m^2	$I_{HW2} = EC_{HW} / A_{floor}$

Since all type 2 end uses relate to services to the building occupants, it is suitable to use as a unit the EC per capita rather than the EC per floor area.

For type 3 end uses, it's difficult to establish the suitable basis for comparisons only by a simple unit. Elevators, hot water pumps and supply/drainage pumps, all provide services to the building occupants, but the reasonable sub-EC for these end uses depends on the number of occupants, but also on various other factors. The sub-EC of elevators for instance depends also on the building geometry (number of floors). For indoor lighting and emergency lighting, their reasonable sub-EC depends on the installed power, illumination requirement and sunlight condition. The usual unit per floor area reflects the level of installed power and illumination requirement to some extent, but it does not reflect the influence of sunlight condition.

In this article, only index models for computer EC are presented in details (see below).

Examples of the use of index models for computer and AC / heating EC are presented in the second part of the article

<u>Index models for computer EC</u>

In office buildings, computers are very common and important equipments. The EC of computers is included in the "Others" end use. Several indexes can be used to analyze computer EC data. Those are presented here.

Because of the periodicity between weekdays and weekends (holiday) of computer EC, two indexes can be used : a weekday index and a weekend index:

$$I_{computer\_weekday} = \frac{EC_{computer\_weekday}}{N_{occupant}} \quad (1)$$

$$I_{computer\_weekend} = \frac{EC_{computer\_weekend}}{24 \times P_{computer}} \quad (2)$$

$EC_{computer\_weekday}$ and $EC_{computer\_weekend}$ are the daily computer EC for weekday and weekend respectively. $N_{occupant}$ is the corresponding number of occupants. $P_{computer}$ is the average EC per hour of a computer.

The unit used for the weekday index for computer EC is kWh per capita. It characterises the average computer use of the building occupants.

$I_{computer\_weekend}$ indicates the average number of computers working during weekends.

When sub-metering data is not available, the weekday index can be estimated as follows:

$$I_{computer\_weekday} = T_{weekday} \times P_{computer} \quad (3)$$

Where $T_{weekday}$ is the total number of working hours for a computer in a weekday. In average, $T_{weekday}$ has a value of 8 hours. To take into account the fact that in most buildings, the attendance ratio is not equal to 100 percent all the time, it is necessary to modify $T_{weekday}$. $T_{weekday}$ can be estimated as follows:

$$T_{weekday} = T_{weekday\_normal} \times R_{attendance} \quad (4)$$

Where $R_{attendance}$ indicates the average attendance ratio of the occupants of the building working with computers.

$T_{weekday}$ indicates the computer use intensity. It can also be calculated directly from computer sub-metering data as follows:

$$T_{weekday} = \frac{EC_{computer\_weekday}}{N_{occupant} \times P_{computer}} \quad (5)$$

$T_{weekday}$ can be used as a third index to characterise the building EC for computers.

The weekday and weekend indexes can also be used to estimate the building computer EC as shown in equation (6) below, as long as $N_{occupant}$, $R_{attendance}$, $N_{weekday}$ (number of weekdays), $I_{computer\_weekend}$ and $N_{weekend}$ (number of weekends) are known.

$$EC_{computer} = T_{weekday\_normal} \times R_{attendance} \times P_{computer} \times N_{occupant} \times N_{weekday} + I_{computer\_weekend} \times 24 \times P_{computer} \times N_{weekend} \quad (6)$$

The index models developped for computer EC (equations 1 to 6) can be used in different ways : either to calculate indexes from EC data or to estimate EC from the building characteristics (correlative information).

The estimating models

To calculate appropriate indexes for the type 1 end uses, an estimation of the cooling and heating loads of the building, $Q_{AC/H}$, is needed.

There exist different methods to calculate the value of $Q_{AC/H}$: by detailed dynamic simulation; by measurement / metering; by a simplified estimating method. Each of these methods requires different inputs. All these three methods are complementary one to another since they use data of different scales and they provide results with different scales. As far as the data model is concerned, all these three methods can be used to calculate the $Q_{AC/H}$ value. It will be profitable to develop three kinds of universal models to use these three methods within the data model.

CASE STUDIES

Four case studies are presented here, two of them being Chinese office buildings and two of them being French office buildings.

General description of the buildings

The characteristics of the four buildings are summerized in following table:

Table 4 Main characteristics of the studied buildings

BUILDING	FLOOR AREA (M^2)	CAPITA	LOCATION
Building A	1 289	47	Close to Paris, France
Building B	54 490	2 202	Beijing, China
Building C	16 663	600	Lyon, France
Building D	15 797	400	Beijing, China

The measured data used in this paper is presented in the following tables:

Table 5 Measured data for Building A for 2005

SUB-METERING	SUB-EC	DATA FORM
Sub-metering1	AC Source; AC Pump; AC Power terminal; Heater;	Hourly data
Sub-metering1_1	chiller	Hourly data
Sub-metering1_2	Heating heater	Monthly data
Sub-metering2	Computers	Hourly data

Table 6 Measured data for Building B for 2002

SUB-METERING	SUB-EC	DATA FORM
Sub-metering1	Total	Daily data
Sub-metering1_1	Chillers	
Sub-metering1_2	Primary pumps	
Sub-metering1_3	Secondary pumps	
Sub-metering1_4	Cooling water pumps	
Sub-metering1_5	Cooling tower; Split units	
Sub-metering1_6	AHUs	
Sub-metering1_7	Hot water pump; Heating pump	
Sub-metering1_8	Exhaust blower; Forced blower;	
Sub-metering1_9	Heat recovery	

Table 7 Measured data for Building C for 2005

SUB-METERING	SUB-EC	DATA FORM
Sub-metering1	Total	Hourly data
Sub-metering1_1	Heat pump 1	Hourly data
Sub-metering1_2	Heat pump 2	Hourly data
Sub-metering1_3	All pumps for	Hourly data

	AC/heating	
Sub-metering1_3_1	Pump for underground water	Monthly data
Sub-metering1_3_2	Secondary pump for cooling	Monthly data
Sub-metering1_3_3	Secondary pump for heating	Monthly data
Sub-metering1_4	AHU for reception	Hourly data
Sub-metering1_5	AHU for meeting room	Hourly data
Sub-metering1_6	AHU for office rooms	Hourly data
Sub-metering2	Cooling energy	Monthly data
Sub-metering3	Heating energy	

Table 8 Measured data for Building D for 2004

SUB-METERING	SUB-EC	DATA FORM
Sub-metering1	Indoor lighting; Emergency lighting; Others; Fan on socket; Indoor units of VRF system;	Yearly data; Daily data for two weeks in summer
Sub-metering2	Outdoor units of VRF system	

Use of the unified EC classification structure

In accordance with the different situations for the end uses in each building, the unified EC classification structure was used to get the EC data structure for each building (step 1 of the methodology) as shown in Fig 4, Fig 5, Fig 6 and Fig 7 (every colored box in the EC data structure corresponds to an end use that exists in the building).

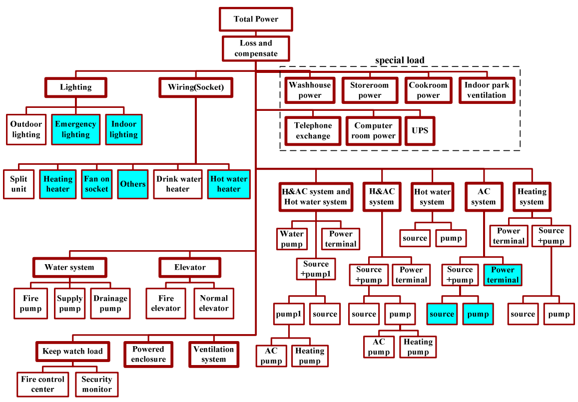

Figure 4 EC data structure of building A

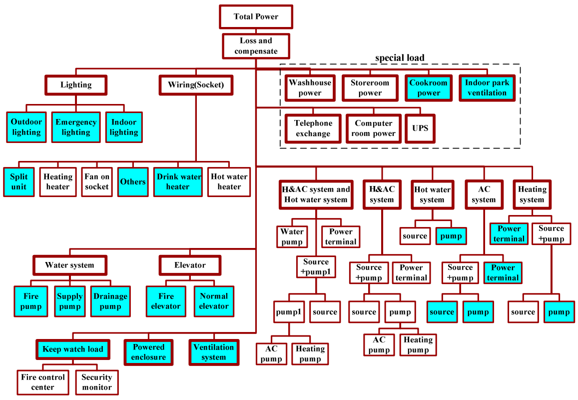

Figure 5 EC data structure of building B

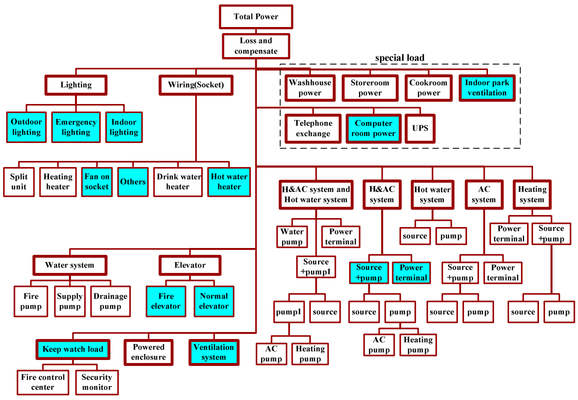

Figure 6 EC data structure of building C

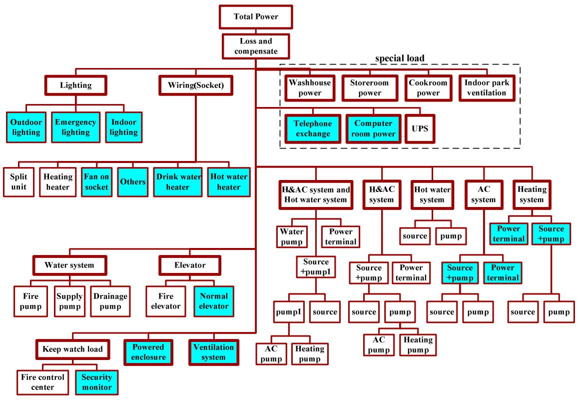

Figure 7 EC data structure of building D

Make the relation between sub-metering and EC structure clear

For example, the relation between sub-metering and EC structure of building A is shown in Fig 8.

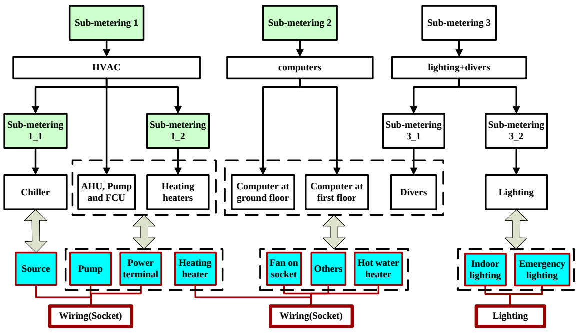

Figure 8 Relation between sub-metering and EC structure of building A

The colored boxes with the name of sub-metering indicate the sub-meterings used in this article. The colored boxes located in the bottom of Fig 8 are the end uses in the unified structure for building A.

Analysis of AC/heating system EC

The AC and heating systems are different in the four buildings. Building A uses an air-cooled chiller for cooling and electrical heaters for heating. Building B was cooled by a hydrocooling chiller and heated by district heating. A heat pump system was used for building C and a VRF system was used for building D. Some sub-ECs for the AC/heating systems of buildings A, B, and C are presented in Table 9.

Table 9 Sub-EC for AC/heating systems (kWh/y)

BUILDING	A	B	C
EC_{AC+H_S+P}	——	——	1057665
EC_{AC_S}	28111	904357	——
EC_{AC_P}	11419	238716	——
EC_{H}	173262	——	——

In Table 9, for building A, EC_H indicates the heating EC for the whole year, whereas EC_{AC_S} and EC_{AC_P} relate to ECs from June to November. For building B, EC_{AC_S} and EC_{AC_P} refer to ECs from March to October. EC_{AC_S} for building B and EC_{AC_P} for building A have been obtained from disaggregation. To calculate AC/heating indexes it is necessary to compute the cooling and heating requirements that the systems need to meet. For building C, the consumed cooling and heating energy that have been metered were used as the building load in this article. For buildings A and B, simulated cooling load and heating load have been used. The software used to compute the building loads is DeST (Yan D, Tang W, and Jiang Y, 2005). The dynamic building thermal process model of DeST is based on State Space solution method. With three kinds of validations: analytical tests, inter-model comparisons and empirical validation, the reliability of the result of DeST can be proved. The related indexes are shown in Table 10.

Table 10 Index of AC/heating system EC

	A	B	C
$I_{AC+H3} = \dfrac{EC_{AC+H\_S+P}}{Q_{AC+H}}$	——	——	0.4
$I_{AC3} = \dfrac{EC_{AC\_S} + EC_{AC\_P}}{Q_{AC}}$	1.3	0.41	——
$I_{H1} = EC_H / Q_H$	2.53	——	——
$* I_{H2} = EC_H / A_H$	134 kWh/m^2.y	——	——
$I_{AC\_S1} = EC_{AC\_S} / Q_{AC}$	0.92	0.33	——
$* I_{AC\_S2} = EC_{AC\_S} / A_{AC}$	22 kWh/m^2.y	16.6	
$I_{AC\_P1} = EC_{AC\_P} / Q_{AC}$	0.38	0.09	——
$* I_{AC\_P2} = EC_{AC\_P} / A_{AC}$	8.9 kWh/m^2.y	4.4	——

From the results in Table 10, the EC of source and pumps per unit of cooling load is similar in the cases of buildings B and C (0.4), while it is much lower than that of building A. This result indicates that the energy efficiency of source and pumps for buildings B and C are much better than that of building A. At the same time, in building A, the EC for heating per unit of heating load is much higher than the EC for cooling per unit of cooling load. The EC for heating is about 2.53 times the heating load, which shows that the heating heaters management of building A can be improved. The EC of the source per unit of cooling load of building A is about 2.8 times that of building B while the EC of pumps per unit of cooling load of building A is about 4.2 times that of building B. Compared to building B, in building A, the energy efficiency of the pumps is worse than that of the source. One explanation may be that the pumps of building A were working continuously, even when no cooling was required (pumps are not needed for heating since building A uses electrical heating). A similar conclusion regarding the pumps EE can be derived from the ratio EC_{AC_S} / EC_{AC_P}.

Analysis of computer EC

For building A, the computer EC data has been separated into weekday data and weekend data as shown in Fig 9. The daily computer EC is very stable during weekends and keeps within a small range during weekdays.

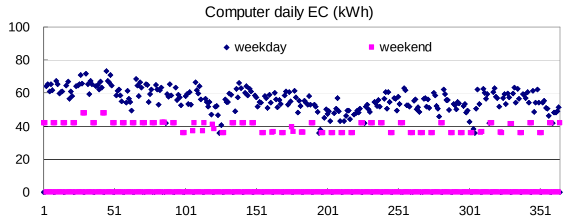

Figure 9 Weekday and weekend daily computer EC

For building D, it was necessary to disaggregate the measured data to get the computer EC. The disaggregation results are shown in Table 11.

Table 11 Disaggregation results for building D

END USES	Daily EC during weekdays (kWh)	Daily EC during weekends (kWh)
Indoor lighting; Emergency lighting	324	162
Others	993.6	496.8
computer	833.6	416.8
Fan on socket	76.8	76.8
Power terminal	58	58

The weekday and weekend indexes for computer EC have been calculated based on the EC data shown in Fig 9 for building A and in Table 11 for building D. A value of 0.2 kWh was assumed for $P_{computer}$.
The calculated indexes are presented in Table 12.

Table 12 Indexes for computer EC for buildings A and D

INDEX	Building A	Building D
$I_{computer\_weekday}$	1.2	2.1
$T_{weekday}$	6.0	10.4
$I_{computer\_weekend}$	8.3	86.8

In Table 12, the $I_{computer\_weekday}$ values indicate the average weekday EC of computer per occupant and the $T_{weekday}$ values indicate the average number of working hours for computers during weekdays. These results show that the consumption intensity for computers in building D is almost double than that in building A. In general, the working time of people in office buildings amounts to about 8 hours. Therefore, it seems that $T_{weekday}$, the number of working hours for computers in building D, is too high.
The $I_{computer\_weekend}$ values indicate that the average number of computers working on weekend in building D is about 10 times that of building A. In fact, the rationality of this value is easy to analyze. There does not seem to be any reason to keep so many computers working during weekends.

CONCLUSION

The data model presented in this paper can be used for different buildings. It provides a structure to organize building EC data in an optimized way as well as estimating models and index models to analyse these EC data. The data model presented here highlights end uses EC that can be analysed and compared from one builidng to another.

To analyse the EC efficiency of different end uses in large-scale commercial building, it is necessary to develop an appropriate set of indexes. The indexes presented in this paper have been used for the EE analysis of four different office buildings successfully. By using these indexes, it is easier and less empirical to compare the EC efficiency of different buildings.

ACKNOWLEDGMENT

The data for buildings A, B, C and D were all provided by the buildings' owners.

NOMENCLATURE

The index models

$Q_{AC/H}$ = corresponding cooling or heating load

$A_{AC/H}$ = corresponding floor area for AC or heating

$EC_{AC/H}$ = total energy consumption for AC or heating

EC_{AC/H_S} = source energy consumption of AC or heating system

EC_{AC/H_P} = pump energy consumption of AC or heating system

EC_{AC/H_T} = terminal energy consumption of AC or heating system

EC_H = total energy consumption for heating

Q_H = corresponding heating load

A_H = corresponding floor area for heating

EC_{SU} = total energy consumption of split units

EC_O = total energy consumption of those equipments belong to "Others"

N_O = corresponding occupant number for "Others"

A_{floor} = building floor area

EC_{DW} = total energy consumption of drink water heaters

N_{DW} = corresponding occupant number for drink water heaters

EC_{HW} = total energy consumption of hot water heaters

N_{HW} = corresponding occupant number for hot water heaters

Analysis of AC/heating system EC

EC_{AC+H_S+P} = source and pump energy consumption for AC and heating

EC_{AC_S} = source energy consumption of AC system

EC_{AC_P} = pump energy consumption of AC system

Q_{AC+H} = corresponding cooling and heating load

Q_{AC} = corresponding cooling load

A_{AC} = corresponding floor area for cooling

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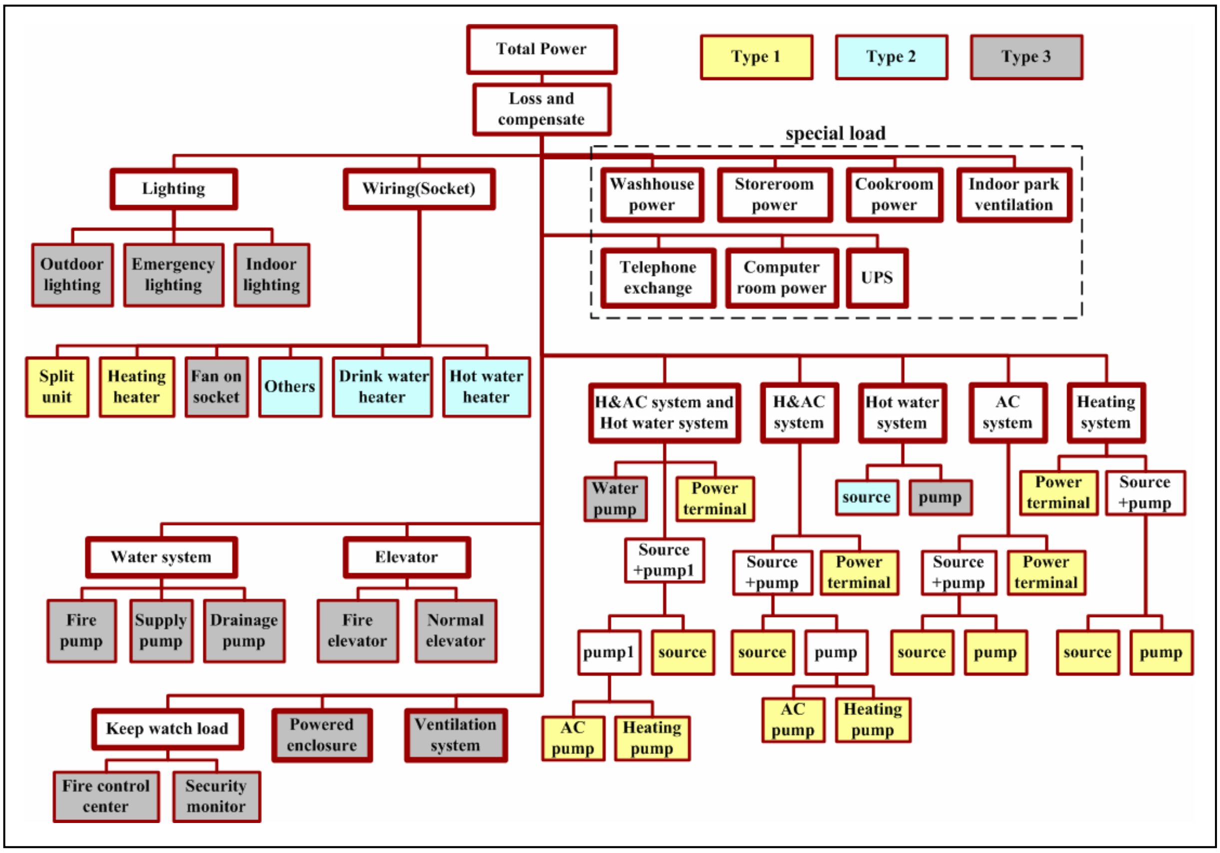

Figure 1 Unified tree structure of energy consumption data.