An Operational Energy Consumption Evaluation Index System for Large Public Buildings[1]

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Abstract: Large public buildings have been the emphasis of energy conservation in China. In this paper, the design and operational energy consumption evaluation indices for large public buildings are generalized, their differences and deficiencies are analyzed, and the evaluation indices of each kind of key equipment and the whole heating and air-conditioning system are put forward from the point of view of usage efficiency of energy. The energy consumption evaluation index system for large public buildings is primarily established. The calculation method of each kind of energy consumption evaluation index is given, which provides the foundation for further studies on energy consumption for large public buildings.

Key words: large public buildings, energy consumption, evaluation, indexes system

1. PREFACE

With the continuous development of urbanization level, the lack of energy and the increasing of society's requirement for energy has become one of the prominent contradictions restricting the development of society. Increase of quantities of new buildings, expanded buildings and rebuilt buildings results in sharply increases of energy consumption. Great energy consumption of large public buildings has more and more attracted people's attention. Large public building refers to the public or commercial building using central air-conditioning, whose area is above twenty thousand square meters, such as supermarkets, emporiums, hotels, official buildings, traffic hinge, and so on[1].The area of this kind of buildings is 5%~6% of the sum of town area, but it's electric consumption is 100~300 kWh/(m^2·a), about ten times of that of residential buildings(heating consumption is not included).So the energy saving of large public buildings are the emphasis of the energy conservation in China, and there is vast potential in them[2].

The issues existing in the process of operation of building energy system can be found timely though building energy consumption measurement and diagnosis, and some measures can be taken to optimize the system resource as to realize the retrofit of existing buildings. The evaluation of energy consumption is a necessary step in the process of energy measurement and building retrofit. As the contents and methods of building's energy consumption measurement vary with different organization in China, there isn't a complete system of energy consumption indexes for large public buildings. As to large public buildings, the emphasis of energy conservation is not wall insulation, but the complex energy system, such as the air-conditioning, heating and lighting system including those equipments. Taking into account the characteristic of this kind of building, the emphasis of evaluation is turned to the actual operation of system and equipment of buildings.

2. SUMMARIZING OF EXISTING ENERGY CONSUMPTION EVALUATION INDEX

However, there isn't a complete evaluation index system for building energy consumption. These indexes always be included in the design principle for

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energy conservation and the evaluation standard of green buildings according to the research in state and abroad, such as the <Design standard for energy efficiency of public buildings> and <Green Buildings evaluation system for Olympic>.Obviously, each index of the design standard is put forward from the point of view of designing, which is the detailed index for designing work condition and can not be used in practice better. The difference of operational energy consumption index and the design index is that the data used in calculation of operational index is from real operation by on-site measurement. Energy consumption appraisal is also included in green buildings evaluation standard, but haven't form a integrated system.

Generally speaking, the energy consumption index can be divided into compulsory index and integrated index. The compulsory index is regulation of maximum energy or energy efficiency for the local or whole energy-consuming system, such as the heat transfer coefficient of building envelope, form –volume coefficient, area ratio of window to wall, shade coefficient, etc, and energy efficiency index of heating and air-conditioning system, for example: COP, EER,IPLV, etc. These indexes are detailed and independent, lacking of necessary relationship. The integrated indexes are the requirements to building whole energy consumption taking account of each respect relate to energy consumption, such as the building cold consumption index, heat consumption index, annual electric consumption of air-conditioning and heating, electric consumption per unit square meter, and so on. These indexes are put forward from quantity, not related to energy efficiency. So it would better not to be evaluation index only, other indexes are needed.

The existing energy consumption indexes are listed as followed. There are Perimeter Annual Load (PAL) and Over thermal transfer value(OTTV)aiming at building envelope. PAL refers to the annul hot load of perimeter building per unit area, OTTV is the average value by the area of building envelope considering the heat transfer from out wall, out window, and sun radiation though out window . As for large public buildings, the thermal performance of building envelope is not the emphasis of evaluation, no need to consider here. Several evaluation indexes are summarized by Jiang Yi , such as CEC, AEC, EUI, ECI, DEC, SEC and the energy quality coefficient[3]. The CEC index is brought forward by scholar from Japan, which is used to judge the energy saving and energy use efficiency of equipment by comparing operational annual energy consumption of air-conditioning facilities with imagined annul air-conditioning load by calculation. AEC index is the annul electric consumption per square meter of air-conditioning parts(kWh/m^2). EUI is the index of whole energy consumption unit building area, which is also used by Shi-Ming Deng who analyzed the energy consumption of 16 hotel buildings in Hong Kong[4]. ECI is the ratio of real energy consumption to design consumption. DEC and SEC are annul energy consumption of designing building and standard building calculated by energy simulation software , as the principle of constructing standard building according to real building, which is made by ASHRAE 90.1. The dimensionless index E is brought which is calculated by DEC/SEC, as the standard according to whether E is smaller than 1. The energy analysis of a school building of a province in central Italy is presented by Umberto Desideri, Stefania Proietti. The main thermal and electric evaluation index are calculated to judge the condition of energy consumption, in which, the thermal and electric indexes are referred to the annual heat and electricity consumption for a student or a class per stere[5]. The performance indices which is energy consumed per year per square meter is used by Caglar Selcuk Canbay to evaluate the energy use for a shopping center[6].

In sum, with the increasing understanding, the energy conservation is transformed from restraining requirement to improving energy efficiency, the "energy conservation for buildings" also transformed to "reasonable energy use for buildings". Accordingly, the evaluation indexes are transformed from "quantity" to "quality", that is energy consumption indexes turned to energy efficiency indexes. However, many indexes are made from the angle of designing, the operational energy efficiency indexes are involved less. As for some indexes, the imagined building(standard or ideal building) need constructed, such as CEC, DEC ,SEC, etc. Although these indexes can be used to judge the building's energy consumption considering all kinds of factors, it's not easy to construct and specify the imagined buildings. Some margin is need, which required careful research and all-around investigation[7]. Besides, the calculation is relatively complicated to calculate the energy of imagined building and constructed building[8]. Great deal weather information is lacked in China, which is necessary to calculate the CEC index[9]. Computer simulation is need to use DEC and SEC indexes, but great errors existing between simulation and reality. Other indexes can reflect the energy consumption to some extent, but can not make an overall evaluation of building's energy consumption by themselves, considering the complexity of system.

So, it's necessary to establish a simple and practical evaluation index system from two aspects of energy consumption and energy efficiency, in order to make a quickly and general judgment and diagnosis for buildings.

3. ESTABLISHMENT OF ENERGY CONSUMPTION EVALUATION INDEX SYSTEM

3.1 Basic Idea and Structure

The energy consumption index system is established based on the on-site measurement in this paper. It includes five parts, which are the evaluation about key equipment, pipeline system, air-conditioning, indoor environment and the whole building. And these indexes can be divided into measurable parameter indexes and integrated indexes. The measurable parameter index uses the measured data as the evaluation index, such as the supply temperature, power factor, and so on. The integrated index refers to the index calculated by measured data. The structure of the evaluation index system is showed in figure 1.

3.2 The Calculation Methods of Each Energy Consumption Evaluation Index

3.2.1 Key equipments

The key equipment includes chillers, pumps, fans, cooling towers, boilers, and so on.

(1) As for chiller, the temperature difference of supply and return water and the ratio of temperature difference can be used to evaluate the operation of chillers primarily. The ratio of temperature difference is the ratio of actual temperature difference and design temperature difference. The actual temperature difference is only 40%~60% of design temperature difference, even more little. COP is the consistent index that used to evaluate the efficiency of chillers, also can be used here to practical system. IPLV is brought forward by ARI aim to evaluate the operational performance in part load work condition. The calculation equation is given by ARI550/590-98, and the following equation is given in the <Design standard for energy efficiency of public buildings> that accords with the weather condition of China.

$$IPLV = 2.3\% \times A + 41.5\% \times B + 46.1\% \times C + 10.1\% \times D$$,

where A、B、C、D are the COP of chillers when the load rate is 100%、75%、50%、25%, (W/W), the corresponding inlet temperature of cooling water are 0□、26□、23□、19□. SEER is used to evaluate the performance of chiller in the whole cold supply season, the calculation equation is that: $SEER=Q_{season}/W_{season}$, where, Q_{season} is the refrigeration capacity of chiller in the whole cold supply season, kJ; W_{season} is the consumed work during the whole cold supply season of chiller, kJ.

(2) As for pump, some ratios are used as the evaluation indexes. They are :1) the ratio of effective power of pump, defined as the ratio of actual effective power and normal effective power; 2) ratio of motor power, defined as the ratio of actual input motor power and normal input power; 3) general efficiency of pump, defined as the ratio of actual general efficiency of pump and normal general efficiency. The calculation formula of effective power of pump is that: $N_e=\rho gQH$, where, N_e is the effective of pump, W; ρ is the density of water, kg/m^3; g is the gravity acceleration, m/s^2; Q is the flow rater of pump, m^3/h; H is the head of pump, m. The calculation formula of general efficiency of pump is

that : $\eta = \frac{Ne}{N} = \frac{\gamma QH}{\sqrt{3}UI\cos\varphi}$,where, N is the input power of motor, W; U is the input line voltage，V; I is the line current，A; $\cos\varphi$ is the power factor.

(3) As for cooling tower, the cooling tower efficiency is used more widely, that is: $\eta = \frac{T_{hc} - T_{gc}}{T_{hc} - T_w}$, where, T_{gc} , T_{hc} is the supply and return water temperature cooling tower, □, T_w is the wet-bulb temperature of outdoor air， □.Also, the energy efficiency ratio of cooling tower can be used to evaluate the performance of cooling tower, that is the ratio of cooling capacity of cooling tower and fan power. The formula is $EER_{ct} = \frac{\rho cQ(T_{hc} - T_{gc})}{W} = \frac{\rho cQ(T_{hc} - T_{gc})}{\sqrt{3}UI\cos\theta}$, where, c is the specific heat of water，kJ/kg·℃; Q is the flow rate of cooling water，m^3/h; W is fan power，W; T_{gc} 、$T_{hc}$is the supply and return water temperature of cooling tower，□.

(4) As for AHU, the index are similar to those of pump, include fan full pressure, ratio of fan effective power, ratio of motor power, fan general efficiency, radio of fan general efficiency. In addition, the efficiency of heat exchanger and humidity usage efficiency can be used. The formula is : $\eta = \frac{Q_a}{Q_w} = \frac{(h_{ai} - h_{ao})\rho_a V_a}{c_w \rho_w V_w (t_{wo} - t_{wi})}$, where, η is the efficiency of heat exchanger, Q_a is the cold got by air-side, kW; Q_w is the cold liberated by water-side, kW; h_{ai}，h_{ao} are the enthalpy of water for inlet and outlet, kJ/kg; ρ_a，ρ_w are the density of air and water separate，kg/m^3; V_a is the air volume，m^3/h; V_w is the flow rate of water，m^3/h. $\varepsilon = \frac{D_a}{D_w} = \frac{\rho_a V_a (d_{ao} - d_{ai})}{D_w}$, where, ε is the humidity usage efficiency; D_a is the humidity got by air，g/h; D_w is the humidity supplied by humidifier, g/h; d_{ai}、d_{ao} are the humidity of air before and after humidifier，g/kg.

(5) As for boiler, the formula of boiler heat efficiency is $\eta = Q_{b1}/Q_{b2}$， where, Q_{b1} is the heat supplied by boiler, kJ；Q_{b2} is the heat consumed by fuel, kJ.

(6) As for heat exchanger, the formula of heat efficiency is $\eta = \frac{Q_c}{Q_h} = \frac{c_c \rho_c V_c \Delta t_c}{c_h \rho_h V_h \Delta t_h}$, where, Q_c is the heat absorbed by cold fluid, kW; Q_h is the heat liberated by hot fluid，kW; c_c、c_h are the specific heat of cold and hot fluid seperate, kJ/kg·□; ρ_c、ρ_h are the density of cold and hot fluid separate, kg/ m^3; V_c、V_h are the flow rate of cold and hot fluid separate, m^3/h; Δt_c、Δt_h are temperature difference of inlet and outlet for cold and hot fluid, □.

3.2.2 Pipeline system

(1) Water pipeline The transportation energy efficiency ratio and ratio of imbalance can be used to evaluate the performance of water pipeline. The transportation energy efficiency ratio is showed as followed: $ER = \frac{N}{Q} = \frac{\sqrt{3}UI\cos\phi}{c\rho V_w \Delta T} = \frac{\sqrt{3}UI\cos\phi}{4182 \times 10^3 \times V_w \Delta T}$, where, N is the input power of motor, W; Q is the transporting cold by water pipeline, W；ΔT is the temperature difference of supply and return water for water pipeline, ℃. The imbalance ratio of parallel branch is show as followed: $\alpha_w = \frac{Q_1 - Q_2}{Q_1} \times 100\%$, where, αw is the imbalance ratio; Q1 is the real flow rate of first branch，m^3/h; Q_2 is the real flow rate of second branch，m^3/h. The imbalance ratio of operational to design work condition is showed as followed: $\beta_w = \frac{Q - Q'}{Q'} \times 100\%$, where, βw is the imbalance ratio, Q' is the design flow rate of pipeline, m3/h.

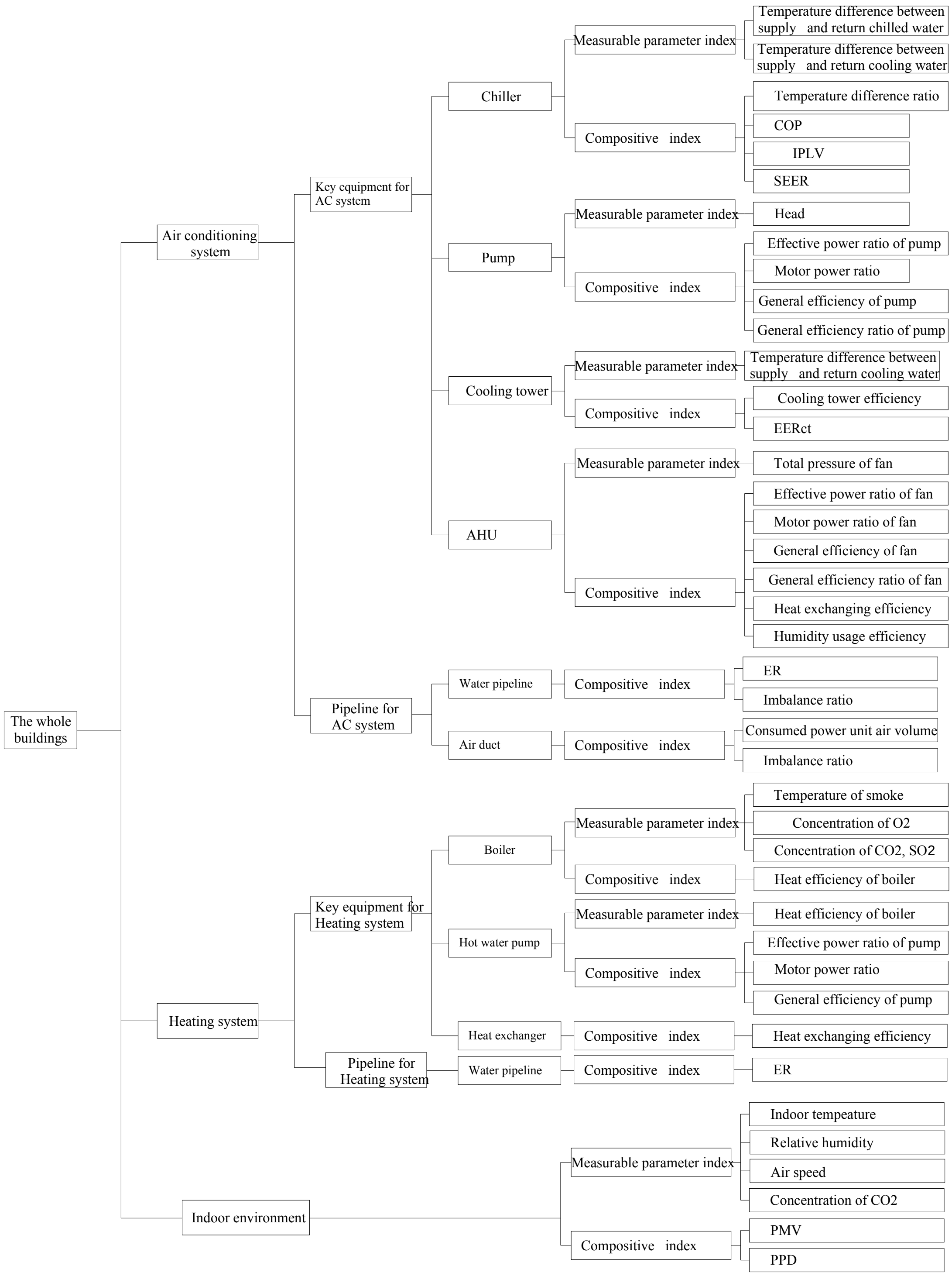

Fig. 1 Energy consumption evaluation index system for large public buildings

(2) Air duct Power per unit air volume and the imbalance ratio of air duct can be used to evaluate the energy efficiency of air duct. Power per unit air volume is show as followed: $W_a = \frac{N}{V_a} = \frac{\sqrt{3}UI\cos\phi}{V_a}$, where, N is the input power of motor in AHU, W; Va is the air volume of fan, m3/h. The air duct imbalance ratio includes αa,imbalance ratio for parallel ducts, βa, imbalance ratio of operational to design work condition for the same duct, and γa , imbalance ratio of operational to design air volume for terminal openings. The calculation of αa and βa are similar to water pipeline, just changing the water

flow rate to air volume. The imbalance ratio of opening is the ratio of real volume to design air volume

3.2.3 Energy consumption evaluation for air-conditioning system

(1) Electric Energy Consumption Operation Index(EECOI) and Gas Consumption Operation Index(GECOI). The calculation is showed as followed: *EECOI=Q/A*, where, *Q* is the general electric consumption of air-conditioning system, kW; *A* is the area of building, m^2; $GECOI=Q'/A$, where, Q' is the gas consumption of air-conditioning system with lithium bromide refrigeration，m^3.

(2) Energy efficiency index for air-conditioning, includes the design energy efficiency radio for air-conditioning and operational energy efficiency ratio for air-conditioning. The design energy efficiency radio for air-conditioning is show as followed: $\varepsilon_d=Q_d/W_d$, where, Q_d is the design cold capacity，kW; W_d is the sum of power consumed by each equipment to satisfy the design cold capacity, kW, which can get from the nameplate of each equipment. The operational energy efficiency ratio for air-conditioning is showed as followed: $\varepsilon_p=Q_p/W_p$, where, Q_p is the real supplying cold of chiller, kW; W_p is the sum of real power of each equipment, kW.

3.2.4 Evaluation on building thermal environment

As the energy conservation shouldn't be implemented at the cost of sacrifice of indoor air quality and peoples' comfort, so the indoor thermal environment need to be evaluated. The available indexes include: indoor temperature *T*, relative humidity φ, average air speed *v*, the concentration of CO_2, PPM and PPD index, in which, the grade of PMV is show as table 1.

Tab.1 Grades of PMV

Heat feeling	heat	warm	little warm	Mode-rate	little cool	cool	cold
PMV	+3	+2	+1	0	-1	-2	-3

The calculation formula of PPD is showed as followed:

$PPD = 100 - 95\exp[-(0.03353PMV^4 + 0.2179PMV^2)]$, the recommend value is that : PPD<10%，5% for the lowest.

3.2.5 Energy consumption evaluation for the whole building

(1) total index. The annaul energy consumption of building can be used, which contains the total electric consumption of air-conditioning , heating , lighting system and total fuel consumption including coal consumption and gas consumption(the energy can be transformed by the product of fuel consumption and their heat value). $Q_{all} = \Sigma\ Q_i$, where, Q_i is the energy consumption of every kind of energy resource, including electric consumption and fuel consumption.

(2) relative index. The Energy Consumption Unit Area(ECUA) can be used. The formula is showed as followed: $ECPUA=Q_{sh}/A$, where, Q_{sh} is the operational energy consumption of building, kW; *A* is the total area building, m^2.

4. CONCLUSION

The energy consumption evaluation index system for large public buildings is established primarily, which begins with the key equipment of building and extends to system and the whole building. There is close relationship between the total energy consumption and the energy efficiency of equipments and pipeline, further research is need. The rational range of each index in this paper can be got under the analysis and statistic of energy consumption data for large number of buildings.

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