

Status and prospects of building energy efficiency in China

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Abstracts: The paper briefly describes situation of building energy consumption in China. The authors indicate some relations in building energy efficiency should be dealt with properly: energy saving and energy efficiency, envelopes and building services systems, energy use and indoor environment, electric power saving and energy saving, devices and system, energy efficiency at stable state and at dynamic state. The authors suggest to use Coefficient of Energy Consumption as a Indicator of building energy efficiency.

Keywords: building energy efficiency; energy saving; coefficient of energy consumption (CEC)

1. Rapid growth of building energy consumption

China's GDP reached to 10.2×10^{12} RMB (about 1.244×10^{12} USD) in 2002 with an average annual increase of 7.7%, calculating in constant prices. The gross economic amount has ranked the sixth in the world. Per capita GDP of China exceeded 1000 USD in 2002, while this figure of metropolises like Shanghai,

Guangzhou and Shenzhen has been closed or exceeded 5000 USD. The development of building industry benefits from the high growth of economy in China.

By the end of 2002, there are totally 13.178×10^9 m² of building floor area in Chinese cities. Among others, the floor area of residential buildings is 8.185×10^9 m². Fig.1 illustrates the rapid growth of building construction in China over the past years.

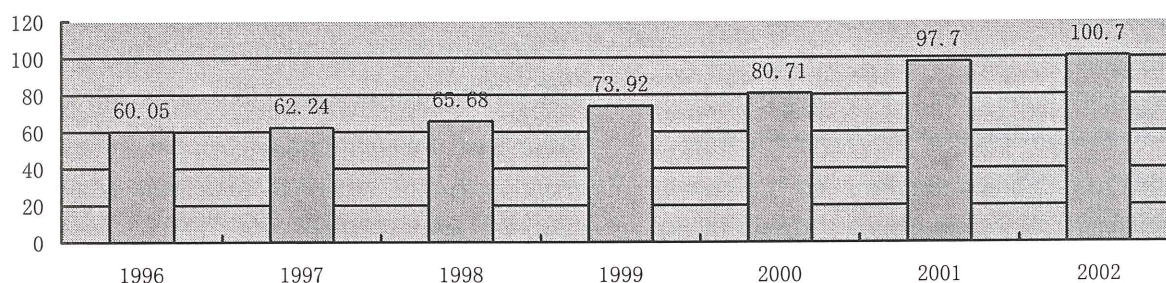


Fig 1 Floor space of new buildings completed each year

Completed areas of residential buildings in cities and towns across China has reached 3.4×10^9 m² for the past 5 years (the number of year 2002 was 7×10^8 m², approximately). About 5×10^8 m² of shabby houses were rebuilt, while nearly 50 million families living in cities and towns improved their living conditions. The average annual completed areas of residential buildings reached 680×10^6 m². Per capita gross living area in cities and towns rose from 17.6 m² in 1997 to nearly 22 m² in 2002, with living area per family reached 70 m². Along with improving conditions of living spaces and increasing of income, the inhabitants pay more attentions to indoor environment quality. Room air conditioner (RAC) becomes the necessary for most families of cities, as shown in Tables 1 and 2.

Table 1 RAC owned by one hundred families in 2001 (Source: National Bureau of Statistics of China)

Province/City	Per capita annual income / (RMB)	Quantity of RAC owned by one hundred families
Beijing	11 658.99	89.70
Chongqing	6755.45	85.67
Fujian	8384.64	55.24
Guangdong	10 534.67	107.91
Jiangsu	7427.51	52.73
Shanghai	12981.53	100.40
Tianjin	8999.37	73.80
Zhejiang	10 540.37	71.00
Average in whole country	6907.08	35.79

Table2: Possession of household equipment per hundred families
(Source: Tongji University)

Equipment	Quantity
Electric water heater	35.1
Gas water heater	69.7
Solar water heater	3.4
Electric drinking water heater	77.9
Refrigerator	103.5
Room air conditioner	182.3
Microwave oven	88.7
Electric cooker	93.7
Kitchen fume extractor	90.0
Gas oven	93.2
Washer	94.1
TV set	173.6
Drying machine	11.0
Dust catcher	59.5
Hi-fi audio	66.6
Desk top computer	64.6
Laptop computer	14.4
Electric fan	206.7

On the other hand, China's entrance into WTO gave a further stimulation to the development of economy. The actual usage of foreign funds accounted to 52.7×10^9 USD in 2002. More and more multinational companies moved their manufacture base into China. Technologies such as IT, bio-pharmacy and semiconductor industries became to be the main investment way of foreign funds. Large numbers of high-tech workshops and industrial zones had been constructed. These industries are all indoor environment reliant, transferring their energy consumption from processing equipments in traditional industry to workplace.

After success of Beijing Olympic 2008 and Shanghai EXPO 2010 bid, a lot of building construction projects has been initiated and urban infrastructure as well.

The using of so many electric-driven air conditioning and building services had caused oppressive pressure on power supply of eastern metropolises in summer, on-peak and off-peak difference increasing annually, when annual usage ratio of generators decreasing.

The impacts of building energy consumption are:

- 1) Serious shortage in the supply of peak load power;
- 2) Latent danger of power grid due to unstable building energy usage;
- 3) Coal-fired thermal power plants and heating boilers are main pollution source and greenhouse gases emission source in most urban area; and
- 4) Proportion of building energy consumption in total is increased

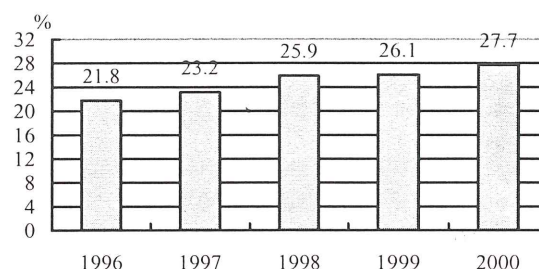


Fig 2 Percentage of building energy consumption in total

Importance of building energy efficiency was much in evidence.

2. Characteristics of building energy efficiency in China

Main part of building energy consumption is heating energy in North China. Therefore the emphasis of energy efficiency is set on:

- 1) Heating buildings, among which housing buildings are in priority;
- 2) Thermal insulation of building envelopes;
- 3) Building design for newly constructed building; and
- 4) Separated thermal meterage of central heating system in multifamily housing buildings.

But we can see from Table 3 even according to Energy Conservation Design Standard for New Heating Residential Buildings (1995) the thermal insulation of building envelopes is still poorer than in other countries. Therefore the indoor thermal comfort performance in winter is unperfected due to lower temperature on the inside surface of wall, especially for convection-type heating. Because there are no related regulations on the heating system design it was hard to save energy substantially only by well insulated walls. Sometimes occupants have to open the widows during the freezing weather due to too high room temperature.

Table 3: Comparison of envelop heat transfer coefficients between China and other countries

Country			Envelop heat transfer coefficient		
			Roof	Wall	Window
China	Beijing	Original	0.91	1.28	6.40
		New	0.60	0.82	4.00
	Haerbin	Original	0.64	0.73	3.26
		New	0.30	0.40	2.50
	Sweden		0.12	0.17	2.00
			0.31	0.27	2.22
	Canada		0.40	0.38	2.86
	Denmark		0.20	0.35	2.90
	UK		0.45	0.45	--
Japan	Hokkaido		0.23	0.42	2.33
	Tokyo		0.66	0.87	6.51
Germany			0.22	0.50	1.50

In the recent years, the Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Cold Winter Zone (2001) has been published. The Design Standard for Energy Efficiency of Residential Buildings in Hot Summer and Warm Winter Zone is being in the approval process. Drafting of Design Standard for Energy Efficiency of Public Buildings has

been initiated.

As to building services equipments, the energy efficiency standards are only aimed to its performance under the rated conditions. For example, the EER value of RACs prescribed in standard of the limited values of energy efficiency and evaluating values of energy conservation for room air conditioners is still lower.

Table 4 Performance index of RACs in Standard

Type	Rated Cooling Capacity /W	Energy Efficiency Ratio (EER)	
		Cooler	Heat pump
Integrated type	≤4500	2.35	2.30
	>4500	---	---
Split type	≤2500	2.85	2.75
	(2500, 4500]	2.70	2.60
	(4500, 14 000)	2.55	2.45

3. Idea on building energy efficiency

3.1 Energy saving vs. energy efficiency

Essentially, the target of building energy consumption is to provide services to occupants, such as comfort, health and convenience. Dr. Alan Meier, LBNL, has explained this idea using a service plot.

We can see from Fig. 3 that for a building the

standby loss of energy means the energy has been lost or wasted due to poor insulation of building envelope. This part of consumed energy must be saved. The slope of the service line indicates the building system efficiency at converting energy into a service, such as heating or cooling. A flatter line corresponds to higher conversion efficiency.

Therefore, for certain service we have to decrease

standby loss (energy saving) and to increase conversion efficiency of building system (energy efficiency). But we have never to restrain reasonable energy demand of occupants and to reduce the service standard.

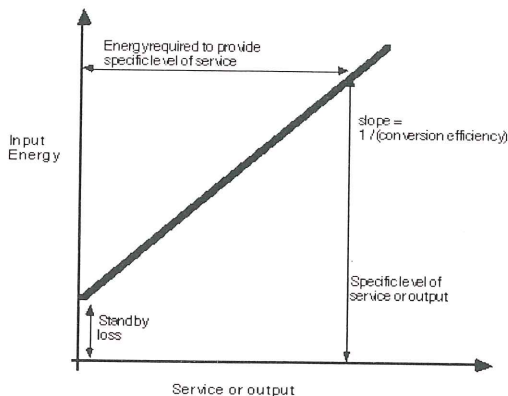


Fig. 3 A service plot to illustrate the idea of energy consumption

3.2 Envelopes vs. building services system

Reducing standby energy loss at the building envelope is a fundamental measure of building energy efficiency. It is easy to implement at the design stage and to be evaluated by some mandatory index. But

virtual energy saving will come from improving efficiency of building services systems. In public and commercial buildings, the percentage of thermal load formed by envelope is small in total. Sometimes we have to do tradeoff when we decide whether to use well-insulation or not.

For example, we can see from Fig 4 that if good insulated window is used the total cooling load during the whole summer would be increased on the contrary. The reason is in the buildings with intermittent operating air conditioning, after turning the system off the room temperature will raise. If outdoor air temperature would fall down to lower than indoor, heat transfer from indoor to outdoor will be occurred. But the insulation will restrict heat flux.

As illustrated in Fig. 5 annual energy saving ratio due to well-insulated wall in an office building is 8.1 % in Harbin (maximum) and 2.8 % in Guangzhou (minimum). That means the energy saving potential of envelopes is not large enough in public buildings.

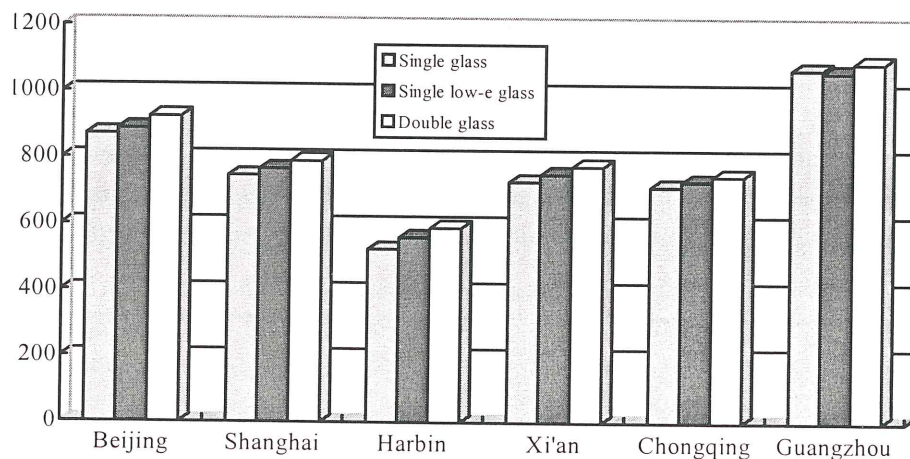


Fig. 4 Total air conditioning cooling load of various window types

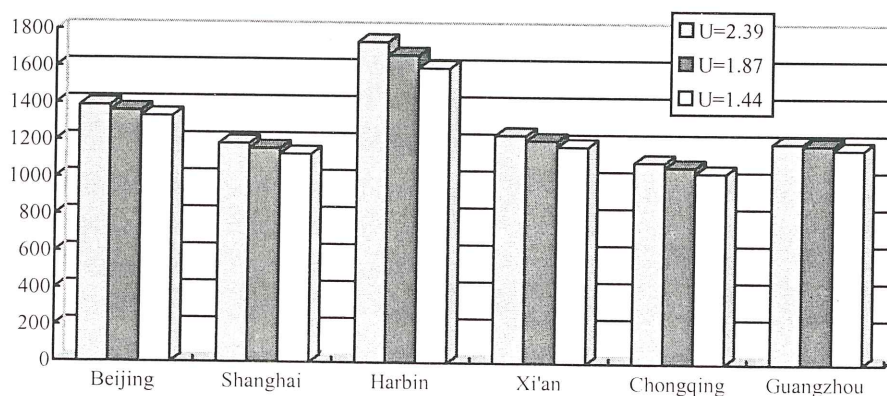


Fig 5: Annual cooling and heating load with various U-values

3.3 Energy vs. environment

Requirements of occupants on indoor environment quality become higher after SARS. But in most air handling units only one filter (lower than G grade by European standard) was installed. If the filter reached F7 grade would be added the duct resistance will be increased 200Pa at least.

On the other hand, fresh air volume in most buildings is not met to requirement of the standard. Increasing fresh air volume means increasing energy consumption.

We never use immolation of indoor environment as the cost of building energy efficiency. Baseline of building energy efficiency must be indoor environment quality.

A lot of new technologies can be used to solving the conflict between energy and environment, such as dedicated outdoor air system (DOAS), displacement air supply and desiccant air conditioning system.

3.4 Electric power saving vs. energy saving

In summer of 2003, 19 provinces and cities in China have faced serious power supply shortage. At the same time Northeastern United States & Canada, London, Sweden and Italy suffered blackout and breakdown of power grid. These indicated building energy usage is a unstable load and a danger for power supply safety.

Some measurements like ice storage air conditioning system can move the peak load to off-peak, but it will consume more power when making ice in night. The power generation plant can be benefited from it. For example, a 300MW coal-fired generator can consume less fuel up to 15% at full-load than at 40% load, and pollutant emission as well.

Some measurements like direct-fired absorption chiller using natural gas would consume more energy a little bit, but it is an environment-friendly looked as a green technology.

Thus consideration of building energy efficiency has to find balancing among energy, environment and economy.

3.5 Devices vs. system

Energy efficient devices not always linked an energy efficient system. For example, it is well known the BCHP (Building Cooling Heating & Power) system is an energy efficient option theoretically. But if both of

electric and thermal load profile had not been analyzed distinctly, the efficiency and benefits of BCHP would decrease evidently. There is a balancing relation between power output and heat output of BCHP system. If you want to draw more heat and higher temperature from BCHP system, the electric generation efficiency of system will be lower, vice versa. So we have to optimize BCHP planning and operating.

Another example is the conflict of lighting and air conditioning. If you want to save lighting power, you could use daylighting; the windows can not be well-shading. Thus the cooling load would be increased due to excessive solar heat gain. Contrarily, installing shading devices on the windows to reduce solar heat gain, you have to turn on the lighting at daytime to keep proper necessary indoor illumination. The cooling load will still be increased due to inner heat gain. All devices and equipments in the building should be looked as an integrated system.

3.6 Static state vs. dynamic state

Building services engineers used to be familiar with energy efficiency at static state, such as COP of chiller at the rating condition and cooling load at the design condition. But more significant factors for building energy efficiency are the performances at dynamic state. When we analyze a building performance we should use IPLV (Integrated Partial Load Value) or SEER (Seasonal Energy Efficiency Ratio) of chillers instead of COP, and use seasonal or annual energy analysis instead of cooling/heating load calculations.

Using site measurement data and computer simulation, the authors have established an IPLV equation based on Chinese meteorological data

$$\text{IPLV} = \frac{1}{\frac{0.005}{A} + \frac{0.28}{B} + \frac{0.262}{C} + \frac{0.45}{D}}$$

Originally, the IPLV in Chinese chiller standards has quoted from ARI standard. But early IPLV in ARI standard was calculated only by meteorological data of one America city, Atlanta. In 1990's ARI has updated the IPLV by using meteorological data from 29 cities which distribute in 11 different latitude zones. We could learn from this issue that we should have own IPLV adapted to climate in China.

Because energy charge is a main part in life cycle

cost of the buildings, we have to pay more attentions to efficient operating of building system. Most important measure for building energy management is energy consumption measures. Necessary data for calculating the efficiency of whole system (not only chillers) every hour should be included. These data have not been gained till now by current building automation system (BAS).

4. The indicator for building energy efficiency

There are only mandatory indexes for envelopes but

no performance guidelines for energy systems in our building energy efficiency standards. The reason is the energy efficiency of building systems are too complicated to be evaluated, especially in public and commercial buildings.

The coefficient of energy consumption (CEC) which characterized the efficiency of conversing energy to service should be used as Indicator of building energy efficiency.

Equation of CEC for air conditioning system is:

$$CEC/AC = \frac{\text{Annual energy consumption of air conditioning system (MJ)}}{\text{Estimated annual cooling and heating load (MJ)}}$$

The CEC could be used for benchmarking energy efficiency of buildings with various types and functions.

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