Prof. Long Weiding *is Head of the Department of Facilities Engineering & Management, at Tongji University in Shanghai, China. He was formerly Associate Professor and Dean of Studies, then Director of HVAC Division, Shanghai Institute of Urban Construction. He began his career as a designer and technician with one of China's largest steel manufacturers, Xinin Steel Works, Qinghai Province, after having obtained a Bachelor's Degree at the Dept. of Architecture & Civil Engineering, Tsinghua University; a postgraduate degree from the Institute of Air Conditioning Engineering, China Academy of Building Research (CABR), Beijing; and a Master of Science from Tongji University.*

His current research focuses include: research on distributed energy (CCHP, i.e. Combined Cooling, Heating and Power technology); means of improving Interior Air Quality (IAQ) status in office buildings; development of design standards governing the energy efficiency of public buildings and also relating to central air-conditioning and ventilation systems; development of local standards applying to household central air-conditioning systems; macro- and micro-economic analysis of gas-cooling technology in China; and the setting up of a local green-building rating system for residential buildings.

Prof. Long Weiding was nominated President of Commission E1 (Air conditioning) of the IIR in August 2003; he is Executive Director of the Chinese Association of Refrigeration (CAR); Vice-Chairman, Air Conditioning & Heat Pump Committee (CAR); Vice President and Secretary General, Shanghai Society of Refrigeration (SSR); Chairman, Air Conditioning & Heat Pump Committee, SSR; Executive Director, Shanghai Society of Architecture (SSA); Vice Chairman, HVAC Committee of SSA; Member of the Expert Council, Intelligent Building Engineering Committee, State Ministry of Construction; Member of the Editorial Board of HV & AC Journal; Member of ASHRAE; and Affiliated Member, Chartered Institute of Building Services Engineers (CIBSE).

Long Weiding is the author of many articles and papers, particularly in the following fields: HVAC, building engineering, energy and environmental issues in high-rise buildings, intelligent buildings, IAQ and green buildings. He has worked on many state-funded and private (Chinese and foreign corporations) air-conditioning projects in the residential, commercial and public sectors.

China: the Issue of Residential Air Conditioning

by

Weiding Long, Ting Zhong, Beihong Zhang

Dept. of Facilities Engineering & Management

Tongji University, 67 Chifeng Road, Shanghai 200092, China

e-mail: weidinglong@online.sh.cn

I. INTRODUCTION

In 2000, the percentage of the population living in cities and towns was 36.1% in China, which means that about 457 million people lived in cities and towns. Shanghai ranked first, with more than 88% of its citizens living in the urban area. In 2000, the population of Shanghai had reached 16.7 million, but the land area of Shanghai is only 6340.5 km²; therefore, the population density in the downtown area is very high — up to 53 326 people/km².[1]

The providing of settling spaces for such a large and dense population is a daunting challenge. By the end of 2001, the total floor area of residential buildings in China rose to 6.7 billion m² in urban areas, this being far higher than in 2000 (*China Statistical Yearbook*, 2003) The per-capita gross living area was 15.5 m², which was still at a low level if one considers global figures; therefore, about 5.7 billion m² of residential buildings will need to be constructed in the coming 5 years.

With the fast development of housing construction, the residential building service sector has

expanded dramatically in recent years in China. According to the 2003 *China Statistical Yearbook*, in 2001, the production of room air conditioners (RACs) reached 23.3 million units, ranking first in the world (see *Figure 1*).

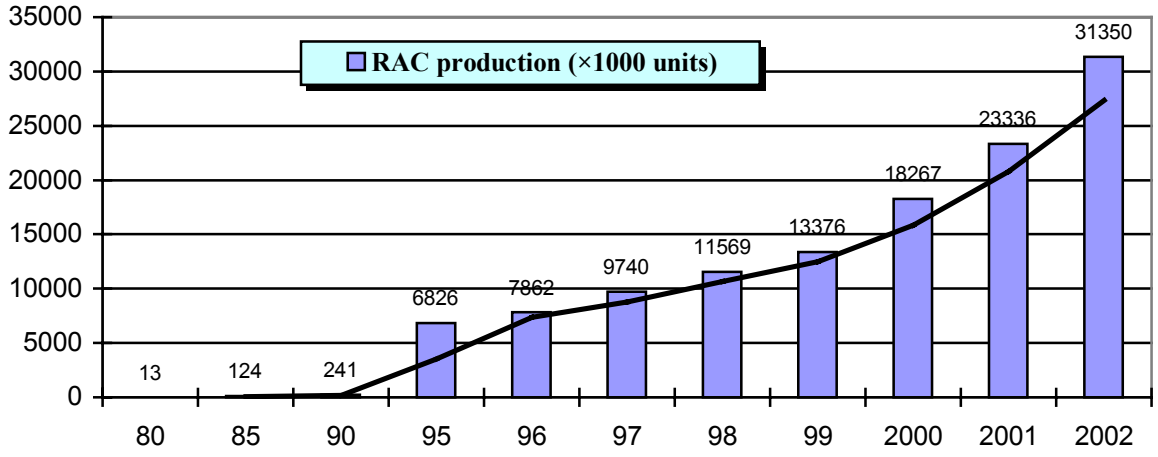


Figure 1. Rapid growth of room air conditioner production in China

Evolution de la production de conditionneurs d'air unitaires en Chine (China Statistical Yearbook, 2003)

II. RACs IN RESIDENTIAL BUILDINGS: THE SITUATION

Table 1 shows the number of RACs owned by 100 families in some economically developed Chinese provinces and metropolises in 2001.

Table 1. RACs owned by 100 families in 2001 (Source: National Bureau of Statistics of China)

Province/City	Per capita annual income (RMB)	Per capita annual income (USD) 1 RMB = 0.1215 USD	RACs owned by 100 families
Guangdong	11 137	1353	126
Shanghai	13 249	1610	114
Beijing	12 463	1514	106
Chongqing	7238	879	107
Tianjin	9337	1134	77
Zhejiang	11 715	1423	82
Fujian	9189	1116	74
Hubei	6788	825	71
Jiangsu	8177	994	67
Anhui	6032	733	51
Whole-country average	7702	936	51

We set up a survey involving 780 randomly sampled families in summer 2001 and in 400 families in 2002 in Shanghai; students supervised by the authors performed the survey, entitled Study on the Status and Energy Consumption of Residential Air Conditioning in Shanghai. The

average household size was 3.2 people. The average monthly income of each family was 3680 RMB (about 447 USD). The average floor area per household was 78 m^2 and the average number of air conditioners owned by each family was 1.8 units. The findings differed from those of the National Bureau of Statistics (NBS), since different statistical methods were used. We used a simple random sampling method, whereas NBS used a symmetrical equidistant sampling method.

Of the 1143 families surveyed and for whom data were available, only 37 families did not have a RAC. This means that RAC penetration had reached 96.8% in Shanghai, which is striking. However, within the group of 1143 families surveyed, only two had an installed household central air-conditioning system, meaning that penetration was only 0.17%; in the US, the 47.1% of households have central air-conditioning systems. About 39.7% of families in Shanghai had installed only one RAC unit serving one of several rooms, and about 39.5% of families owned two RAC units. It is hard to ensure a comfortable indoor environment in all rooms during hot summers or cold winters if only one or two RAC units are installed.

On the other hand, the operating hours of RACs in Shanghai homes are shorter than in the US. The actual survey data from 1106 families are summarized in *Table 2*.

Table 2. Usage of RAC in Shanghai families (Survey Report)

Summer (1106 families)		
Conditions for RAC operated	**%**	**Estimated average operating hours per day**
Basically never turn on	3.7	6 hours
Turn on once occupied	6.7	
Turn on when feeling a little bit hot	35.5	
Turn on when feeling hot	54.1	
Winter (1106 families)		
Conditions for RAC operated	**%**	**Estimated average operating hours per day**
Basically never turn on	32.7	3 hours
Turn on once occupied	2.9	
Turn on when feeling a little bit cold	18.8	
Turn on when feeling cold	45.6	

It can be seen from *Table 2* that although all the RACs in 1106 Shanghai families were air-source heat pumps, most families with no other heating facilities rarely used them in winter. It is rather cold in Shanghai in winter, with 109 days when the mean daily temperature is lower than 8°C.[1] The main reason for the low usage in winter is the high cost of electricity with respect to income.

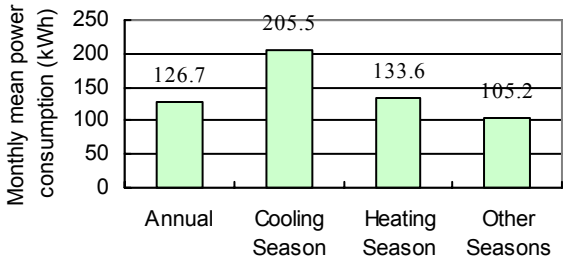


Figure 2. Monthly electrical consumption per family (*Statistical Yearbook of Shanghai*)

Figure 2 shows the average monthly electrical consumption per family in 2001. From these data, we estimated that per-capita annual residential electrical consumption in Shanghai is 485 kWh (about 1520 kWh for each family). The annual electrical consumption of RACs, on a per-family basis, can be estimated as being 450 kWh, which means that about 30% of the electricity budget of a family is spent on air conditioning.

III. IMPACT OF RESIDENTIAL AIR CONDITIONING ON ENERGY AND THE ENVIRONMENT

After analysing the number of household RACs owned by 100 families in Shanghai, we can conclude that the total electrical load accounted for almost 70% of the local power generation capacity. This constitutes a potential critical danger for the power supply grid. Due to the use of air conditioning, the peak load and on-peak/off-peak load difference of electric power in Shanghai on summer days has risen greatly in recent years (see *Figure 3*).

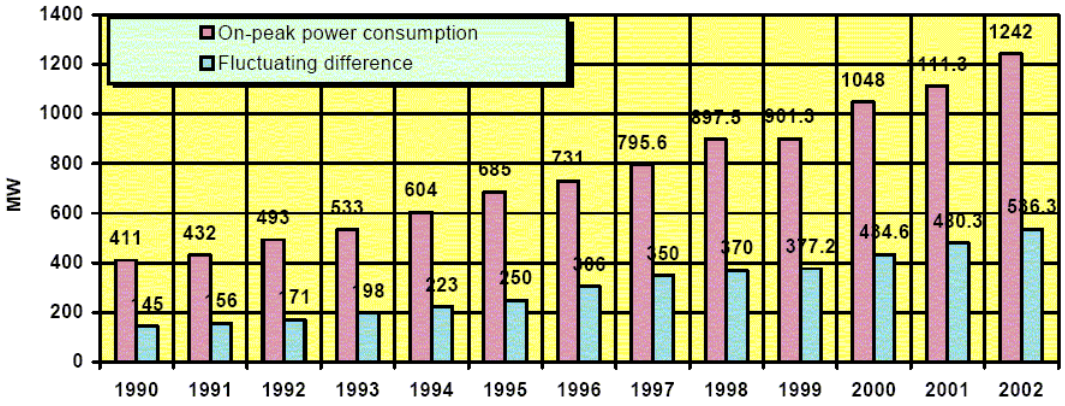


Figure 3. Peak load and on/off-peak load difference of electric power on summer days in Shanghai

Demande maximale en électricité et différence entre la demande en période de pointe et la demande en période creuse à Shanghai en été

Because the electric power in coastal Chinese cities is mostly supplied by coal-fired thermal power plants, electrically-driven RAC is a serious source of air pollution. If we assume that there are 4 million household RACs in Shanghai, and that these RACs operate average 1000 hours full-loaded annually, then we can estimate that 30 000 tons of SO_2 will be produced, accounting for 7.4% of the total SO_2 emissions in Shanghai in 1999. This quantity represented almost twice the total

SO_2 emissions of Hainan Province in 1997. According to an UNDP Human Development report, it can also be estimated that 5.1 million tons of CO_2 will be emitted, which is equal to the total amount emitted by the whole nation of Georgia or Bosnia in 1998.

The total population of open coastal cities and special economic zones in China is 91.9 million (*China Statistical Yearbook*, 2003). The average per-capita GDP in these areas is about 2500 USD. If the GDP growth rate was 10% in these areas, per-capita GDP would increase to 4000 USD in the coming 5 years (per-capita GDPs in Beijing, Shanghai, Guangzhou and Shenzhen have already reached 4000 USD). Over the same time period, the quantity of household RACs in these areas would increase to 22.4 million and the total electric load will exceed 2000 MW, which would account for 18% of the total power generation capacity of China in 1999. Annual SO_2 and CO_2 emissions would be about 180 000 tons (equal to the total SO_2 emissions in Jilin Province in 1997) and 32 million tons (equal to the total CO_2 emissions in Vietnam in 1998) respectively.

IV. RESIDENTIAL AIR CONDITIONING IN CHINA: DEVELOPMENTAL TRENDS

In their survey, the authors rated user satisfaction with the current household air-conditioning modes. Over 50% of the surveyed families were dissatisfied with their RACs. The main complaints are given in *Table 3*.

Table 3. Complaints concerning current household air conditioning systems

Main complaints	Percentage (%)
Stuffy, stale indoor air with an unpleasant odour	40.5
Electrical consumption is too high and too costly	37.3
Air conditioning can not cover all zones in the house Sudden warming up or cooling down when somebody enters or leaves rooms	29.1
Noise	10.2
Troublesome maintenance	10.1

For the question: “Is DHC (District Heating and Cooling) a trend for future residential air conditioning?”, the statistics concerning answers are presented in *Table 4*.

Table 4. Questionnaire on DHC trends

Answer	Percentage (%)
Yes	47.9
No	6.0
Cannot say	33.8
Do not know	12.3

Due to the dense population and the shortage of land resources in Chinese cities and towns, the best way to solve housing problems for the Chinese people is to construct residential buildings with higher densities and higher Floor Area Ratios (FARs). According to a speech made by a representative of the Chinese Ministry of Construction, a recent survey conducted in 20 cities showed that about 87.7% of families live in buildings without elevators and only 3.7% live in buildings with elevators. Only 64.4% of potential house-buying families have incomes of 1000-3500

RMB per month. We can thus expect that multi-family residential high-rise buildings with higher densities and higher FAR will be the main type of residential buildings in the coming years in most cities of China.

The most suitable air-conditioning system for multi-family residences is the central air-conditioning system, i.e. DHC. DHC has already been successfully used in several central-city areas in China. Currently used cooling and heating sources include:

a) water-cooled electrically driven chiller for cooling + gas-fired boiler for heating and hot water supply;

b) direct-fired LiBr absorption chiller for cooling, heating and hot water supply;

c) LiBr absorption chiller driven by waste heat from a power generation plant + waste heat for heating and hot water supply;

d) water-cooled electrically driven chiller + ice storage system + gas-fired boiler for heating and hot water supply;

e) water-source heat pump/ground-source heat pump + auxiliary heating source.

DHC is an energy-efficient option for the cooling and heating of residential buildings. The simultaneous usage factor (SUF) of air conditioning in typical central-city residential areas is very small. According to the authors' study, SUFs for cooling in typical central-city areas in Shanghai are listed in *Table 5*.

Table 5. Simultaneous Usage Factor (SUF) of air conditioning in residential uptowns

Number of families living in the downtown area	**SUF**
<100	0.70
100-150	0.65-0. 70
150-200	0.60
>200	0.50

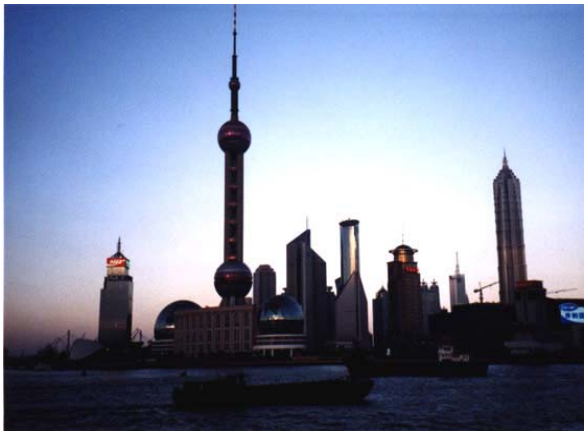
Therefore, the cooling capacity of DHC can be defined as 50-60% of design cooling load, although the heating capacity must meet the design heating load of total floor areas. In the climate zone of Shanghai and the Yangtze River drainage basin area, the heating load of well-insulated residential building is about 50-70% of the cooling load. This means that chillers with a higher Energy Efficiency Ratio (EER) may be used, and the peak electric load, along with the operating costs, would decrease a lot.

A magnificent project designed to enable natural gas to be transported from Western to Eastern China is under way. According to the plan, 30 billion m^3 of natural gas will be transported to Shanghai annually by the end of 2004. Therefore, Combined Cooling, Heating and Power (CCHP) generation using a gas-fired micro-turbine, a gas engine, a fuel cell, an absorption chiller and/or a waste heat boiler, will be the best choice for cooling and heating sources for residential air conditioning in Eastern Chinese metropolises in the near future.

Household central air conditioning, which is "one family with one air-conditioning system", is still the main type of air conditioning used for individual houses (or town houses). The currently used types of cooling and heating sources are:

- air-source heat pump/ground-source heat pump/water-source heat pump (chiller);
- air-source heat pump/ground-source heat pump/water-source heat pump (air-handling unit);

- variable-refrigerant-volume multi air-conditioning system (VRV);
- packaged electrically driven chiller and ice-storage system;
- gas engine heat pump (GEHP);
- small direct-fired LiBr absorption chiller.



Finally, RACs will still have a broad market in old buildings, retrofitted buildings and apartments in the future. According to the authors' survey, about 40% of families in Shanghai owned only one RAC unit. If half of these families were to buy a new one in the coming 5 years, demand will rise to 900 000 units. If 10% of existing RACs were to be retrofitted, this would involve an estimated 800 000 units. If RACs were to be installed in half of newly constructed housing in Shanghai in the coming 5 years, about 700 000 units would be needed. However, the EER, the indoor environment improving function and the automation control level of RACs must be updated.

V. CONCLUSION

China has the biggest residential air-conditioning market in the world. The production of RACs in China ranks first in the world. Penetration of residential air conditioning in Shanghai has reached 96.8%. However, the usage ratio in Shanghai is still low due to high energy costs. Use of large numbers of RACs has already caused enormous pressure on energy supply and the environment of China. Electrically driven RACs have created the biggest unstable power grid load and the biggest source of CO_2 emissions in most Chinese metropolises.

The residential-air-conditioning trend in Chinese metropolises should be DHC with CCHP using natural gas as an energy source. Household central air conditioning will become the main type of air conditioning for individual houses or town houses. RACs will still have a broad market.