

GREEN BUILDING IN MAINLAND CHINA

Philip C.H. Yu

Trane Asia Pacific, Hong Kong

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ABSTRACT

This paper reviewed the contemporary movement of Green Building and its rationale behind. The future development of Green Building in China would probably be focus on energy efficiency. Various building components and some critical factors to achieve energy-efficient building's requirement were analyzed and discussed with reference to the current situation and needs in China.

1. INTRODUCTION

With the civilization and modernization, human life has been improving in comfort, mobility, communication and so on. In China, the residential building has been rapidly developing since the 80's. Fig. 1 shows the average floor area of new-built per year less than 100 million m² in 1980 has been increased more than 5 times by 1999. This also comes with a corresponding increase in demand of air-conditioners; and so is the energy consumption in buildings. In the past 10 years, an export energy of 45.82 MTCE (metric ton of coal equivalent) has been turned to 47.06 MTCE net energy import.

We all know that clean air and soil, pure water, food reserves, and energy sources are fundamental to life. We also know that our way of life — the buildings we live in, the vehicles we drive, the modern conveniences on which we rely — jeopardizes these finite resources. According to the U.S. statistics, buildings use 1/3 of the total energy, 65.2% of electricity consumption, 30% of greenhouse gas (GHG) emissions, 136 million tons of construction and demolition waste (ie. about 2.8 lb/person/day), 12% of potable water, 40% of raw materials used globally (or 3 billion tons annually), etc. Atmospheric emissions from the use of energy lead to acid rain, ground-level ozone, smog, and global climate change. In 1990, CO₂ emission per person per year is 22 tons in the USA, 2 tons in China and 0.9 tons in India. If nothing is done, China will catch up with the USA by 2020 and India will be 16 tons/person/year. This will require the Earth to absorb seven times as much carbon dioxide as today! The resulting global warming— one estimate is 2.5°F to 10.4°F (1.4°C to 5.8°C) over the next century—may affect weather patterns, sea levels, agricultural zones, and the quality of life for future generations. The scientists warn that, if the carbon dioxide level were to rise up to two times of the pre-industrial level, the global warming will reach 3.6°F (2°C) which is

considered to be “dangerous level”. Note that it has already been raised 1°F (0.6°C) in the last 150 years [1].

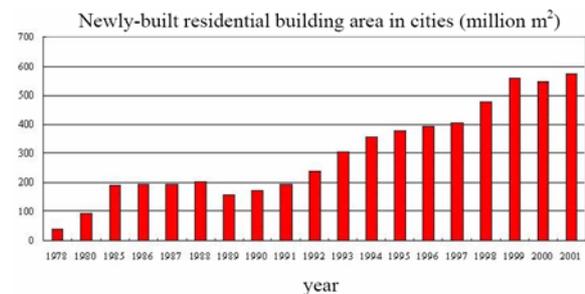


Fig.1: Residential building in cities of Mainland China

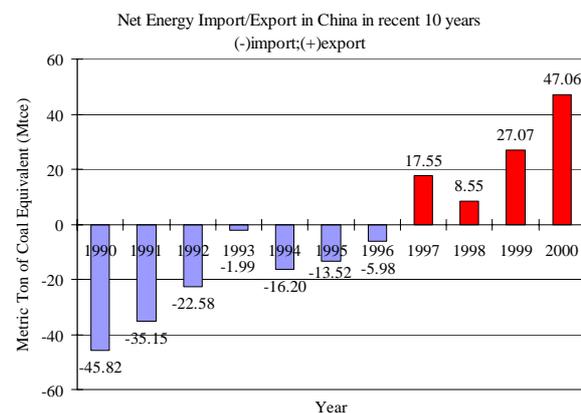


Fig.2: China energy import/export

2. THE “GREEN BUILDING” MOVEMENT

It is only recently that concerns about the environment have taken center stage in the political arena, both internationally and in China. The World Green Building Council (GBC) was officially launched in November 2002 by its nine

founding member countries including Australia, Spain, Brazil, Canada, Japan, Mexico, India, Korea and USA. A so-called “China GBC” is being formed at the moment.

Regardless of the organization, the Green Building movement aims at reducing or eliminating negative impact of buildings on environment and occupants. According to Australia GBC [2], buildings consume one-third of the world’s resources; they use 42% of Australia’s energy; 12% of water demand is consumed by buildings; up to 40% of waste going to landfill is from construction and deconstruction activities (predominantly the churn of refurbishments); and 40% of Australia’s air emissions are from buildings.

“Green building”, “whole building”, “sustainable building” or “high-performance building”... no matter how it is called, the fundamental concept attempts to optimize cradle-to-grave performance of the entire building. Economic, environmental, and sociocultural effects receive as much weight as operating costs and initial investment. Performance goals for the building address occupant productivity, comfort, and well being, along with the use of energy, materials and the land. Waste production and transportation need to be considered, as in the adaptability of the building over time. Realizing such ambitious goals requires a very different approach to the building process – one that is collaborative, integrated, and comprehensive rather than fragmented and linear. Professionals from various disciplines as well as the building owner and even end-users work together from the pre-design phase. They set the purpose, scope, and performance goals for the building. Subsequent design decisions are based on their effect on the entire building rather than system-by-system or component-by-component. For example, meeting the building goal for energy efficiency requires more than the selection of energy-efficient equipment. It also entails consideration of orientation, envelope, window placement, glazing methods, shading, etc. The results of the whole-building design process are compelling. According to U.S. experience, school districts can save 30 to 40% on utility costs each year for new schools and 20 to 30% on renovated schools [3]; and green buildings cost about 50 to 60 cents per square foot to operate compared with one to two U.S. dollars for a standard building. The increase in productivity can be out of expectation, which is illustrated by the example of Main Post Office at Reno Nevada, USA [4].

There are many different rating systems available in different countries to define the common metrics for “green building” such as LEED of USA, BREEAM of UK, CASBEE of Japan, GBTool of

Canada, Green Star of Australia, LND of Germany, ESCALE of France, Eco-Profile of Norway; and in China Eco-Building rating system was published in 2001 (revised in 2002) for residential buildings. Recently, an “Assessment system for Beijing Olympic Green Buildings” has been published but it is not a statutory document. Although all these rating systems are different in terms of the assessment methodology, priority of environmental issues to be addressed, or local policy and procedures, they share the same common objectives, such as:

- sustainable site planning;
- maximizing energy efficiency or minimizing energy use;
- safeguarding water and water efficiency;
- conservation of materials and resources; and
- protecting both indoor and outdoor environment from pollution or damage.

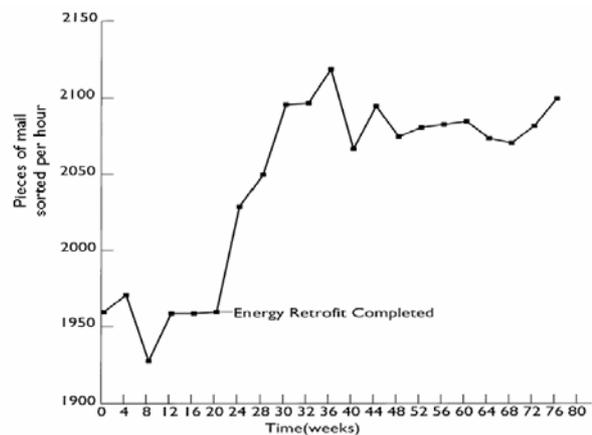


Fig. 3: Productivity gain after retrofit, Reno Post Office

Recently, a lot of coastal cities and economic zones in China have been suffering from power shortage or brownout. Energy Efficiency is the center of issues today and will be the focus of future development in green building. Chinese government has committed to the Agenda 21 of the UNCED (United Nations Conference on Environment and Development) on sustainable development, which included energy efficiency as one of the Priority Programmes. Energy requirements are continuously growing as the economy expands rapidly and the population increases. The per capita sources of energy are limited and energy shortages are increasingly common; therefore, China’s future economic development will inevitably shift from its previous inefficiencies towards efficiency, and focus on energy conservation [5].

Building energy control may include the following major systems or components:

- building envelope
- air-conditioning and heating equipment
- ventilation and exhaust systems
- service hot water supply
- vertical transportation (for high-rise buildings)
- lighting
- building automation

A comprehensive energy code or standard (e.g. ANSI/ASHRAE/IESNA Standard 90.1) is required to define the minimum performance levels that can be met by the majority or 75 % of the buildings in the market. However, green buildings must achieve increasing levels of energy performance beyond the minimum requirements, which typically accounts for the top 25 % in the market. In order to reach the top 25 %, designers ought to look for innovative alternatives among the building components. For residential buildings, “Energy Labeling” is one of the effective measures to control energy use of home appliances and it is being adopted in many countries including China. It is a market-driven approach to promote energy conservation because products with better energy label (or higher efficiency) will cost less to operate in the future. End-user education will be an important factor to determine its successfulness. For commercial buildings or public buildings, the energy consumption of the HVAC systems accounts for 60 to 70 % of the total building energy use [6] and the majority of them are using central plant. The energy efficiency of “big” equipment such as chiller and/or boiler becomes the focus of innovative solution. For chillers, the available technology to improve the efficiency may include selection of the right refrigerant for the right applications, full-load and part-load performance, multi-chiller plant control, etc.

3. THE RIGHT REFRIGERANT FOR THE RIGHT APPLICATIONS

In compliance to Montreal Protocol, CFC refrigerants are being phased out in China. According to U.S. EPA, the most commonly used alternative refrigerants for large building air conditioning applications – HFC-134a and HCFC-123 – are allowed, approved, or endorsed for use by Environment Australia; Environment Canada; the Japan Ministry of Economy, Trade and Industry; the Japan Ministry of the Environment; the U.S. Environmental Protection Agency; and most other environment ministries worldwide [7]. In China, the technical requirement of a qualified substitute to an Ozone Depleting Substance (ODS) is that the

Ozone Depletion Potential (ODP) cannot be higher than 0.11 [8]. HCFC-123 has an ODP value of 0.012 and HFC-134a is zero; therefore, both of them are qualified. However, zero ODP does not necessarily mean NOT depleting the ozone layer. Stratospheric cooling caused by the GHG’s has the perverse effect of accelerating the natural depletion of ozone layer, according to William Randel [9], an atmospheric scientist and a lead author of the United Nations Environment Program’s “Scientific Assessment of Ozone Depletion: 2002” [10]. Internationally, particularly in Europe, the Global Warming Potential (GWP) is equally important when assessing the environmental impact. Table 1 shows that HFC-134a has significantly higher GWP value than HCFC-123. This implies that the technology to contain the refrigerant within the chiller without leakage is very important. In other words, low-pressure (e.g. R11, R123) machine is relatively preferred to high-pressure (e.g. R22, R410A) machine; and hermetic-drive compressor is better than open-drive compressor. The best available chiller today can achieve a “near zero” refrigerant leakage or emission less than 0.5% charge per year. Again, absolute zero emission or even zero GWP does not necessarily mean NOT global warming. An inefficient refrigerant or equipment consumes more energy to operate, which causes the power plant to generate more and therefore more carbon dioxide is released to the atmosphere as a result. This indirect global warming effort has been taken into account by the **Total Equivalent Warming Impact** (TEWI) which makes use of GWP for refrigerants relative to CO₂ published by the Intergovernmental Panel on Climate Change (IPCC) and is calculated by:

$$TEWI = GWP \times L \times N + GWP \times m \times (1 - \alpha_{rec}) + N \times E_{ann} \times \beta$$

where m is the mass of refrigerant in the equipment, kg; α_{rec} is the fraction of refrigerant charge recovered; L is the annual loss or consumption of refrigerant, kg/year; N is equipment lifetime, years; E_{ann} is the annual energy use, kWh/year; and β is the CO₂ emissions corresponding to every kWh of energy produced, kgCO₂/kWh. Fig. 4 shows an example in the USA [11]. Obviously, the indirect warming effect outweighed the direct warming effort. For a typical 350-ton chiller over 10-year operation, 100% reduction of the direct effect (i.e. zero emission) means 2 % improvement in TEWI while 10% increase in COP (coefficient of performance) value can bring along 7 % better TEWI.

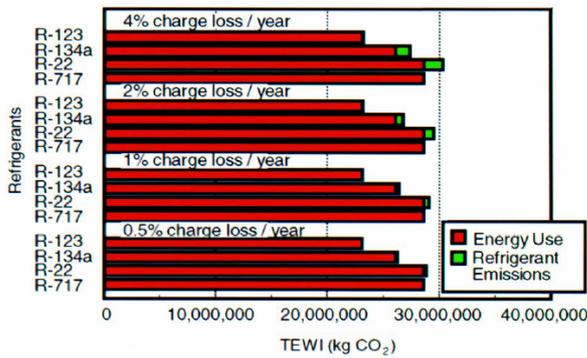


Fig. 4: TEWI for chillers in Atlanta

Today, HCFC-123 chiller technology can achieve the highest energy efficiency with the lowest emission and the refrigerant itself has the shortest atmospheric life as shown in Table 1. The 2002 RTOC assessment report prepared under the auspices of the United Nations Environmental Program (UNEP) stated that “HCFC-123 has favorable overall impact on the environment that is attributable to five factors: (1) a low ODP, (2) a very low GWP, (3) a very short atmospheric lifetime, (4) the extremely low emissions of current designs for HCFC-123 chillers, and (5) the highest efficiency of all current options”. This international assessment cite studies showed that “continued use of HCFC-123 in chillers would have imperceptible impact on stratospheric ozone while offering significant advantages in efficiency, thereby lowering greenhouse gas emissions from associated energy use” [12].

The next best technology is HFC-134a but the opportunity cost is 5 to 20 % lower efficiency that could be translated to environmental cost of the annual power plant emission:

- nearly 9,550 billion grams of CO₂
- over 80 billion grams of SO₂
- over 34 billion grams of NO_x

which is equivalent to:

- removing over 2.5 million cars from the road
- planting nearly 600 million trees each year

4. THE FULL-LOAD AND PART-LOAD PERFORMANCE

The full-load performance of air-conditioning equipment is commonly measured by COP, EER (energy efficiency ratio) or kW per ton. Raising the standard of full load efficiency reduces the demand for electricity; otherwise, the government ought to pay even higher price for more power plants that may become an obstacle to industry and economic development. In the USA for example, this is a mandatory requirement in the energy standard [13]. Table 2 shows the minimum requirement of the current version as compared to an older one.

The part-load performance is commonly described by SEER (seasonal energy efficiency ratio) for smaller or unitary equipment while the IPLV (integrated part-load value at standard ARI conditions) and NPLV (non-standard part-load value) are widely used for larger equipment or chillers by the HVAC industry internationally including China. The number represents the average performance of one single piece of equipment, not a system. For IPLV of a chiller, it is calculated by [14]:

$$0.01A + 0.42B + 0.45C + 0.12D$$

where A, B, C, D are the energy efficiency at the corresponding chiller loading of 100% at 85°F (29.4°C) condenser water temperature, 75% at 75°F (23.9°C), 50% at 65°F (18.3°C) , 25% at 65°F (18.3°C) respectively; and the coefficients are weighting factors of the corresponding part-load operation. Particularly pointed out by the Air-conditioning and Refrigeration Institute (ARI), the equation was derived for a single chiller installation and was based on an average part-load operation; therefore, it cannot represent a particular job [15].

Table 1: Refrigerant environmental properties

Refrigerant	Montreal Protocol ODP	Atmospheric Life, years	100-Year GWP
CFC-11	1.0 (index)	45.0	4680
CFC-12	1.0	100.0	10,720
HCFC-22	0.034	12.0	1780
HCFC-123	0.012	1.3	76
HFC-134a	0.0	14.0	1320
R-407C (HFC blend)	0.0	4.9~29.0	1674
R-410A (HFC blend)	0.0	4.9~29.0	1997

Source: Montreal Protocol Science Assessment of Ozone Depletion 2002

Table 2: Comparison of equipment efficiency requirements in USA [11]

	Minimum Efficiency ^a		Test Procedure
	Per 90.1-1989	After 29/10/2001	
Rooftop air-conditioner, 15 tons	8.5 EER ^b	9.7 EER ^b	ARI 340/360 ^c
Water-source heat pump, 4 tons	9.3 EER (85°F EWT)	Cooling: 12.0 EER (86°F EWT) Heating: 4.6 COP (68°F EWT)	ARI 320 ^d (ARI/ISO-13256-1 after 29/10/2001)
Water-cooled screw chiller, 125 tons	3.80 COP	4.45 COP	ARI 550/590 ^e
Water-cooled centrifugal chiller, 350 tons	5.20 COP	6.10 COP	ARI 550/590 ^e

^a Coefficient of performance (COP), energy efficiency ratio (EER), entering water temperature (EWT), integrated part-load value (IPLV)
^b Deduct 0.2 from the required EER if the rooftop air conditioner includes a heating section other than electric resistance heat.
^c ARI 340/360, *Commercial and Industrial Unitary Air-Conditioning and Heat Pump Equipment*
^d ARI 320, *Water-Source Heat Pumps*
^e ARI 550/590–1998, *Water Chilling Packages Using the Vapor Compression Cycle*.

In most cases, a high value of IPLV/NPLV does not imply more energy savings because 80 % of the chillers (in USA) are installed in multi-chiller plants. Fig. 5 shows the chiller load profile of typical multi-chiller plants. It can be seen how the loading of the chillers is affected by the number of chillers in the plant. The individual chiller load profile bears little resemblance to the system load profile. The more chillers there are in a plant, the more operation is near full-load; and chiller unloading or condenser water temperatures will be very different from the ARI standard conditions based on an average single chiller plant. Besides, the IPLV/NPLV rating is a function of the entering condenser-water temperature (ECWT) relief schedule based on the interpretation of cataloged cooling-tower performance at part load given the average weather data of 29 cities (in USA). However, neither IPLV nor NPLV takes into account of different locations that may have very different condenser water temperatures. Once installed, the chilled water plant’s energy consumption is determined by the tradeoff between chiller, tower and pump power. At many part-load conditions, the coldest water temperature possible does not result in optimal system operation [16]. Load, ambient conditions and the part-load operating characteristics of the chiller and tower will ultimately determine the optimum ECWT for a given installation. Some chiller manufacturers are able to offer advanced controls such that the chiller and tower operation may be optimized in accordance with the outdoor ambient conditions [17].

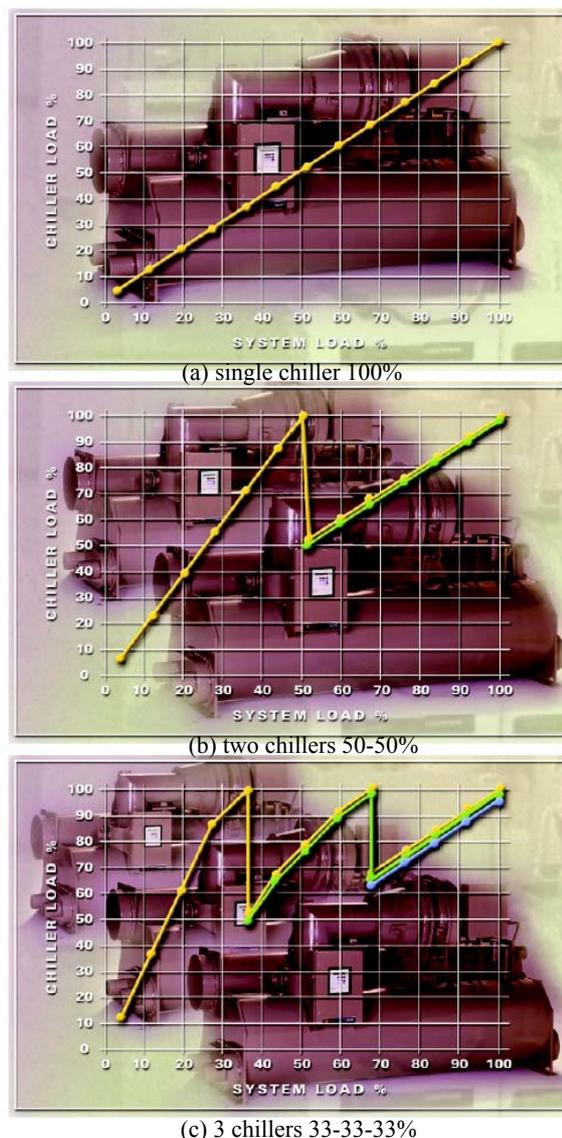


Fig. 5: Chiller load profile of typical multi-chiller plants

Therefore, the IPLV is not a good yardstick for evaluating energy performance, and could be misleading if it is being specified in energy standard. Because of the minimal weighting factor (0.01) of full-load, some chillers with a good IPLV have very poor full-load efficiency. These chillers may be using variable speed devices that may degrade the full-load performance indeed (see Table 3 for typical examples).

To successfully optimize the performance of a multi-chiller plant and deliver the greatest possible energy cost savings, the designer must account for these facts:

- Variables other than the dry bulb temperature of outdoor air – for example humidity, solar loads and operation schedules – greatly affect cooling loads in commercial and industrial applications.
- System loads and individual chiller loads in multi-chiller plants are distinctly different.
- Changing loads affect cooling-tower operation and entering-condenser water temperatures.

ARI encourages the use of comprehensive analysis tools that reflects the actual weather data, building load profile, number of chillers in use, operational hours, and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the overall chiller plant system efficiency.

5. THE AUTOMATIC CONTROLS TECHNOLOGY

Variable-flow in primary circuit of chilled water system is almost not possible ten years ago. Today, it is not difficult to find successful installation examples with lower first costs and better energy efficiency. A recent research done by ARI confirmed that variable flow, primary-only systems reduced total annual plant energy by 3 to 8 %, first cost by 4 to 8 %, and life cycle cost by 3 to 5 % relative to conventional constant primary flow with variable secondary flow systems [18]. It may cure “low delta-T syndrome” as well [19].

Fig. 6 shows a typical “decoupled” chilled water system that consists of a primary circuit (or chilled water production loop), a secondary circuit (or distribution loop) and a decoupler (bypass line). Conventionally, it is advised to maintain a constant flow through the chiller evaporator – that is the primary circuit. The overriding concern has been the risk of nuisance shutdowns or even freezing and rupturing of the chiller evaporator due to water flow reducing faster than the chiller safeties could respond. With the advancement of microelectronic control technology, strategically placed sensors and real-time response allow the modern chillers to perform its primary function of producing cold water even when evaporator water flow varies. The range of many chillers today is 3–12 fps (0.9–3.6 ms⁻¹) [20] but some of them can accommodate as low as 1.5 fps (0.4 ms⁻¹) [21]. However, the rate of change of water flow is critical. Table 4 gives examples of the allowable flow-rate change for different types of chiller; and Fig. 7 shows how a chiller control responds to flow-rate reduction.

Now that the primary circuit can vary water flow, the secondary pumps may be eliminated but the bypass line still remains in order to assure that the rate of chilled water flow through each operating chiller never falls below the allowable limit required by the manufacturer. Here is a list of best practice as the key to success:

- chiller optimization for a minimum evaporator flow limit that is less than 60 % of the chiller’s design flow;
- chilled water pump sizing to accommodate the pressure drop of the system as well as the chiller evaporator;
- selection of isolating/check valves with linear relationship between valve position and flow rate;
- series arrangement for 2-chiller system to avoid flow transition [22];
- air handling units or other airside terminal devices grouping such that shutdown schedules shall be implemented at 10-minute intervals.

Table 3: Typical examples of chiller with low NPLV but more energy-consuming

Operating Data				Chiller A (with VSD) ^b			Chiller B (standard starter)		
Tons	NPLV Weighting ^a	Hours	Ton-Hours	NPLV= 0.436			NPLV= 0.448		
				kW/ton	kW	kWh	kW/ton	kW	kWh
500	0.01	30	15000	0.682	341	10,230	0.514	257	7,710
375	0.42	1260	472500	0.52	195	245,700	0.448	168	211,680
250	0.45	1350	337500	0.38	95	128,250	0.428	107	144,450
125	0.12	360	45000	0.416	52	18,720	0.536	67	24,120
Total Hours: 3,000				Total kWh: 402,900			Total kWh: 387,960		

^a ARI 550/590–1998, *Water Chilling Packages Using the Vapor Compression Cycle*

^b VSD = variable speed drive

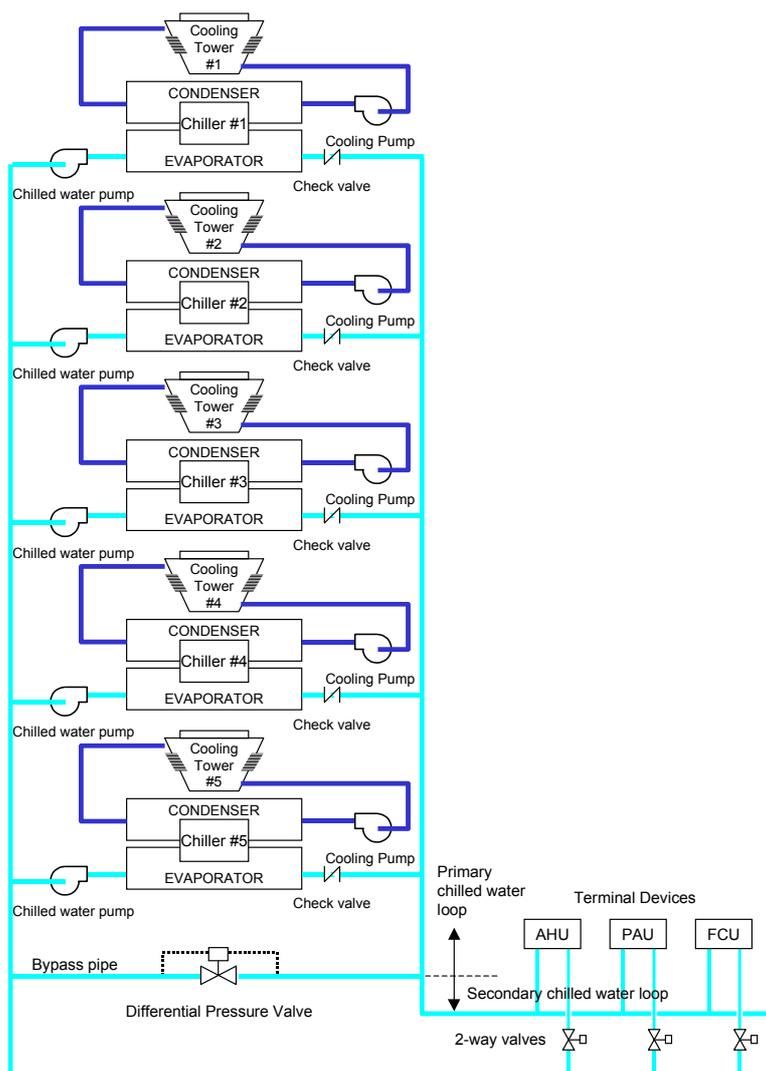


Fig. 6: A typical chiller plant schematic diagram

Table 4: Variable-flow tolerance of chillers

Chiller type	Controller type	Allowable flow change rate (% of design flow per min.)
Absorption	1 st Generation	Not recommended
	2 nd Generation	30% for comfort cooling 10% for process cooling
Scroll	All	10%
Screw	1 st Generation	Not recommended
	2 nd Generation and after	30% for comfort cooling 10% process cooling
Centrifugal	1 st Generation	Not recommended
	2 nd Generation	30% for comfort cooling 10% for process cooling
	Advanced with flow compensation	See Fig.7

Source: Trane Engineers Newsletter, Vol. 31, No .4, 2002

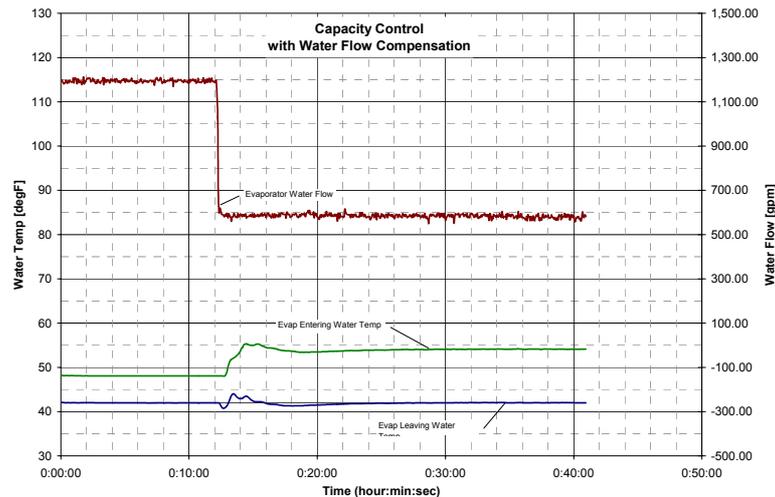


Fig. 7: Example of chiller controls in response to flow-rate reduction

6. SUMMARY

Although Green Building is a very broad topic and it covers many different disciplines, the future development in China is likely to focus on energy efficiency area. A well-constructed building energy standard will be inevitable, especially for public or non-residential buildings. Since the Green Building is targeting the top 25 % of the buildings in the market, it is necessary for the designers to search for innovative solutions. For commercial buildings, HVAC system takes 60 to 70 % of overall building energy consumption and the majority of them are using central plant. Chiller technology associated with the selection of refrigerant is critical to the improvement of the building energy efficiency. HCFC-123 technology provides the highest efficiency for centrifugal chillers with the lowest annual emission rate. The refrigerant itself has the shortest atmospheric life, very low GWP, very low ODP and is a qualified alternative refrigerant as per SEPA of China. As mandatory requirement in building energy standard, equipment full-load performance is considered to be far more important than part-load performance. In particular, the IPLV/NPLV value is an indication of the average part-load performance of a single chiller installation and should not be used for evaluating the energy performance of multi-chiller plants. Instead, ARI encourages the use of comprehensive analysis tools that reflects the actual weather data, building load profile, number of chillers in use, operational hours, and energy drawn by auxiliaries such as pumps and cooling towers, when calculating the overall chiller plant system efficiency. With the advancement in automatic controls technology, modern chillers are allowed variable chilled water flow. Recent research showed a savings of total annual plant

energy by 3 to 8 %, first cost by 4 to 8 %, and life cycle cost by 3 to 5 % as compared to conventional chilled water systems.

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