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Optimization of China´s centralized domestic hot water system by applying Danish elements

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Abstract

Regardless of where they are in the world, people depend on a reliable and sufficient supply of domestic hot water (DHW) for daily use. Some countries that have district heating (DH) infrastructure, such as Denmark and China, combine spacing heating (SH) and DHW together, with the aim of having a smart, energy efficient and environmentally friendly energy-consumption system. Nevertheless, the development of centralized DHW (CDHW) systems in these two countries differs significantly. This article details the challenges China's CDHW system is currently encountering and proposes to apply the flat station concept to improve China's CDHW system. Meanwhile, the technical advantages of the Danish CDHW, which would benefit China, are analyzed. Overall, from a technical point of view, the flat station concept is not only in line with China's current DH conditions but would compensate for some technical defects of the existing CDHW system.

Key words: Domestic hot water, district heating, heat loss, flat station, Legionella.

1. Introduction

Energy consumption to generate DHW in China´s urban residential buildings has increased steadily from 18.94 petajoule (PJ) in 1996 to 169.86 PJ in 2011 [1], due to more and more Chinese households having been supplied with DHW, see the histogram part of Figure 1 as well as the corresponding number in the primary axis . The trend is for DHW energy consumption to continually grow along with the rising living standard. In 2011, DHW consumed 9.5% of total residential buildings' energy consumption in China's cities [2]. On the other hand, the most common DHW solution in China is individual water heaters. The secondary axis of Figure 1, the red dot plot, shows the number of water heating units owned per 100 urban households, which has risen from around 30 units in 1996 to 89.1 units in 2011[3]. According to [4], in 2005, the number was 72.7 units per 100 urban household, while gas water heaters accounted for 57.4%, electric water heaters for 31.3%, and solar water heaters for 11.3%. However,

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CDHW had the small market share with only about 5% average coverage rate [5] [6],and was mainly developed in the cold and severe cold climate zones of China where space heating was legally required.

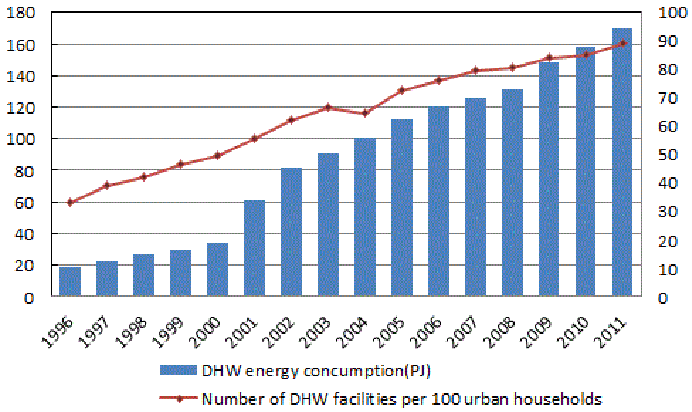

Fig. 1. The development of DHW in China, 1996-2011

However, many cases verify that DH is an efficient use of local multi-heat sources, substantial energy saving and CO_2 emission reductions in cities. One encouraging example is Denmark's blooming DH industry. Denmark has one of the highest shares of district heating in the world, with more than 55% of the net energy demand for heating being supplied from DH systems [7], where the DH system continues working for the whole year and binds SH and DHW together. It is said that CDHW system has quite a high share rate, compared to other varieties of individual DHW solutions. Since the 1970s oil crisis, Denmark has released a series of legislations to promote the development of the DH industry; a wide range of energy-saving measures have been witnessed in this country. Similar to China, Denmark is also confronted with the growing desire for hygienic, comfortable, and safe DHW, which will necessarily require greater energy. From 1997 to 2007, DHW consumption increased from 10 m^3 per capita per year in 1987 to 15m^3 per capita per year in 2007, whereas total cold water consumption observed a decrease from approximately 70m^3 to 45m^3 per capita per year [8]. Meanwhile, an increasingly stringent energy policy requires a considerably decreased unit energy consumption in Danish houses: the annual energy consumption including hot water, space heating, and electricity for existing houses is 117 kwh/m^2, for new houses is 85kwh/m^2, and for BR08 class 2 houses is 66 kwh/m^2[9]. Moreover, the future trend of the Danish DH is expected to be in the low temperature DH (LTDH)-the temperature level of DH will shift from the current 70/40°C to 55/25°C[10], such that SH and DHW will share nearly equal proportions of building energy consumption. With this background, Denmark has developed specific techniques to reduce wasted energy and continuously support the well-being of the CDHW system. Among these factors lie some inspirations for China, for reversing the negative situation of its CDHW system.

2. Technical comparison

In CDHW systems, heating water is the basic activity, but this hot water has to be produced, stored, distributed, and pumped back to the generation site. In this process, energy loss is inevitable. Generally, the efficiency of a CDHW system is stated as the quantity of energy used to heat the cold water divided by the total energy for the CDHW system, including all losses. Typically, energy consumption for CDHW can be divided into four parts: ① Q_1 energy consumption for heating the cold water to hot water; ② Q_2 heat loss from hot water pipes and circulation; ③ Q_3 heat loss from hot water heaters, heat exchangers, and associated piping and valves; and ④ Q_4 electricity consumption of the circulation pump.

It could be said that $Q_1 > Q_2+Q_3+Q_4$, as such, the advantages of centralized hot water supply mode can be well reflected. Therefore, minimizing the heat loss items is the fundamental idea of an efficient CDHW system.

2.1 Efficiency of heat generation for CDHW system in China

In China, for most of the existing CDHW system, the typical model is that gas-fired or coal-fired boilers produce hot water, transfer energy via substations to heat cold water, and then supply hot water to a group of high-rise or multi-story buildings. A storage tank is generally installed in the secondary side of the substation and connects to the buildings. Depending on the height of the building, sometimes an internal pressure partition is essential.

Based on the above principle, it could be said that the heat generation part of China's DH system has huge potential for improvement. The efficiency of a coal-fired boiler is around 70%, even much lower. However, although the efficiency of a gas boiler is up to 90% due to the fact that many gas boilers have set timing schedules for opening or closing, the efficiency of a gas boiler is compromised. Following the Danish experience, multi-heat sources are available for DH systems; gas boilers are usually for the peak load. Utilizing local energy otherwise wasted is the fundamental idea for DH in Denmark. One fuel resource is surplus heat from industrial processes. Can China learn from this experience? In reality, for China, utilizing industrial heat waste is not at all infeasible. Surplus heat from industrial processes can be found within a 30 km radius of China's cities, which can meet almost 70% [11] of the heat demand of North China's mandated heating regions. Moreover, in these regions, the district heating distribution infrastructure, originally aimed at supplying SH in winter, is also available. It seems surplus industrial heat waste is a practical resource when expanding CDHW systems in China. Additionally, this resource can enable DH systems to operate through the whole year, whereas China's current DH system only operates in winter to supply SH; and combining DHW systems together. Due to the free fuel coming from wasted energy, the efficiency will make less sense for the heat generation part, let alone energy saving and emission reduction no more burning fossil fuels like coal, oil and natural gas.

2.2 Flat station concept and heat loss of DHW system

In general, hot water circulation systems have a large heat loss. According to [9], heat loss from the circulation, Q_2, represents the largest share of total energy consumption, greater than the energy for heating the cold water to hot water. The proportion could be even bigger, especially for multi-story

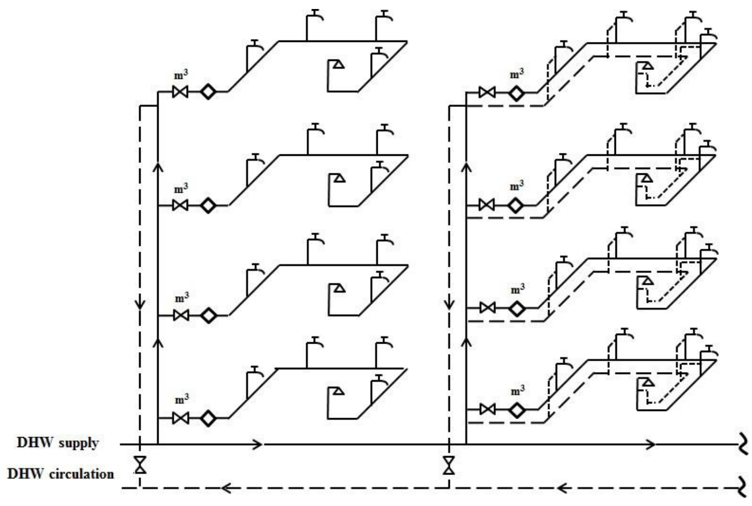

Fig. 2. Two typical circulation systems of DHW in China

buildings with large circulation systems, whereas high-rise and multi-story buildings are typical building structures in China. Compared to Q_2, heat loss from hot water installations, Q_3, represents a small part of the energy, and electricity consumption for circulation pump, Q4, is even smaller. Danish data showed, taking multi-story buildings as an example, that Q_1, Q_2,Q_3,Q_4 are, respectively, 33%, 60%, 5%, and 2% [9]. For China's existing CDHW system, the heat loss from circulation pipes is reported to be around 45%-74% [2]—this is the major influence leading CDHW to be in serious financial difficulty. On the other hand, the Chinese consumers supplied by CDHW complain that they have to drain off quite a large amount of cold water before they get hot water with the desired temperature, though the drained-off cold water is still billed at the hot water price. This indicates that the CDHW circulation system doesn't work well. Figure 2 shows the two types of circulation pipes of CDHW systems in China. In most of the buildings, space has been reserved in stairwell for general utilities (electricity, cable TV, heating, water) where continuous vertical rise pipes, known as distribution pipes, connect the main pipes from the basement to branch pipes within each apartment. It is said that type 1 (right) is more common than type 2 (left), due to lower initial investment and easier hot water consumption measurement. Water in the branch pipes has no circulation, called null cold water, which actually implies long waiting time for hot water, low comfort, waste and an increased risk of bacteria.

The Danish standard, DS439:2009, [12] stipulates that, "To avoid the wastage of water, the DHW system should be designed so that hot water at a flow rate of 0.2l/s reaches the taps within approximately 10 seconds (maximum) with a temperature never below 50°C." In order to meet this requirement, applications have been implemented to minimize the heat loss from circulation pipes, as well as to maintain the hot water temperature, such as: pipe-in-pipe principle, which presents the casing pipe but the inner tube leads circulating water back and the outer pipe leads it away; pre-insulted pipes are generally better insulated than normal pipe; electric heating cables are corded in some hot water installations to maintain hot water temperature, thus omitting circulation pipes but no lower losses are reported compared to conventional circulation systems due to power consumption.

But the most revolutionary and most likely to be adapted to the Chinese CDHW system may be the flat station concept. The flat station concept could be described as the individualization of control equipment, which can simultaneously meet internal SH and DHW heat demands for each apartment by transferring the energy from DH supply via two internally embedded heat exchangers [13]. Simply put, flat station is a kind of miniaturized heat exchange unit but with comprehensive control functions and metering measurement. If a flat station is mounted in each apartment in China, e.g. in the space of the stairwell where reserved for pipes and cables, eliminating circulation pipes will reduce the initial investment cost of pipes, and minimize the heat loss of DHW systems. According to [14], comparing the common building heating system in China to the riser pipe system, flat station will save 40% more pipes, in addition to the corresponding heat loss. Moreover, instantaneous hot water supply will improve the DHW comfort level and avoid null cold water, so that much more water is saved. Since flat station concept assumed DHW temperature at 45°C, demanding a primary temperature of 55°C [15], which will drastically reduce the energy required for DH generation. Meanwhile, space heating supply can be integrated in the same flat station unit, with DHW together.

Apart from the priority for the reduction of energy consumption and heat loss, flat station also provides the individualization of heat metering for each apartment, which is the core content of China's current heat reform and is expected to save more energy by influencing heat consumers' behavior. In fact, individual metering and billing will lead to 10-30% savings on heat consumption [16]. Moreover, since China's high-rise buildings have to utilize pressure partitioning, flat station will make sense based on this issue because the equipment is very close to each apartment. Furthermore, the flat station concept could be ideal for the hydraulic balance situation of China's DH system. It can be said that the closer the control equipment is to the heat consumer the better network control is achieved. It is best to move the control components towards each heat consumer, in order to defend against the inevitable consequences for other consumers when one consumer draws on the supply. Flat station improves energy efficiency and allows more advanced solutions to be applied.

2.3 Temperature factor and the Legionella issue in CDHW systems

The temperature of CDHW determines the outlet temperature of HEX, which will subsequently determine the tapping temperature and the temperature of the circulation flow and return in the system. The requested temperature level of CDHW systems, according to Denmark's [12] and China's [17] national standards, is 55-60°c. However, at the actual operational level, controlling the CDHW system's temperature value within the appropriate range, it is necessary to correctly choose the CDHW preparation types, which will influence hot water quality factors, such as hygienic condition, lime deposits, safety, and comfort. However, Denmark and China have paid unequal attention to the temperature issue in CDHW system, especially as related to Legionella concerns.

Generally, three models apply for generating CDHW, see Figure 4. Instantaneous DHW preparation with heat exchanger (HEX) (Figure 3(a)) is highly respected due to multiple advantages, such as the fact that DHW can be generated instantaneously and constantly through the HEX up to an unlimited amount, no regeneration time, reduction of the heat loss and space required when competing storage tank, lower total system cost [18], it minimizes the risk of bacterial growth, and so on. In China, Figures 3(b) and (c) are common applications for existing CDHW systems. Due to high heat density in urban populated areas where DH infrastructure utilities are built, centralized DH systems generally are on a large scale, thus, substations as well as associated components also are large. Long distribution pipeline and large pipe diameter increase the surface area of pipeline, which means much more heat loss and high power consumption of the circulating pump. Moreover, if no exclusive circulation pipes are set for hot water outlets, like type 1 (right) in Figure 2., in addition to the large size of the storage tank, hot water temperature in the whole CDHW system is uneven. This inevitably increases the risk of Legionella growth. Unfortunately, China does not pay enough attention to this issue and, so far, has not released specific standards to prevent Legionella in CDHW systems.

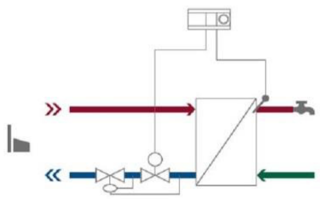

Figure 3.(a). Instantaneous preparation DHW with HEX

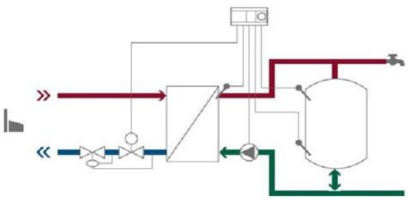

Figure 3.(b). DHW preparation with HEX + tank

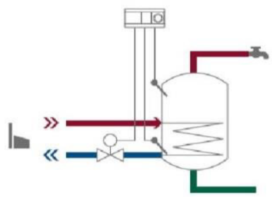

Figure 3. (c). DHW preparation with

Denmark and other EU countries have been concerned with this issue for some years and have carried out relevant research work. For instance, Denmark is in the transition from 3rd DH to 4th generation DH (4DH), which refers to LTDH, in which supplied DH temperature could be as low as 55° C—this value could be a sensitive limit when considering the Legionella issue. Preventing Legionella from occurring in CDHW systems is again becoming a hot research topic.

Legionella, a kind of bacteria, can live in all "warm" water systems, see Figure 4 for the relationship between temperature and the growth of Legionella. In unfortunate circumstances the contaminated water

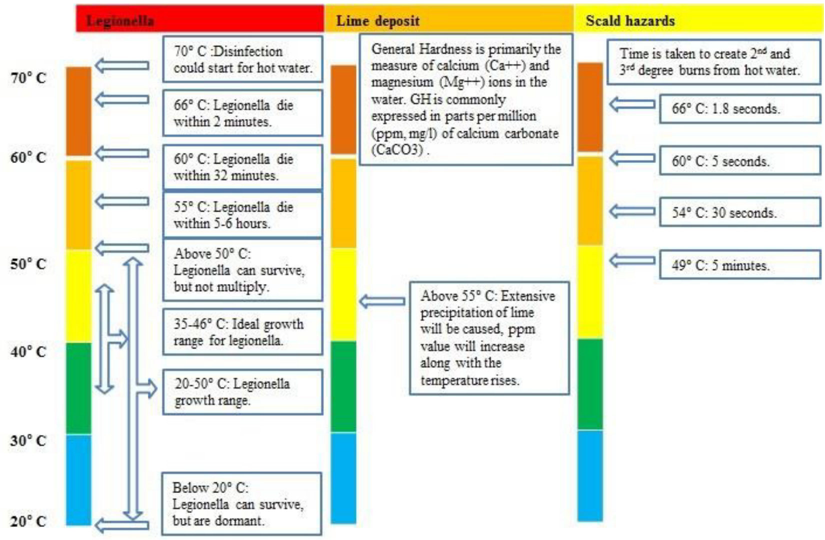

Fig. 4. Temperature factor and Legionella, lime deposit and scale hazards issues in DHW system

is atomized into aerosols when the water comes out of the tap or shower, and is transmitted by inhalation, which can cause "Pontiac fever" and "legionnaire's diseases," such as chronic lung disease, immunodeficiency, or even death [19]. In accordance with the Danish standard, if the concentration of Legionella in contaminated hot water has reached 1000 cfu/l, sterilization treatments should be utilized. In [20] some alternative disinfection methods have been introduced to prevent and control Legionella bacteria. However, the implementation of these methods is usually closely linked to higher energy consumption. For instance, the thermal techniques method is to carry out a "scalding" at raising the temperature of the DHW system to approximately 70℃, by improving the entire DHW system temperature level or using special heating cables, which also means increased energy consumption. Other alternatives like photochemical (UV light) and physical techniques (ultrafiltration) also increased electricity consumption due to lighting or pump operation. Energy consumption notwithstanding, the system will be safe with temperatures below 50°C if the total water volume of the DHW system, excluding HEX, is less than 3 liters, according to Germany standard w551 [21].Under this circumstance, the flat station concept again could be a better solution to prevent Legionella, based on the significantly lower volume compared to traditional systems. Typically, the total volume is 1.5-2 liters per flat [15]. Furthermore, the internal pipe connection from flat station to each tap within each apartment has a limited pipe length and small pipe diameter. Based on w551, Legionella bacteria risk is reduced in the flat station concept. Some Danish research institution think that the flat station concept could be the best solution so far to prevent the Legionella issue in CDHW systems. For China's CDHW systems, the result is also very relevant for upgrading the hygiene and safety of the entire system.

3. Conclusion

Ideally, the task of CDHW is heating the water immediately before it is to be used. However, in order to achieve this goal, all heat losses in the CDHW system have to be controlled through appropriate methods. Meanwhile, it is necessary to take into account the temperature of the water to ensure the hygienic condition, safety, and comfort. Currently, China's CDHW system is encountering a series of challenges, which have hindered the expansion of CDHW systems, whereas DH as the method for centralized energy utilization has been verified as the most effective, eco-friendly, and appropriate for China. Based on the above analysis, it could be said that the flat station concept is a practical solution for China's CDHW system because the flat station concept not only copes with the technical requirements of China' CDHW but is also in line with China's national conditions:

- As decentralized model, flat station concept can utilize local surplus heat sources, such as waste heat from industrial processes, thus save the energy consumption and reduce burning fossil fuel's environmental influence. Moreover, flat station can integrate SH and DHW together, such that improve the efficiency of DH system.
- Instantaneous DHW principle of flat station eliminate the circulation pipe of CDHW system not only reduce the initial investment cost of CDHW, the heat loss thereafter , the risk of Legionella, consequently improve the hygiene , comfort and safety of the entire system.
- Individual metering can be realized by implementation of flat station concept, which is the requested by current heat reform of China.
- Being close to each consumer can provide more precise and effective control than traditional systems. Furthermore, the compact size is easy to install in small spaces.
- Pressure partitioning for high-rise buildings' internal DHW systems is no longer needed.
- Hydraulic balance is easy to achieve, due to differential pressure devices mounted in flat station exclusively for each apartment.

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Biography

Lipeng Zhang is an industrial PhD student, salaried by Danfoss and currently studying at DTU. In April 2005 she joined Danfoss and worked in District Energy Division for 7 years. In May 2012 she started her PhD study, with research work focused on“Techno-Environmental-Economical Evaluation of Implementation of High EfficiencyDH System in China”.