District Heating:
Steam System Optimization or Hot Water Conversion?

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Executive Summary

For the past few years, the trend in district heating has been to use low-temperature hot water for thermal distribution instead of steam, and even to convert steam-based district heating systems to hot-water systems. But is this really the best approach? Should existing systems be converted, or optimized?

There are a number of advantages to using low-temperature hot water (i.e., with a temperature of less than 100°C) as the heat transfer fluid instead of steam.

The main benefits of low-temperature hot water include:

- Easy to integrate renewable energy sources
- Easy to incorporate recovered energy
- Lower installation costs when preinsulated pipes are used
- Maintenance costs are usually lower
- Lower heat loss during distribution

However, steam also entails benefits:

- High-level energy density (BTU/lb)
- High temperature available for sterilization, processes, humidification, etc.
- Low mass density (no distribution pumps)
- Possibility of using combined cycles in summer to generate extra electricity from steam
- Improved performance for absorption chillers

Practically speaking, both systems coexist because each has its own pros and cons. From an economic perspective, it is rarely advantageous to convert a steam system to a hot-water system unless the existing system is dilapidated and in disrepair. Due to the cost of converting the heat source, adding pumps and making the necessary changes (e.g., replacing exchangers, adding electric humidifiers and replacing fresh air coils), conversion usually does not provide a worthwhile return on investment.

For existing systems, it is generally more cost-effective to upgrade the installations to improve their energy efficiency than to convert them to hot water. In some cases, it may be beneficial to choose hot water to expand the systems using recovered heat, as was done for the district heating systems in Paris (CPCU) and Montréal (CCUM).

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Business Challenge

Historically, high-pressure steam (with a pressure higher than 100 psig) has been the preferred heat transfer medium with district heating systems for cities as well as for university campuses, hospitals and military bases. This comes as no surprise, since steam is used to produce electricity in thermal power plants. Examples include major district heating systems around the world, like those of New York City (1,700 users), Paris (480 km of pipes, the equivalent of 500,000 housing units) and certain cities in eastern Europe, including Moscow (10,400 km) and Warsaw (1,650 km). Closer to home, district heating is used in Vancouver, Toronto and Montréal as well as by hospitals, universities and military bases. Almost all of them use steam.

Many systems were developed in the late 1970s after the oil shock, especially in northern Europe. For instance, in Sweden, 85% of multi-dwelling buildings and almost all public buildings are connected to a district heating system. The availability of preinsulated pipes reduced installation costs and led to the development of low-temperature hot-water systems (with a water temperature of less than 100°C). These are more efficient and less costly and allow for the use of several energy sources such as geothermal energy, industrial heat recovery and small cogeneration plants with reciprocating motors.

Conventional steam systems are less efficient than hot-water systems, which suggests that steam systems should be converted to hot-water systems to increase energy performance. But is this really the best approach? Is there a way to improve steam systems without converting them? This paper examines two cases in which steam systems were optimized, and where hot-water and steam systems were combined: CPCU (Paris) and CCUM (Montréal).

Comparison of Advantages

Practically all district energy and heating systems around the world use steam or hot water as the heat transfer fluid. District heating presents unique benefits for efficient heat generation and is the favoured way to efficiently distribute heat in urban or community settings.

Historically, district heating was developed using steam. However, in the past 30 years, hot water has been preferred because it is more cost- and energy-efficient.

The table below compares the benefits of both systems.

Table 1: Comparison of system characteristics (steam and hot water)

Characteristic	High-pressure steam	Low-temperature hot water
Temperature of use and versatility	High (> 200°C) ▪ In addition to meeting heating and domestic hot water needs, the high temperature meets the needs of industries (food processing plants, laundering facilities) and hospitals that require steam. It can also be used to humidify buildings.	Low (< 100°C) ▪ The low temperature can only meet the building heating and domestic hot water needs.
System complexity, maintenance costs and sustaining capital	Moderate to high ▪ Steam systems have two pipes, one for high-pressure steam and the other (smaller) for condensed water. ▪ Service life is unlimited for the steam system, whereas the condensate system lasts about 40 years due to the carbonic acid in the water. ▪ Steam traps must be periodically installed throughout the system to remove condensed water. Steam trap chambers may be required. ▪ The system has no predetermined direction of flow. ▪ Since density is low, the steam is moved by the pressure differential (no system pumps). ▪ The high temperatures make it harder to use prefabricated, preinsulated pipes. ▪ Due to the high level of thermal expansion, loops and expansion joints must be planned.	Low ▪ The system has two low-temperature pipes. ▪ The use of prefabricated and preinsulated pipes compliant with European standards (e.g., EN 253) facilitates construction and reduces costs. ▪ Pumping stations are required. ▪ The system flows only one way, which complicates system looping.

Characteristic	High-pressure steam	Low-temperature hot water
Energy efficiency	Moderate ▪ The heat loss and lower efficiency of these systems translate to a seasonal efficiency of roughly 70% to 75%, or 80% when conditions are optimal. ▪ System heat loss is limited (2% to 3%) for compact systems like CCUM's in Montréal. ▪ More efficient than a decentralized steam plant, the seasonal performance of which is generally less than 70%. ▪ When a heat recovery system is installed, plant efficiencies of close to 90% can be achieved.	High ▪ Little heat is lost from pipes, as with steam plants. Heat recovery options are better than with steam. System efficiency generally exceeds 80% and can reach 90%.
Dangers / risks	Moderate ▪ Because temperatures are high, burn hazards are also higher. ▪ Fatal accidents are rare, but since steam is a compressible gas, an enormous amount of energy builds up in the pipes. Accidents from sudden depressurization can lead to catastrophic failure resulting in significant damage and deaths. The Con Edison explosion in 2007 and the Paris explosion in 2000 are examples of this.	Low ▪ Since water is a liquid and cannot be compressed, the only potential hazard is water leakage causing burns and flooding. There is no risk of explosion, unlike with steam systems.

As outlined above, hot water involves numerous advantages over steam for new district heating systems. Unless industries or hospitals specifically require higher temperatures, hot water should be favoured over steam.

However, converting steam systems to hot-water systems is generally neither cost-effective nor desirable. Conversion costs are high: pipes usually need to be replaced, as hot-water pipes are typically larger in diameter than steam pipes for the same capacity.

Conversion work includes excavation, replacing piping and supports, installing new insulated pipes and adding pumping rooms and valve chambers. In urban settings, these major works can cost from $1 million to $2 million per kilometre of district heating system.

In addition, building heating systems often require changes as well. This can be even more costly for multistorey buildings. For example, it cost over US$10 million to convert the University of Rochester steam system to a hot-water system.

The best solution is to optimize the performance of existing systems to make them more energy-efficient. This can be done a number of ways, including by optimizing combustion and by installing economizers as well as condensate and heat recovery systems. Financial assistance is often available, which means a return on investment (ROI) can be achieved in less than three years.

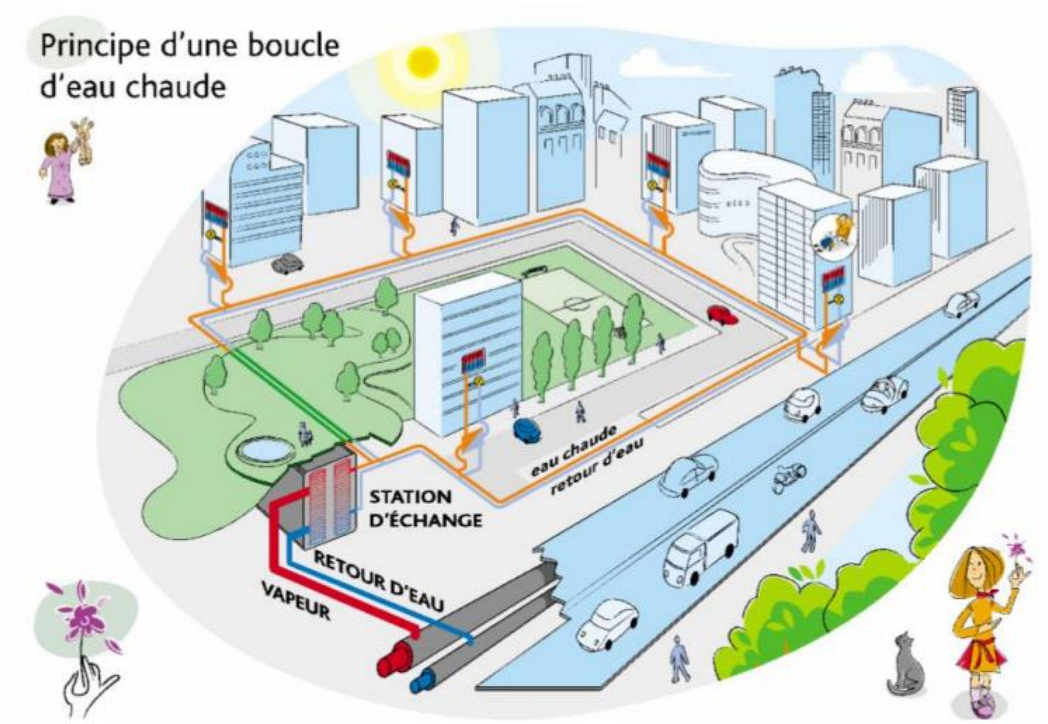
Another solution is to create a hybrid steam/hot-water system to maximize the performance of steam systems while benefiting from the advantages of hot water for expansion purposes. This approach cuts the installation costs for expansion of the district heating system while improving steam system efficiency with cooler condensate return temperatures. System expansions can also incorporate other low-temperature heat sources, like geothermal pumps and industrial heat recovery. Two concrete examples are the district heating systems in Paris (CPCU) and Montréal (CCUM).

Solutions | Two Examples: Paris and Montréal

To improve energy performance, the Paris and Montréal district heating systems optimized the efficiency of their steam systems and added segments with low-temperature hot water.

Paris

The Paris district heating system (CPCU) is among the world's largest steam systems with over 450 km of piping. The system is fuelled by waste incinerators, cogeneration plants and a coal plant. To continue expanding while enhancing its efficiency, CPCU decided to build hot-water loops around its main network. These loops are fed by the steam system using a steam/water exchanger and can incorporate other energy sources such as geothermal energy. For example, in northeastern Paris, geothermal energy is used to provide heat and cold for hot-water and chilled-water distribution systems. Peak demand in winter is met by the CPCU steam system. So far, CPCU has added 19 hot-water loops around its steam-based district heating system.

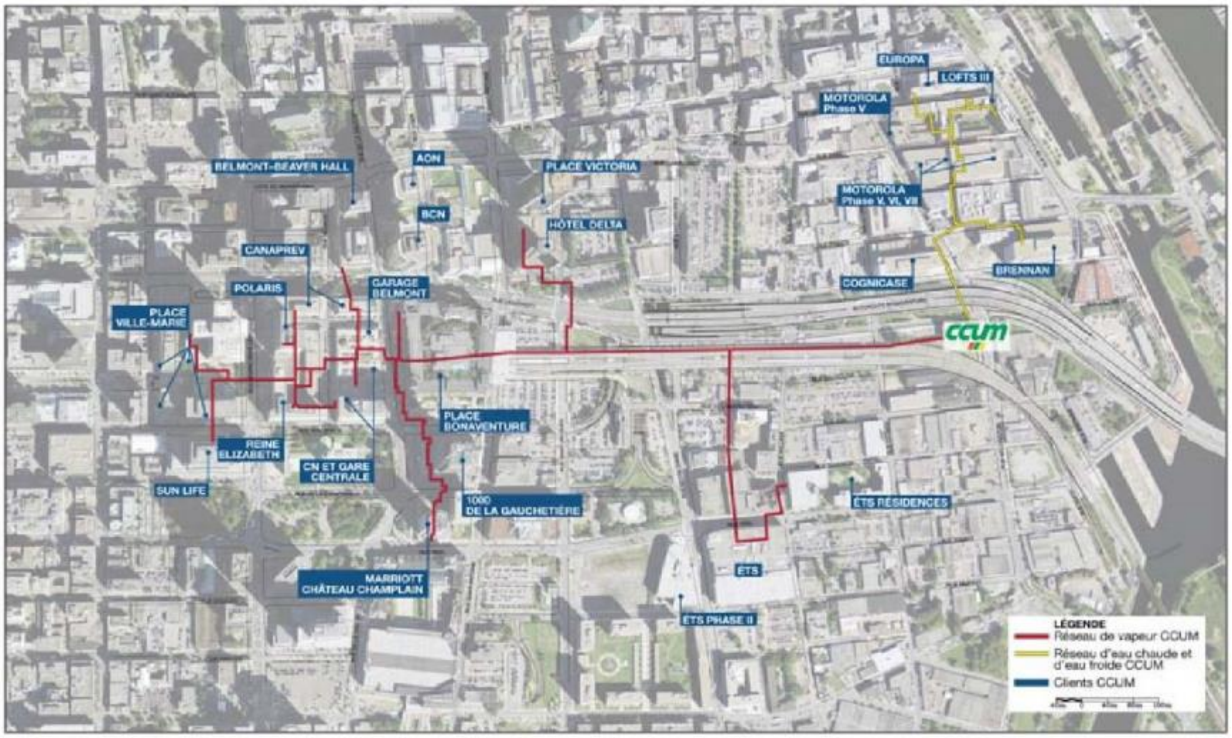


CPCU

Montréal

The Montréal district heating system (CCUM, or Climatisation et chauffage urbains de Montréal) powers the city's downtown core. When it expanded to the Cité du multimédia area in the early 2000s, CCUM installed two water loops for neighbourhood heating and air conditioning needs: one for hot water and the other for chilled water. The hot-water loop was at first mainly heated by the low-pressure steam from its steam turbine, generating a portion of steam plant electricity in winter.

CCUM is currently finalizing the installation of a condensate recovery system that will reduce the temperature of the combustion gases for its two main steam boilers to about 30°C, thereby increasing the efficiency of the boilers to over 90%. The two-step recovery process first heats up the condensate return water, then produces 65°C hot water to preheat fresh air and combustion air. The rest of the heat is reinjected into the hot-water loop for the Cité du multimédia area. As such, efficiency comparable to that of hot-water systems can be achieved by combining a steam system with a hot-water system.



CCUM

Benefits of This Solution

In the short and medium terms, it is generally more economic to optimize existing steam-based district heating systems than to convert them to low-temperature hot-water systems. Conversion costs are steep, as the process usually involves replacing underground pipes and making changes to building interiors. Improving energy efficiency with heat recovery systems optimizes steam-based systems and does so in a less costly and much simpler way than, for example, excavating to replace piping. Hybrid solutions that combine steam and hot water also allow for incorporating clean energy sources and recovering heat from existing systems, which leads to highly efficient systems. This approach works well with district heating systems for cities and for universities, hospitals and military bases.

Conclusion

As with most systems, steam and hot-water systems each have their own pros and cons. Despite the many benefits of low-temperature hot-water systems, in some cases steam systems are better suited to the requirements of industry or health care facilities. In general, conversion of existing steam systems to hot-water systems is a costly endeavour. Optimizing these systems or hybridizing them by adding hot-water loops is likely the best solution from a technical and economic perspective.

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Réal Olivier is a mechanical engineer with over 30 years of thermal power experience in the industrial sector, including 15 years as a consultant. He is recognized for his expertise in industrial steam plants, district heating (steam and hot water), cogeneration plants and energy efficiency. Réal's experience combines theory and practice, which allows him to fully understand production imperatives as well as the technical and economic aspects of his projects.

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