A Century of Innovation at University of Toronto

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Take a walk downtown Toronto, Ont., on one of those clear, cold February mornings and what you will notice against the skyline are dozens, even hundreds, of puffs coming from chimneys across the city. If on the same day you strolled across the St. George campus of Canada’s largest university, in the heart of downtown, you may find that, while there are a few little chimneys puffing away at the periphery of the campus, your focus will be drawn to a giant stack at the southwest corner. And this may be all you notice of one of the best-kept secrets at the University of Toronto (U of T): the district energy system.
In 2012, the St. George campus is celebrating the centennial of one of the first institutional district energy systems in Canada, which has provided the university with efficiently produced energy through two world wars, from the Jazz Age to the Space Age and beyond. The U of T was green when most people still thought that was just a color!

Originally, the earliest U of T buildings were heated by individual boilers or furnaces located in each building, but 100 years ago a central plant was constructed with sufficient capacity to supply steam to all campus buildings. Much later system enlargements included distribution of hot water for heating, centralized production and distribution of chilled water for air conditioning, and even generation and distribution of high-voltage electricity to service the “city within a city” that the U of T has evolved into. To trace the history and growth of the university’s district energy systems is to trace the history and growth of the university itself.

1912: The Power House

In the 1900s, Toronto had a population of approximately 210,000 people; horses and carriages were still common on city streets, and in 1904 the city suffered one of the worst fires in its history. A year after the fire, James Whitney became premier of Ontario, returning the Tories to power for the first time in 33 years. Whitney’s government laid the basis for Ontario’s industrial development by creating the Hydro-Electric Power Commission of Ontario, renamed the Ontario Hydro Commission in 1906 and eventually known as Ontario Hydro.

In 1912, the University of Toronto built the second university district energy system in Canada. At the same time, the U of T was experiencing a rapid increase in student enrollment – from well under 2,000 in 1901 to 4,000 by 1910. Recognizing the university’s need to expand and its important role in Toronto’s development, Premier Whitney introduced a bill that removed the existing university deficit and generously provided the U of T funding for future construction. As a result of the Ontario Hydro-Electric Power Commission and its growing need for engineers, the department of engineering continued to expand, opening the Thermodynamics and Hydraulics Building (the oldest part of the present-day Mechanical Engineering Building) in 1909.

Prior to this time, several separate plants, most of which were old and inefficient, heated the university’s widely scattered buildings. However, by 1912, with government financial support, the university was able to build the Power House, later known as the Centralized Heating Plant, to provide high- and low-pressure steam and electric power (direct current) to 20 buildings via an underground distribution system. This pioneering distribution network created what was then only the second university district energy system in Canada. The Power House was located east of the Medical Building and adjacent to the southwestern corner of the Ontario Legislative Building in Queen’s Park.

High-pressure steam was used in prime movers to generate electricity, and the exhaust steam was discharged into a low-pressure distribution system for building heating and domestic hot water. This was, in effect, a total energy system with coal as the principal fuel. The plant’s five watertube boilers consumed 15,000-20,000 tons of coal annually. Approximately 90 percent of the condensate was collected and returned to the plant. By the 1914-1915 heating season the Power House heated 200,000 sq ft in 20 buildings. Electrical production was phased out over 25 years, but the plant continued to produce steam until 1952 when a new power plant was commissioned.

1952: The Russell Street Central Steam Plant

In the post-war years of the late 1940s, the university was faced with an expansion program to cope with a large increase of public and secondary school students who would be going on to higher education. An increased birth rate meant this growth would continue for many years.

It was quite obvious that the old plant would never be capable of supplying enough steam for the university’s projected requirements. As the major part of the campus expansion was planned for the area on the west side of St. George Street, it was logical that a central plant should be located in this area from a distribution standpoint and for coal and ash handling. The firm of H.G. Acres Engineers and Consultants was engaged to design and supervise the construction of the new Central Steam Plant on the south side of Russell Street between St. George and Huron Streets. Work on the plant and a new section of tunnel under St. George Street started early in 1951. The plant went into operation in September 1952, and the old Power House was eventually demolished.
The new plant contained two 75,000-lb/hr Inglis boilers operating at 200 psig and fired with pulverized coal, with provision made to add a third boiler in the not-too-distant future. The plant boasted a 175-ft radial brick stack, which at that time was considered ample for the ultimate plant size.

During the mid-1950s a new concept in heating was proposed by Acres Engineers for the new buildings to be constructed on the west side of St. George. This was to be a high-temperature hot water system with the lines buried in the ground in insulated pipes. Valve connections were to be installed in the mains at the proposed building locations. The university accepted the firm’s proposal, and the system was built and tied into the central plant. It went into operation during the 1955-1956 season. (See figure 1 for a current campus heating system map.)

As more students came to the U of T, it soon became evident that the original plans to add a third 75,000-lb/hr boiler would in no way be adequate for the steam requirements. Acres was requested to reassess the expansion situation, and the company proposed that the Central Steam Plant be enlarged to incorporate two more 125,000-lb/hr boilers, for a total output of 400,000 lb/hr, still using pulverized coal. This expansion took one and a half years to complete; the newly enlarged plant went into operation in 1960.

As many organizations became “pollution-conscious” and regulations more stringent in this regard, the university was faced with a problem of stack emissions. In 1961-1962, annual fuel consumption was 24,000 tons of coal with an average heat value of 12,000 Btu/lb, costing 36 cents/MMBtu or just over CA$200,000. Fuel costs were low and plant efficiency was high. However, stack emissions of 50,000 cu ft of flue gas per minute carried sulfur dioxide and entrained fly ash. At the time, the standard option to control emissions was a costly installation of electrostatic precipitators that involved considerable construction and the risk of operating problems.

The plant became one of the leading examples of heating efficiency and a destination for visiting American and European engineers.

Consumers’ Gas approached the university with a very attractive fuel contract proposal for using natural gas (in cheap and plentiful supply at the time) as the main fuel with oil as a standby fuel. As a result, the plant was converted to gas and oil firing in 1964. Operating efficiencies for the new plant, based on “fuel in” and “dry steam out,” averaged

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Figure 1. University of Toronto
St. George Campus Heating Systems.

Source: University of Toronto.
83 percent. The Metro Toronto Air Pollution Control Branch had found the gas conversion to be an efficient means of abating the air pollution problem. The plant became one of the leading examples of heating efficiency and a destination for visiting American and European engineers.

As the section to the west of St. George continued to expand with the construction of more university buildings, more load was being added to the central plant. Plans were also made to ultimately pick up more loads at the north end of the steam main. The new Medical Sciences Building planned for the south end of campus would add a major portion to the steam load and would entail the installation of a separate steam main to supply the south campus group of buildings.

This meant another major plant expansion would be required. The project this time called for larger mains and condensate lines throughout the tunnel system on the east side of St. George Street. The magnitude of this project necessitated that it be spread over a three-year period with work proceeding during the summer. Meanwhile it was decided to demolish the two original Inglis boilers and replace them with two 200,000-lb/hr B&W low-excess air boilers.

A new 300-ft concrete stack containing three steel flues with room for a fourth was to replace the radial brick one. The high-temperature water lines were to be increased in size in the plant and more pumping capacity and auxiliaries added. This last expansion commenced in 1966 with the demolition of the original boilers. The new No. 1 boiler was erected on the site and commissioned in 1967 with No. 2 following a year later.

By the late ’70s, the boilers were producing steam to heat more than 8 million sq ft of space. Besides the principal U of T buildings on the St. George campus, the federated and

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System Snapshot: University of Toronto, St. George Campus

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<th><strong>Startup Year</strong></th>
<th>Steam/Cogeneration and Hot Water System</th>
<th>Chilled-Water Systems</th>
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<td>1912 – Steam production and distribution system</td>
<td>1968 – Medical Sciences Building Chiller Plant system</td>
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<td>1955 – Hot water distribution system added</td>
<td>1972 – Northwest Chiller Plant system</td>
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<td>1992 – Cogeneration facility added</td>
<td>2001 – Bahen Centre Chiller Plant system</td>
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| **Number of Buildings Served** | 98 total: 81 steam only, 17 hot water only | 23 total |
| **Square Footage Served** | 12,450,000 sq ft | 5,324,270 sq ft |
| **Plant Capacity** | 600,000 lb/hr steam (includes output used to make hot water) 6 MW electricity | 20,000 tons |
| **Number of Boilers/Chillers** | 5 boilers | 19 chillers |
| **Fuel Types** | Natural gas and No. 2 oil for backup | Steam and electric |
| **Distribution Network Length** | 3 miles | 2.6 miles |
| **System Pressure** | 200 psig | 100 psig |
| **System Temperatures** | Saturated steam with 160 F condensate return, 388 F hot water | Medical Sciences Building system – 42 F supply/55 F return Northwest system – 48 F supply/58 F return Bahen Centre system – 44 F supply/54 F return |

Source: University of Toronto.

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into the basement of the Medical Sciences Building. Today the
southeast corner of the campus. The plant is incorporated
into the facilities at the university. Engineering and medical research buildings clustered in the
water system on the St. George campus to serve the high-demand
buildings totaling nearly 2.5 million sq ft. The distribution system has
been extended a number of times and now counts as customers
iconic university buildings such as the 1907 Convocation Hall.

The Northwest Chiller Plant and distribution system started
up in 1972. This plant was built as a separate industrial facility
to serve an anticipated redevelopment of that largely residential
quadrant of the campus into academic buildings; this large-
scale development, however, never occurred. For almost three
decades, the plant served only the 1 million-sq-ft complex
consisting of the Robarts Library, the Fisher Rare Books Library
and the Bissell Building as well as Innis College. It wasn’t
until the mid-1990s that development of the north part of the
plant added the Rotman School of Management, Massey
College and two residential buildings. This plant now has nine
electric chillers with a total capacity of 4,400 tons. It serves
1.6 million sq ft of space in eight buildings.

A third chilled-water plant, in the Bahen Centre for
Information Technology, was added in 2001 as the result of
good planning. When construction of the new IT building was
announced, adequate space was allowed in the mechanical
room to house the future chillers that would be necessary to
replace capacity provided by R-11 machines in several nearby
buildings. (Between 1997 and 2007, the U of T upgraded its
entire fleet of chillers to eliminate ozone-depleting chloro-
fluorocarbon refrigerants and to improve efficiencies, as part of
a CAS$20 million energy retrofit.) In addition, a supply and
return piping loop was installed in the underground parking
garage with valve connections for attaching these buildings,
and a full complement of cooling towers was installed during
initial building construction. Equipped with three electric chil-
ers, the Bahen Centre plant now supplies chilled water to six
buildings totaling 1.26 million sq ft of space.

Three separate chilled-water systems were built instead of
one larger one for several reasons having to do with campus
geography: the cost to extend distribution networks across
the city streets that penetrate the campus, limitations on the
space allowed for expansion within the original plant buildings
(all of which are on constricted sites) and the increased power
that would have been required to pump the cooling media
longer distances.

1992: Cogeneration

Another milestone in the U of T heating system history
was the installation of a 6 MW cogeneration unit at the Central
Steam Plant in 1992. This facility has enabled the university
to generate a quarter of its own electricity and to capture and
reuse the resulting waste heat to heat water and make steam.
During the summer, the two 1,500-ton absorption chillers
installed in the Medical Sciences Building Chiller Plant in 1995
and 2000 use half of this steam. Using waste heat rather than
electricity to provide cooling saves the university 1 million kWh
annually. As a result, the Medical Sciences Building was one of
the few campus facilities allowed to have air conditioning in the

1968: The First Chilled-Water Plant

In 1968, the U of T constructed its first centralized chilled-
water system on the St. George campus to serve the high-demand
engineering and medical research buildings clustered in the
southeast corner of the campus. The plant is incorporated
into the basement of the Medical Sciences Building. Today the
affiliated colleges (St. Michael’s, Victoria, Trinity, Wycliffe and
Knox), the Royal Ontario Museum, Ontario Hydro building and
several other buildings were also heated by this system.

The heat was distributed in two ways. The first was in the
form of high-pressure steam at 200 psig, which was sent to all
buildings east of St. George Street. When the steam reached the
buildings, the pressure was reduced from 200 psig to 15 psig.
Heat was also delivered to buildings for special uses in a variety
of pressures up to 200 psig. Eighty percent of the steam was
returned to the plant in the form of condensate to be recycled
into the process, further boosting efficiency.

The newer buildings west of St. George Street were sup-
plied by the high-temperature hot water system. (See sidebar
for a history of high-temperature hot water systems.) The hot
water was generated in the steam plant at 388 F and pumped
to the buildings, where it passed through exchangers. The
majority of these were used to heat secondary water to pro-
vide heating in the buildings, but steam was also generated in
special exchangers in the buildings for process requirements
and humidification. This high-temperature system is still in
operation today.

In the 1970s, amid the OPEC oil embargo, fuel costs
increased rapidly (more than 500 percent in less than eight
years), prompting a very active energy conservation program.
By the fiscal year 1977-1978, the university’s fuel bill had
risen to CA$2 million. However, in the following years, there
was actually a marked decrease in the amount of fuel burned,
due to the conservation efforts. Had consumption continued
at the same rate as before, the fuel bill would have increased
by a half-million dollars every year.

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Installation of a 6 MW cogeneration unit in 1992 has enabled the university to generate a quarter of its own electricity.

**2000: Flue Gas Heat Recovery System**

In 2000, the U of T installed a flue gas heat recovery system at the Central Steam Plant. Through a combination of direct and indirect contact heat exchange, heat is harvested from the hot exhaust gas that would normally be wasted. The low-grade hot water is then piped to a number of buildings including Lash Miller, Medical Sciences and the Bahen Centre. This project has resulted in annual energy savings of 73,000 GJ (69,200 MMBtu), enough to heat more than 800 Ontario homes. In 2002, when the Bahen Centre was connected to the waste heat recovery system, it became the first campus building to be 100 percent heated with energy that would otherwise have gone up the chimney.

**The Way Ahead**

Today the U of T heating system that got its start in 1912 serves a total of 12.45 million sq ft of space in 98 buildings. As the campus continues to grow, new buildings such as the Goldring Centre for High Performance Sport will be fed from this heating infrastructure as well. However, to ensure that campus energy services remain reliable, an ambitious program of work is under way: Underserved research buildings are being made to the boiler plant’s fuel delivery system and storage facilities, “bottlenecks” in the plant that have limited the quantity of steam produced are being rectified, and the chiller plant capacities are being increased to serve new research areas.

In hindsight, those who set the University of Toronto on the course of centralized energy services at the beginning of the 20th century made the right decision – one that is still benefiting the campus in the 21st century. In this centennial year of 2012, the U of T celebrates the foresight that pioneered greener energy production in Toronto and paved the way for growth of the St. George campus to what it is today.

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High-Temperature Hot Water District Heating: A brief history

**Morris A. Pierce, Adjunct Professor of History, University of Rochester**

The first high-temperature hot water district heating system was patented by the American inventor Angier March Perkins in 1831 and was widely used in Britain throughout the 19th century; some systems remained in service into the 1930s. The Perkins system used small-bore (less than 1-inch) piping that distributed hot water at 300-600 degrees Fahrenheit and 300-3,000 psig. Although none of these systems is known to have been used to heat multiple buildings, Perkins said in 1836 that he could “heat a whole parish from one fire.”

After Birdsill Holly introduced commercial district steam heating in 1877, several competitors appeared including William Prall, who in 1878 patented a “superheated” water system that could deliver heat over a much longer distance than the low-pressure steam networks then in use. His National Superheated Water Co. developed systems that distributed hot water at 400 F to individual buildings, which was flashed into steam for heating and to power engines. The condensate was then metered and returned to the plant through a low-pressure condensate return line.

Small Prall systems were built in New York and Washington, D.C., before he convinced Bell Telephone founder Theodore Newton Vail to invest in a much larger system to serve the financial district in Boston, which was being rebuilt after a large fire in 1872. Vail’s Boston Heating Co. began construction in 1886 and started serving 70 customers in January 1888. In November 1889 the system was shut down and went out of business due to the complete disintegration of the open return lines from atmospheric oxygen corrosion. Unlike a district steam system that can operate reasonably well without the return condensate, the Prall network was not economically viable without it. The abandoned hot water pipes were (and may still be) used as conduits for telephone wires.

German engineers in the 1920s resurrected high-temperature hot water systems, recognizing as Perkins did that a closed system was not subject to corrosion. Large high-temperature hot water systems were installed in many German industrial facilities prior to World War II, and a few were installed in American factories in the 1930s. The German systems proved to be resistant to damage from aerial bombs and could be quickly repaired, which the U.S. Air Force discovered in its survey of wartime damage. In 1947 a high-temperature hot water system operating at around 400 F was installed at the new Loring Air Force Base in Maine. Within 10 years, more than 30 similar systems were installed at other air bases, while the U.S. Navy also adopted the technology for many of its facilities. Rutgers and Brigham Young universities installed similar systems in the 1950s, with many more installed on other campuses and military bases in later years.

One notable installation was the high-temperature district heating network at the new U.S. Air Force Academy in Colorado Springs, which began service in 1957. This system operates at 454 F and 440 psia – the highest known temperature and pressure to have been used on such a system.