District Energy

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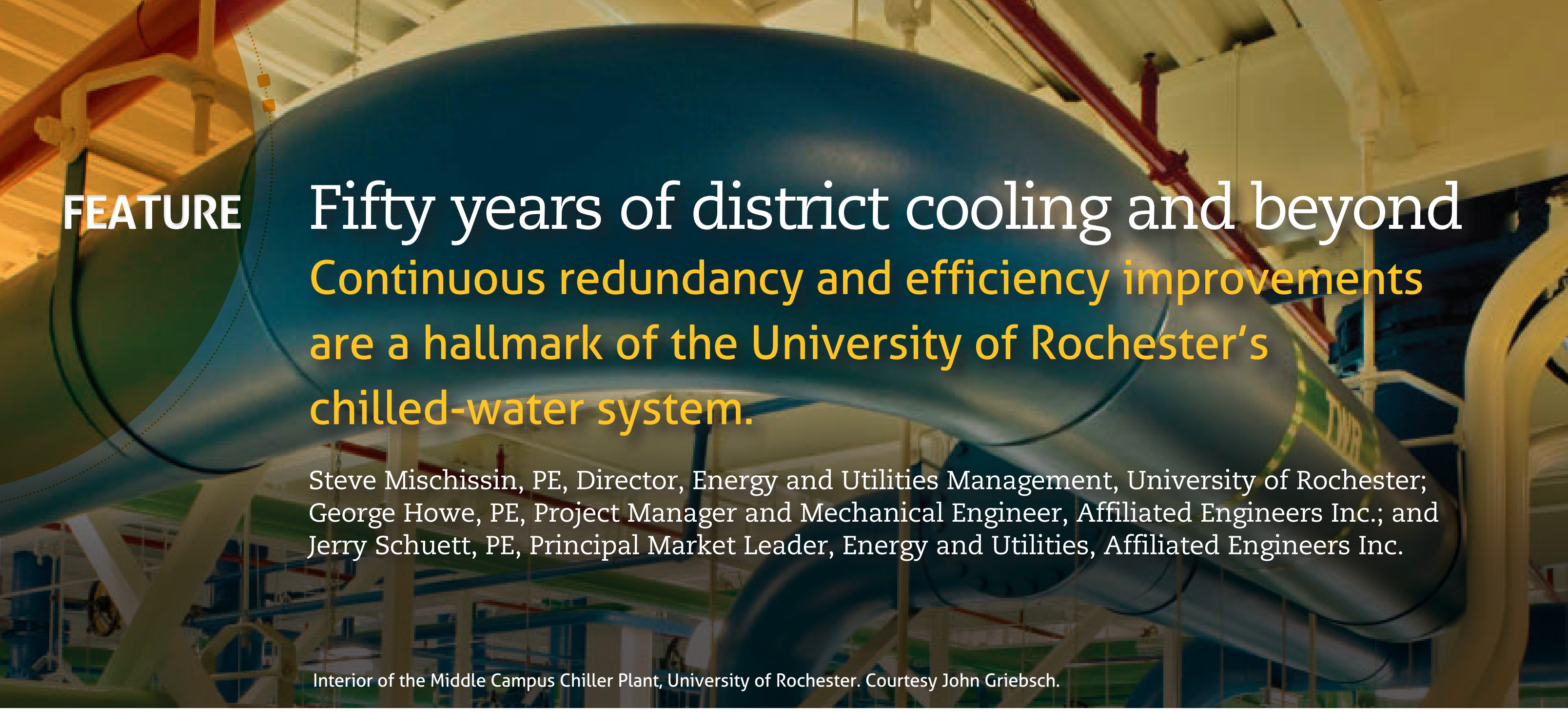

FEATURE

Fifty years of district cooling and beyond

Continuous redundancy and efficiency improvements are a hallmark of the University of Rochester's chilled-water system.

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Interior of the Middle Campus Chiller Plant, University of Rochester. Courtesy John Griebsch.

The University of Rochester, located along the Genesee River in Rochester, N.Y., has been producing chilled water for campus buildings since the mid-1960s. The university's original chiller plant, installed in the heart of the campus as an expansion to the Central Utilities Plant, was able to satisfy the demands of the growing university for nearly 40 years before major upgrades were needed. This plant continues to produce chilled water for the campus; but with a constantly increasing demand for cooling and the evolving options and increasing efficiencies of new chilled-water equipment, the university recently embarked on expansion projects focused on increasing system redundancy and energy efficiency.

REACHING FOR REDUNDANCY

Rochester's Central Utilities Plant, originally built in the early 1920s, has been expanded to provide steam, hot water, electricity and chilled water for the university campus. Technically speaking, the "campus" it serves today actually comprises three contiguous areas: the 154-acre main River Campus; the University of Rochester Medical Center Campus, a nucleus of research, education and patient care; and Mid Campus, south of the Medical Center. Ever since the Central Utilities Plant was established, the university has been dedicated to supplying its campus with reliable utility services. This focus on reliability has led over the years to such projects as the installation of a 25 MW cogeneration system in 2005 to reinforce campus electrical and heating systems. Enhanced reliability has also been the aim of recent campus chilled-water system improvements, with a universal goal of having N+1 redundancy in chiller capacity in order to satisfy the peak chilled-water demand should the largest chiller in the system not be operational.

ROCHESTER'S LARGEST CHILLER REPRESENTS "A LOT OF EGGS IN ONE BASKET" – A RISK, SHOULD A SINGLE COMPONENT ON THE CHILLER FAIL AND PREVENT IT FROM OPERATING.

Rochester's largest chiller is 6,300 tons, accounting for roughly one-third of installed chilled-water capacity. While this chiller, one of the largest in the Northeast, can produce a large amount of cooling in a relatively small footprint, it also represents "a lot of eggs in one basket" – a risk, should a single component on the chiller fail and prevent it from operating.

In 2005, Affiliated Engineers Inc. was engaged to work with the university's Central Utilities department to develop a chilled-water master plan in response to an overall campus master plan that was nearing completion. The team investigated several potential campus cooling system improvements that would allow the university to augment its chilled-water capacity to meet the N+1 redundancy goal with ever-increasing chilled-water load demands. As part of the campus master plan, these upgrades would be funded through long-term bonds.

During the conditions assessment phase of chilled-water master planning, the university's prior work to optimize its cooling system demand side became evident. The system delta T was nearly 15 degrees F in the summer and shoulder seasons, minimizing excess pumping and the need to operate additional chillers due to system flow. The high delta T was a result of Rochester's efforts to retrofit existing buildings by removing three-way valves and installing chilled-water bridges as well as its required specification of high delta T coils for new buildings.

The University of Rochester's year-round cooling loads are largely driven by the medical facilities and research labs on campus, as the academic classrooms and the one dorm currently connected to the chilled-water network are only partially occupied in summer. The campus master plan showed the majority of anticipated square footage growth – i.e., in dorms, academic buildings, research labs and some hospital expansion – would be located away from the Central Utilities Plant. The plan projected that the total area of campus buildings connected to the cooling system would nearly double over the next 25 years – from around 5.5 million gross sq ft to more than 12 million gross sq ft.

Using this as a basis, the planning team developed various options for satisfying the projected cooling loads. It performed an economic analysis from which it was apparent that the best solution for the university was to invest in a new chiller plant – one located relatively close to the expected campus growth while still within close proximity to the existing large chilled-water distribution system that forms a loop around the Medical Center Campus. Having two physically separated plants feeding this chilled-water piping loop at two different locations would provide an increase in redundancy that the university could not achieve if it only chose to expand the existing central plant. This would be especially critical for serving the medical campus facilities with their progressively stringent requirements for humidity and air-temperature control.

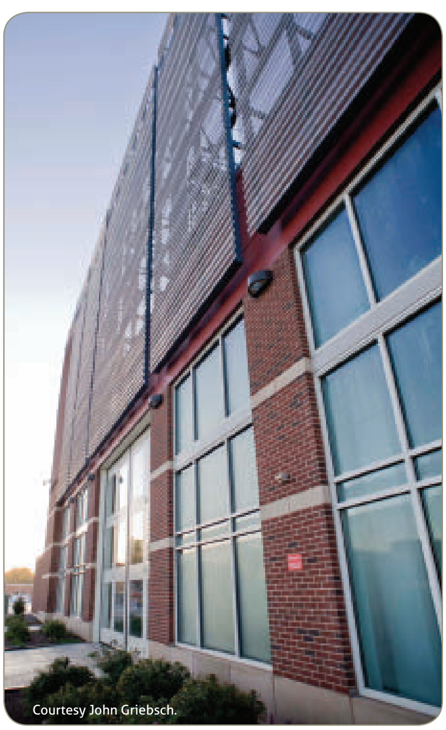
The new plant option would also provide the quickest means of increasing chilled-water capacity to meet the N+1 redundancy goal. It would also allow for this capacity to be constructed totally isolated from the existing plant, minimizing the risks associated with making major renovations within an operating chiller plant.

The university and the designers of the original Central Utilities chiller plant had the foresight to create a plant that could meet the campus cooling needs for nearly 40 years. However, the growth of the campus and the increasing criticality of chilled-water service to the medical center required Rochester to become a multiple chiller plant campus.

MULTIPLE CHILLER PLANTS

With the decision made to construct a second chiller plant, potential plant configurations needed to be reviewed for this project to take shape. Did the university wish to continue producing chilled water in a similar manner to the Central Utilities chiller plant, with steam-driven chillers and heat rejection to the Genesee River? What capacity should each new chiller have? How would the campus hydraulics be affected with the addition of a new chiller plant?

There were considerations that steered the team away from again using steam to produce chilled water. One of these was the recent installation of the cogeneration plant, which generates medium-temperature heating hot water as the result of producing steam and electricity. With the construction of the cogeneration plant, the university had already begun to move in the direction of distributing hot water, in place of steam, to heat new and existing campus buildings, thus reducing the need to expand the steam distribution system. Fur-


Courtesy John Griebsch.

Exterior of the Middle Campus Chiller Plant, University of Rochester.


Courtesy John Griebsch.

View of chillers No. 6 and No. 7 within the MCCP.

thermore, the existing steam-driven chillers require complicated procedures to start, compared to today's electric-driven chiller options. Instead of relying solely on steam, having a mix of steam- and electric-driven chillers would also represent a diversified blend of machines, providing Rochester with the flexibility to capitalize on advantageous natural gas and electricity rates.

Options for heat rejection were also reviewed. Due to the invasion of non-native zebra mussels in the Genesee River in the 1970s, the fouling of the condenser tubes for the chillers in the Central Utilities Plant had become more rapid, necessitating monthly tube cleaning. Additionally, warm river temperatures coincide with the peak cooling demands, reducing output capacity of the central plant chiller during times it could least be afforded. At the new plant, utilizing cooling towers for heat rejection would be practical and would reduce the requirements for tube cleaning seen at the central plant.

With these items defined, design began in 2006 of a new 4,000-ton chiller plant, expandable to 12,000 tons, equipped with 4,160 V electric-driven chillers plus cooling towers located on the roof.

The 4,000 tons would be divided between two 2,000-ton chillers, with redundant pumps mitigating the chance of a single equipment failure causing a large loss of capacity. An hourly chiller plant performance modeling tool was created and analysis performed that proved superior payback for 4,160 V variable-frequency drives (VFDs) for these chillers. Given that this was a relatively new technology at the time, it was decided that a VFD coupled with one 2,000-ton chiller would be provided, as reliability concerns overrode operational efficiency. Space was planned for the addition of free cooling and a thermal energy storage tank in a future phase of implementation.

This new plant was called the Middle Campus Chiller Plant, or MCCP, and it became operational in 2008.

UPGRADING TO SERVE A CONTINUALLY GROWING UNIVERSITY

By summer 2012, the university had already initiated actions to increase its chilled-water capacity – to address additional large chilled-water demands from several new buildings – by constructing the shell for Phase II of the MCCP. That sum-

System Snapshot: University of Rochester

	Steam and hot water/cogeneration system	Chilled-water system
Startup year	1924 – Original Central Utilities Plant constructed; coal-fired boilers begin producing steam. 1997 – Central plant boilers converted from coal to natural gas/oil. 2005 – Cogeneration system installed. Medium-temperature hot water system added.	1967 – Steam-driven chiller plant at Central Utilities Plant and river pump house start operation. 2008 – Middle Campus Chiller Plant becomes operational. 2015 - Middle Campus Chiller Plant expansion completed.
Number of buildings served	71	46
Total square footage served	8,507,861 sq ft	7,209,000 sq ft
Plant capacity	498,000 lb/hr steam, 394 MMBtu hot water, 25 MW electricity	Central Utilities Plant: 21,250 tons Middle Campus Chiller Plant: 12,000 tons
Number of boilers/chillers	4 boilers	9 chillers
Fuel types	Natural gas, fuel oil	Steam, electric
Distribution piping type	Steel in walkable tunnel system and preinsulated, bonded direct-buried steel	Ductile iron, coated direct-buried steel and PVC
Piping diameter range	Up to 14 inches	Up to 36 inches
System pressure	Steam distribution: 165 psig Hot water distribution: 130 psig	105 psig
System temperatures	Steam: 383 F supply/140 F condensate return Hot water: 225 F supply/160 F return	40 F supply/56 F return
System water volume	250,000 gal hot water	800,000 gal

Source: University of Rochester.

mer, a failure prevented the operation of the largest chiller in the system for a few months, requiring the university to rent temporary chillers to ensure redundancy for campus cooling. This chiller failure further reinforced the need for system upgrades to provide resiliency and additional capacity to the university's chilled-water system.

One related project improved chiller reliability, increased capacity and eliminated chlorofluorocarbon refrigerant use by two of the existing chillers in the Central Utilities Plant. This project consisted of replacing chiller tubes with high-performance tubes, replacing R-12 refrigerant with R-134a and repowering the existing steam turbine drives to increase these chillers' peak output capabilities by 11 percent.

In parallel with these chiller upgrades, the university focused on increasing the reliability of its pump systems at the Central Utilities Plant. The three existing chilled-water distribution pumps at the central plant, installed in the late 1960s, and a fourth pump, added in the late 1990s, did not have matching drive systems, motor voltages or design head pressures. Each of these factors negatively affected pump redundancy and maintenance costs, besides limiting operational flexibility.

The university was able to provide hourly data that showed flow and pressure trends for the central plant. This data was analyzed and used to calibrate computerized hydraulic models to match the current operating conditions and simulate future loads. This model was used to test multiple failure scenarios at both plants.

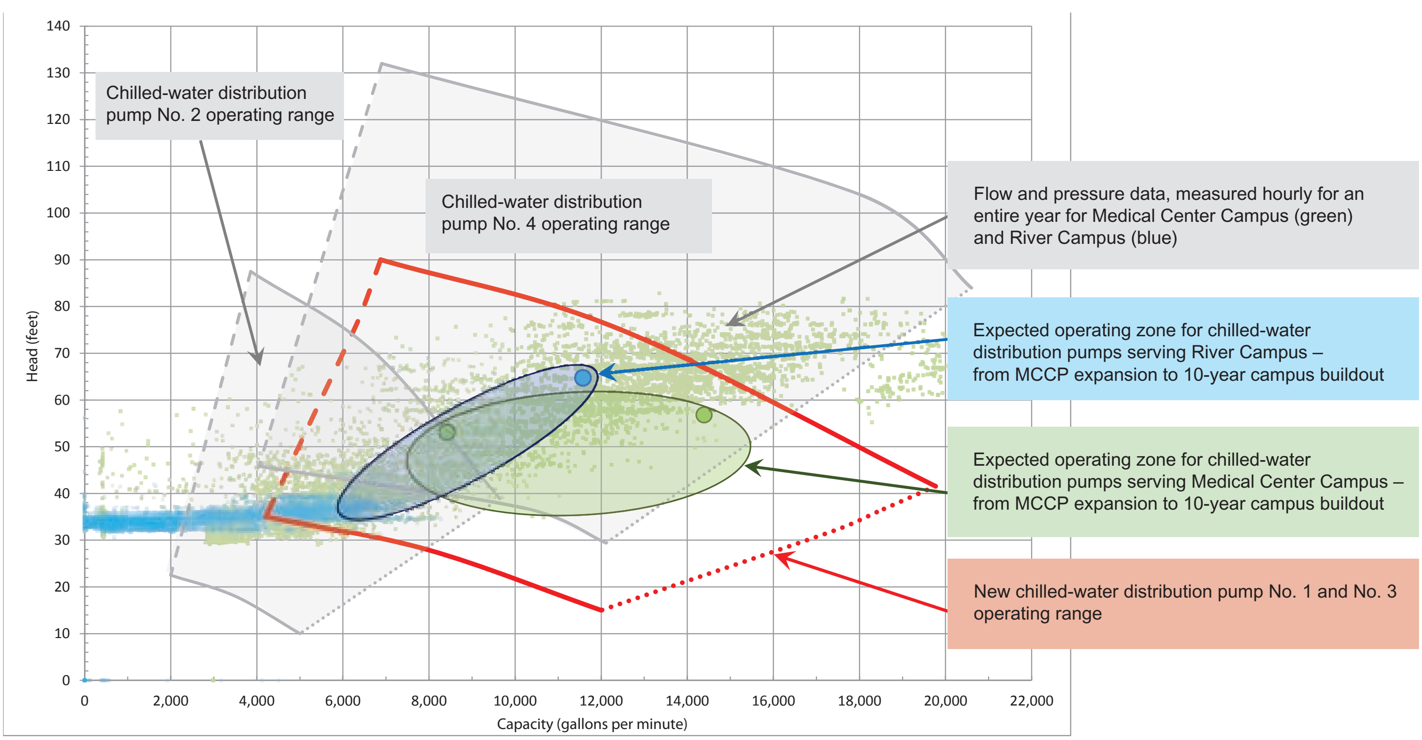
Mapping the hydraulic model data on a flow-versus-pressure chart and overlaying the existing pumps' operating ranges on top of these hydraulic scenarios made it evident that the expansion of the MCCP would signify a paradigm shift in how the four central plant pumps would be operated (fig. 1).

Along with selecting new pumps appropriately sized for all expected future and failure hydraulic situations, Affiliated Engineers and the university's Central Utilities department performed a review of the electrical system serving these pumps. One of Rochester's goals was to remove the antiquated fluid drive systems from two of the pumps and add VFDs for all of the pumps. The university also desired that all four pumps be provided with 480 V motors and VFDs, which are less expensive and have more available replacement components than 4,160 V VFDs.

The team also reviewed the source of the electrical feeds for these pumps to maximize redundancy. The selected option was to segregate the electrical feeds of the principal and backup pumps on separate electrical substations.

These upgrades, completed prior to the 2013 cooling season, increased the capacity and reliability of the Central Utilities Plant; however, the next step was to select the appropriate chillers to be added to the MCCP.

Figure 1. Hydraulic scenario map for Central Utilities Plant chilled-water distribution pumps, before and after Middle Campus Chiller Plant expansion, University of Rochester.



Source: Affiliated Engineers Inc.

MCCP EXPANSION AND DRIVE FOR EFFICIENCY

The plans for Phase II of the MCCP included an expansion of approximately 8,000 tons. Many of the essential design criteria pertaining to chiller type and heat rejection possibilities were defined by Phase I, but a few questions still remained: How many chillers and what size? Should they be provided with VFDs?

The chilled-water master plan had suggested installing two 4,000-ton packaged, dual-compressor chillers. However, the push for efficiency and redundancy with smaller chiller increments required the design team to reevaluate all available chiller possibilities. Affiliated Engineers analyzed configurations with varying chiller capacities, quantity, VFD options and appurtenances, from as many chiller vendors as possible. Based on these combinations, more than 30 possibilities were generated. After an initial screening was performed, 13 remained. Detailed qualitative and quantitative analysis was conducted for these remaining options. Each option's first cost – which in some instances required different pumping, cooling tower and electrical systems – was calculated to ensure that all configurations were being compared "apples to apples."

A more advanced chiller plant performance modeling tool was used to compare the chiller options and determine which one provided the optimum chiller plant efficiency. This chiller plant performance modeling tool, first developed by Affiliated Engineers for Phase I of the MCCP, had since been further refined through use at multiple other district cooling systems to determine their optimal equipment and operational strategies. This would be used to select the most efficient equipment for Phase II of the MCCP.

Within this model, different chiller and cooling tower performance curves were converted to mathematical equations and coupled with ambient wet-bulb and campus chilled-water demand measurements provided by the university. The model then determined plant operation for each hour of the year and generated the expected annual electrical and water consumption values at these conditions.

Many decisions were based on the analysis results. Three smaller chillers totaling 8,010 tons (2,670 tons each) were found to be the most efficient and were able to fit within the building shell that was constructed. These smaller chillers also represented reduced increment sizes, helping bolster the project's redundancy goals.

The analysis also showed that selecting three new chillers with 4,160 V VFDs would allow for the most efficient plant operation. There was, however, a point of diminish-

Table 1. Profile of current chillers, Central Utilities and Middle Campus Chiller Plants, University of Rochester.

	Chiller name	Chiller capacity (tons)	Chiller drive system	Condenser water system	Year built
Central Utilities Plant	Chiller 2	5,225	Steam turbine	Genesee River	1969
	Chiller 3*	5,225	Steam turbine	Genesee River	1971
	Chiller 4*	4,500	Steam turbine	Genesee River	1972
	Chiller 5	6,300	Steam turbine	Packaged counterflow cooling towers	1999
Middle Campus Chiller Plant (MCCP)	Chiller 6	2,000	4,160 V motor with starter	Field-erected cooling towers	2007
	Chiller 7	2,000	4,160 V motor with VFD	Field-erected cooling towers	2007
	Chiller 8	2,670	4,160 V motor with VFD	Field-erected cooling towers	2013
	Chiller 9	2,670	4,160 V motor with starter	Field-erected cooling towers	2013
	Chiller 10	2,670	4,160 V motor with VFD	Field-erected cooling towers	2013
	Free cooling heat exchanger	2,000	-	Field-erected cooling towers	2013

* Wintertime free cooling with refrigerant migration.

Source: Affiliated Engineers Inc.

What's next at Rochester?

Since May 2015, data has been collected on the performance of the University of Rochester's Middle Campus Chiller Plant (MCCP). Not only will this data help Affiliated Engineers Inc. and the university further calibrate the chiller plant modeling tool, but it will also be provided to the New York State Energy Research and Development Authority (NYSERDA). Due to Rochester's installation of optimally efficient chillers to meet campus cooling demand, NYSERDA has granted the institution a $605,000 rebate as part of its Super-Efficient Chiller program, with an additional $404,000 expected to be provided after the measurement and verification is complete.

Rochester is not finished upgrading its chilled-water system, however. With the completion of the MCCP expansion and as operators and maintenance staff become more familiar with its operation, the university plans to add dashboard graphics to the control system to display real-time chiller and overall plant efficiencies, which can be used to further enhance plant operation and efficiency.

Plans also include the addition of a thermal energy storage tank south of the MCCP, which will enable the university to trim electrical consumption peaks and hedge against electrical demand prices. With a thermal energy storage system coupled with an emergency generator, Rochester will have the ability to discharge the tank and provide critical cooling for medical campus facilities during a major electrical failure event.

ing returns for each subsequent VFD-driven chiller. This was due to the load profile and because, for portions of the year when there is low load, not all VFD-driven chillers could operate. With the utilization of each additional chiller reduced, the payback period for each VFD-driven chiller was increased.

It was determined that the capital expenditure to purchase one chiller VFD could be utilized in a more effective manner; and it was decided that it would be appropriate to install a plate-and-frame heat exchanger for free cooling at the MCCP. (See table 1.)

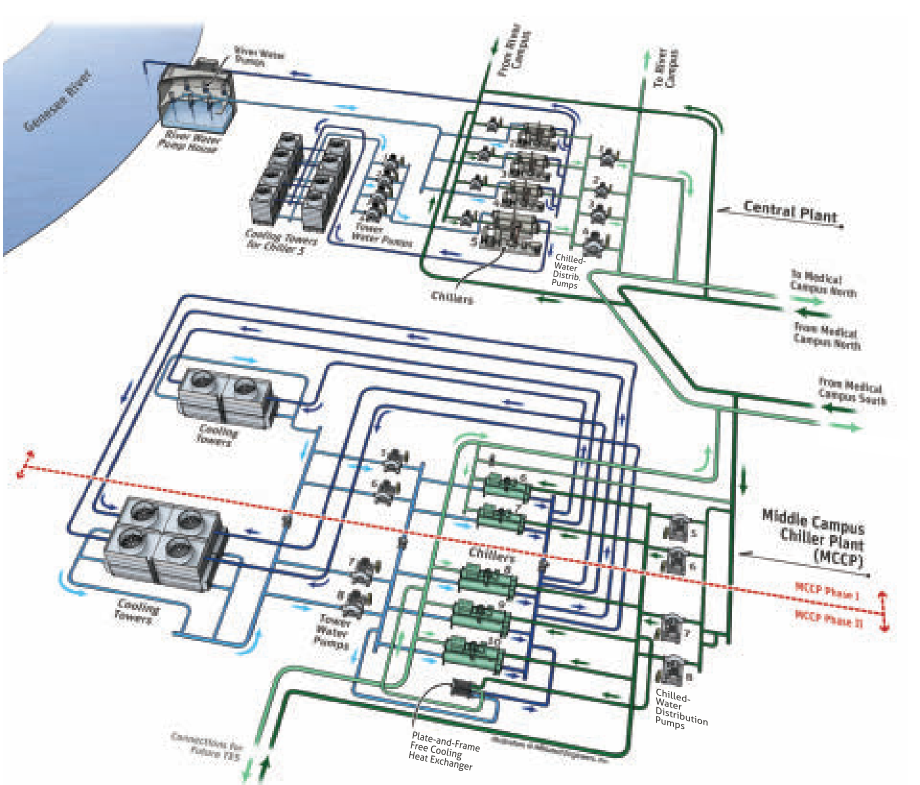
The MCCP free cooling system differs from the the free cooling system at the Central Utilities Plant, as it produces cold water by using cooling towers during low ambient wet-bulb conditions with a dedicated heat exchanger. In contrast, the central plant uses cold water from the Genesee River and refrigerant migration within a few of the chillers themselves.

Adding free cooling at the MCCP has multiple benefits. Since the system produces chilled water from ambient air temperatures, there are times in early October when those temperatures are conducive to producing chilled water before the Genesee River becomes cool enough to be utilized for free cooling. This extends the overall free cooling season for the university. Also, having this free cooling system at the MCCP allows for flexibility in scheduling preventive maintenance on the river water pumps and chillers at the central plant without the interruption of free cooling – and its energy savings.

The major equipment for MCCP Phase II (chillers, cooling towers, pumps, VFDs, switchgear and control system) was prepurchased, and construction started in October 2013. Final commissioning was completed in May 2015 (fig. 2).

With the completion of the Middle Campus Chiller Plant expansion, 10 years of campus chilled-water master planning became a reality. The University of Rochester is now able to meet the cooling demands of its growing campus more efficiently, and with greater flexibility and reliability than ever before.

Figure 2. Schematic of the current University of Rochester chilled-water system.



Source: Affiliated Engineers Inc.

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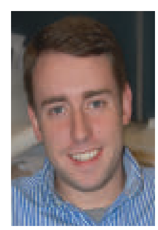

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