Cooling buildings on a historic New England campus

The University of Vermont's hybrid chilled-water system is ready for the future while preserving architectural heritage.

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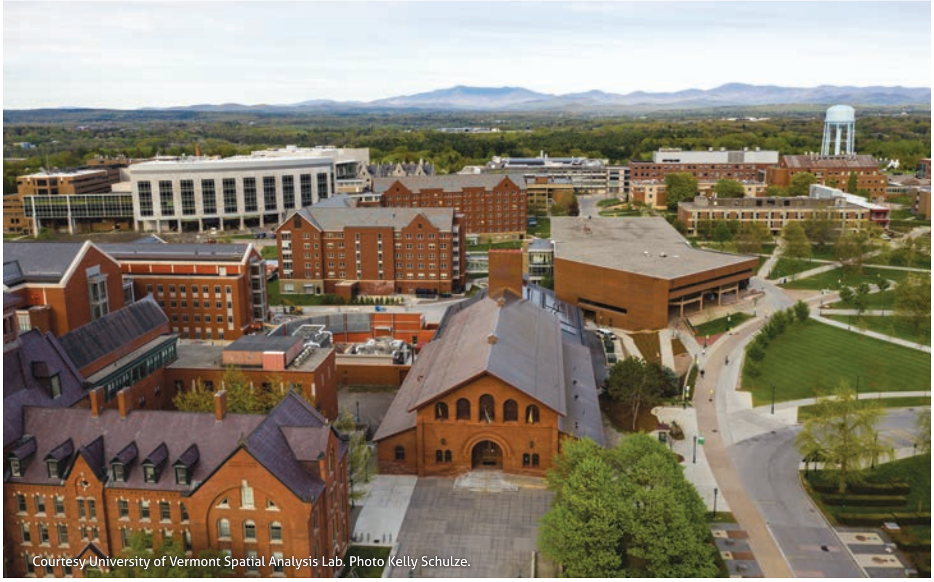
University of Vermont chiller plant expansion.

University campuses are places where people have expectations of feeling comfort in their space and being inspired by the beauty of the buildings and grounds. Nothing disrupts this more than the hum of mechanical equipment – including that coming from a chilled-water plant – which elevates background noise. Providing cooling on historic campuses poses a particular challenge for utility professionals who are constrained by operating and locating equipment in existing spaces while tasked with meeting modern thermal energy demands.

Such has been the case at the University of Vermont in Burlington – the fifth-oldest university in New England, founded in 1791. Over the past 15 years, this historic institution has developed a central chilled-water system that today serves more than 1.9 million sq ft of building space on the 460-acre campus. Building on an existing central steam system, the hybrid cooling network has evolved to meet the needs of expanding campus facilities while preserving the architectural character of the university, which features more than a dozen buildings on the National Register of Historic Places.

NEW EXPECTATIONS FOR COOLING OLD BUILDINGS

The University of Vermont, known as UVM (for *Universitas Viridis Montis,* Latin for "University of the Green Mountains"), is home to 12,000 undergraduate and graduate students. Its iconic University Row across from the formal University Green is lined with late 19th- and early 20th-century buildings. Among these is a 1901 Old Gymnasium and its 1915 extension, which at one time housed a dirt running track and batting cages. Around 1970, the front half of this building was converted into the Royall Tyler Theatre, and the rear extension was repurposed into a Central Heating Plant with steam infrastructure that has provided reliable heating for 85 percent of the campus for nearly 50 years.



Courtesy University of Vermont Spatial Analysis Lab. Photo Kelly Schulze.

The Central Plant, located on the opposite end of the Royall Tyler Theatre (center), is nestled between other historic buildings and a new STEM complex and residential hall.

In the early 2000s, when the university embarked on a major capital expansion plan for the 21st century, it added over 500,000 sq ft of newly constructed and renovated space within its historic core, including a new 200,000-sq-ft student center. (Of note, the Dudley H. Davis Center was the first student center in the U.S. to earn LEED Gold certification.) Because of this growth, the university's Physical Plant Department faced the challenge of determining how to strategically cool these areas while minimizing the visual effects in the middle of campus.

Historically in Vermont, air conditioning was considered a luxury reserved for laboratory research facilities and the highest-profile classrooms and public spaces. Limited cooling was accomplished on a building-by-building basis, usually driven by lowest first cost or to satisfy individual requests for localized cooling. But with climate change warming trends and changing customer expectations, UVM leaders now considered air conditioning to be a necessity in order to remain competitive and increase summertime utilization of its campus facilities.

INITIAL VISION: CENTRALIZED COOLING AND SUSTAINABILITY

Large institutions like universities can be bound by legacy choices concerning their energy systems. At UVM, lower first cost was often allowed to drive building project budgets without consideration of campus systems as a whole. The Physical Plant Department was facing the need to renew its aging utility infrastructure, address rising energy costs and reach targets to reduce greenhouse gas emissions – all while the Campus Master Plan was calling for growth.

In 2004, the department embarked on a Utilities Master Plan. The prevailing themes called for a centralized cooling plant to replace the aging, less-efficient building-centric systems. A centralized system could provide cooling at lower costs per ton produced and allow for a higher level of oversight and maintenance of the equipment. This concept was not new to the department, which already had a cadre of experienced staff operating a 24/7/365 central steam boiler plant for nearly 50 years.

As the university began designing the new student center, Physical Plant Department Director Sal Chiarelli saw the opportunity to bring the vision of centralized cooling to reality. With the development of the Utilities Master Plan, it became apparent that a centralized approach (rather than another isolated chiller) was the smartest option for the future student center in the heart of campus. It certainly helped that the site was a stone's throw from the Central Heating Plant where a new chilled-water plant could feasibly be developed.

IT BECAME APPARENT THAT A CENTRALIZED APPROACH WAS THE SMARTEST OPTION FOR THE FUTURE STUDENT CENTER IN THE HEART OF CAMPUS.

The Utilities Master Plan examined the short- and long-term cooling needs of the campus while adjusting for elements in the Campus Master Plan. Load estimates implementing cooling density ranges from 185 sq ft/ton in laboratory facilities to 516 sq ft/ton in academic buildings were applied. In addition to the estimated 30 percent reduction in the operating costs, many intangible benefits were taken into account. A centralized plant would

- reduce localized noise at individual buildings,
- eliminate unsightly equipment enclosures on historic building facades,
- consolidate refrigeration storage locations,
- assure unified maintenance practices and
- simplify water treatment service.

The final decision was to install two 1,365-ton stream-driven turbine chillers inside the existing heating plant, which was renamed the Central Plant.

Convincing senior leaders and finance officers to fund capital-intensive energy projects can be a challenge at any institution. Having a project "champion" helps. Chiarelli dug through historic Board of Trustees documents to identify and emulate the precedent set back in 1969 when university leaders first approved the concept of central heating. With a solid design and expected future savings in hand, he put it simply: "Some really smart people sat around a table 50 years ago and decided to invest in a central steam boiler plant for heating the campus … and here we are again at that same table with an opportunity to create a central chilled-water plant." The board approved $19 million in February 2005 to fund utility improvements.

STEAM AS THE GREENER OPTION

For UVM, the availability of affordable electric power was (and still is) a major concern due to a complex rate structure with demand peaks and ratchet charges. Conversely, the steam produced at UVM's existing heating plant – the lifeblood of the campus during long Vermont winters – is readily available during other seasons. Steam loads typically peak in late January at just over 120,000 lb/hr. (The peak has decreased from 150,000 lb/hr in 2000 as a result of earlier upgrades to the plant control system and to underground steam distribution piping.) Seasonally, steam demand dropped 40 percent to 50 percent between April and October – the same period in which campus electrical accounts hit their peak and incur costly penalties.

The decision was to use plant steam at 225 psig to power two 1,365-ton turbine chillers for the new cooling system. It was considered the most advanced, best-fit method to avoid creating significant new electrical loads and demand ratchets.

The existing interior of the heating plant was reconfigured to make space for the new chillers, and a modest concrete masonry block cooling tower enclosure was constructed adjacent to the facility.

The proven alternative technology was the perfect fit for the existing plant location. The chillers are integrated with a surface condenser used to condense the exhaust steam from each turbine. Three 200 HP variable-speed-driven primary chilled-water pumps replaced dozens of small pumps in the adjacent connected buildings.

Positioning chilled-water operations at the Central Plant achieved the goal of load-leveling the steam output of the existing five boilers. The institutional goals to develop greener solutions for

The east facade of the Central Heating Plant in 2007, when two steam chillers were first installed.

The LEED Gold Dudley H. Davis Center, completed in 2007, is a hub of campus life and student services.

cooling and to consolidate refrigeration equipment into a centrally monitored location were also met. Lastly, the project helped the new Dudley H. Davis Center obtain the LEED enhanced refrigerant management credit since no refrigerants would be used for space cooling inside the building.

The project was finished in June 2007 on budget and on schedule with construction completed in just 11 months. The initial system supplied chilled water to the new student center as well as new space cooling for several older facilities in the historic district including the Howe Library, the Old Mill/Lafayette Hall academic complex and the Royall Tyler Theatre.

REFOCUSED VISION: REDUNDANCY AND RESILIENCY

The 2007 investment proved to UVM decision makers that initial expansion costs are offset by reduced ongoing costs of individual building systems and that further investment in centralization would benefit the entire campus, not just a particular building or academic department. The Physical Plant Department shifted its focus to operational resiliency and coined the acronym ROAMS (Reliability, Operability, Availability, Maintainability and Sustainability) to guide decision-making about its future energy system.

Adding system redundancy

The department was always thinking two steps ahead. The very first chillers and the initial mile of chilled-water piping installed in 2007 were sized for anticipated growth. By the time the project was finished, several more miles of pipeline and new building connections were being engineered. In 2009, during construction of Jeffords Hall – a new life sciences laboratory also to be connected to central chilled water – a strategic decision was made to extend a 1-mile section of the steam and chilled-water pipeline to the nearby College of Medicine complex, which had its own major satellite boiler plant and a 2,000-ton chiller plant. This enabled the connection of the two plants, thus adding load and redundancy to the central utility loop.

TO ACCOMMODATE A MAJOR EXPANSION OF THE CHILLED-WATER SYSTEM, A 7,500-SQ-FT ADDITION WAS NEEDED ON THE HISTORIC CENTRAL PLANT BUILDING

Choosing electric as the flexible option

By 2015, the original chilled-water plant was clearly successful as all of its capacity was being fully utilized. But the campus was now planning another major capital expansion in its historic district. This included demolishing an auditorium building, an old science building and a post-World War II residence hall – along with their window air-conditioning units and small split systems. This would make way for a new STEM learning complex and a 700-bed residential and dining hall that would add cooling load to the campus.

To accommodate a major expansion of the chilled-water system, a 7,500-sq-ft addition was needed on the historic Central Plant building in order to house a new chiller and associated pumps and equipment. A larger cooling tower enclosure was also needed because there was no more space in the original enclosure.

Initially, campus cooling was entirely driven by steam turbines or absorbers. This time, a 1,500-ton electric chiller was selected because of its rapid startup capabilities and flexibility. Whereas steam turbines and absorbers can take up to 30 minutes to initiate cooling, the electric chiller can provide full cooling within three minutes. The chiller can provide cooling to campus customers during UVM's annual steam shutdown, and is powered year-round by renewable electricity (UVM buys 100 percent GreenE-certified power).

Creating hybrid system resilience

The now-"hybrid" chilled-water plant, completed in 2017, better positions UVM to address peak, shoulder and winter cooling loads. The flexibility to use electricity or steam or a combination of the two enables the system to use energy in the most efficient and strategic way.

During the expansion, resiliency aspects were implemented with the pump replacements and piping connection of two existing electric chillers in nearby academic buildings. This connection added 400 tons of capacity to serve shoulder season startups or supply additional cooling to supplement the Central Plant units.

The expansion also added a free cooling condenser water system, utilizing a plate-and-frame heat exchanger that provides energy savings when weather conditions allow cold outside air temperature to be used instead of the chiller for year-round internal cooling needs of the new buildings.

The Central Plant has multiple industrial-grade programmable logic controllers for control of equipment and remote sensors on a fiber optic cable extending to a few remote areas for data measurements. These remote locations have differential pressure transmitters for chilled-water pump variable-frequency drive reset control in the Central Plant. This PLC system is separate from the individual building management systems, and all systems do not communicate directly with the PLCs. Chillers and ancillary equipment are sequenced semiautomatically in the operating program logic.

The Central Plant operators will get a notice on the operating screen that additional equipment may be required, and they will then decide whether to energize it or not based on the time of day and weather forecasts. Conversely, when a low-load notice appears, the operators will decide if equipment should be powered down. Plant operators have additional duties to monitor all UVM operations on second/third shifts and weekends. They have all the operating screens for the various building management systems in the Central Plant and can monitor or control chillers, air-handling units, pumps and boilers.

The goal of increasing operational resilience is of critical importance as the campus load has grown to the point that all equipment must be ready to function on hot days. To optimize plant operations while reducing energy consumption, UVM can now empirically determine primary-only pump setpoints based on chilled-water valve positions out in the system. UVM is installing a software application that communicates with selected Central Plant PLCs, the various building management systems and Modbus devices. This data is used for load calculation, trending, utility allocation and troubleshooting, and all of it can now be stored at the same time stamp instead of at the random five-minute or greater intervals used in the various systems.

The operators can use the data from this system to modify the leaving water temperature as a function of building system air-handling fan power and the polling of chilled-water differential pressures in the distribution network.

Other steps to increase resiliency and efficiency included

- enhancing maintenance of cooling tower fans with the addition of fan vibration trending analyses,
- creating manifold headers for pumping,
- eliminating chiller islanding,
- increasing pumping options and
- establishing better monitoring of operations.

System snapshot: University of Vermont

	Steam system	Chilled-water system
Startup year	1970 – Centralized steam service began	2007 – Two steam-driven turbine chillers were first installed 2017 – Major expansion added electric chiller
Number of buildings served	74	28
Total square footage served	3.9 million sq ft	1.9 million sq ft
Plant capacity	Central plant: 224,000 lb/hr steam Satellite locations (7): 115,000 lb/hr steam	Central plant: 4,200 tons chilled water Satellite locations (2): 2,500 tons chilled water
Number of boilers/chillers	Central plant: 5 boilers Satellite locations (7): 12 boilers for backup only	Central plant: 3 chillers (2 steam turbine, 1 electric) Satellite locations (2): 5 chillers (2 steam absorption, 3 electric)
Fuel types	Natural gas (interruptible) with No. 2 oil backup	Steam, electricity
Distribution network length	5.5 miles of piping	2.3 trench miles
Piping type	Preinsulated carbon steel	Preinsulated carbon steel, ductile iron and polyvinyl chloride
Piping diameter range	3 to 14 inches	4 to 20 inches
System pressure	225 psig (saturated)	100-125 psig
System temperatures	398 F steam	42 F supply/54 F return
System water volume	NA	200,000 gal

Source: University of Vermont.

DESIGN CHALLENGES IN A HISTORIC DISTRICT

On the UVM campus, as elsewhere, the placement of chillers, boilers, cooling towers and support equipment around historic buildings can consume valuable real estate and create industrial-looking environments that detract from the character of the area.

UVM's initial strategic decision to locate a centralized chiller plant at the existing heating plant precluded adverse impacts such as noise, vibration, unsightly equipment, traffic and exhaust plumes that would have disrupted the character of individual historic buildings.

Prior to adding air conditioning to a historic building, it is also important to determine the effect this might have on the building's interior. This means investing in predesign studies to ensure that there would be no adverse impacts on the building envelope. Evaluation includes determining the location where condensation will occur by modeling the movement or accumulation of moisture and heat within the wall assembly.

During the 2017 plant expansion, the university *truly* had the opportunity to "get it right" and accomplish a complete visual transformation of the plant itself. Getting it right meant designing an industrial building that, despite its function, would be a positive addition to the architectural character of the area and be a quiet neighbor to the existing and planned buildings in the historic core of campus.

IT WAS NOT UNTIL THE 2017 PROJECT THAT UVM *TRULY* HAD THE OPPORTUNITY TO ACCOMPLISH A COMPLETE VISUAL TRANSFORMATION OF THE PLANT.

The plant's new east-facing facade features a central arch to match the robust entry of the Royall Tyler Theatre on the other end of the building. The new steel sash windows, brick buttresses, sloped metal roof with broad overhangs and the cupola all specifically reflect elements of the existing structure. Its form and masonry detailing complement the late-19th-century brick-and-stone building context of the historic core.

New cooling towers were placed next to the existing ones, and the original modest masonry enclosure was partially removed so that a larger courtyard enclosure with adequate clearances for equipment delivery and air flow could be built. The new screen wall was designed to visually and acoustically shield the cooling towers and associated pumps and equipment from the surrounding area.

It took great rapport between the owner and the design team to make the project successful. All team members were supportive of the basis of design and of each other's perspectives and positions.

Always thinking ahead, the department made sure that extra bays in the plant space and header piping were integrated into the project design to accommodate future chillers and equipment. (Currently, a fourth chiller, replacement of old equipment and additional network piping are on the drawing board.)

Courtesy University of Vermont. Photo Stephan Toljan.

A pedestrian walkway wraps around the newly expanded Central Plant.

Courtesy RMF Engineering Inc. Photo J. Michael Worthington Jr., www.worthingtonimages.com.

Cooling towers, pumps and associated equipment are visually and acoustically shielded behind a new brick enclosure.

WELL-POSITIONED FOR THE FUTURE

After a 15-year undertaking and a transformative facility expansion, the university now has a hybrid central chilled-water system that includes steam-driven, steam absorption and electric-driven centrifugal chillers with many miles of underground piping. The system is cooling more than 1.9 million sq ft of space, enabling UVM to optimize the year-round usage of its campus, host more summer visitors and events, and accommodate more advanced scientific research.

Forward-thinking leaders and an institutional commitment to preserving the historic character of the campus resulted in a modernized system that will serve UVM into the future without disrupting the beauty and serenity of its historic core. During the 2017 dedication ceremony of the new facility, then-Vice President of University Administration Tom Gustafson proclaimed, "Who would've thought that our chiller plant would be arguably the most beautiful building on our campus?" Indeed.

David Blatchly, PE, CEFP, *is the capital renewal engineer for the University of Vermont. He began his career at UVM in 2002 as a project engineer for the Physical Plant Department. For 10 years, he managed major utility projects including the first chiller plant, development of the utility master plan and the strategic expansion of the campus underground piping network. He then served as a facilities manager leading a team charged with maintaining 1.4 million sq ft of campus facilities including the district served by the chilled-water system. Blatchly received his Bachelor of Science degree in mechanical engineering from the University of Vermont. He can be reached at David.Blatchly@uvm.edu.*

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