

Columbia University's Campus Energy Renewal Project:

Modernizing infrastructure, lowering emissions

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Courtesy Columbia University.

The new cooling towers were installed by crane on the roof of the University Building, where the Old Powerhouse chiller plant is located underground.

Columbia University in New York City, one of the top academic and research institutions in the world, is also one of the oldest universities in the United States, established in 1754 as King's College. In 1896, the university moved to its current location in the city's Morningside Heights neighborhood and started in the district energy business with the installation of its original steam plant. This expanded to include chilled-water service by the mid-1960s. While much of the campus energy system, located within the Con Edison electric service territory, was replaced and upgraded over the past century, there had not been a comprehensive systemwide renovation and upgrade until recently.

In 2008, Columbia faced a problem not uncommon among many post-secondary education facilities today: the need to renew aging utility infrastructure while addressing both rising energy costs and targets to reduce greenhouse gas emissions. The university had set an initial greenhouse gas reduction target of 30 percent compared to 2006 levels over a 10-year time frame starting in 2007. A 30 percent reduction amounts to 48,363 metric tons of carbon dioxide equivalent per year across a portfolio of campus buildings totaling in excess of 13 million sq ft. In terms of gross metric ton reduction, this goal is among the most aggressive in the New York City Mayor’s Carbon Challenge,

originally conceived by Mayor Michael Bloomberg as PlaNYC and today known under the de Blasio administration as One City: Built to Last.

In order to work toward the extensive greenhouse gas reduction, as well as reduce operating costs and improve efficiency, the university’s operations team focused on the campus district energy system, launching a multiyear strategic initiative in 2010 to renew key system infrastructure.

CHILLER PLANT RENEWAL

The first part of the program entailed the renewal of chilled-water production. Plans to add a new research building, the Northwest Corner Building, in 2010 had resulted

in a requirement to add 1,500 tons of new chilled-water capacity to the aging system. However, rather than incrementally add capacity solely to meet the needs of the new building, the university took this as an opportunity to perform an expansive multiple-year chiller plant renovation.

Prior to the execution of this project, chilled water was produced in four separate locations connected by a common distribution loop to 46 buildings and 4,886,017 sq ft of mixed-use space across the campus. The chiller plant locations (table 1) included the Mudd Building, Schapiro Center for Engineering and Physical Science Research, Old Powerhouse and International Affairs Building.

An initial goal was to consolidate all campus chilled-water production into the Old Powerhouse (OPH) chiller plant located below University Hall. As part of this project, two new 2,800-ton chillers and ancillary systems and equipment including cooling tower, pumps, piping, electric gear and a state-of-the-art SCADA control system were installed in 2011.

The first chiller (table 2) installed in the OPH plant and connected to the central loop was a new York YK 2,800-ton electric unit equipped with a variable-frequency drive. Based on its high efficiency, this chiller became the lead chiller in the plant lineup, replacing the need to operate the older constant-speed electric chillers



In 2011, new cooling towers were installed as part of Columbia’s Old Powerhouse chiller plant renewal.

Table 1. Chiller Plant Overview, 2010, Columbia University, Morningside Heights Campus.

Plant Location	Chiller Type	Capacity (Tons)	Vintage
Mudd Building	Steam turbine	970	1963
	Steam turbine	650	1963
	Steam turbine	650	1963
Schapiro Center for Engineering and Physical Science Research (CEPSR)	Electric centrifugal	1,350	1990
	Electric centrifugal	1,350	1990
	Electric centrifugal	1,350	1990
Old Powerhouse (OPH)	Electric centrifugal	1,500	1985
	Steam turbine	2,000	1997
	Steam turbine	1,600	2003
International Affairs Building (IAB)	Electric centrifugal	1,600	2007

Source: Columbia University.

Table 2. New Electric Chiller, Old Powerhouse Chiller Plant.

Model	YKZSZSK7-DKG
Refrigerant	R-134a
Rated Capacity	2,800 tons
Input Power	1,630 kW
Voltage	4,160 V
Condenser Water Flow	3.0 gpm/ton
Condenser Water Temperature	85 F
Chilled-Water Temperature	42 F
Full-Load Steam Rate	0.582 kW/ton
Nonstandard Part-Load Value	0.349 kW/ton
Steam Rate	

Source: Columbia University.

located in the OPH (~0.7 kW/ton) and Center for Engineering and Physical Science Research (CEPSR) (~0.8 kW/ton) during the winter and peak summer cooling periods.

The new electric-drive chiller is operated at part-load conditions and met the eligibility requirements for New York State’s Super Efficient Chiller Bonus incentive of \$1,050,788, paid to the university by the New York State Energy Research and Development Authority (NYSERDA). The NYSERDA incentive process included measurement and verification for a two-year period following the project installation. This demonstrated annual electricity savings of 5,499,050 kWh, annual utility cost savings of \$895,795 (based on FY13 annual cost of electricity at the Morningside campus) and annual emissions savings of 2,324 metric tons of CO₂e.

The second chiller installed at the OPH and tied into the central distribution loop was a new York YST 2,800-ton steam-driven centrifugal unit (table 3). The installation of this chiller complied with the university’s N+1 operating requirement and further allows for enrollment in the Special Case Resources program with the New York Independent System Operator (NYISO), providing 1,500 kW of on-peak, on-call electric load reduction to support statewide power grid operations. Based on the commitment to support the grid, this chiller also received a NYSERDA incentive upon

Table 3. New Steam-Driven Centrifugal Chiller, Old Powerhouse Chiller Plant.

Model	YSTZSZ4K7-KDG
Capacity	2,800 tons
Shaft Power	2,070 HP
Refrigerant	R-134a
Steam Supply Pressure	102 psig
Steam Supply Temperature	339.2 F
Design Steam Flow	26,153 lb/hr
Nonstandard Part-Load Value	6.26 lb/ton
Steam Rate	
Full-Load Steam Rate	9.34 lb/ton

Source: Columbia University.

installation and demonstration of the ability to curtail load. The incentive from the state for this element of the project was \$220,000, with the university also receiving a three-year performance incentive bonus of \$477,093 for participation in NYISO’s demand response program, paid by the utility.

Along with the two new chillers, the new auxiliary equipment was also installed in 2011, to further improve system efficiency and address certain distribution bottleneck issues that had become increasingly problematic in recent years. These auxiliaries included two 400 HP condenser water pumps, two 600 HP chilled-water pumps and six 100 HP cooling tower fans with new motors and variable-frequency drives (table 4).

The addition of this high-efficiency auxiliary equipment (pumps and fans) with new motors and variable-frequency drives further reduced electricity consumption by 735,097 kWh and resulted in an additional 310 metric tons of annual CO₂e reduction toward the university’s goal.

In addition to the equipment upgrades at the OPH, the plans to consolidate chilled-water production at that facility also involve the relocation of CEPSR chiller capacity to the OPH and the decommissioning of the chill-

ers in the Mudd Building. Although not currently in operation, the IAB plant chillers remain in place to accommodate the potential use of thermal storage in the future.

Today, the total peak load on the chilled-water distribution system is approximately 13,500 tons.

BEYOND EQUIPMENT: OPTIMIZATION

Further enhancing the value of the chiller plant work, and with the goal of continued reductions in operating cost as well as improvement in chilled-water delivery to building occupants, the university also aimed to optimize the chilled-water system efficiency. The facilities engineering and physical plant team sought a qualified firm to design and install a chilled-water optimization system that would allow for ongoing and real-time chilled-water asset dispatch to improve operating conditions in the central OPH plant and provide consultative services to improve operational efficiency.

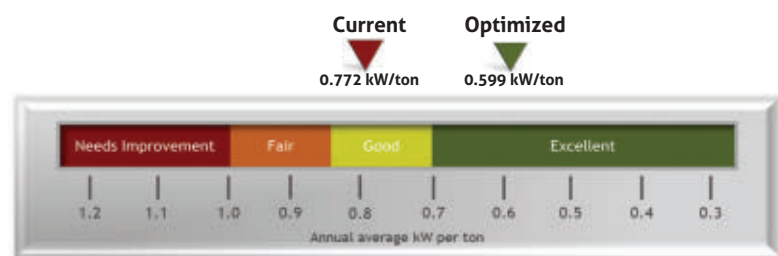
This solicitation resulted in the selection of a chiller-plant optimization system from Johnson Controls Inc. (JCI), which partnered with Optimum Energy to provide OptimumLOOP™ – a state-of-the-art con-

Table 4. New Auxiliary Equipment, Old Powerhouse Chiller Plant.

Pump/Motor Usage	Number	HP	Efficiency	Speed
Condenser Water Pumps	2	400	Premium	Variable
Chilled-Water Pumps	2	600	Premium	Variable
Cooling Tower Fans	6	100	Premium	Variable

Source: Columbia University.

Figure 1. Illustration of Average Annual Efficiency of the Old Powerhouse Plant Before and After Optimization, Using Optimum Energy’s Chiller Plant Efficiency Scale.



Source: Columbia University.

figurable control software platform that offers continuous, system-level optimization of central chilled-water plants. Its relational control algorithms calculate the most efficient operation of an entire chilled-water system and automatically and continuously optimize plant performance in real time, dynamically adapting system equipment to fluctuating load, weather and occupancy conditions.

The JCI/Optimum Energy team's first step was to calculate the current performance of the central chilled-water plant to determine the level of energy savings that could potentially be realized by converting the existing plant to an optimized system controlled through OptimumLOOP. To benchmark current plant performance, the team utilized the central chilled-water plant efficiency scale (fig. 1), developed by Optimum Energy. This scale encompasses the entire central chilled-water plant energy

usage including chillers, tower fans, condenser pumps and chilled-water pumping. It expresses the average annual efficiency of a chilled-water plant in kilowatts per ton. The analysis demonstrated that the plant was operating at an average annual electrical plant efficiency rate of 0.772 kW plus 10.42 lb/hr of steam per ton of chilled water produced.

A detailed engineering simulation and analysis by the JCI/Optimum Energy team determined that optimizing the Columbia University central chilled-water plant with the OptimumLOOP software would improve operating efficiency, drive substantial energy savings and achieve additional reductions in carbon footprint. As part of the engineering site analysis, an 8760 report was produced for the OPH plant, which included an hour-by-hour simulation of plant performance against existing weather data and load pro-

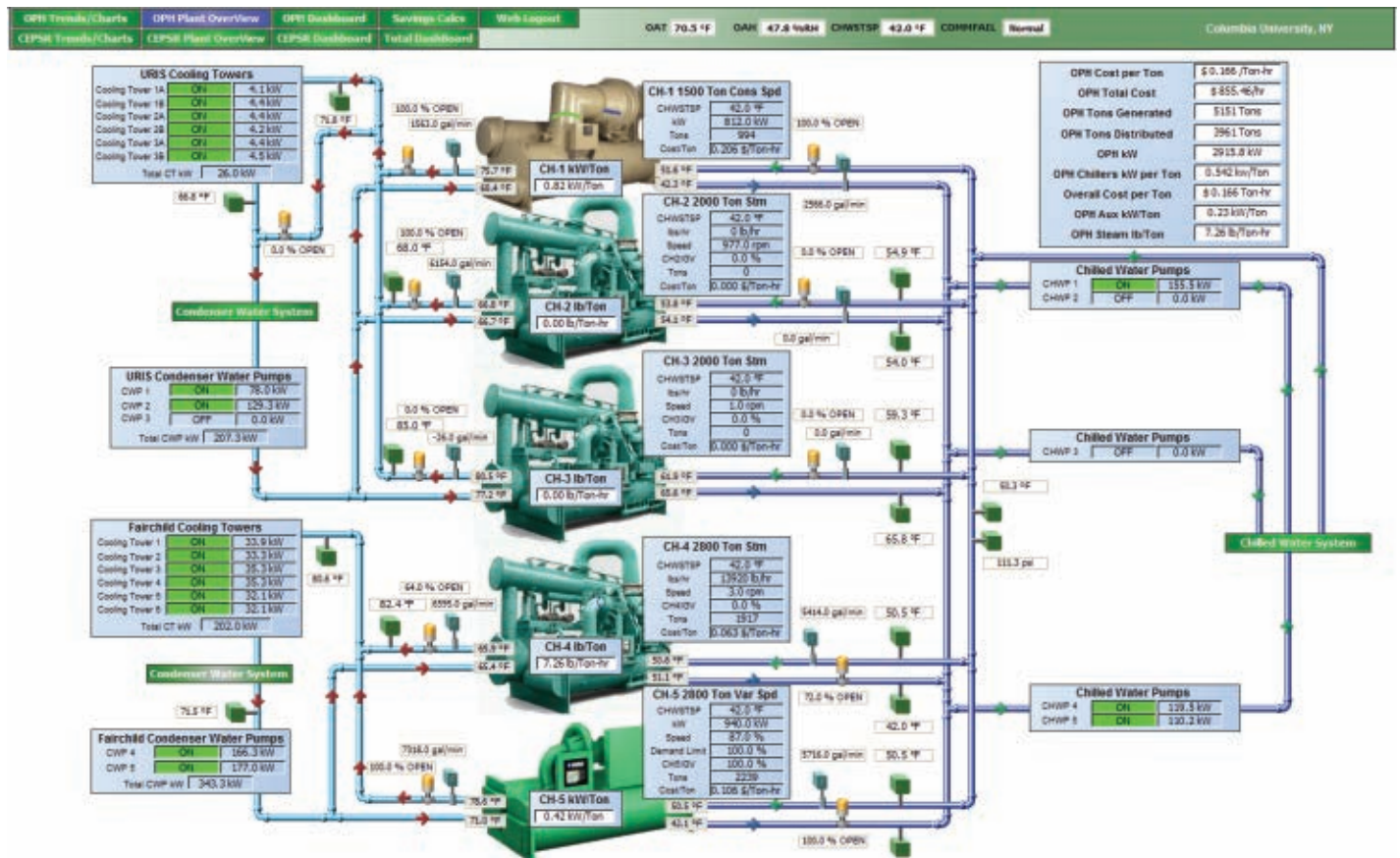
file for a full year. The resulting data clearly demonstrated to Columbia how the plant was operating versus how it could potentially operate once optimized. It included a forecast of the total energy and cost savings that would result from the implementation of the optimization project.

The cost savings achievable with OptimumLOOP would be driven in the following four key ways:

1. Economic dispatch of chiller plant assets

The chilled-water plant consists of both electric- and steam-driven centrifugal chillers, which gives the OptimumLOOP system the flexibility to provide cooling from multiple fuel sources (electricity versus natural gas). Factoring in utility time-of-use fuel costs, the algorithms determine when to operate each specific chiller in real time based on overall system cost efficiency rather than solely energy efficiency.

Figure 2. Screenshot of Old Powerhouse Plant Overview, OptimumLOOP Dashboard, Columbia University.



Source: Columbia University.

2. Campus chilled-water distribution optimization – By utilizing various sensors and meters located throughout the chilled-water distribution system, OptimumLOOP is able to save significant chilled-water pumping energy by delivering the required amount of chilled-water flow at the lowest system pressures possible.

3. Relational control of condenser water systems – OptimumLOOP utilizes its patented algorithms to control both condenser water pumps and cooling towers based on the relationship of all chilled-water system components (condenser water pumps, cooling towers and chillers) to each other. This method of holistic optimization ensures peak efficiency at all times.

4. Measurement, verification and monitoring – By utilizing Optimum-

LOOP’s cloud-based performance and energy management platform (fig. 2), the Columbia facilities team is able to monitor and track system performance and verify overall project savings. In addition, enhanced visibility into real-time operations (fig. 3) assists the plant operations team and ensures savings are maintained over time.

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THE END RESULT OF OPTIMIZATION WAS AN ADDITIONAL \$634,000 ANNUAL ENERGY COST SAVINGS ABOVE AND BEYOND THAT OF THE EQUIPMENT RENEWAL.

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The end result of the optimization project was an additional \$634,000 annual energy cost savings above and beyond what was achieved with the

equipment renewal. Today, utilizing the optimization sequencing, metering and real-time monitoring approach, Columbia University is able to closely measure and monitor the chiller plant’s energy usage and optimize cost through the strategic deployment of assets based on the utility time-of-day rate.

Through a special utility program offered by the Con Edison Green Team for commercial and industrial efficiency, this project received an incentive check in the amount of \$468,902, which was presented to Vice President of Operations Frank Martino in a spring 2013 ceremony on campus.

The measured and verified energy consumption savings from the optimization program were

- 3,075,300 kWh of electricity;
- 243,600 therms of natural gas; and

Figure 3. Screenshot of Total Dashboard View, OptimumLOOP Platform, Central Chilled-Water System, Columbia University.



Source: Columbia University.

- 2,594 metric tons of annual CO₂e emissions.

According to Optimum Energy’s July 2015 report, the trailing 12-month actual measured electrical chilled-water plant efficiency is 0.42 kW/ton and \$10.47 lb/ton-hr.

THE THERMAL SIDE OF THINGS

Once the chiller plant optimization project was completed in 2012, the facilities engineering and physical plant team shifted its focus to renovating the central steam plant, the Columbia Powerhouse, located below the CEP SR building and adjacent to the chiller plant. This project, begun in late 2012 and still under way, involves the overhaul and refurbishment of three of the plant’s existing 86-Mlb/hr, 125-psig steam boilers and ancillary systems and equipment located in the Columbia Powerhouse.

(The fourth boiler will be demolished as part of the overall system renewal plan.) These boilers are dual-fuel, capable of burning both natural gas and distillate fuel oil. The backup fuel was No. 6 fuel oil up until 2012 when the university converted to a significantly cleaner No. 2 ultralow-sulfur diesel with a 2 percent biofuel component. (New York City has a mandatory 2 percent biofuel requirement for all liquid distillate fossil fuels.)

THE FUTURE

In many ways, the improvements performed across the central district energy system are a “make-ready” for a larger central utility improvement project presently in the design stage. Columbia University is planning for a proposed installation of 13.7 MW of on-site power production using a gas turbine generator coupled with the

efficient use of exhaust heat from the turbine to economically cogenerate steam using a heat recovery steam generator.

In addition to the gas turbine generator and heat recovery steam generator, the proposed combined heat and power plant will consist of a gas compressor, electrical gear, and ancillary systems and equipment. The CHP system and equipment will be located in the CEP SR steam plant. It will occupy space originally reserved for CHP equipment during plant construction in 1990 plus space that will be made available by the demolition of the 50-plus-year-old redundant fourth boiler and the relocation of all chilled-water production from the CEP SR plant to the OPH chiller plant.

The new CHP plant will generate approximately 71 percent of the university’s electricity needs and nearly

System Snapshot: Columbia University

	Steam System	Chilled-Water System
Startup Year	1896 – Central steam service begins 1990 – Columbia Powerhouse plant replaces original plant	1960s – Original chillers installed in science building, with other buildings connected later 1985 – New electric chiller installed at site of original steam plant, interconnected to buildings
Number of Buildings Served	63	46
Total Square Footage Served	6,538,128 sq ft	4,886,017 sq ft
Plant Capacity	Columbia Powerhouse: 344,000 lb/hr steam	Old Powerhouse: 10,700 tons Satellite Plants: CEP SR – 4,050 tons; IAB – 1,600 tons
Number of Boilers/Chillers	Columbia Powerhouse: 4 boilers	Old Powerhouse: 5 chillers (2 electric, 3 steam turbine) Satellite Plants: CEP SR – 3 chillers (electric); IAB – 1 chiller (electric)
Fuel Types	Natural gas and No. 2 ultralow-sulfur diesel with 2% biofuel as backup to meet utility curtailment obligations	Steam and electric
Piping Type	Primarily in tunnels with minimal direct-buried	Primarily in tunnels with minimal direct-buried
Piping Diameter Range	2 to 14 inches	2 to 30 inches
System Pressure	125 psig	150 psig
System Temperatures	350 F condensate return	42-44 F supply/52-54 F return
System Water Volume	NA	1.1 million gal

Source: Columbia University.

all of its annual steam needs. The plant will contribute 13.7 MW toward a campus coincident peak electric demand that is upward of 25 MW and approximately 60 Mlb/hr toward a campus peak steam demand of approximately 215 Mlb/hr. Following installation of the CHP system, the Columbia Powerhouse boilers will continue to run on peak days and when CHP is down for maintenance or has an unplanned outage.


Part of the cogenerated electricity will be distributed by direct transmission through hard wire from the CEPSCR CHP plant to campus buildings. The balance will be exported to the Con Edison grid through the high-voltage transformer system and will be made available to proximate campus buildings under a tariff mechanism for remote net metering. The low-cost cogenerated steam will be used to heat the campus in winter and to cool it in summer using the steam turbine-driven chillers that were installed in the OPH chiller plant in the first part of the renewal program.

The benefits of the proposed CHP plant include reduced operating costs, increased resiliency and decreased greenhouse gas emissions. The CHP plant will eventually increase resiliency by enabling the supply of cogenerated power to nearby hardwired

plants (the OPH and, potentially in the future, the IAB plant) and buildings during any future Con Edison electrical grid blackout similar to what New York City experienced during and immediately following Superstorm Sandy. The CHP plant will be installed with islanding capabilities and with provisions for connecting a diesel generator in the future for blackstart capabilities that will allow it to start, operate and transmit power to the nearby buildings during a blackout.

The CHP project will reduce campus greenhouse gas emissions by 9,817 metric tons per year or by 1.66 lb of CO₂e per square foot from 27.28 lb/sq ft in the base year. This will contribute approximately 6.1 percent toward the university's targeted PlaNYC greenhouse gas reduction goal of 30 percent when the city's current custom method of calculating greenhouse gas reduction is used. The university has proposed an alternate method of calculating greenhouse gas benefit that, if accepted by the city, would increase the contribution of the CEPSCR CHP plant toward the university's greenhouse gas reduction goal from 6.1 percent to 38.8 percent.

The approach that Columbia University has taken to achieving these aggressive goals has been a strategic one: renewing aging district

energy infrastructure with measures that reduce operating costs, improve efficiency and lower campus carbon emissions. Still under way, the project will upgrade the heating and cooling systems of this historic campus – which first employed district energy nearly 120 years ago – enhancing its reliability, resiliency and contribution to the air quality of New York City for decades to come. 



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development and deployment to institutional energy consumers such as hospitals, universities, colleges and cultural centers. She is also the acting director of energy programs for Columbia University, in which role she oversees all elements of energy management from conservation projects to energy procurement and demand response participation. Kearney previously served as director of energy programs for New York-Presbyterian Hospital. She holds a Bachelor of Science degree in management from the University of South Carolina-Columbia. Kearney may be contacted at jkearney@gotham360.com.

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