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Case study
Astor Place

Out of the lab and into the real world: Proving the significance of overall system efficiency

Research demonstrates energy targets can be achieved to improve HVAC performance

At first glance, the sleek and sculptural 21-story Astor Place tower in New York City appears out of place in the heart of the fabled bohemian East Village. But true to the spirit of the neighborhood, Astor Place is challenging convention and advancing the ideals of energy conservation and sustainability.

These advancements were accomplished through a collaboration among water technology company Xylem Inc., building manager Related Management Co. and the Sustainable Engineering Lab at Columbia University, to test assumptions of energy efficiency in a retrofit of the building's hydronic HVAC system, later documented in a doctoral dissertation.[1]

The Astor Place Energy Improvement Project consisted of three primary steps: conducting an initial energy assessment of the hydronic system, updating the system with technologically advanced pumps and controls, and adjusting the system in real time to evaluate the effects of the HVAC modifications.

"The impact of energy efficiency improvements is often difficult to demonstrate at the individual system level because buildings typically get billed for energy use at the building level. Partnering with Xylem and Columbia allowed us to gain a granular understanding of exactly how much energy we would save by implementing a complex HVAC enhancement," said Luke Falk, Assistant Vice President at Related and adjunct professor at Columbia University.

The key finding that right-sized pumps paired with variable frequency drives powering the chilled water portion of a hydraulically balanced system can deliver a dramatic **95 percent reduction in pumping energy** far exceeded the team's expectations.

As noted by the Columbia research team: "The pumping electricity reduction with VFDs was far more significant than the effects of (reduced pump size and pressure-independent control valves): Annual replacement ChW distribution pump electricity was 92 percent lower with VFDs than without. When comparing the combined effects of the replacement pumps and the VFDs, the ChW distribution pumping electricity reduction was 95 percent."[2]

Coupled with the findings in an ASHRAE Journal article that concluded energy improvements in the HVAC system could substantially influence 43 percent of a building's total energy, this has a dramatic impact on the overall building energy footprint. **Figure 1**[3].

Energy improvements can substantially influence 43% of the energy footprint of a typical commercial office building.

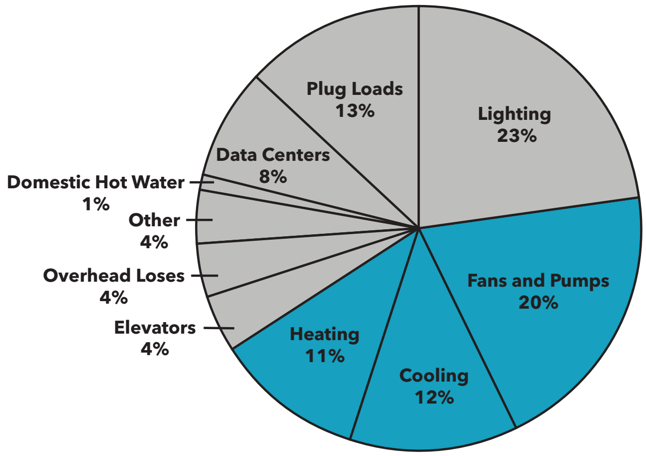

Figure 1
Typical commercial office building energy use[3]

Using data collected during the initial energy assessment, Columbia University researchers and Bell & Gossett engineers jointly reviewed the information. Researchers then calculated potential energy savings and tracked key system parameters following the renovation of the chilled and hot water systems, developing a mathematical model from the data. This prescriptive pathway to assess performance offers relevant technical data that heretofore has been extrapolated solely from laboratory test results or obtained through time-consuming proprietary energy assessments.

The test subject

Astor Place was developed by Related Companies and completed in 2005. It includes 39 residential units with commercial space on the building's first and second floors. The HVAC system uses hydronic space heating through boilers and cooling with central absorption chillers. Fan-coil units provide HVAC to residential floors; HVAC in the common and commercial spaces employs air-handling units. Only the central plant equipment and air handling equipment in the commercial and common spaces were included in the retrofit and subsequent evaluation. The approach to the ChW and hot water (HW) systems was nearly identical, though monitoring was more comprehensive on the ChW systems, the details of which are outlined here.

On the cooling side, the original 30-horsepower condenser water pumps were replaced with Bell & Gossett e-1510 20-hp pumps. The lower horsepower but more technologically advanced B&G pumps immediately delivered savings in electricity use – from 25.3 kW to 18.0 kW.

Other modifications included new piping to create primary/secondary chilled water loops out of the original primary only system, and the addition of B&G Series 80 7.5-hp primary pumps. Constant primary chilled water flow optimizes chiller performance. Decoupling the loops in the original one-loop system allowed for the installation of variable flow technologies on the secondary loop. B&G e-1510 15-hp pumps replaced the original 20-hp distribution pumps and were outfitted with variable frequency drives **Figures 2-3**[2].

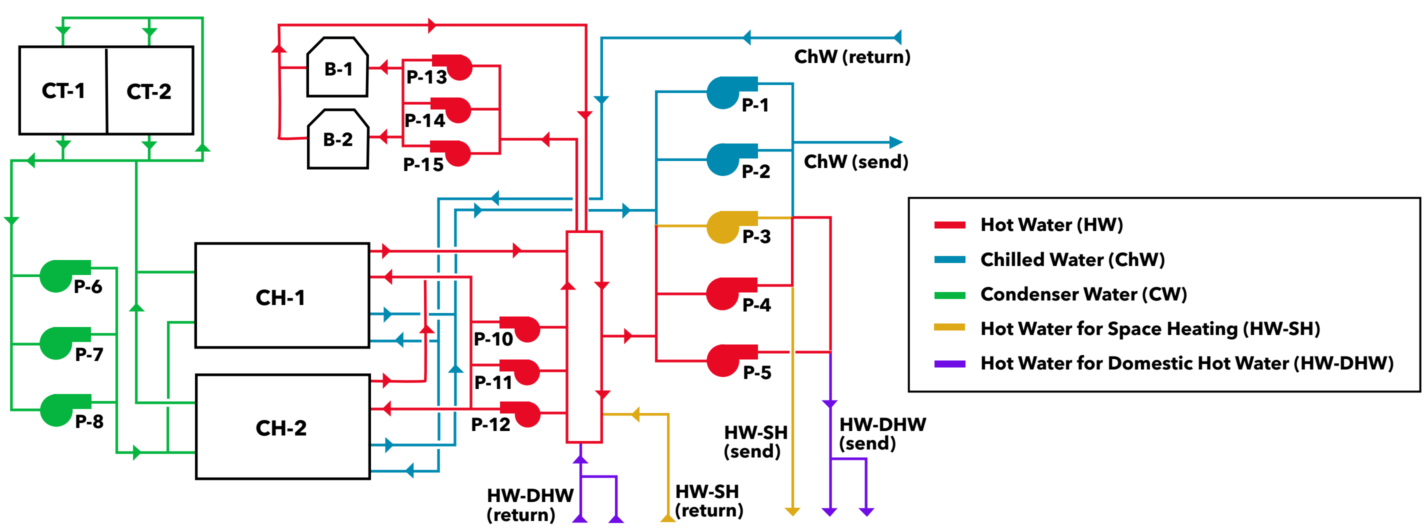

Figure 2
Original system schematic[2]

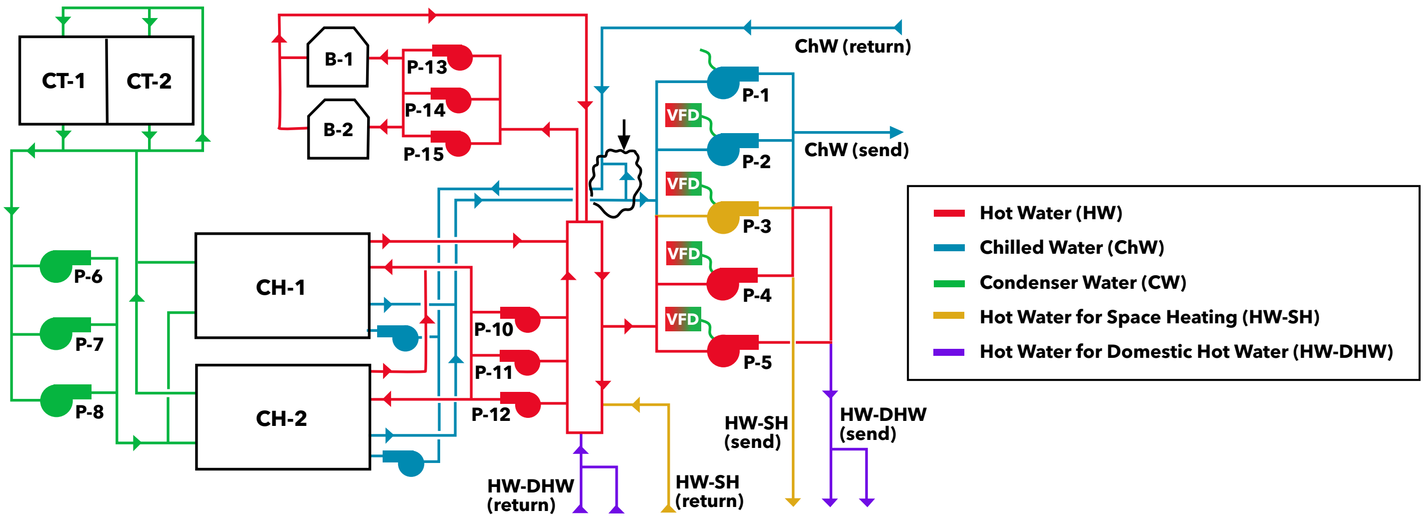

Figure 3
Post-retrofit system schematic[2]

"The head losses were lower than expected, so we were able to use smaller replacement pumps," said Florin Rosca, Director, Advanced Technology and Innovation, Xylem. "This created more energy savings potential with the VFDs than on the larger pumps. Savings from dynamic adjustment using VFDs offset any additional electricity required to operate the new primary pumps."

In providing their expertise, along with the pumps, drives and monitoring equipment for the project, Xylem engineers obtained specific real-time data on pump and system performance.

"Our engineers simulate real-world conditions in laboratory testing, but they don't often get the chance to follow the pumps into the field to track performance data," Rosca said. "Our intent was to improve the energy efficiency of the system without modifying the heating and cooling loads. In the lab we can test the efficiency of a pump, but in the real world there are often unexpected variables and more complex behavior within the system that affect efficiency," Rosca said.

Other partners in the project included Bell & Gossett representative Wallace Eannace Associates Inc., Steven Winter Associates, Fresh Meadow Mechanical, Advanced Control Solutions, Blake Electric and the Astor Place Condominium Association, as well as Columbia University's Michael Waite, a postdoctoral research scientist in Professor Vijay Modi's Sustainable Engineering Lab. Waite predicated a research thesis on a new mathematical model to assess a building's energy profile that was derived from the research data.

"There is a clear research gap for the evaluation of hydronic systems for large buildings. Their complex systems demand a different mathematical model and approach to predict energy use," Waite said. "You also need to get into the building to see how it's responded to the energy conservation measures you have made."

Energy-savings opportunity

Prior to the retrofit, nearly 30 percent of the building's common system utility costs were for pumping electricity, due primarily to the pumps being oversized for the demands of the system and the constant speed operation at partial loads. Oversized pumps were found to cause unnecessarily high pressure differentials and flow rates in the system.

Oversizing pumps is a common industry practice and there are a number of reasons why it is done, such as adding safety margins beyond those factored into the design by pump manufacturers and accounting for marginal over performance at system peak loads. However, this common practice comes at a cost – namely increases in the system's operation, maintenance and capital costs over the system's entire life cycle.

When considering both heating and cooling, the retrofit resulted in a computed annual pumping electricity usage of 316 MWh, a 41-percent improvement in pumping energy requirements and an estimated 12-percent reduction in the building's central operations' energy bills.

Commercial buildings account for 36 percent of all U.S. electricity consumption and cost more than $190 billion in energy every year, according to the U.S. Department of Energy. With more than 80 percent of the existing commercial and institutional buildings in the United States expected to be operating beyond 2030, as reported by the Colorado-based Rocky Mountain Institute, demand for HVAC system retrofits will be great.

"The existing built environment presents a huge amount of opportunity for saving energy, creating better value for building owners and promoting sustainability," Falk said.

In addition, the populous states of New York and California have in place some of the country's most stringent environmental policies – much stricter than existing federal rules – dictating that efficiency will continue to be a major consideration in selecting equipment for retrofit projects, regardless of potential federal policy changes.

The VFD story

Centrifugal pumps installed in HVAC systems typically operate in variable load applications that see a fluctuation of flow requirements based on the heating or cooling load of a building at any given time. The original pumps specified for Astor Place were running at constant speed along with being oversized for the true operational demands of the building.

"VFDs were the perfect solution to address the pump oversizing," Rosca said. Even at peak cooling load, electricity reduction was more than 50 percent compared to constant-speed pumps, according to the test data. "VFDs do bring the most benefit in terms of energy consumption," Rosca said. "The pumps consumed just enough energy to provide proper service for that part of the cooling loop."

In addition to the VFD testing, the research team set up four retrofit combinations to collect additional data and assess the energy savings contribution of the various retrofit measures installed at the same time. The following scenarios were analyzed:

A: VFD and pressure independent control valves (PICVs) in operation (final post-retrofit condition)

B: VFD in operation; original air handling unit (AHU) valves

C: VFD bypassed; PICVs in operation

D: VFD bypassed; original AHU valves (replacement pumps and primary-secondary loop modification only)

Sensors were installed at the end of each branch to provide vital performance data. All data was logged at one-minute intervals and accessed through a newly installed building management system (BMS). The combination of VFDs and PICVs provided the most savings in terms of electricity consumption, detailed in **Figures 4-6**[2,1].

"A very robust monitoring effort was essential to developing these fundamental understandings and the data needed to form analyses and to develop energy conservation measures," Waite said.

"This study further illustrates that replacing constant speed pumps with more appropriately sized equipment

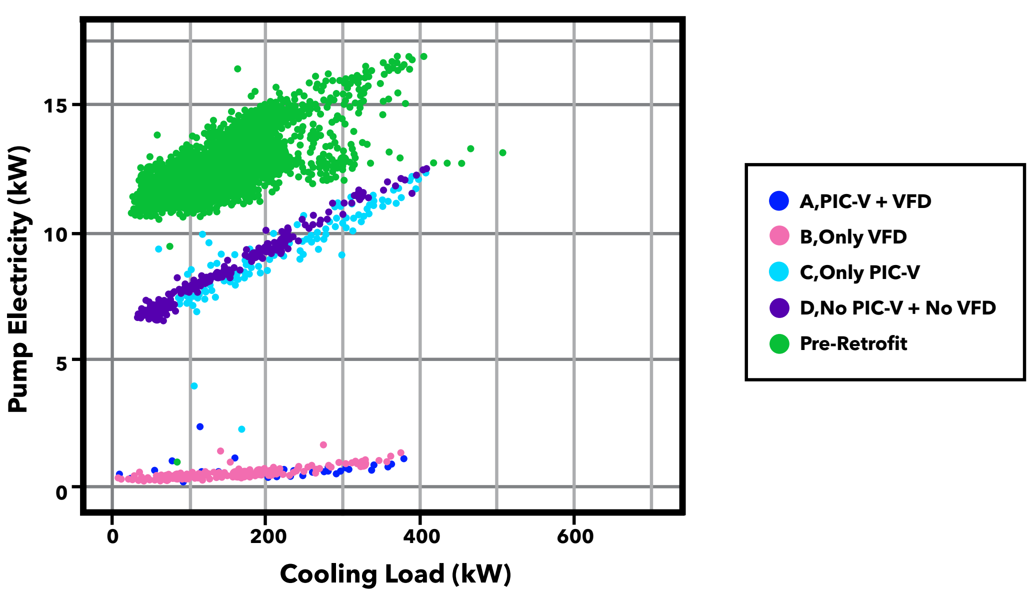

Figure 4
Pump electricity versus cooling load (hourly resolution)[2]

can significantly reduce their energy usage. Replacing the constant speed, constant flow primary HW and condenser water (CW) pumps provided estimated annual electricity savings of 20 percent in primary HW pumping and 29 percent in CW pumping," Waite reported in his thesis.

Doing the math

With all retrofits considered, the total annual cooling pumping energy reduction was computed to be 36.1 percent compared to the original system **Figure 6**[1].

The data analysis of the pre- and post-retrofit conditions formed the basis for the mathematical model to assess energy consumption, calculating the following:

- Pump power at thermal loads within monitoring range
- Pump power at loads beyond monitoring range
- System hydraulic behavior
- Pump power

"The mathematical model can provide a fast and accurate energy assessment of a hydronic system," Rosca said. "From there, we can install sensors at various points and recommend specific system improvements that can immediately reduce energy consumption and costs."

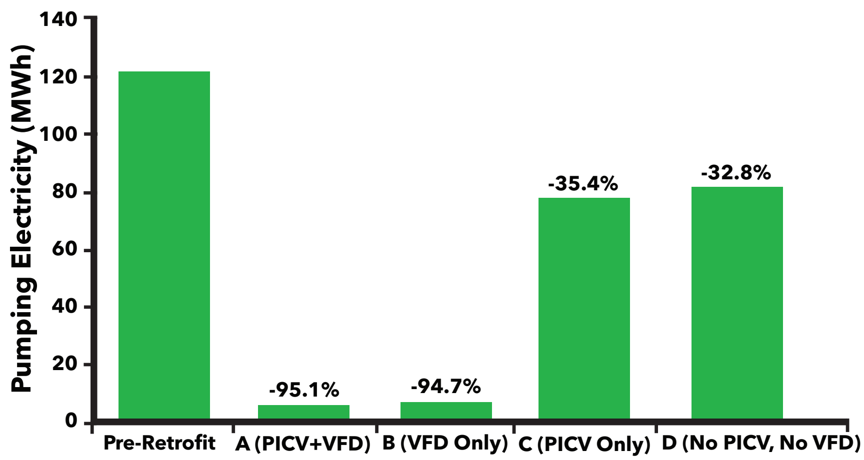

Figure 5
Chilled water distribution annual pumping electricity[2]

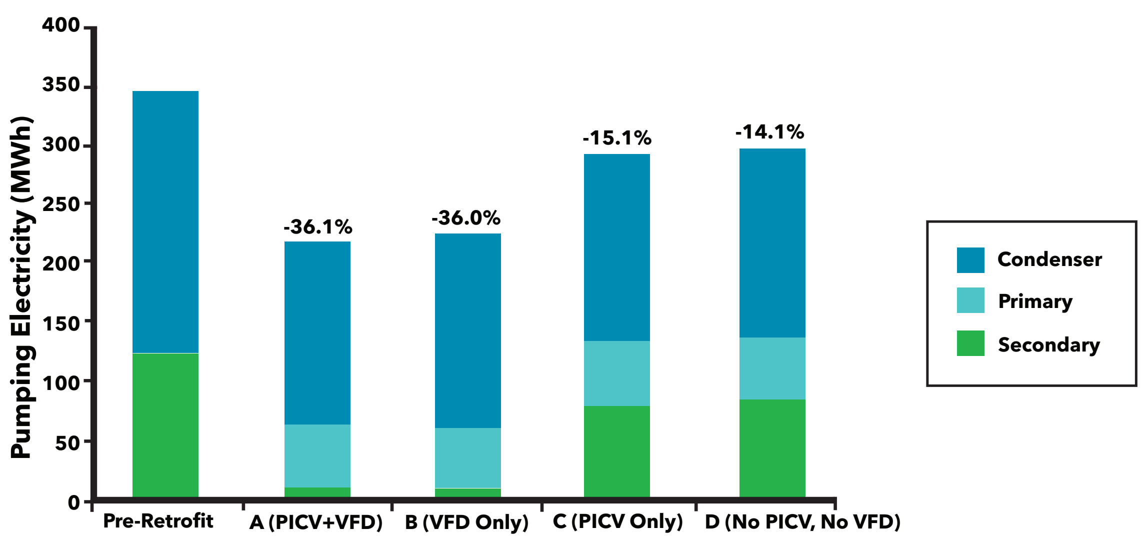

Figure 6
Total annual cooling system pumping energy[1]

Monitoring system behavior at Astor Place yielded three primary benefits: determine if equipment was operating as designed; assess the amount of energy being used and the dynamic adjustments to the load's demands; and gain a broader understanding of system behavior, the last of which is most intriguing for Waite. "This will allow us to develop theories on how systems behave as a whole rather than a collection of individual parts," he said.

For Falk and Related Management Company, the granular focus of the project was insightful. "One of the interesting questions that I've grappled with over the years is how to establish a clear chain of cause and effect when dealing with energy efficiency," Falk said. "Having an opportunity to do that while driving value to our condo owners through energy savings made this a great project."

Future implications

As owners seek to improve efficiency of building systems, HVAC upgrades are often last on the list due to high perceived upfront costs. The results from the Astor Place Energy Improvement Project can help inform decisions about new equipment and its energy-savings potential. "It's not very cost-effective to replace a large pump as a stand-alone efficiency measure," Waite said. "But if your BMS tells you that over a decade a 25-hp pump never operated over 15 hp, you can replace it with properly sized equipment that's both cost effective and energy efficient."

"In response to the demand for sustainable buildings and systems, our focus at Xylem is how to make these systems operate as efficiently as possible," Rosca said. "This research is a step forward in giving facility owners the tools to monitor actual system operation and make smart, responsible decisions. A few simple changes can have a significant impact."

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[1] (Waite M.B. Analyses of energy infrastructure serving a dense urban area: opportunities and challenges for wind power building systems and distributed generation (Doctoral dissertation). Columbia University. 2016)

[2] (Waite M, Deshmukh A and Modi V. Experimental and analytical investigation of hydronic system retrofits in an urban high-rise mixed use building. Energy and Buildings 2017;136:173-188.)

[3] (Copeland C. Improving Energy Performance Of NYC's Existing Office Buildings. ASHRAE Journal 2012.)