TECHNICAL FEATURE

Improving Energy Performance Of NYC's Existing Office Buildings

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New York City's compressed urban footprint and extensive mass transit system make it more sustainable than most American cities. Its greenhouse gas emission level, at 6.5 metric tons per person, is lower than that of 16 of the largest U.S. cities and well below the national average of 19.0.

The average New Yorker consumes less than half the electricity of a Dallas resident and approximately 33% that of a resident in Washington, D.C.[1] Recent legislation, stricter energy codes, and incentive and cost-sharing programs have pushed sustainability goals to the forefront. As nearly 75% of the city's carbon emissions result from building energy use,[1] owners of the large commercial properties dominating the Manhattan landscape are driven to serve as models for efficiency upgrades.

Working with the New York State Energy Research and Development Authority (NYSERDA), our firm has had the opportunity to audit more than 32 million ft^2 (297 290 m^2) of this existing, mostly Class A, commercial building stock. This work includes one of the largest NYSERDA contracts of this kind.

This article is an introductory overview of the most effective technical strategies for improving HVAC energy performance in this important building type. Although real estate decisions can influence upgrade strategies in any locality, most of these techniques are transferable to other major cities.

Characteristics of HVAC Systems

Many of the city's skyscrapers, especially in Midtown Manhattan, were built in the middle of the 20th century between the advent of the modern HVAC system and the acute awareness of energy issues resulting from the 1973 OPEC oil crisis. The invention of HVAC allowed architects to build these structures primarily using glass and steel, without concern for solar or thermal fluxes, or ventilation through operable windows; interior spaces could now be climate controlled. Energy was also relatively inexpensive, further reducing the need for designers to incorporate passive strategies to minimize heating and cooling loads. The predominant style of the time is known as the International Style, epitomized in New York City by the Lever House, the city's oldest major "curtain wall" building, completed in the early 1950s.

HVAC systems in many of these legacy office buildings generally consist of:

• High-pressure (and high horsepower) perimeter air-handling systems sup-

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Building	Year Built	ft^2 (Millions)	ENERGY STAR Score	Annual Electric (MMBtu)	Annual Steam (MMBtu)	Natural Gas (MMBtu)	Fuel Oil (MMBtu)	Total (MMBtu)	$kBtu/ft^2$	Total Annual Energy Cost in Millions $	$\$/ft^2$
A	1906	1.14	81	61,000	22,000	18,899	0	102,000	90	$4.4	$3.80
B	1923	1.14	83	56,000	42,000	0	0	99,000	87	$4.0	$3.54
C	1925	0.97	75	53,000	0	0	9,167	62,000	64	$2.8	$2.80
D	1928	0.75	79	41,000	0	239	6,985	48,000	65	$2.4	$3.10
E	1949	0.36	79	25,000	4,000	0	0	29,000	82	$1.6	$4.36
F	1951	0.58	85	31,000	23,000	0	0	54,000	94	$2.3	$3.98
G	1956	0.48	78	34,000	24,000	0	0	58,000	123	$0.9	$1.88
H	1960	0.54	45	39,000	36,000	0	0	74,000	139	$2.7	$5.04
I	1961	1.73	61	145,000	86,000	3,521	0	235,000	136	$8.1	$4.65
J	1961	1.23	24	104,000	95,000	0	0	199,000	162	$8.0	$6.51
K	1963	2.99	41	229,000	216,000	8,415	0	453,000	151	$16.0	$5.35
L	1963	2.11	71	142,000	114,000	0	0	255,000	121	$10.4	$4.92
M	1963	1.85	61	110,000	149,000	0	0	259,000	140	$10.2	$5.47
N	1963	0.82	80	44,000	37,000	0	0	82,000	101	$4.0	$4.91
O	1964	0.89	44	59,000	51,000	431	0	110,000	124	$4.2	$4.69
P	1965	1.49	79	94,000	38,000	0	0	132,000	89	$7.2	$4.83
Q	1966	0.89	37	52,000	26,000	0	0	78,000	88	$2.9	$3.20
R	1966	0.38	74	18,000	22,000	0	0	40,000	108	$2.4	$6.32
S	1967	0.34	76	21,000	15,000	0	0	36,000	109	$1.9	$5.47
T	1968	0.80	80	46,000	36,000	0	0	82,000	104	$3.4	$4.22
U	1968	0.57	54	34,000	40,000	0	0	74,000	132	$3.2	$5.57
V	1969	0.58	78	27,000	32,000	0	0	59,000	102	$2.5	$4.30
W	1970	2.28	80	121,000	144,000	110,904	0	376,000	165	$13.3	$5.84
X	1970	0.84	59	66,000	52,000	14	0	118,000	142	$4.8	$5.69
Y	1972	0.79	67	47,000	42,000	0	0	88,000	112	$4.2	$5.29
Z	1988	2.10	76	101,000	31,000	0	0	132,000	63	$4.6	$2.18
AA	1988	0.60	76	314,000	0	0	0	314,000	523	$9.2	$15.33
BB	1990	1.44	82	105,000	0	1,502	1,047	108,000	75	$4.5	$3.08
CC	2003	1.47	55	189,000	46,000	3,250	0	238,250	163	$9.6	$6.52
Total	–	32.15	–	2,408,000	1,377,000	143,925	17,199	3,994,250	3,652	$154.5	$142.84
Average	1962	1.20	68	83,000	49,000	16,353	5,733	137,733	126	$5.4	$4.93

Table 1: Energy use in 32 million ft^2 (2.9 million m^2) of New York City commercial buildings.

plying induction unit air systems (serving areas approximately 15 ft [5 m] from the exterior);

- Central air-handling systems, which serve the interior of multiple floors;
- Secondary water systems (perimeter zones);
- Constant flow chilled water pump systems and two-way chilled water valves on all heat transfer equipment;
- High-pressure steam turbine or absorption driven chillers (or, to a lesser extent, electric chillers) with heat rejection by cooling towers;
- Steam heating via air-handling steam coils or the secondary water induction system; and
- Building management systems (BMS), the majority still connected to pneumatically operated valves and dampers.

Table 1 reflects energy use information gathered during energy audits of 29 buildings, 84% of which were either built, or had HVAC systems retrofitted, between 1950 and 1970. Despite having similar vintages and systems, there is wide variety in the energy use of the audited buildings. This range is partly explained by the occupant and equipment density, and partly by the efficiency of the systems.

Central Steam Distribution System

One of the features that distinguishes HVAC systems in many Manhattan office buildings is the use of utility steam for heating and cooling. The Con Edison steam system, operating via 105 miles of underground mains and service piping, is the largest commercial district steam system in the United States.[2] Almost 70% of the buildings in *Table 1* use steam chillers.

Utility steam use aids in meeting NYC's clean air goals through more rigorous control and monitoring of CO_2, NO_X, and SO_2 than do equivalent capacity central or local boilers burning oil or gas.[3] Since 150 psi (1034 kPa) steam is piped directly from the mains to each building, the customer benefits from a gain in rentable space (no boilers), aesthetics (no flues), and some lower capital costs.

Chiller Option	Net Part Load Value COP (Source)	Summer Operating Cost (lb/ton·h)*	Full Cooling Season Operating Cost (1,200 Hours)		
			500 Tons	1,000 Tons	2,000 Tons
New Steam Turbine Chiller	1.34	0.096	N/A	N/A	$251,720
Electric Chiller	3.19	0.123	$74,376	$148,752	$297,504
New Two Stage Absorption Chiller	1.04	0.124	$81,200	$162,400	$324,800
Upgraded Existing Steam Turbine Chiller	0.69	0.186	N/A	$243,600	$487,200
Standard Existing Steam Turbine Chiller	0.59	0.217	N/A	$284,200	$568,400
Oversized Existing Steam Turbine Chiller (Hot Gas Bypass)	0.46	0.279	N/A	$365,400	$730,800

*Based on average use. Prices do not reflect CW pumping costs, which will be lower for electric chillers.

Table 2: Chiller performance comparisons.

The utility has installed sophisticated steam meters for larger steam users, which provide hourly interval data, and thus a window into the building's steam use, which is especially advantageous to the energy auditing process. Furthermore, approximately 57% of the steam comes from cogenerated (combined heat and power [CHP]) electricity plants,[3] thereby improving the thermal performance over conventional non-CHP electric plant electricity. As the ENERGY STAR rating process demonstrates and as others have observed,[4] chiller efficiency should be discussed in the context of source rather than site efficiency. That, to some extent, changes the overall view of efficiency, especially with regard to the New York City steam grid, since the majority of the steam is cogenerated.

Even considering source efficiency, steam chillers currently have a lower coefficient of performance (COP) than

Air Systems	Typical Payback (Years)	Observations
Reduce Excess Damper Air Leakage	1 to 5	Replace existing dampers or replace motors, linkages
Connect Return Air to 100% Outside Air Perimeter Systems (Within MERs)	3 to 6	Speculative office building designs often used 100% OA to reduce cost of return ducts
Modulate Airflow in Intermediate Seasons Semi-Automatically by Installing VSDs	0 to 1	Sometimes possible to reduce airflows in mild weather
Demand Controlled Ventilation (DCV)	3 to 6	CO_2 sensing on a floor-by-floor basis; further checking by staff
Retrofit Duct Systems With VAV Distribution	5 to 15	Vintage constant volume systems redesigned to VAV (as spaces are leased)
Cooling Plant	**Typical Payback (Years)**	**Observations**
Optimize existing plant operation	1 to 5	Meter All Plant Equipment to Optimize Operation
		Modulate Condenser Water Temperature Efficiently
		Minimize Use of Hot Gas Bypass
Install VSDs on Chilled, Condenser and Secondary Water Pumps	3 to 5	Vary and Reduce Chilled and Condenser Water Flow
Modify Controls for Variable Primary Chilled Water Flow	3 to 5	Close Off Bypass Chilled Water Valve
Modify Cooling Tower to Optimize Performance	1 to 5	Add VSDs and Perimeter Weirs or Extended Cups To Improve Low Flow
Replace or Add Smaller Chiller for Better Part-Load Performance	5 to 10	Minimize Inefficient Chiller Operation
Heating	**Typical Payback (Years)**	**Observations**
Deactivate Steam Risers in Summer	<1	Some Buildings With Plants on Lower Floors Can Turn Off Risers in Summer
Convert from Oil to Gas	3 to 6	Oil Significantly More Expensive Than Gas With Differential Expected to Increase Over the Years
Implement Steam Demand for Utility Steam Operation	1 to 3	Use Secondary Water System for Thermal Storage
Install Wireless (or Wired) Thermostatic Sensors	1 to 3	Mainly Applies to Older Steam Heated Buildings
Controls	**Typical Payback (Years)**	**Observations**
Reduce Equipment Operational Time	< 1	Some System Operation Can Be Reduced
Change Air Economizer From Enthalpy to Dry Bulb[9]	<1	Wet-Bulb Sensors Go Out of Calibration
Use Dashboard for Real-Time Energy Use Per Ton	3 to 5	In Conjunction With Meter Installation, Improves Performance
Modify Chiller Plant Algorithms	1 to 5	Optimize Chiller Plant, Pumps and Condenser Water Temperature

Table 3: Typical energy conservation measures (ECMs).

new electric chillers, but because summer electricity is so costly, steam chillers can be competitive in operational cost (*Table 2*, Page 30).

Despite its assets, New York City's underground steam system faces challenges, since much of the infrastructure is old, costly to repair, and, like all technologies, not without its risks. Winter utility steam is also significantly more expensive than summer steam, which, although less of a concern to large commercial buildings, can be a drawback in other types of properties. Moreover, steam chillers tend to have significantly higher installation costs, especially under 2,000 tons (7035 kW). However, the use of steam-operated chillers in lieu of electric chillers helps to offset the electrical demand on NYC's constrained power grid. (Other options to reduce electrical demand during peak load include ice storage, currently used in several NYC buildings, voluntary load reduction, and operation of on-site electrical generators.) Many of the following examples of steam-driven chiller improvements apply to electrically driven units as well.

Opportunities to Optimize Energy Use

Table 3 summarizes typical energy conservation measures effective for HVAC systems in high-rise commercial buildings. Payback years are estimated averages from audited building stock. Typically, building managers and owners can only regulate the energy used by the base building. Tenant use is generally not under management control.

In many cases, summer comfort cooling uses a significant share of the energy consumed. One of our key findings is that many NYC buildings are overventilated, resulting in cooling of warm excess outside air.

Test Building	Standard 62.1-2007 Outside Air Requirement (cfm)	Measured Outside Air (cfm)	Percent Outside Air vs. ASHRAE Required*	Excess Air (cfm)
1	145,040	694,448	479%	549,408
2	94,120	210,978	224%	116,858
3	234,040	282,026	119%	47,986
4	49,452	72,986	148%	23,534
5	97,800	177,017	181%	79,217
6	124,599	163,266	131%	38,667

* Dampers open to minimum position.

Table 4: Excess outside air is common in these large, commercial vintage buildings.

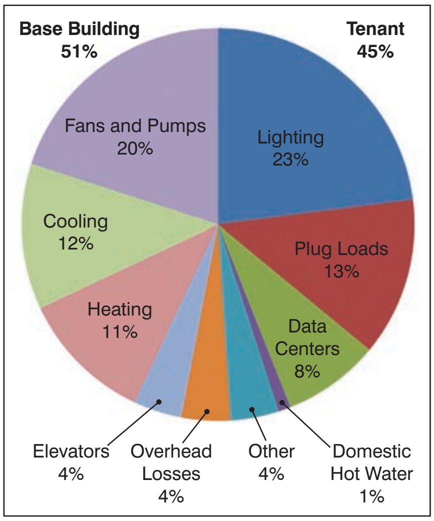

Figure 1: Typical commercial office building end use.

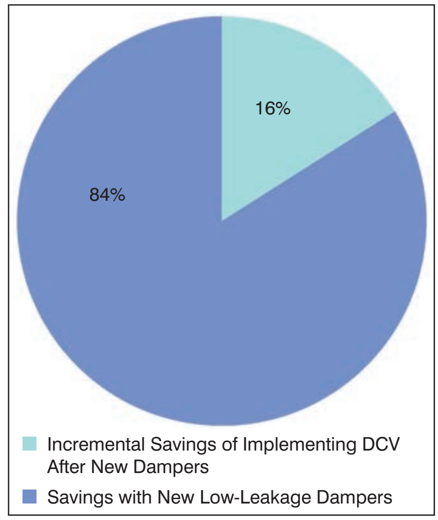

Figure 2: Test Building 1 proportional outside air savings; low-leakage dampers vs. demand controlled ventilation (DCV).

Air-Handling Systems

Excess Outside Air

During an early demand controlled ventilation (DCV) multiyear study in one major office building (see Test Building 1 in *Table 4*), we discovered that the CO_2 level seldom varied much above the outdoor level of roughly 450 ppm. When the outside air quantities were eventually field tested, it was apparent that leaking dampers allowed significant amounts of excess outside air to be introduced into the building. Moreover, upon further testing, even with ostensibly closed dampers the leakage rate exceeded 40%, which results in more outside air than suggested by the ASHRAE Standard 62.1-2007; sometimes, several times more. Testing in subsequent buildings confirmed that a large majority of older commercial office buildings are overventilated, resulting in wasted energy, some for heating, but mostly for cooling (*Figure 1*). Understandably, many of these dampers date from the original construction of the building. *Table 4* shows the results of air testing of several properties.

If a majority of Manhattan office buildings have excess outside air quantities similar to *Table 4*, installing new dampers would significantly reduce CO_2 emissions, as well as overall energy costs.

Clearly, unless new tight-closing dampers are installed in these overventilated buildings, DCV will not be fully effective. Using Test Building 1 as an example, *Figure 2* shows the extent to which installing low-leakage dampers can be crucial to effective use of DCV.

Unfortunately, some dampers constructed by local shops have not been engineered adequately to minimize excessive outside air. The linkages and damper motors do not properly close the large damper assemblies (often 10 ft [3 m] high and as much as 20 ft [6 m] wide) and the damper blades become misaligned. Outside air dampers must be installed on a modular basis, with appropriate damper motors and linkages, to provide adequate torque to close the dampers leaktight. Only when good dampers are installed can DCV become effective. In many of these vintage buildings, even with relatively tight-closed dampers on the interior air systems, we rarely see interior air CO_2 levels exceed 600 or 800 ppm, well below the 1,100 ppm (400 outside + 700) recommended by ASHRAE Standard 62.1-2007 for indoor air quality. This is in part due to the perimeter induction air systems, which are generally fixed at 50% to 60% outside air (in some cases, 100%), which contribute significant amounts of fresh air to the system.

Variable Speed Drives

Installing variable speed drives (VSDs) on the fan motors and upgrading to premium efficiency motors permits staff to reduce fan speed during the shoulder seasons by as much as 15% without adversely affecting occupant comfort. During periods of peak cooling or heating demand, the fan may require 100% airflow. Encouraging owners to implement variable air volume (VAV) interior systems in these older buildings will save the most energy. Many tenants want the additional control of VAV, even on interior systems. This factors into leasing decisions and may sway owners, especially of these older Class A buildings, to implement VAV to compete with newer properties already using VAV.

Central Cooling Plants

Since the largest consumer of energy in a typical commercial building in this climate is cooling, significant time and consideration must be put into chiller plant analysis. The 40-to-50-year-old centrifugal chillers often use hot gas bypass, or even thermal loading, to avoid surging and potential compressor damage at cooling loads less than 50% or 60% of capacity. Hot gas bypass greatly reduces operating efficiency because the bypassed vapor does no useful cooling. In some cases, this can result in double the steam energy consumed for a given load.

Hourly utility steam interval data in one high-rise commercial building revealed an extreme case of part-load inefficiency due to a substantial reduction in building cooling load from a separate chiller plant installation by a large tenant. This property used more steam for cooling at a relatively mild outdoor temperature of 55°F (13°C) (*Figure 3*), than both at peak cooling load and heating at a cold 6°F (–14°C) outdoor temperature (*Figure 4*). The high consumption at 55°F (13°C) was due to the use of hot gas bypass and steam heat through the air handlers, providing a false load.

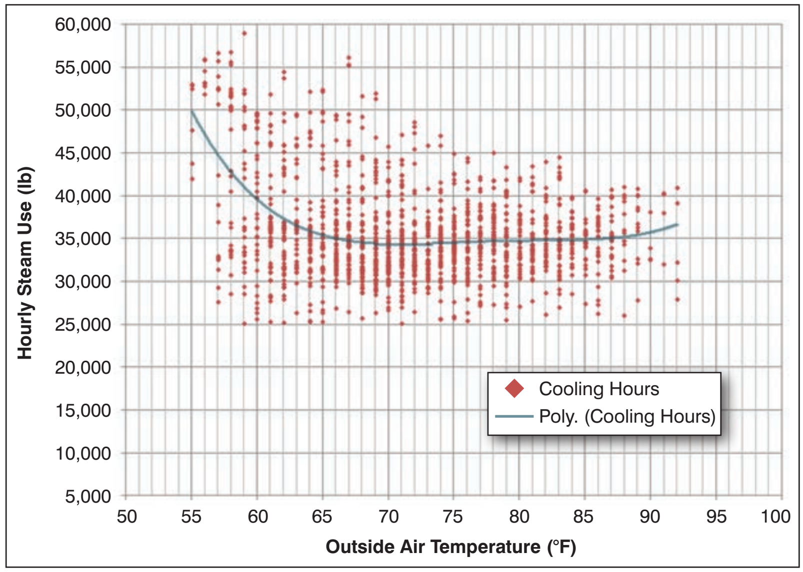

Figure 3: Total cooling steam use vs. outside air temperature. (At 55°F [13°C] this building peaked at 50,000 lb/h [14 200 kW] of steam for cooling.)

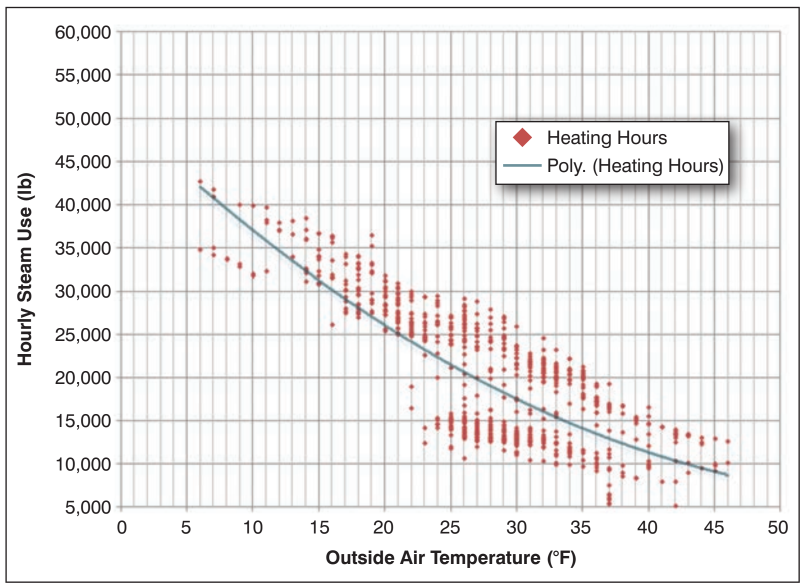

Figure 4: Total heating steam use vs. outside air temperature. (At 6°F [–14°C] the same building peaked at only 47,000 lb/h [13 362 kW] of steam during a winter heating month.)

An improvement is to use tighter controls on the centrifugal chiller, allowing it to operate closer to the surge point while optimizing the use of speed control vs. guide vane operation. Since the existing heat transfer surfaces in this property have new tubes, another cost-effective option is to replace the existing dual-stage compressor with a single-stage unit. This option offers significantly reduced operational cost without requiring additional space or incurring the capital cost of a complete plant replacement. A single-stage compressor allows for more efficient part-load operation by delaying the onset of hot gas bypass. (Higher backpressure associated with multistage compressors requires higher speeds to maintain proper operation and prevent surge.)

The heat transfer shells on these older 1950s/60s industrial-grade chillers are extremely robust and, in many cases, could last another 40 or 50 years with tube replacements. Obviously, another option is to replace this plant with new, smaller steam or electric chiller(s). However, in these high-rise buildings this decision is not necessarily that clear; it is affected by costly rigging of these chillers into tall buildings, availability of electric service if steam-to-electric conversion is considered, and ultimately, economic payback.

Managing Condenser Water Temperature with Cooling Load

Steam and electrically driven water-cooled centrifugal chillers using multi-cell cooling towers, as typically found in these urban office buildings, can be upgraded to perform significantly better by optimizing the condenser water temperature, and in some cases, flow. *Table 5* shows how a newer single-stage centrifugal chiller (in this case steam-turbine driven) has an improved COP as the cooling load and condenser water return temperature decline. The best strategy is to measure the chiller plant cooling output vs. energy input consistent with ASHRAE Guideline 22-2008[5] and implement a control strategy that modulates the input energy from the cooling tower fans vs. the chiller energy. This control strategy is possible with a traditional proportional integral derivative (PID) algorithm.

Since many older buildings do not have meters on their plant equipment, nor in many cases is it practical to install them, a reasonable approximation of cooling tower performance is to use a 7°F (3.9°C) ΔT approach. This is clearly not possible if the cooling load is constant, as in a process application, but for comfort cooling, the cooling load typically falls off proportionally with declining wet bulb. Following a 7°F (3.9°C) ΔT approach can, in many cases, significantly reduce cooling tower fan energy. *Figure 5* is an extrapolation of the performance curves for a 3,000 ton (10 551 kW) cooling tower.[6]

Cooling Load	Capacity (tons)	Percentage Steam Flow	COP	Steam Flow (lb/h)	Water Temperature (°F)			
					CHWR (Entering)	CHWS (Leaving)	CWS (Entering)	CWR (Leaving)
15%	406	11%	1.54	2,744	45.5	44	65	66.4
20%	540	14%	1.62	3,473	46	44	65	66.9
30%	810	19%	1.79	4,722	47	44	65	68.7
40%	1,080	24%	1.89	5,946	48	44	65	68.7
50%	1,350	29%	1.99	7,085	49	44	65	69.7
60%	1,620	38%	1.80	9,461	50	44	69	74.7
70%	1,890	50%	1.62	12,305	51	44	73	79.7
80%	2,160	63%	1.48	15,553	52	44	77	84.8
90%	2,430	79%	1.34	19,498	53	44	81	89.9
100%	2,700	100%	1.18	24,647	54	44	85	95

Table 5: Steam chiller performance data: declining load and condenser water temperature.

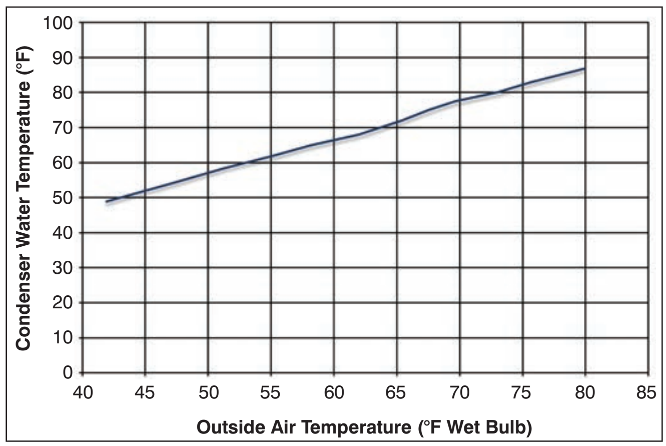

Figure 5: Typical cooling tower approach as load and outdoor wet-bulb decline.

Cooling Tower Improvements

Adding VSDs and variable flow strategies to cooling tower operation (as opposed to cycling fans on and off or shutting off flow to cells) improves performance significantly. This is because when multiple cells are active, the entire heat transfer surface is used. Additionally, fans operating at part load through VSDs use less energy than fewer fans at full load. Adding extended cups (or weirs) to cross-flow style cooling tower distribution pans allows for flow reductions of 50% or more and ensures a uniform flow of water at the "perimeter" of the cooling tower during lower condenser water flows (*Photo 1*). This maximizes contact between water and air and reduces non-contact dry areas within the fill.

Photo 1: Adding cup extensions to the center pan orifices maximizes contact during low flow at the tower perimeter.

Variable Chilled and Condenser Water Flow

Adding VSDs to pumps is an effective measure that reduces plant energy use, allowing the pump speed to vary in response to the building load. New premium efficiency motors also improve energy use and are compatible with the VSDs. Because of very conservative pump friction calculations, most of the balancing valves on these older chilled and condensed water systems are partially closed to compensate for excess pump capacity. Opening these valves and using VSDs can reduce energy consumption significantly.

Also, to minimize chilled water pump energy use, older chiller controls can sometimes be retrofitted to permit variable primary pumping in cases when throttling chilled water valves close off. When the minimum flow is met, a bypass valve must allow circulation of flow through the chiller. On the other hand, reducing condenser water flow through the chiller is generally only possible with newer chillers. The combination of pump and chiller consumption energy is often lower at 2 gpm/ton than 3 gpm/ton (0.037 L/s·kW than 0.054 L/s·kW) (*Figure 6*). In some cases, varying the condenser water flow depending on cooling load may be advantageous.

Controls

Many of the preceding improvements must be matched with appropriate controls. A BMS centralizes monitoring and automated control of all building equipment and setpoints interfaced to the system. In some buildings, the installation of dashboard displays of real-time energy use has motivated the building engineering staff to tweak operation still further. We have observed that some operating staff manually change VSDs or change setpoints to lower peak demand based on the dashboard display. Once the controls are centrally located, further improvements to their function are possible. Anomalies in operation are quickly alarmed and observed. Moreover, building engineers can implement many simple no- or low-cost retrocommissioning procedures through the BMS such as: adjusting equipment start/stop schedules, modifying off hours/setback temperatures, selected tenant overtime operation, etc.

Cogeneration

Generating electricity on-site and using the waste heat for heating or cooling has been an option in some office buildings. The author has designed both microturbine and reciprocating engine installations in a number of NYC office buildings. Other types of facilities with constant thermal loads, like hospitals, can be even more cost-effective. Significant incentives from NYSERDA are offered provided that emissions and the overall annual thermal efficiency exceed a minimum annual threshold.

From the perspective of overall sustainability, generating electricity and using the waste heat for useful cooling or heating is much more efficient than central utility plant electricity. Usually, by the time the utility electricity reaches the consuming device, the thermal efficiency (typically gas in the NYC area) is only 30%.[7] Seventy percent is lost to the environment either at the power plant or in transmission. On the other hand, typical cogeneration plants using the waste heat effectively are at least 60% efficient on an annual basis. The most important criterion for selecting a cogeneration plant size is the availability of waste heat use.

Conclusions

As much as energy saving projects might be compelling, building owners have other criteria affecting their decisions, such as:

• How long they plan to own the property;

• Whether provisions in the tenant leases incentivize the owner to upgrade;[8] and

• Other, more profitable investment opportunities.

On the other hand, many corporate tenants are demanding improvements in building performance, including LEED compliance, prior to lease renewal, which is motivating property owners to invest in their assets. Also as noted, some state or municipal codes are mandating more stringent requirements.

As engineers who work in the built environment, upgrading the energy efficiency of the large stock of existing buildings is perhaps our most important challenge and legacy.

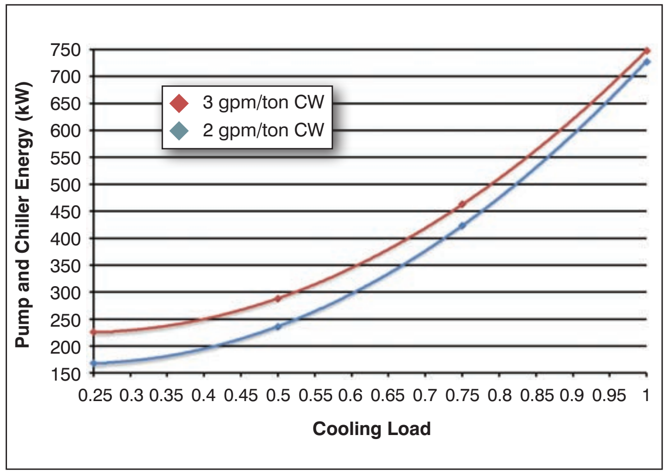

Figure 6: Pump and chiller energy use at 2 vs. 3 gpm/ton (0.037 L/s·kW vs. 0.054 L/s·kW) condenser water in a sample 1,000 ton (3517 kW) plant demonstrating reduction in total energy use with lower condenser water flow.

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8. NYC.gov. 2012. "Energy Aligned Clause." www.nyc.gov/html/gbee/html/initiatives/clause.shtml. *One of the mayor's energy conservation committees, of which this author was a part, included an initiative to remove the landlord/tenant split incentive by creating an Energy Aligned Clause benefiting both parties while reducing energy use. Property owners offset the amortized cost of a capital improvement that reduces operating expenses.*

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