

Manhattan HVAC Modernization

Engineering Analysis and System Schematic

Step 4 • 23 October 2026 • Independent hypothetical building study

1. Engineering scope

I compare three ways to provide the same assumed cooling and ventilation service to a 500,000 ft² Manhattan office building. The aim is to explain where the modeled electricity savings come from and what evidence would be needed to confirm them. This report uses the existing Base case without changing the workbook. [P1, P2]

Project assumption	Value and boundary
Building and cooling plant	500,000 ft ² ; two assumed 600-ton water-cooled chillers, totaling 1,200 tons. Existing equipment age: 20 years.
Operating profile	3,000 chiller hours/year in four load bins; 3,600 supply/return fan hours/year; 3,000 pump and tower-fan hours/year.
Scope of electricity model	Chillers, supply/return fans, water pumps and cooling tower fans. Other building electricity and gas use remain unchanged.

How the assumed system works

Water and refrigerant: pumps circulate chilled water between the chillers and air-handling unit (AHU) coils. Water absorbs building heat at the coils and returns warmer. In each chiller, refrigerant removes that heat at the evaporator. The compressor raises refrigerant pressure, and the condenser transfers heat to a separate condenser-water circuit. The expansion device completes the refrigeration cycle. The two water circuits do not mix. [R08]

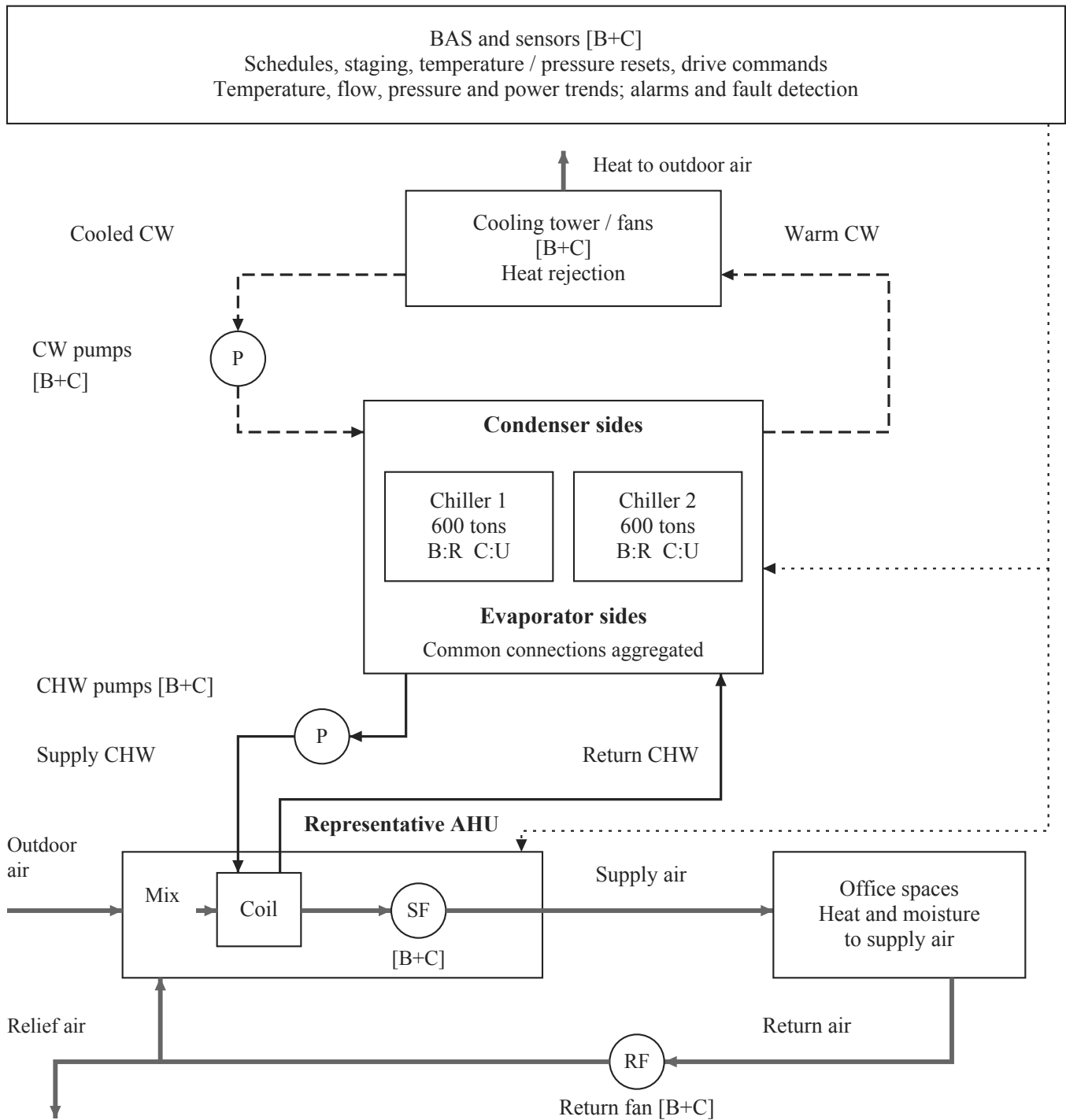
Heat rejection and air: condenser-water pumps send heat to a cooling tower, where water is cooled through contact with outdoor air, including evaporation. Tower fans assist airflow. AHU coils cool the air; supply fans move it into rooms. Return fans bring air back, with outdoor-air mixing and relief shown conceptually. Heat rejected by the chiller includes cooling load plus compressor input. [R08]

Controls: the building automation system (BAS) coordinates schedules and equipment commands. Sensors and trend data help operators identify faults and adjust operation. The proposed control functions are engineering concepts, not a completed sequence of operation. [R07]

Assumed, not surveyed: the water-cooled arrangement, common connections, representative AHU and fan layout are conceptual. Equipment models, counts of AHUs/pumps, pipe sizes, water temperatures and flow rates have not been established. [P1, P2]

2. Conceptual HVAC system schematic

Hypothetical system only. Not an actual building design or construction drawing.



Legend: thin solid arrows = chilled water (CHW); dashed arrows = condenser water (CW); thick gray arrows = airflow; dotted arrows = BAS signals. P = pump group; SF = supply fan; RF = return fan. [B+C] = affected by both upgrade options. B:R = replace; C:U = retain and rebuild.

Chiller connections represent common plant headers, not internal piping. The two water circuits stay separate. Pump symbols are groups, not quantities: the workbook uses one combined 150 kW pump allowance. Isolation/bypass valves, expansion tanks, tower makeup/blowdown, heating and detailed refrigerant piping are omitted. [P1; R08]

3. What changes under each alternative

The alternatives retain the same assumed 1,200-ton capacity and cooling load. The changes below interpret the existing CapEx line items. They do not define equipment selections or a site installation plan. [P1: CapEx!C8:I21]

Component	A - Existing	B - Full modernization	C - Partial upgrade
Chillers	Continue using both existing units.	Replace both 600-ton units; use the lower modeled kW/ton curve.	Retain and rebuild both units; use the smaller modeled efficiency improvement.
Cooling tower	Continue operation and maintenance.	Refurbish tower equipment. Lower average fan power is assumed.	Selective refurbishment; smaller assumed fan-power reduction.
Water pumps	Existing pump operation.	Broader pump and variable-speed-drive upgrades.	Selective pump/drive improvements.
AHUs and fans	Existing supply/return fans and damper operation.	Fan, drive and damper upgrades. Complete AHU replacement is not specified.	Selective fan, drive and damper improvements; retain the main AHU arrangement.
BAS and monitoring	Continue existing controls; condition unknown.	Broader BAS, sensor and automation work, monitoring and training.	Targeted BAS and sensor improvements, monitoring and training.
Distribution / enabling work	Continue existing distribution.	Electrical and piping modifications, rigging and commissioning allowances.	More limited electrical/piping and commissioning allowances.
Initial planning budget	No initial upgrade outlay; ongoing repair/capital needs remain.	\$5,000,000	\$1,669,000

Why these changes could save electricity

Older equipment may use more power because of inefficient part-load operation, fouling, wear, poor schedules or unnecessary throttling. Age alone does not establish the loss. Maintenance and performance measurements are needed to separate correctable faults from limits of the original equipment. [R08]

Variable-speed operation can reduce the energy used to move water or air when demand is lower. Savings depend on system resistance, minimum flows, ventilation requirements and drive/motor efficiency. The workbook uses assumed average electrical power fractions; it does not calculate them from speed or flow. [R03; P1]

Both upgrades include cooling-tower refurbishment, not a documented new tower installation. Neither option establishes a new heating system, new ductwork throughout the building or a guaranteed extension of service life. [P1, P2]

4. Chiller electricity: worked load-bin calculation

Capacity is a rate of cooling: 1 ton = 12,000 Btu/h, approximately 3.517 kW of thermal cooling.

Ton-hours measure cooling delivered over time. **Electrical kWh** measure electricity consumed. A 1,200-ton plant does not consume 1,200 kWh just because it runs for an hour.

$$\text{Cooling in bin } i \text{ (ton-hours)} = 1,200 \text{ tons} \times \text{load fraction } L_i \times \text{hours } h_i$$

$$\text{Chiller electricity (kWh/year)} = \sum [1,200 \times L_i \times h_i \times \text{efficiency}_i]$$

Efficiency is electrical kW per cooling ton. The dimensional check is $\text{ton} \times \text{h} \times \text{kW/ton} = \text{kWh}$. Lower kW/ton means less electricity for the same cooling service. [P1]

Plant load	Hours/year	Cooling ton-hours	A kW/ton	B kW/ton	C kW/ton
25%	750	225,000	0.950	0.500	0.840
50%	1,250	750,000	0.800	0.480	0.730
75%	750	675,000	0.750	0.520	0.700
100%	250	300,000	0.720	0.585	0.700

Bin / total	A electricity kWh/year	B electricity kWh/year	C electricity kWh/year
25%	213,750	112,500	189,000
50%	600,000	360,000	547,500
75%	506,250	351,000	472,500
100%	216,000	175,500	210,000
Total	1,536,000	999,000	1,419,000

$$\text{B at 50\% load: } 1,200 \times 0.50 \times 1,250 \times 0.48 = 360,000 \text{ kWh}$$

The bins total **3,000 operating hours** and **1,950,000 ton-hours**. Equivalent full-load hours = $1,950,000 \div 1,200 = \mathbf{1,625 \text{ hours}}$. Treating all 3,000 hours as full load would overstate cooling output.

These are plant-level load bins and assumed efficiency curves. At 25% plant load (300 tons), one 600-ton machine could run at 50% load or both at 25%. The workbook does not resolve that staging choice. The bins are not an AHRI integrated part-load value (IPLV) calculation or a certified equipment performance map. [R02; P2]

Trace: Assumptions!E10 and C33:G36 → Energy!C8:H11 and F13:H13.

5. Fans, pumps and cooling tower electricity

The workbook models each auxiliary group with rated electrical power, an average electrical power fraction and annual run hours. These inputs are aggregated allowances, not measurements of individual motors.

$$E_{\text{fans}} = \text{fan rated kW} \times \text{average power fraction} \times \text{fan hours/year}$$

$$E_{\text{pumps}} = \text{combined pump rated kW} \times \text{average power fraction} \times \text{pump hours/year}$$

$$E_{\text{tower}} = \text{tower-fan rated kW} \times \text{average power fraction} \times \text{tower-fan hours/year}$$

Group	Rated kW A / B / C	Hours/year	A fraction	B fraction	C fraction
Supply/return fans	350 / 350 / 350	3,600	0.80	0.48	0.60
Water pumps	150 / 150 / 150	3,000	0.85	0.45	0.65
Cooling tower fans	60 / 60 / 60	3,000	0.65	0.50	0.55

Worked calculation	A - Existing	B - Full	C - Partial
Fans (kWh/year)	$350 \times 0.80 \times 3,600$ = 1,008,000	$350 \times 0.48 \times 3,600$ = 604,800	$350 \times 0.60 \times 3,600$ = 756,000
Pumps (kWh/year)	$150 \times 0.85 \times 3,000$ = 382,500	$150 \times 0.45 \times 3,000$ = 202,500	$150 \times 0.65 \times 3,000$ = 292,500
Tower fans (kWh/year)	$60 \times 0.65 \times 3,000$ = 117,000	$60 \times 0.50 \times 3,000$ = 90,000	$60 \times 0.55 \times 3,000$ = 99,000

Units: kW × dimensionless fraction × h/year = kWh/year. For example, B fan average input is $350 \times 0.48 = 168$ kW while operating. The value 0.48 does not mean 48% fan speed, 48% airflow or a 48% savings rate.

Schedules: the ventilation input is $12 \times 5 \times 50 + 600 = 3,600$ hours/year. The additional 600 hours are an unverified allowance. Chiller load-bin hours, pump hours and tower-fan hours each total 3,000. These are separate schedules; they do not prove simultaneous operation in every hour.

Boundary: the 150 kW pump group is counted once for all modeled water pumping. The schematic separates the water circuits to explain operation; it does not create two 150 kW allowances. Supply and return fans share the 350 kW group. Tower heat rejection is thermal energy; only the tower fans are in the separate 60 kW electrical group.

Unchanged rated kW across options means the modeled auxiliary savings come entirely from lower average power fractions. DOE's pump guidance supports evaluating variable speed at the system level, but does not validate these fractions. [R03]

Trace: Assumptions!E12 and D41:J43 → Energy!F14:H16.

6. Energy savings and the operating-cost link

$$E_{\text{HVAC}} = E_{\text{chillers}} + E_{\text{fans}} + E_{\text{pumps}} + E_{\text{tower}}$$

This sum is annual electricity consumption in **kWh/year**. Peak electrical demand in **kW** requires coincident interval loads and is not calculated by summing annual energy.

Annual electricity (kWh)	A - Existing	B - Full	C - Partial
Chillers	1,536,000	999,000	1,419,000
Supply/return fans	1,008,000	604,800	756,000
Water pumps	382,500	202,500	292,500
Cooling tower fans	117,000	90,000	99,000
Total HVAC	3,043,500	1,896,300	2,566,500
Savings versus A	0	1,147,200	477,000
HVAC reduction	0%	37.6934%	15.6727%

$$\text{Annual savings} = E_A - E_{\text{upgrade}}; \text{reduction (\%)} = \text{savings} \div E_A \times 100$$

B: 3,043,500 - 1,896,300 = **1,147,200 kWh/year (37.7%)**.

C: 3,043,500 - 2,566,500 = **477,000 kWh/year (15.7%)**.

Auxiliaries contribute 610,200 kWh (53.2%) of B's savings and 360,000 kWh (75.5%) of C's. With the assumed unchanged 6,000,000 kWh of other electricity, whole-building electricity is 9,043,500 / 7,896,300 / 8,566,500 kWh for A/B/C. The reductions become **12.7% / 5.3%**. Gas use is unchanged. The 37.7% figure is not a whole-building total-energy reduction.

$$\text{Year 1 electricity saving} = \text{annual kWh saving} \times \$0.20/\text{kWh}$$

Year 1 pretax operating change (USD)	B - Full	C - Partial
Electricity saving	\$229,440	\$95,400
Maintenance / repair reduction	\$195,000	\$110,000
Less: recurring software / analytics	(\$25,000)	(\$15,000)
Net operating saving at 100% owner retention	\$399,440	\$190,400

\$0.20/kWh is illustrative, not a verified Manhattan building tariff. Actual avoided cost needs energy, demand and fixed-charge billing analysis. No separate demand-charge savings are added here. Maintenance savings are independent dollar estimates, not energy savings. [R10; P2]

Base realization multiplier = 1.00. Trace: Energy!F18:H29; Assumptions!E14, E22, E47:G49, E60:E66.

7. What still needs engineering evidence

The arithmetic is reproducible. Expected performance remains conditional on the assumed load profile and equipment behavior. The following work would test the main uncertainties without assuming the modeled savings are guaranteed. [P2]

Uncertainty	Evidence needed and how to use it
Load, schedules and capacity	Collect tenant schedules, BAS start/stop trends, outdoor weather and 12-24 months of utility data. Check the 3,000 / 3,600 hours. Perform a design cooling-load calculation using envelope, occupancy, ventilation and internal loads.
Chiller curves and staging	Trend each chiller's electrical kW, water flow and entering/leaving temperatures. Request manufacturer selections at actual water temperatures, flows and load points. Compare one-unit and two-unit operation and minimum-load limits.
Fans, pumps and tower fractions	Measure group and individual kW with run status, speeds, differential pressure, flow and damper positions. Check minimum ventilation, humidity and equipment-flow constraints before reducing power.
Equipment age and remaining life	Inspect heat exchangers, water quality, compressor condition and service records. Define the rebuild scope and expected reliability. The assumed 20-year age and 23-year reference life do not establish a replacement date.
Interactions and measured savings	Build an hourly plant/building simulation calibrated to bills and BAS trends, with weather, occupancy and controls. Compare options using equal comfort and ventilation requirements, then verify post-installation savings against a weather/occupancy-adjusted baseline.

A practical check on chiller efficiency

$$\text{Cooling rate (kW thermal)} = \text{mass flow (kg/s)} \times c_p \text{ (kJ/kg}\cdot\text{K)} \times \Delta T \text{ (K)}$$

Divide thermal kW by approximately 3.517 to obtain cooling tons, then divide measured electrical kW by those tons. Use calibrated sensors and fluid properties appropriate to the actual water/glycol mixture. This is a proposed measurement method; no flow or temperature measurements were supplied.

Controls must optimize the combined system. For example, a chilled-water temperature reset can reduce chiller input while increasing pumping needed to meet coil loads. Lower condenser-water temperature can improve chiller efficiency but require more tower-fan work. NREL's study documents such interactions; its national results are not this building's savings. [R06]

ASHRAE's service-life evidence includes centrifugal chillers operating beyond 25 years. That is population context, not a remaining-life prediction for this plant. Two 600-ton units provide no full spare when both are required to meet a 1,200-ton peak. [R04; P2]

8. Verification record and references

Step 4 checks: independently recomputed 45 energy and operating-cost outputs from the workbook inputs. All agree with saved workbook values within 0.000001 in their native units. The calculations cover the 12 chiller-bin results, 12 component totals, 15 energy/percentage/electricity-cost results and 6 operating-cost/savings results. This was a Python arithmetic check, not desktop Excel recalculation or a building simulation.

The input workbook was not edited or saved. Its SHA-256 remained:
11b873d72e4da5c49ce35e011be28aae870c5cd9ebcae056a6cc8e2b2c10af1c

Project reference	Document and use
[P1] Existing model	Manhattan_HVAC_CapEx_Final_Validated(1).xlsx. Assumptions, CapEx and Energy cells cited on each calculation page.
[P2] Step 3 report	Manhattan_HVAC_Engineering_Financial_Assumptions_Validation(1).pdf. Pages 3-5, 9-12 and 20-24: engineering inputs, scope and source limitations.
[P3] Step 1 audit	Manhattan_HVAC_Excel_Model_Audit_Report(2).pdf. Prior arithmetic review and engineering evidence gaps; prior tests are not represented as new Step 4 tests.

Validated primary references (IDs retained from Step 3). Accessed 23 October 2026. These sources explain methods and benchmarks; they do not verify the hypothetical building inputs.

[R02] DOE FEMP, Purchasing Energy-Efficient Electric Chillers. October 2024. AHRI ratings and paired full/part-load requirements.

<https://www.energy.gov/cmei/femp/purchasing-energy-efficient-electric-chillers>

[R03] DOE / Hydraulic Institute / Europump, Variable Speed Pumping: A Guide to Successful Applications, executive summary. May 2004. System curves and variable-speed limitations.

https://www1.eere.energy.gov/manufacturing/tech_assistance/pdfs/variable_speed_pumping.pdf

[R04] ASHRAE, 2023 HVAC Applications Handbook, Chapter 38, Table 3 and service-life discussion.

https://handbook.ashrae.org/Handbooks/A23/IP/A23_ch38/A23_Ch38_ip.aspx

[R06] Kim and CaraDonna, NREL, ComStock Measure Scenario Documentation: Chiller Replacement. August 2025. Sections 4-5; plant-control interactions.

<https://docs.nlr.gov/docs/fy25osti/95003.pdf>

[R07] NYSERDA, Real Time Energy Management. Undated webpage. Monitoring, controls and fault detection.

<https://www.nyseda.ny.gov/PutEnergyToWork/Energy-Technology-and-Solutions/Building-Operations-and-Performance/Real-Time-Energy-Management>

[R08] DOE FEMP / PNNL, Operations & Maintenance Best Practices Guide, Release 3.0. August 2010. Sections 9.4-9.5: chillers, towers and maintenance.

https://www.energy.gov/sites/prod/files/2020/04/f74/omguide_complete_w-eo-disclaimer.pdf

[R10] Con Edison, Rates and Tariffs FAQs. Undated webpage. kWh energy and kW demand billing.

<https://www.coned.com/en/rates-tariffs/rates/electric-rates-schedule/faqs>