Vornado Case Study

Playbook Menu

Vornado: Case Study

In April 2020, Vornado released its Vision 2030, a commitment to make its buildings carbon neutral by 2030. Learn about how Vornado is envisioning the decarbonization of the Penn District, leading with Penn One, a 57-floor sky-scraper in Midtown Manhattan. The project includes an innovative thermal dispatch strategy to meet the daily heat demand of the building. The strategy consists of layering the heating capacity from different heat sources available from least to most carbon intensive. As heating capacity from fossil fuel sources reaches end-of-life, new low carbon capacity can be phased in.

Reflections

- **Insight from the energy model**:
    - The calibrated energy model revealed that while the renovations to the building will yield significant energy and carbon reductions, the energy consumption from tenant spaces must also be significantly reduced to further drive down the carbon intensity of the building (and reduce/eliminate exposure to LL97 through the 2030 compliance period).
    - While every effort has been made to ensure that the model reflects the design team's best understanding of the building design and future usage, the modeled energy consumption, energy cost and carbon emission estimates will likely vary from the actual energy, cost, and carbon of the building after construction due to variables such as weather, occupancy, building operation and maintenance, changes in energy rates, changes in carbon emission coefficients, and energy uses not covered by the current modeling scope.
- **In the first iteration of the decarbonization strategy,** the team approached the project with an all-or-nothing electrification mindset. We found that the strategies that achieve the deepest levels of decarbonization and fully eliminate district steam and co-gen waste heat as heating sources may not be practical or cost efficient enough to be implemented in such a complex existing building. So we went back to the drawing board.
- **In the second iteration of the project,** a more holistic strategy emphasizing the following core principles was developed:
    - Re-use existing infrastructure (i.e., piping and ductwork) where possible
    - Electrify heating loads affordably
    - Reduce space requirements for electrification equipment/systems
    - Use thermal storage to shift & smooth loads to promote grid flexibility
- **Resource Efficient Electrification framework:** With these guiding principles, the Vornado team developed a new strategy that follows the Resource Efficient Electrification framework, which JB&B refers to as "Reduce, Recycle, Electrify". Phasing, cost compression, and space compression were prioritized so that measures are more likely to be installed and scaled to other Vornado properties.
- **Invest in a Calibrated Energy Model** – In large and complex buildings, building owners should invest in a decarbonization study with a highly accurate calibrated energy model. Accuracy in the energy analysis really matters and not all energy models are created equal. A decarbonization model should represent the building very closely so that studied strategies and measures have realistic energy and carbon reduction projections.
- **Just Because It's Feasible Doesn't Mean It's Practical** - Anything is possible in an energy model. Technical teams must be aware that building ownership teams care about more than just the energy and carbon results from the model. Strategies must be practical in a real-world sense and should aim to re-use existing infrastructure where possible, minimize disruption, use space efficiently, and compress costs as much as possible. Technical teams must be prepared to show building owners how a particular measure will be installed in a way that makes sense
- **Don't Expect 5–7 Year Paybacks on Decarbonization Measures** - Deep decarbonization measures will likely have long paybacks. This is due to a combination of high upfront costs of electrification technology, electricity prices that are 5 to 6 times more expensive than natural gas, and an inability to capture the true value of decarbonization investments. Ownership teams will have to adjust their payback expectations when considering deep decarbonization measures.
- **Technological Innovation Isn't the Only Innovation** - There is a lot of new and exciting technology out there that could someday revolutionize the way we electrify buildings, but in the meantime, there are innovative approaches to electrifying buildings today with technology that is currently available. Purposeful dispatch of thermal energy sources and optimization for scalability, practicality and affordability are innovative strategies in their own right.
- **Condition Leaving Exhaust Air** - Recycling waste heat from exhaust air streams isn't a new idea...but using the refrigeration cycle to extract and lift heat from exhaust air streams to serve heating loads is a new and innovative concept. Essentially by air conditioning the exhaust air, heat can be recovered and lifted to higher temperatures by a heat pump to offset heating loads. The reverse is also true in the summertime, where exhaust air can serve as a heat rejection medium for the chilled water production of cooling loads.
- **Low Temperature Hot Water in Existing Chilled Water Coils** - Low temperature hot water enables heat recovery and air source heat pumps to have a big impact but reconfiguring all comfort heating systems in existing buildings to be low temp is difficult and costly. A more practical approach is to do the following:
    - Electrify high temp hot water systems (i.e., perimeter systems) with water-source heat pumps and condenser heat recovery. Existing distribution infrastructure can stay in place.
    - Transition AHU steam or hot water coils to low temperature, which can be served by air-souce heat pumps. The cost and scope of coil replacements is much more manageable than replacing all heating systems with low temp hot water infrastructure. In some cases, existing chilled water coils can be used with the low temp hot water and becoming a modified change-over coil where coil replacement is no longer necessary.
- **Operations team adoption:** These ideas are new and complex. Existing operations team must be part of the design and implementation of these systems and training is of critical importance. A system that is designed to be low-carbon will not be successful if it is not operated per the design intent.
- **Disruption and phasing**: Some of the best decarbonization strategies are also some of the most disruptive. Additionally, phasing must be based upon a number of factors including the rate of grid decarbonization, leasing turnover cycles and capital planning cycles.

Contributing Organizations

Building the Decarbonization Roadmap for PENN 1

Vornado Realty Trust (VNO) and their team of consultants shown above, followed the Playbook approach to define the decarbonization roadmap for PENN 1. The iconic midcentury building consists of 57 stories totaling 2.5 million gross square feet.

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Getting Started

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The Vornado sustainability team, in collaboration with the PENN 1 building management team, assembled a project team with deep expertise across multiple disciplines that could address the level of complexity, interdisciplinary thinking, and innovation needed to develop a decarbonization roadmap for PENN 1. The core project team consisted of:

- VNO, building owner and facilities team

- Jaros, Baum & Bolles - Deep Carbon Reduction Group (JB&B DCRG), consulting engineers and energy modeling consultant
- Turner Construction - Constructability and cost analysis consultant
- Blueprint Power - Grid, tariff, rate, tax, and DER expertise

At the onset of the project, the team took an aggressive approach to building decarbonization, and focused on eliminating all dependence on district steam and natural gas. The following guiding questions were used in this first round of analysis:

- What is the deepest level of decarbonization we can achieve?
- How feasible is electrification of heating systems?
- How can we completely remove dependence on district steam?
- Can we eliminate the existing cogeneration plant?

Later in the project, after an initial round of analysis and results, the project team re-evaluated and adjusted the approach to decarbonizing the building. A new set of guiding questions were developed as the study entered a second phase:

- How can we re-use existing infrastructure i.e., existing piping?
- How can we electrify heating end uses affordably?

- How can we compress space requirements for electrification equipment?
- How can we take advantage of load shifting and smoothing for grid flexibility?

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Building Discovery

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Learn the Building

The project team collected, studied and analyzed several key pieces of information over the study period, including:

- Existing building attributes, such as building geometry and facade properties
- Detailed HVAC layouts and configurations
- Historical energy and carbon emissions profiles
- Interactivity of onsite electricity generation

- Low- to high-disruption strategies for energy and carbon reductions

- Feasibility of various strategies under specific infrastructure and space constraints

To keep information organized, the JB&B team deployed a checklist of requested documentation with clear indication of each item's importance to the development of the building's calibrated energy model. The JB&B Team also developed a questionnaire that was used to guide discussions with the building's operations team during building walkthroughs and surveys

Facility Data Collection Checklist

PENN1
1 Pennsylvania Plaza
New York, NY

Importance Key	Description of Data Importance
🟥	Priority 1 – Data is critical, and the model cannot be built without it.
🟨	Priority 2 – Data is of high importance. Without data, modeling activities may proceed, but the error introduced may be significant.
🟩	Priority 3 – Data is useful but is not necessary to proceed.

Importance	Phase 1: Architectural Drawings	Received
🟥	Floor Plans (Above & Below Grade) in CAD & PDF [Below Grade: outstanding]	☑
🟥	Façade Elevation Drawings	☑
🟥	Section Drawings Or Description Of Basement Floor Depths [shown on elevation drawings]	☑
🟩	Façade Cut Sheets [Cut Sheets not available; Details provided instead]	☑
🟩	Window Cut Sheets [Cut Sheets not available; Details provided instead]	☑

Importance	Phase 2: Mechanical Drawings	Received
🟥	Mechanical Schedule Sheets + Schedules of Any Updated Equipment / Descriptions Of Changes	☑ *
🟥	Mechanical Floor Plans and/or Mechanical Riser Diagrams [Electrical Riser provided. Electrical Floor plans not available]	☑ *
🟩	As-Built Drawings	☒
🟥	Electrical Schedule Sheets [For switchboards only]	☑

*Drawings for current Chiller upgrade are not finalized. Will need to coordinate with construction manager to obtain drawings

Importance	Phase 3: Utility Data & BMS Trend Data	Received	
🟥	Hourly Utility Data (12 Months) for the Whole Building (PDF Bills or Login to Utility Account Information Required)	☐	KO
🟨	Hourly Tenant Submeter Data (12 Months) [Bob confirmed tenants have submeters]	☐	KO
🟥	Trended Minimum and Maximum Airflow Rates for Large Supply Fans/AHUs in Each Season (Shoulder, Summer and Winter)	☐	KO
🟨	Trended Outside Air (Ventilation) Airflow Rates for Large Supply Fans/AHUs for a Complete Year	☐	KO
🟨	Trended Hourly Chiller Input Energy and Output Energy Data for a Complete Year	☐	KO
🟥	Building Engineer Describing DCV And Economizer Operation [see facility walkthrough questionaire]	☑	
🟨	Occupancy Schedules [see facility walkthrough questionaire]	☑	
🟨	Additional Trended BMS Data and Setpoints (1 Month Minimum): [BMS Trends are not currently set up, with exception to chiller trends (for old turbines)] • AHUs: – Fan speed/frequency and kW draw if available – Cooling coil valve position – Coil entering and leaving chilled water temperature – Preheat valve position – Return air temperature – Return air humidity – Return air CO2 – Supply air temperature and setpoint – Supply air static pressure and setpoint – Mixed air temperature – Outside air temperature – Outside air humidity – Outside air damper positions – Space air temperature and setpoint • Chilled Water System: – Chilled water supply and return temperature and setpoint – Chilled water flowrates • Condenser Water System: – Fan speed	☐	KO

Figure 1: Sample Facility Data Collection Checklists

JB&B Energy/Carbon Reduction Study
Facility Walkthrough Questionnaire

1 Pennsylvania Plaza
New York, NY
Project No.: 26769.N.001

1.0 FACILITY REVIEW	
Instructions: Complete the questionnaire below during the facility walkthrough. Please include any information about unique facility operational strategies that may impact the building's energy consumption.	
1.1.1.	**Does the facility utilize airside or water-side economizer? If so, please describe below.** Example: "We use airside economizer in the shoulder seasons, and we use a waterside free-cooling plate-and-frame heat exchanger in the winter to reduce the load on our chiller plant".
	Per interview with Chief Engineer, not confirmed at BMS: • Airside economizer: o If OAT < RAT, the operator is given the option to enable airside economizer o While in airside economizer, OA damper modulates between min and max position to maintain supply air temperature set point. • Waterside economizer: o If OAT < 55 F, the operator is given the option to enable waterside economizer o In waterside economizer, condenser water runs through a plate-and-frame heat exchanger to cool CHW loop. Heat exchanger can NOT operate in series/simultaneously with chillers.
1.1.2.	**What are the facility's normal operating hours?** *Example: "8 am to 6 pm".*
	Tenant scheduled vary. Base building schedules: • Monday-Friday: 8 AM – 8 PM • Saturday: 8 AM – 1 PM • Sunday: Closed Morning warm-up/cool-down is initiated prior to occupied hours at the operator's discretion. Chief engineer reported that during winter months, warm-up is typically initiated around 6 AM.
1.1.3.	**List the minimum outdoor air rates for the large supply fans/air handling units identified above.** *Example: "AHU-1-1 has a minimum OA flow rate of 2,000 CFM".*
	Per interview with Chief Engineer, not confirmed at BMS: • In normal operation, OA dampers are at minimum position (20% in most cases) OA dampers remain closed when units are not in operation and during morning warm-up/cool-down
1.1.4.	**Are there any resets or setback schedules for HVAC equipment?** *Example: "Fan powered boxes in admin areas have night setback programs".*
	Per interview with Chief Engineer, not confirmed at BMS: • For secondary HW loop, reset schedule based on OAT: o When OAT = 0 F, SHW temp set point = 150 F o When OAT = 60 F, SHW temp set point = 90 F • For secondary CHW loop, reset schedule based on OAT: o During summer months (temp cutoff to be confirmed), SCHW temp set point = 55 F o When OAT drops (cutoff to be confirmed), SCHW tempe set point increases by approx. 1-5 F (exact amount to be confirmed)

Figure 2: Facility Walkthrough Questionnaire

A summary of the current building systems is shown below:

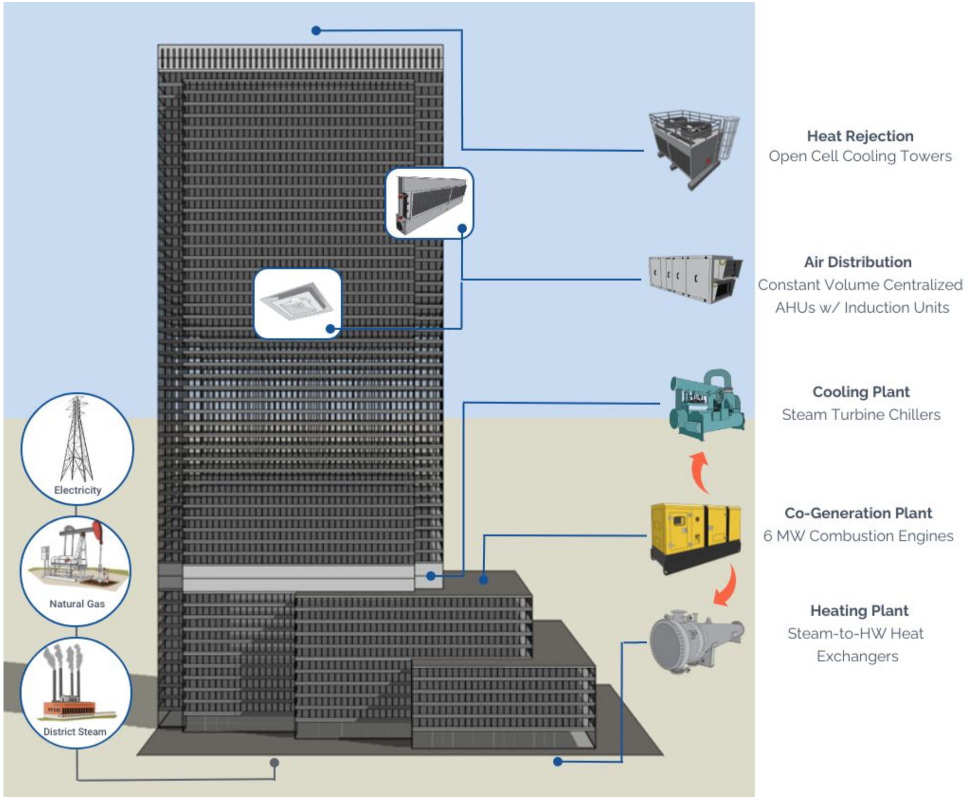

Figure 3: Building Existing Systems

Build the "Business-as-Usual" Base Case

Utility Analysis (Existing Condition)- Annual grid-purchased electricity, natural gas, and district steam fuel data was collected from the building's utility bills for a year spanning May 2019 to April 2020. Due to the onsite electrical cogeneration plant (cogen), each fuel was analyzed at these different instances:

Energy Consumption=Energy Purchased + Energy Produced

The breakdown of annual fuel consumption, production, and utility-purchased energy, along with carbon emissions and energy costs of the existing building are shown below:

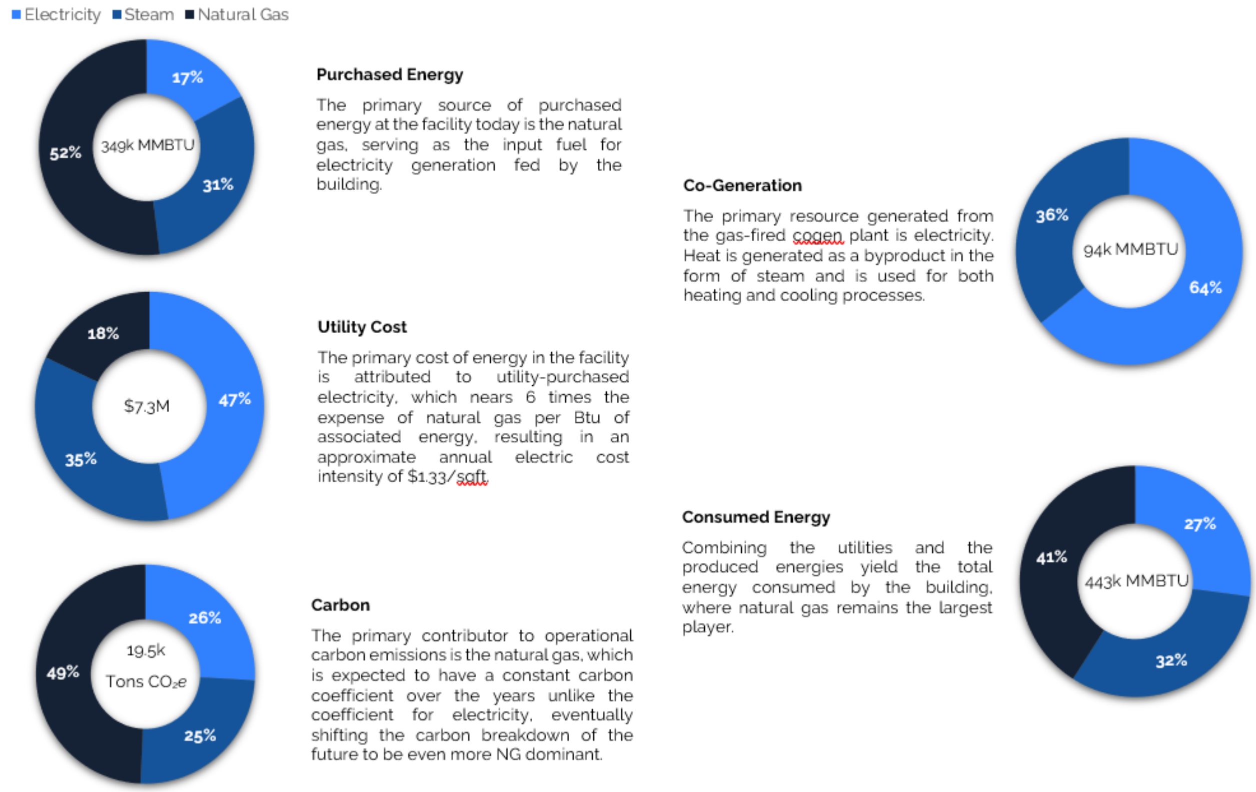

Figure 4: Utility Analysis Overview

Building Performance Standard Impact Analysis– The project team performed a Local Law 97 Impact Analysis for the building based on the facility’s 2019/2020 energy consumption. In a business-as-usual scenario, Penn One is projected to exceed its mandated carbon limits starting in 2030 and continuing through 2050 in both “best”- and “worst-case” grid decarbonization scenarios if current energy consumption remains consistent in the future. The best-case grid decarbonization is based on goals from the State’s Climate Leadership and Community Protection Act (CLCPA), while the worst-case scenario is based on a static Local Law97 coefficient that does not change with time. The project team chose to evaluate both CLCPA grid decarbonization and a lack of grid decarbonization to show the full range of potential LL97 Impact.

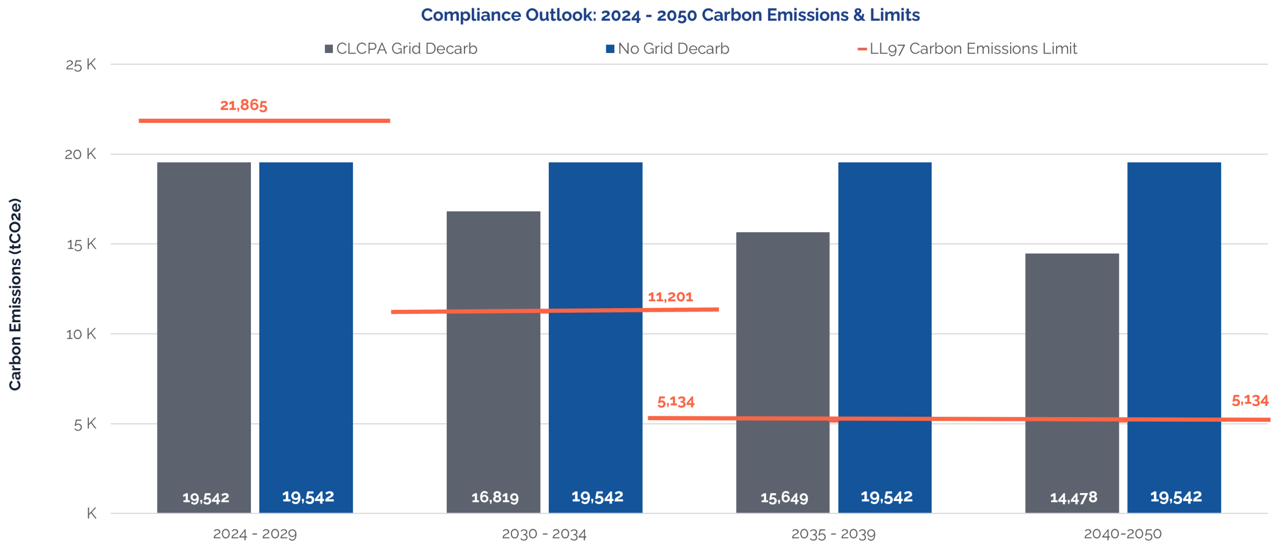

Figure 5 – LL97 Impact Analysis

Identify Preliminary ECMs & Carbon Reduction Strategies

During the decarbonization study process, the team initially identified nine (9) high impact energy /carbon reduction measures (E/CRMs) that would enable the elimination of district steam and natural gas as fuel sources in the building.Because PENN 1 has already addressed several energy efficiency projects in both base building and tenant spaces, selected E/CRMs focus on system-wide capital projects. The initial list of measures were presented to the VNO sustainability and building management teams for feedback and approval. A qualitative assessment of MEP system impacts and building disruption were shared with the VNO teams to inform discussion of how each potential project could impact building operations.

Energy & Carbon Reduction Measures	Systems Impacted	Lighting	Equipment	Fans	Pumps	CoGen	Cooling Plant	Heating Plant	DHW
Tenant Options									
High Efficiency Equipment & Lighting	ECM 1	●	●				●		
Daylighting & Active Shading	ECM 2	●					●		
Chilled Water Computer Room AC	ECM 3				●		●		
Air Source Heat Pump DHW	ECM 4				●			●	●
Airside Options									
Demand Control Ventilation	ECM 5			●			●	●	
Exhaust Air Heat Recovery	ECM 6			●			●	●	
VAV Air Distribution	ECM 7			●					
Dedicated Outdoor Air System	ECM 8			●			●	●	
Envelope Options									
High Performance Glazing	ECM 9						●	●	

Building Disruption Scale: • *Not Disruptive* • *Moderately Disruptive* • *Very Disruptive*

Figure 6 – Identified Energy and Carbon Reduction Measures

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Energy & Carbon Modeling

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Build and Calibrate the Initial Energy Model

The initial energy model was developed using the graphical interface DesignBuilder® with EnergyPlus as the calculation and simulation engine. Building attributes such as floor dimensions, lighting, plug loads, HVAC layouts, and detailed schedules were included in the model to reflect the general parameters of the existing building conditions.

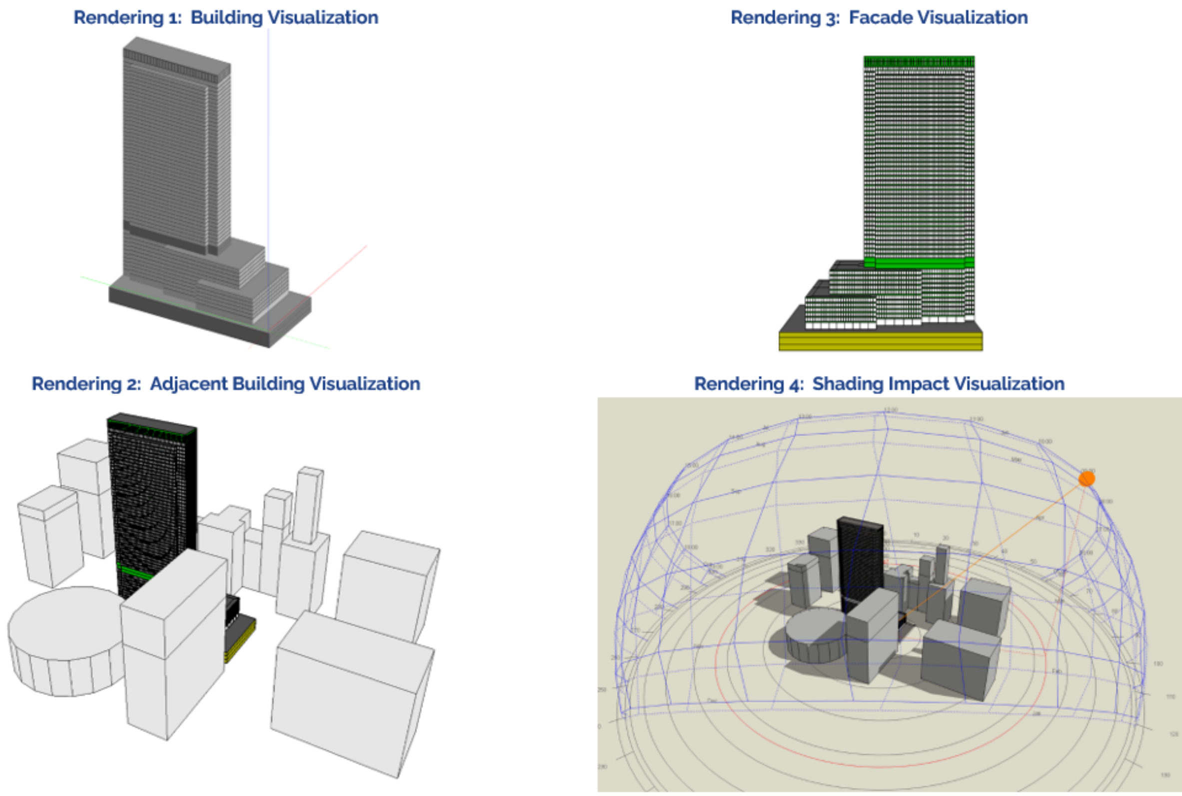


Figure 7 – Energy Model Renderings

Through an iterative process, the energy model inputs were modified to align the calculated energy model outputs with actual building utility data (sample compound years as discussed previously).

The following resources were used in calibrating the energy model:

- Electric, steam and natural gas consumption.
- Electric and steam onsite generation.
- Information on HVAC operation and set points from the Facilities team.

- Actual Meteorological Year (AMY) weather data for a compound calendar year, sourced from White Box Technologies.

- NY_NYC-CENTRAL-PARK
- WMO# 725053
- ASHRAE Climate Zone: 4A

- Onsite lighting and electrical survey of sample offices.

- Domestic hot water was calibrated using shoulder season heating loads.
- Window fenestration U-value and SHGC were estimated using construction descriptions matched with the software's library data.
- Adjusted facade infiltration to improve accuracy of heating demand during the Winter.

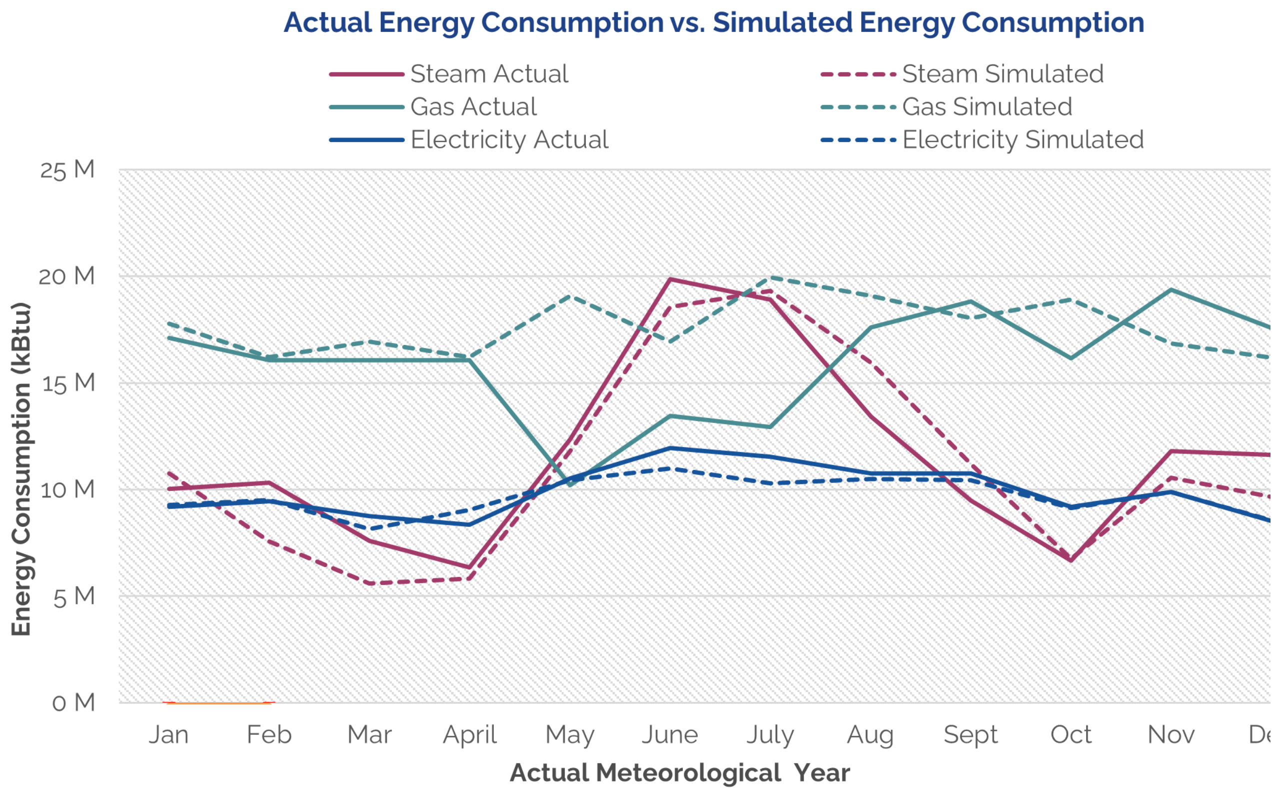


Figure 8 – Energy Model Calibration

It should also be noted that the building's cogeneration plant was undergoing maintenance in May through July. These outages were deemed atypical; consequently, the calibrated energy model ignores this anomaly and was programed to match natural gas consumption during a typical year when the cogeneration plant is fully operational.

Create the Baseline Energy Model

To create a "baseline" model to serve as a starting point for further E/CRM modeling, the calibrated model was altered as follows:

- Weather data was changed to a Typical Meteorological Year (TMY3) file sourced from the modeling software library data.
- Recently completed projects, including the installation of a new chiller plant, were added to the model.

Generate Detailed End-Use Breakdowns- The baseline energy model outputs were utilized to determine the annual distribution of energy across building end uses. This analysis allowed the team to determine where there were opportunities for improvement.

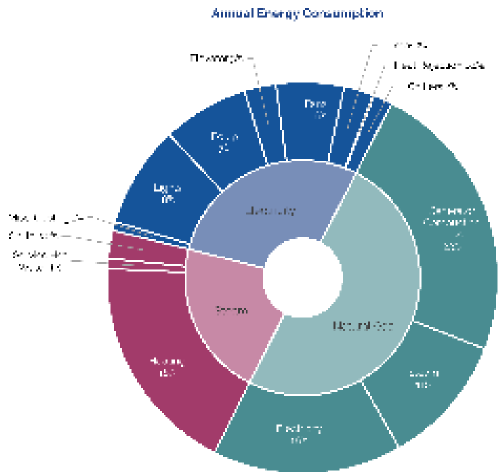


Figure 9 – Annual End Use Breakdown

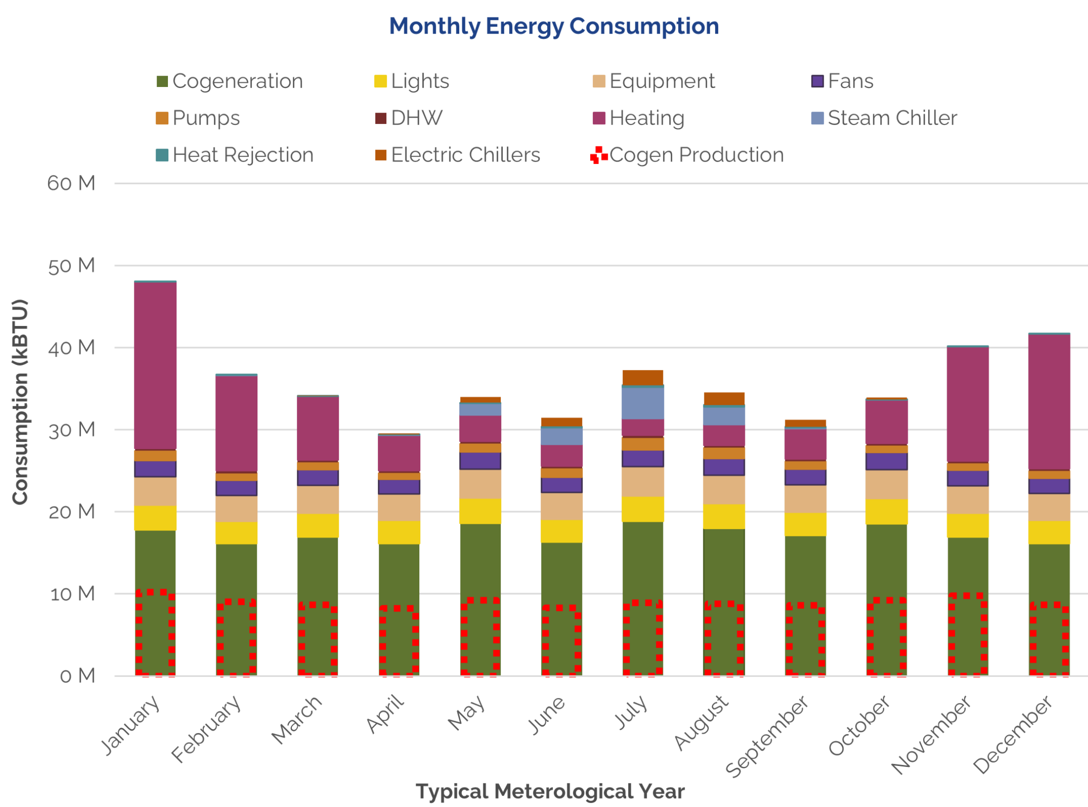


Figure 10 – Monthly Energy Breakdown by End Use

Analyze Individual ECMs

During the study, the project team identified nine (9) decarbonization strategies the building could undertake over the next 10-15 years. The energy modeler analyzed the ECMs through the baseline energy model to extract the associated energy, carbon and cost savings. As examples, below is a list of a few ECMs that the project team studied, with details on the energy modeling methodology used.

ECM	Description	Summary of Energy Modeling Methodology
DOAS Conversion	This measure includes the replacement of all office CV recirculating air handling units and perimeter induction units with 100% central outdoor air units with energy recovery wheels. All induction units and constant volume terminal units would be replaced with DOAS terminal units, similar to overhead fan-powered boxes, that locally mix outdoor air and return air to meet space set point temperature while also providing code-minimum ventilation airflow. Interior- and exterior-zoned DOAS boxes would be provided a cooling coil fed from the secondary chilled water loop for space sensible cooling loads; only exterior boxes would be provided a heating coil for overhead perimeter heating.	• 20% mixed-air AHUs serving interior office spaces and 67% OA AHUs serving perimeter induction units were altered to 100% OA AHUs with energy recovery wheels with the following effectiveness: ▪ Sensible: = 0.69 @ 75% airflow; = 0.67 @ 100% airflow ▪ Latent: = 0.60 @ 75% airflow; = 0.55 @ 100% airflow • 100% OA units were sized based on the non-coincident ventilation requirement for all the spaces served. • Fan static pressures were modified per the following static pressures:

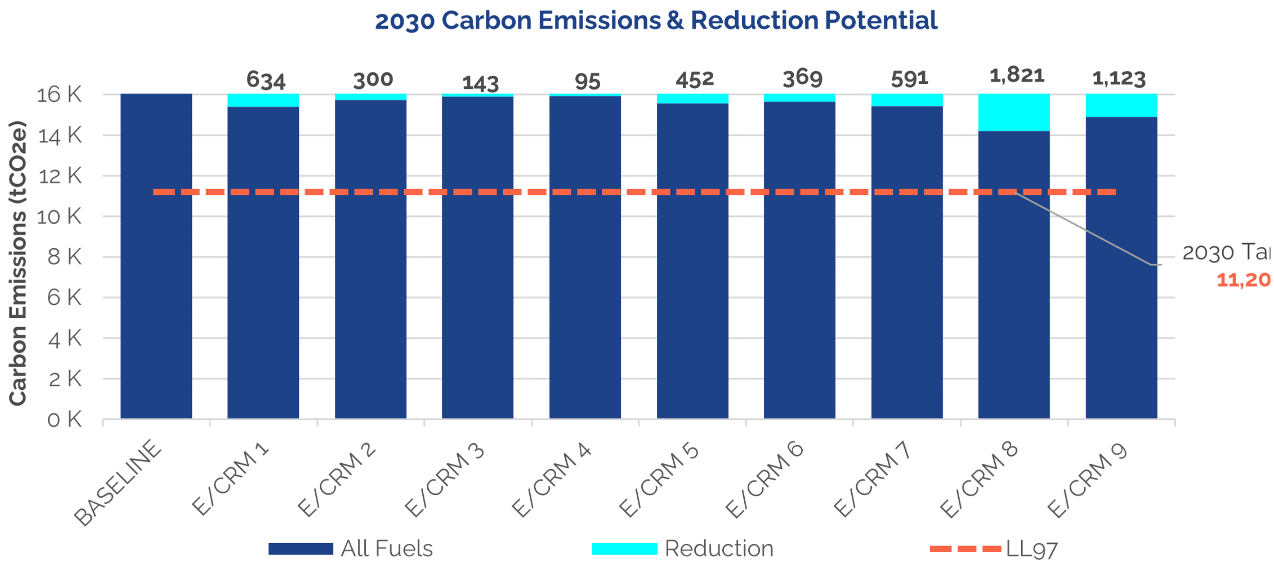
- Existing interior AHUs serving CV boxes: 4.5” W. C. supply, 2.5” W. C. return.
- Existing exterior AHUs serving induction Units: 9.5” W. C. supply, 2.5” W. C. return.
- New 100% OA AHUs: 6 in. w. c. supply, 3 in. w. c. exhaust.
- New DOAS Boxes: 1.5 in. w.c.

			• DOAS boxes were connected to the secondary chilled and hot water loops to provide overhead sensible cooling and perimeter heating. • AHU operation schedules, EPDs, LPDs, and non-office spaces were held constant.

High Performance Glazing	The existing facade at PENN 1 consists of 6 mm single-pane vision glass and spandrel glass with 1” insulation. This measure incorporates replacing the single-pane vision glass with high-performance triple-pane insulated glazing unit1 (IGU). This measure assumed no improvement to the infiltration rate of the existing facade and no modifications to the existing window-to-wall ratio.		• The facade window openings were modified as follows:
			  ▪ Existing Single-Pane: U = 1.022 SHGC = 0.6
			    ○ Outermost pane: Tinted 6 mm glass

- New Triple-Pane IGU: U = 0.21 SHGC = 0.31
  - Outermost pane: Clear 6mm glass
  - Internal gas: 13mm air gap

			◦ Middle pane: Low-e coated 6 mm glass ◦ Internal gas: 13 mm air gap



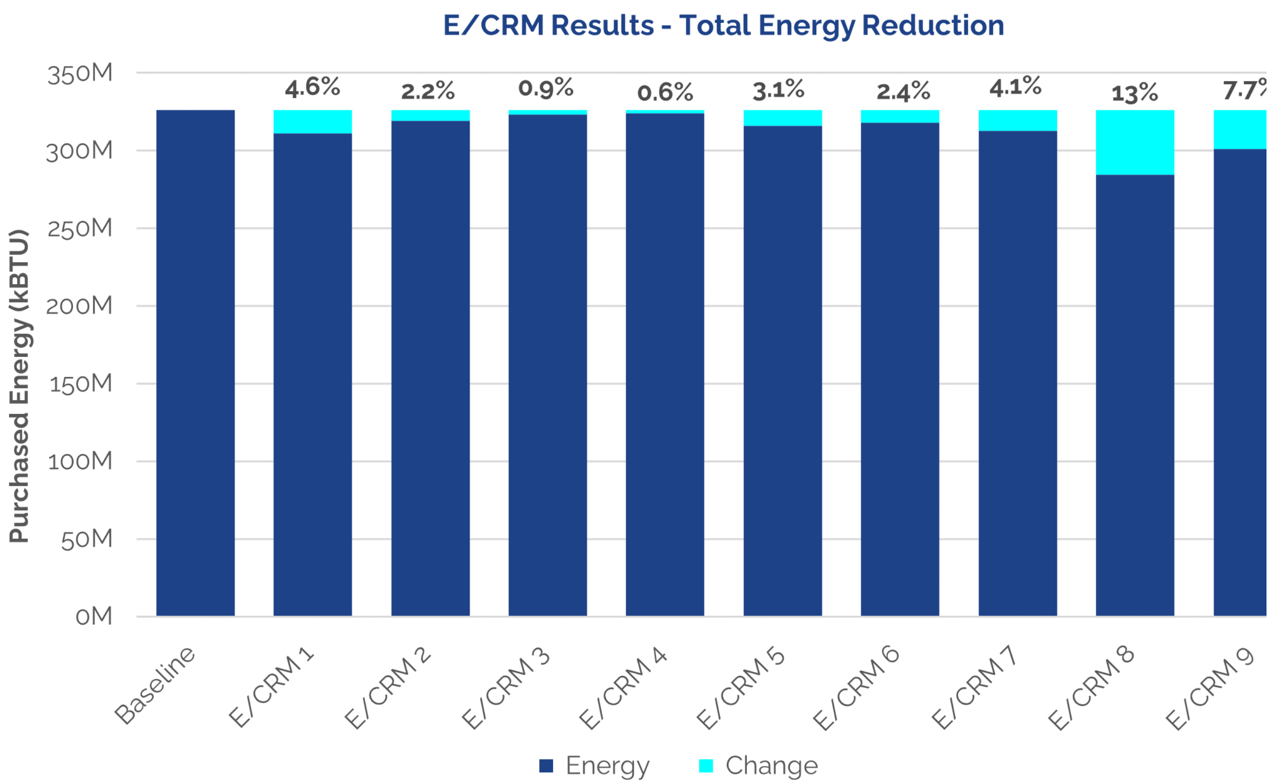


Figure 11 & 12 – Individual Energy and Carbon Reduction Measure Results

Group, Sequence, and Package ECMs

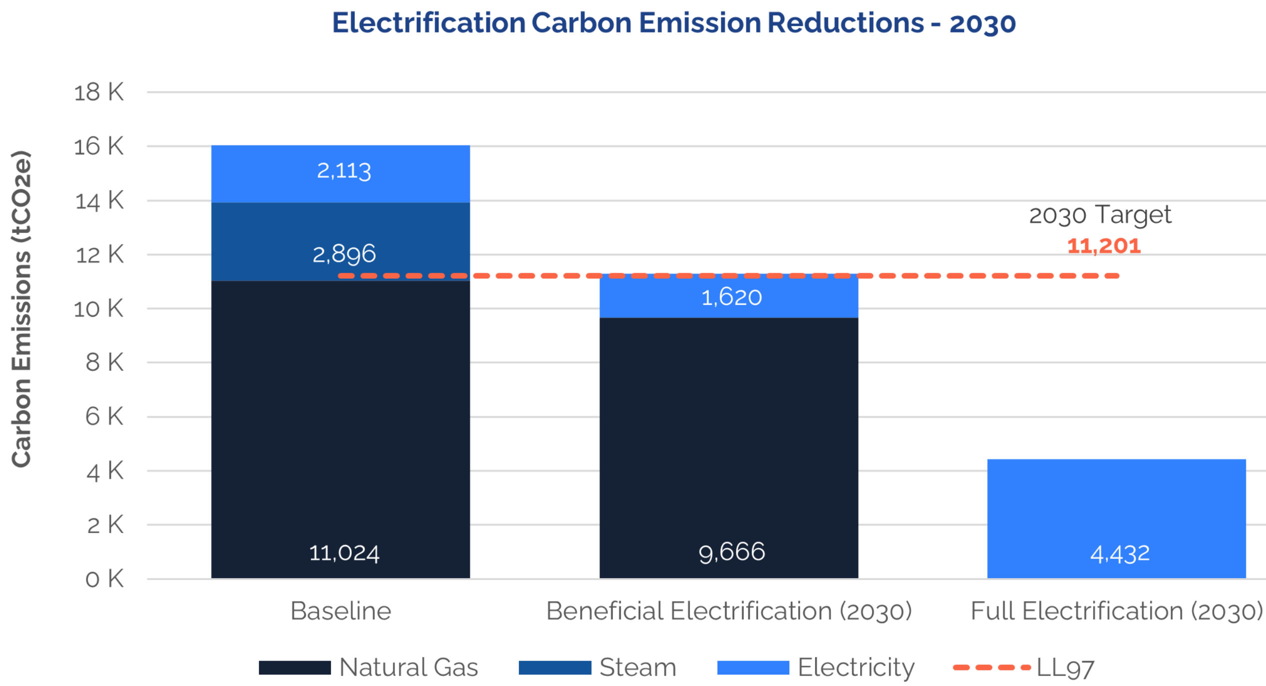
The project team initially explored two (2) packages of combined reduction measures to assess the impact of eliminating fossil fuels and electrifying the building's heating end uses. Individual measures studied earlier in the project were selected and combined with additional infrastructure enhancements to develop two electrification packages summarized as follows:

- Beneficial Electrification: Incorporates a suite of Tenant, airside, and envelope upgrades along with the installation of air source heat pumps working in conjunction with the cogen plant to keep the building heated; eliminates all district steam resources.
- Full Electrification: Incorporates the same set of upgrades but utilizes more air-source heat pumps in place of the cogen plant.

The packages are comprised of the following measures:

Electrification Options:	Beneficial	Full
Phased Steps		
Upgrade Lighting & Equipment	●	●
Install Daylighting & Active Shading	●	●
Convert CRACs to CHW	●	●
Install ASHP for DHW	●	●
Control ventilation with DCV	●	●
Include Exhaust Air Heat Recovery	●	●
Install DOAS Distribution	●	●
Retrofit with High Performance Glazing	●	●
Remove Induction Units	●	●
Install DOAS Terminal Units	●	●
Heat with 'Low-Temp' Hot Water	●	●
Install new ASHP	●	●
Replace Steam Turbine with Electric Chillers	●	●
Utilize Dual Temperature CHW Plant	●	●
Implement Condenser Water HR	●	●
Decommission CoGen Plant		●

The Full Electrification package created the best scenario for PENN 1 to become carbon neutral by 2040, with the assumption that the grid is decarbonized per the CLCPA requirements; however, the Beneficial Electrification package offered a more favorable financial outlook that could be more feasibly attained in the near term.



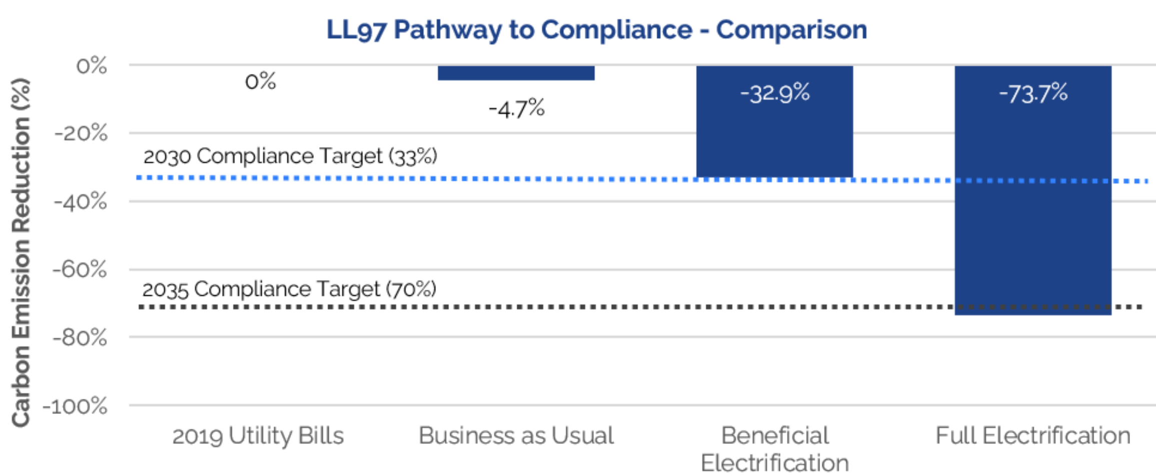


Figure 13 & 14 – Emissions Reductions & LL97 Impact with Electrification Packages

Establish the Final List of ECMs– The project team presented the electrification package results to a various stakeholders within Vornado, and while everyone agreed that that the initial set of ECMs would produce deep carbon emissions reductions, there were certain strategies that were deemed impractical after preliminary capital cost estimates were obtained.

	Penn 1 - Phase 1 (LCB)	Outcomes & Lessons Learned	Penn 1 – Phase 2 (EBC)
Fenestration	• Triple-Pane Glazing w/Low E-Coating	• --	• Same
Ventilation	• DOAS Air Handlers w/DOAS Terminal Boxes (Forced Overhead Air) • Airside Heat Recovery	• Determined to be Impractical • Disruption to Tenants • Phasing • Capital Cost	• CAV to VAV Conversion • VAV Induction Unit Replacement
Cooling	• All-Electric Chillers	• --	• Same
Heating	• Low Temperature Hot Water (95°F) • Condenser Water Heat Recovery • Air-Source Heat Pumps	• Determined to be Impractical • Can't Use Existing Piping Distribution • Space Requirements for ASHP • Capital Cost	• High Temp HW at Perimeter with • Low Temp HW Interior Zones & AH • **Thermal Dispatch Model w/Coge Steam + Heat Pumps + Thermal St**
Cogeneration	• Keep Cogen	• Financially Advantageous • Waste Heat Can be Reused • Does Not Support Decarbonization	• Keep until 2030
	• Remove Cogen	• Supports Decarbonization	• --
Thermal Storage	• None	• --	• Thermal Ice Storage to Flatten Der Peaks and downsize ASHP Equipm

Figure 15 – Phase 1 vs Phase 2 ECMs

At this point, the project team shifted its approach to the project. The team re-evaluated individual ECMs and electrification packages and adjusted measures to align with the following guiding principles:

- How can we **re-use existing infrastructure**?
- How can we electrify heating end uses **affordably**?
- How can we **compress space requirements** for electrification equipment?

- How can we take advantage of load shifting and smoothing for **grid flexibility**?

In addition, the team dialed in on the most impactful phasing of strategies to reduce capital costs, space requirements and infrastructure demand impacts through a Reduce, Recycle, Electrify framework.

Wholistic Building Decarbonization Strategy: Reduce, Recycle, Electrify

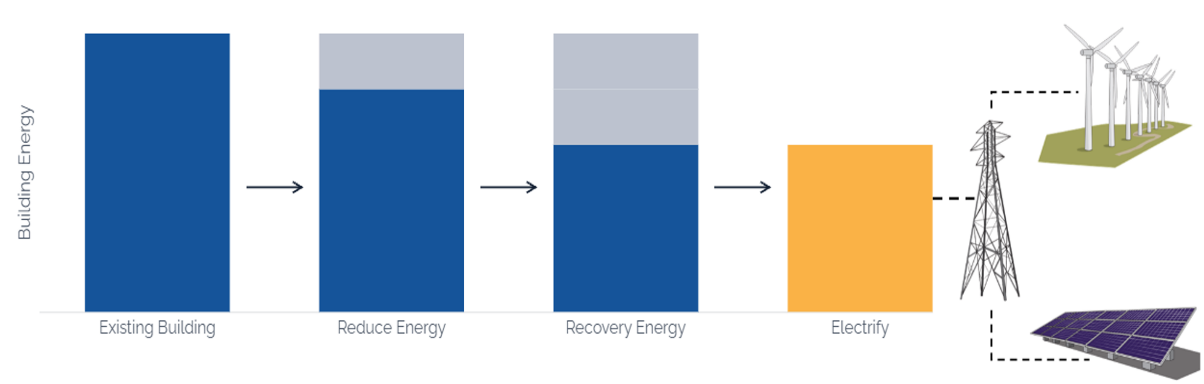


Figure 16 – Resource Efficient Electrification Approach

The team generated a thermal dispatch model to optimize how the building's loads are satisfied. The figure below shows how the various Phase II ECMs are deployed to meet the building's heating demand on a winter day. Instead of eliminating steam and the cogeneration plan immediately, the team settled on a more measured approach which uses some district steam and cogen waste heat in the short term to avoid stranded assets, and then shifts to a substantially electrified building in the 2030 -2035-time frame.

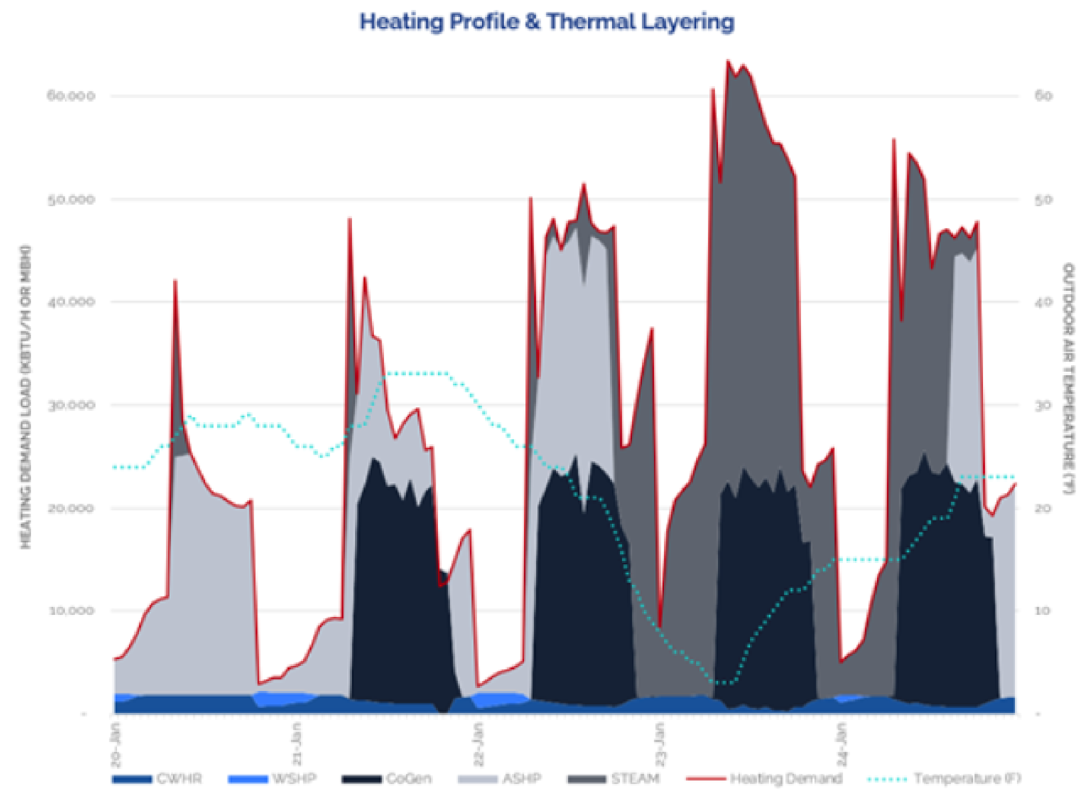


Figure 17 – Thermal Dispatch Model

Generate a Decarbonization Roadmap

Once the finalized phase II ECMs were packaged, the energy model was run for each ECM package to obtain energy and carbon and cost impacts. The project team compared the results of this analysis and calculated the energy and carbon savings from the baseline model.

Penn 1 Decarbonization Strategy	Decarb Approach Category	The "Why"	Timeframe
Interior Zone VAV Retrofit	Reduce	• Re-uses existing airside equipment & infrastructure. • Can be phased with minimal disruption. • Meaningful energy, carbon & cost savings w/ reduced capital expense.	2022 - 2024
Perimeter Zone VAV Induction Unit Replacement	Reduce	• Re-uses existing waterside piping distribution. • Can be phased with minimal disruption. • More control of perimeter ventilation.	2022-2024
Advanced Waterside Heat Recovery	Recycle	• Reduced heating loads enables air-source heat pump equipment sizing and quantity reductions.	2025
Condenser Water CRAC Unit Conversion to Chilled Water	Recycle	• Increases condenser water heat recovery potential.	2026-2027
Partial Electrification of Low Temperature Interior Zone Heating Systems & Domestic Hot Water Systems	Electrify	• Re-uses existing airside infrastructure (coils). • Minimal disruption to tenants • Reduces cost of electrification. • Supports low temperature hot water. • Enables air-source heat pump heating.	2022 – 2023 (DHW) 2025- 2026 (HVAC Heating Systems)
Partial Electrification of High Temperature Perimeter Zone Heating Systems	Electrify	• Can be phased with minimal disruption.	2022 – 2023 (DHW) 2025- 2026 (HVAC Heating Systems)

Figure 18 – Finalized ECMs & Packages

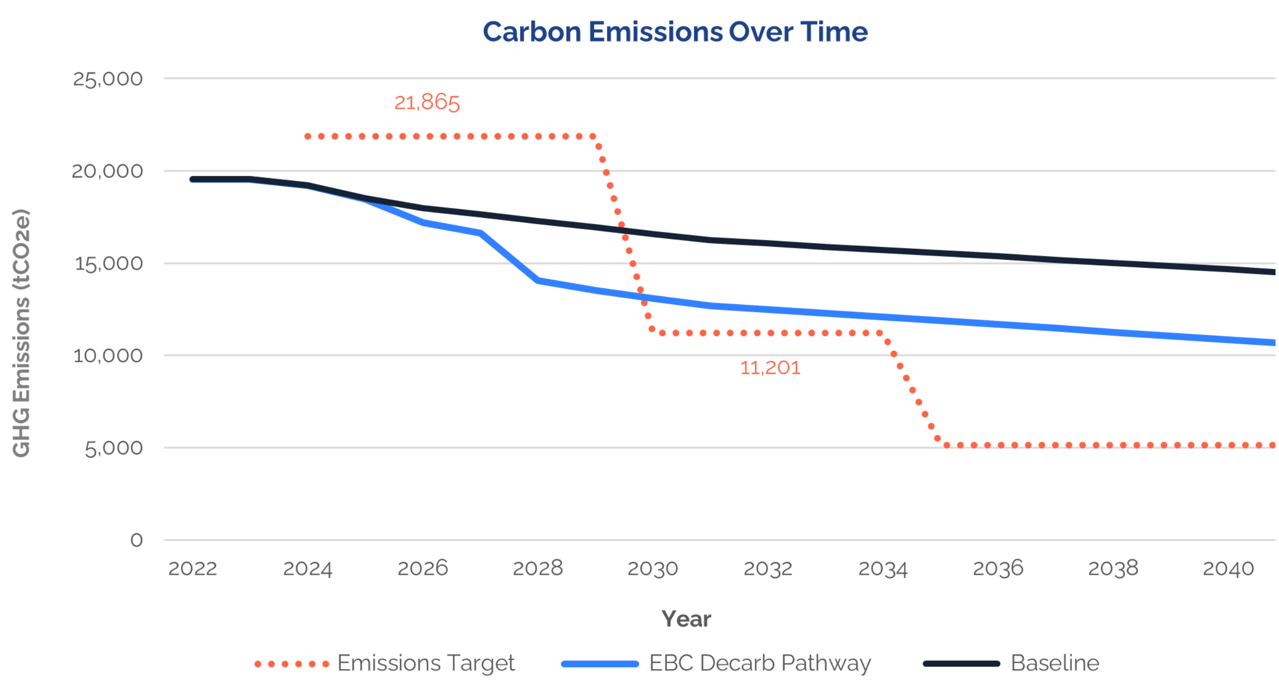


Figure 19 – Deep Decarbonization Pathway

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