CASE STUDY

NEW YORK STATE OF OPPORTUNITY. | NYSERDA

Rudin Management:

Using Real-Time Energy Management To Optimize NYC Commercial Building Operations

$5M+
Demonstrated Energy Savings Across Commercial Portfolio

9.4%
Avg. Annual Normalized Occupied Building Energy Savings

13.6%
Avg. Annual Normalized Non-Occupied Building Energy Savings

SUMMER 2019

Introduction

NYSERDA sponsored this independent study to identify real-world best practices in optimizing building operations using a real-time energy management (RTEM) system.

The Rudin Management Company[1] (Rudin) operates one of the largest privately owned real-estate portfolios of Class-A commercial properties in New York City. The company is also a technology innovator in developing and integrating RTEM systems to optimize building operations and ensure building tenant comfort.

Rudin's experience with RTEM began in 2012 with a pilot deployment of Di-BOSS™, an in-house RTEM system developed in partnership with an integrator. The initial learning experience with Di-BOSS was used to further the commercialization of the RTEM system and the development of the Nantum® operating system (OS). The company also established Prescriptive Data to continue productization and offer NantumOS as a commercial product.

NYSERDA performed an independent assessment of Rudin's use of NantumOS to optimize building operations. The electric utility meter data from Consolidated Edison, Inc. (Con Edison) for the eight Rudin properties upgraded in 2016 to NantumOS with NYSERDA's funding assistance were analyzed using standard industry techniques.

This case study compares the daily and seasonal consumption patterns before and after the 2016 Nantum OS upgrades to identify operational differences and impacts in building electricity consumption. The study identified best practices in minimizing energy usage, based on key observations in the analysis of Rudin's operational processes using NantumOS. These are:

- **Start-Up:** Scheduling building mechanical system start-up at the beginning of the day
- **Capacity Control Strategies:** Automatic adjusting building mechanical system capacity according to the actual building occupancy level during the day

Based on the consumption patterns discernible from the Con Edison meter data, it was determined that the eight Rudin properties selected for this study were well-orchestrated buildings before upgrading to NantumOS. The easily identifiable patterns within the hourly interval data showed the importance the company placed on the timing of the start-up and end of day ramp down of all building mechanical plants. Nonetheless, this study identified weather-normalized savings when the buildings were upgraded to NantumOS.

Based on these findings, NYSERDA asserts that potential savings would be much higher for commercial properties that are new to RTEM or have not yet integrated RTEM into their daily operations.

[1] https://www.rudin.com/

Summary of Findings

Rudin management reported that the initial deployment of Di-BOSS saved an average of 12% in 11 commercial buildings in 2014, equal to more than $5 million in savings for the Rudin commercial portfolio at the time.

The upgrades to NantumOS from Di-BOSS in 2016 resulted in weather-normalized savings from 4.2% to 16.8% during the occupied days on non-holiday weekdays, and from 6% to over 22% savings during non-occupied days on weekends and holidays. This level of savings is in addition to the savings that Rudin has already realized with Di-BOSS. For some buildings, cumulated savings of Di-BOSS and Namtum OS is more than 30% from 2012 to 2018.

Table 1 summarizes the weather-normalized savings of NantumOS.

*Table 1: Nantum OS Relative Savings**

Property Address	Normalized Savings for Occupied Days (%)	Normalized Savings for Non-Occupied Days(%)
41 Madison Avenue	4.2%	11.7%
40 East 52nd Street	4.3%	11.4%
1675 Broadway	8.2%	19.6%
355 Lexington Avenue	10.7%	6.0%
32 Avenue of the Americas	12.3%	10.6%
845 3rd Avenue	16.8%	22.28%

* 3 Times Square and 80 Pine Street excluded from the quantitative portion of the study due unavailability of continuous stream of interval data from 2012 through 2017 from Con Edison.

As attractive as the energy savings obtained by using Di-BOSS and NantumOS are, NYSERDA finds the non-energy benefits may offer higher strategic values to the Rudin organization.

The bullets below summarize NYSERDA's findings for the non-energy benefits of NantumOS:

- Nantum OS serves as a tool for executives to encourage organizational commitment to energy management.
- Nantum OS's automated predictive capabilities reduce manual errors and missed opportunities.
- Nantum OS frees up building staff from routine monitoring to address issues that impact tenant satisfaction proactively.
- Nantum OS preserves staff experience and knowledge for the next generation of building leaders.
- Nantum OS institutionalizes energy-saving practices as repeatable processes, irrespective of the differences between buildings.

- Nantum OS provides "total situational awareness" of building systems, whether for a single property or entire real-estate portfolio.

Methodology

Eight Rudin buildings received NYSERDA assistance in 2016 to install NantumOS as a core element of their energy management upgrades. NYSERDA revisited the eight buildings in 2018 to gather insights into Rudin's experiences and operational results after having used NantumOS for multiple seasons.

Table 2 shows the eight Rudin buildings selected for analysis in the study.

Table 2: Buildings Participating in the Study

Property Address	Square Footage	Floors	Opened/Renovated
3 Times Square	885,000	30	2001
32 Avenue of the Americas	1,170,000	27	2002
40 East 52nd Street	385,000	23	1986
41 Madison Avenue	560,000	42	1974
355 Lexington Avenue	270,000	22	1959
1675 Broadway	800,000	35	1989
80 Pine Street	1,080,000	38	1960
845 3rd Avenue	365,000	21	1963

The primary data used for the study were the hourly interval data gathered from the buildings' Con Edison electric utility meters, because the meter and data predated NantumOS and is also independent from the capabilities of the RTEM system. The analysis covered interval data spanning from 2012 to 2018.

The buildings at 3 Times Square and 80 Pine Street were included during the identification of NantumOS use cases and best practices portion of the study. However, the interval data from these two buildings were not available as a continuous stream from 2012 through 2018 from Con Edison, and consequently these buildings were excluded from the quantitative portion of the study.

NYSERDA also interviewed the property manager and chief engineer of each building listed in Table 1 to understand how NantumOS is used daily by the property staff. Rudin portfolio executives with responsibility for the eight Rudin buildings were also interviewed to explore how executives monitor the buildings using NantumOS.

The map in Figure 1 identifies the locations of the eight Rudin buildings and the location of the weather station providing the data for normalization.

Figure 1: Locations of the Rudin Buildings and Weather Data

Nantum OS Use Cases

Rudin attributed the integration of core building systems into Di-BOSS, and later, NantumOS, as the key to successful optimization. The RTEM system in each building integrated data from the building automation system (BAS), utility meters (electricity, gas, steam and water), and occupancy counts from the security turnstiles. Additional temperature sensors were also deployed to provide increased visibility of the building's interior environments in various tenant spaces. Integrations into other silo critical systems like elevator and fire alarm systems are being implemented for additional insight into all building operations.

Rudin prioritized minimizing the energy consumption of each building without sacrificing comfort obligations. Sophisticated software algorithms would ingest the building's recent historical data and real-time data, marrying them with real-time weather data and weather forecasts, to predict building conditions and to deliver recommended actions for the building operators.

Rudin's management team was focused on optimizing critical operations as far back as 2011:

- **Start-Up:** Scheduling building mechanical system start-up at the beginning of the day
- **Capacity Control Strategies:** Automatically adjusting building mechanical system capacity according to the actual building occupancy level during the day

Before RTEM (Di-BOSS and later, NantumOS), each building with a lease-obligated schedule would start up at a fixed time each day (many hours before the building was occupied), run at a constant capacity throughout the day, and then ramp down at a fixed time each night. This is a common practice of building operators.

The start-up time is determined by the Rudin engineer on duty, based on the forecasted weather conditions for the day, the engineer's knowledge of the building plant, and the time required for the building's various internal environments to reach a comfortable level. It is common for the engineer to start up equipment hours before doors open to ensure the building is within the comfort range by the time the first occupant arrives. The ramp down is usually a fixed time in the evening for non-holiday weekdays; and around noon to 1 p.m. on Saturdays. Some air handling units (AHUs) and make-up air units (MAUs) may continue to operate in reduced capacity to provide ventillation for after-hours activities, such as tenant overtime HVAC request.

For Rudin buildings with a 24x7 schedule, such as demanded by certain types of tenants or for supplying essential services (e.g., chilled water and condenser water for data center conditioning), the central plant operates at a pre-determined fixed capacity, and the operators may only manually start and ramp down AHUs/MAUs serving areas with occupied/unoccupied schedules.

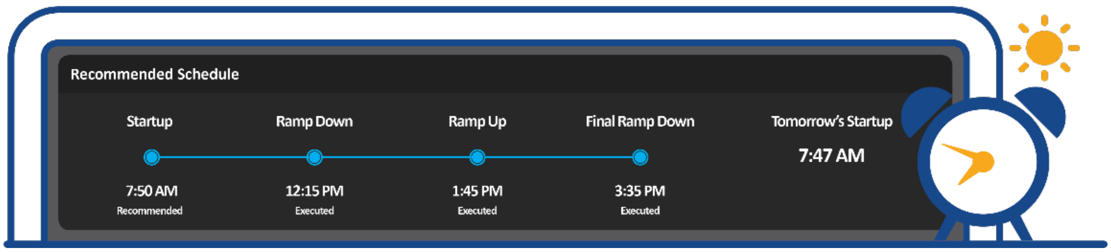
Beginning-of-the-Day Start-Up

Nantum OS predicts a customized start-up time for the next day that would bring building temperatures into compliance with lease obligations by the time the building is occupied. The prediction takes into account the next day's weather, the lease-obligated schedule, the building plant capacity and the likely temperatures within the building just prior to start-up.

The recommended start-up time is designed to consume the least amount of energy to bring the building into compliance with the lease-obligated schedule without sacrificing comfort settings.

Figure 2 shows NantumOS dashboard with a recommended schedule for the current and next day.

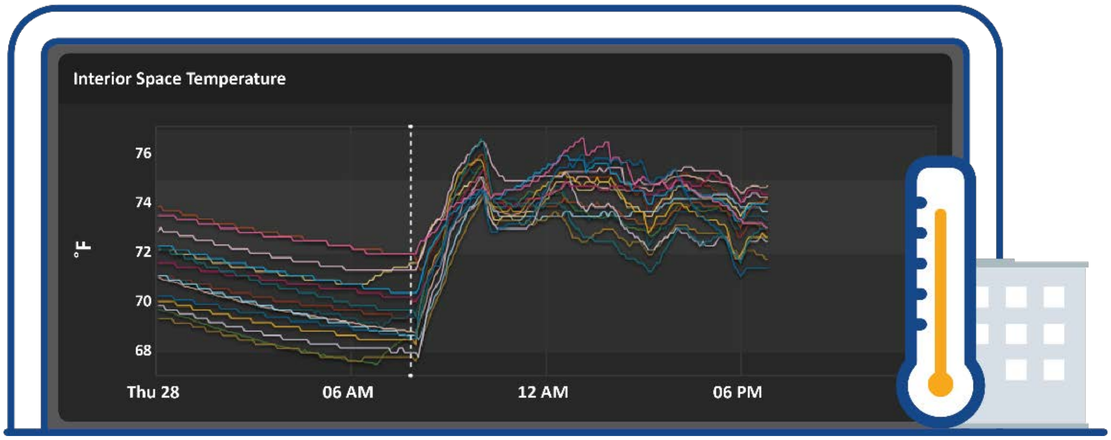
Figure 2: Nantum OS Recommending Next Day's Start-Up Time



The Rudin engineer on duty during the morning start-up, which is usually the building's chief engineer, would review the recommended start-up time, and if agreed, start up the building's plant at the appointed time using the BAS. Building operators would also monitor the various interior temperatures in real time during this critical period to ensure the building environments are conditioned as expected, and intervening as necessary. Interior space temperature monitoring would continue throughout the day so the operators can be proactive in addressing tenant comfort issues before a complaint is reported by an occupant.

Figure 3 shows interior temperature space monitoring for various Rudin building zones.

Figure 3: Nantum OS Displaying Interior Space Temperatures



If the start-up deviates from NantumOS's recommendation by more than 15 minutes, Prescriptive Data would be notified of the decision of the engineer on duty to deviate. This feedback is used to continuously fine tune recommendations. Consequently, the recommended start-up time has been fine-tuned over the years, to the point where Rudin's engineering staff now follow the the recommendations routinely.

Figure 4 shows Nantum OS's recommended start-up time of 7:01 a.m. on a Monday after the building has been idle over a weekend. The start-up time compensated for the interior conditions of the building and the weather forecast for Monday to reach comfort settings by the time the lease-obligated schedule is in force.

Figure 4: Nantum OS's Recommended Start-Up Time of 7:01 a.m. on a Monday

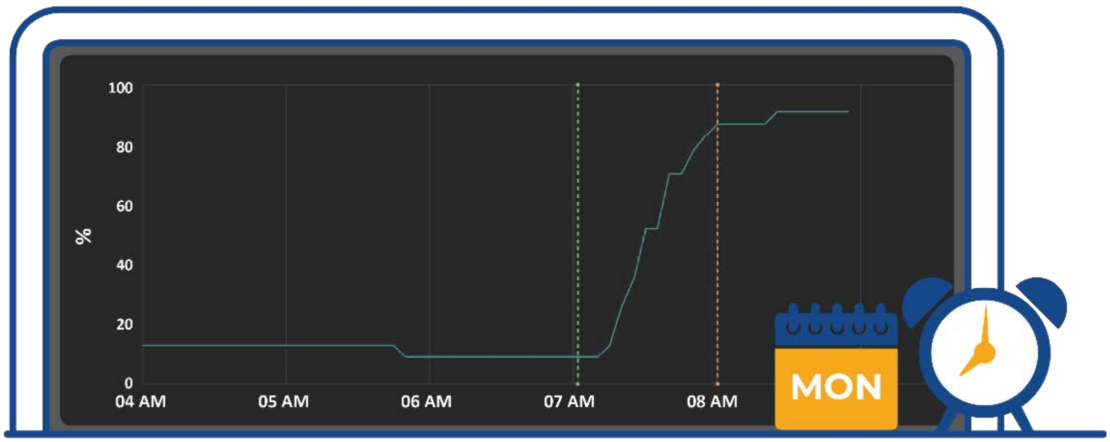


Figure 5 shows Nantum OS's recommended start-up time of 7:42 a.m. on a Tuesday morning. The building's interior temperature and the weather forecast for Tuesday allowed for a later start-up time, saving energy and costs compared to a fixed and unchanging start-up schedule.

Figure 5: Nantum OS's Recommended Start-Up Time of 7:42 a.m. for the Following Tuesday

The continuous fine-tuning of Nantum OS prediction algorithm is a key differentiator of Prescriptive Data's RTEM offering. The years of critiquing and correcting by staff responsible for adhering to the building's lease obligations, minimizing tenant complaints, and lowering energy costs and overtime has produced a robust and reliable product capability that is the core of Rudin's current operating practices.

Automatic Capacity Control Modulation

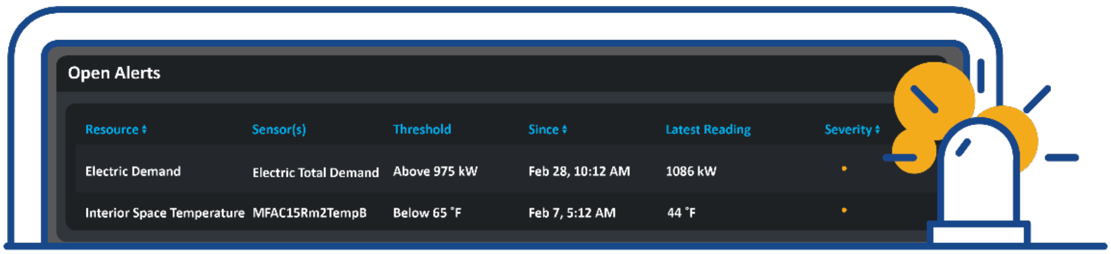
Nantom OS displays a day's forecasted building consumption along with the actual building consumption. Operators are trained to react to excess consumption and to identify the cause of the deviation, such as when a certain plant is consuming excessive electricity or a failure has occurred in the control system to reduce unneeded capacities.

Figure 6 (top left) shows Nantum OS's predicted consumption pattern as a dashed line; the solid shaded plot is the actual consumption. The closeness between the forecasted consumption and actual consumption is a clear demonstration of the RTEM's prediction capability.

Figure 6: Nantum OS Dashboard Display Example

In addition to monitoring, Rudin engineers also rely on Nantum OS's alert function to assist in detecting excessive consumption. Figure 7 shows an example of an alert display.

Figure 7: Nantum OS's Alert Function Detects Excessive Total Demand



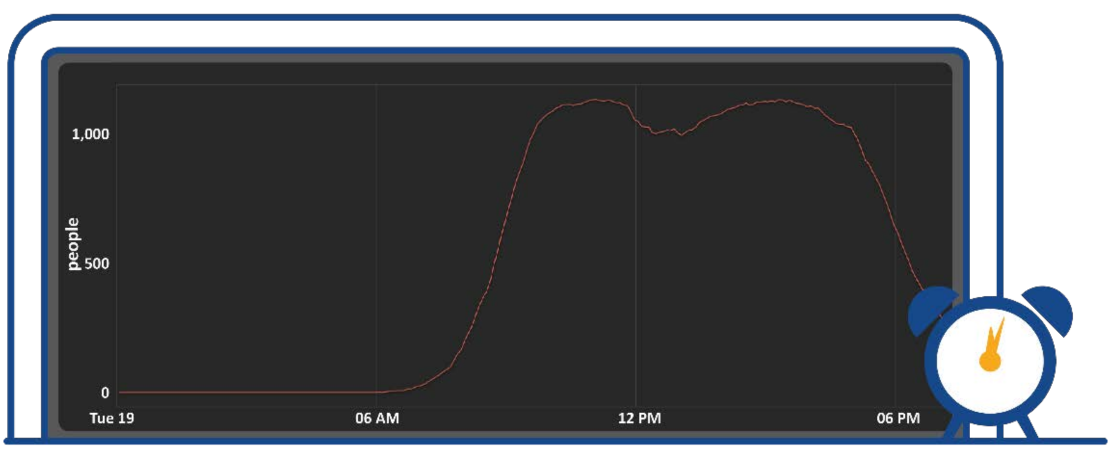
The integration of the security turnstile into Nantum OS enables the building operator to monitor the building's actual occupancy in real time.

Figure 6 (lower left) displays the real-time building occupancy.

Early in the development of Di-BOSS, Rudin staff noticed the occupancy would begin to decrease near lunchtime and rise again in early afternoon. This "double humped" occupancy pattern is an opportunity to reduce energy consumption by adjusting the building mechanical plant capacity using devices such as variable-frequency drives connected to pumps, fans, and compressors to match the building occupancy profile.

Figure 8 shows an example of the "double humped" occupancy pattern.

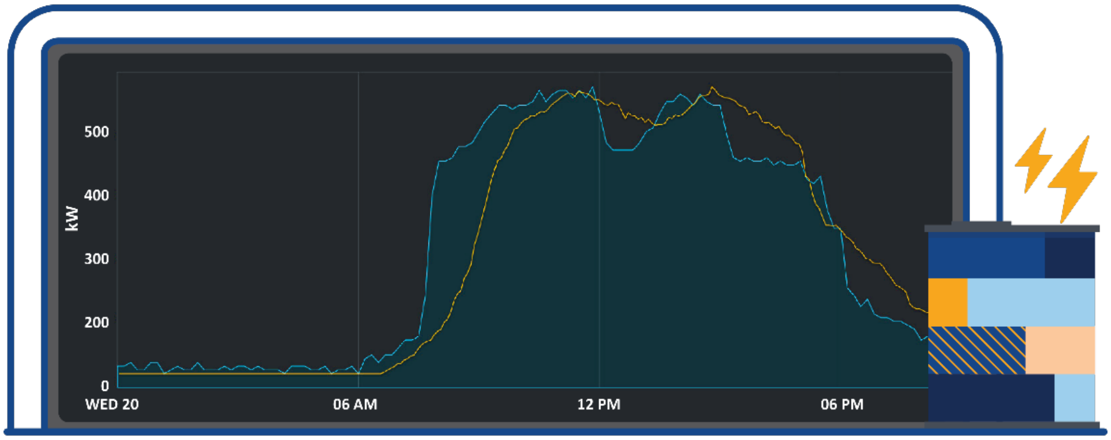
Figure 8: Occupancy Pattern Showing Lunchtime Ramp-Down



Nantum OS would automatically command the BAS to execute a predetermined ramp-down sequence near lunchtime to reduce energy consumption, and also to automatically command the BAS to ramp the building's plant back up as occupancy returns after lunch.

Figure 9 shows the result of adjusting a building's electricity demand (shaded curve) with the actual occupancy level (line curve). Because of Nantum OS's predictive capabilities and automated sequencing, changes in the building consumption are slightly ahead of the actual occupancy changes to ensure the building's comfort environment is maintained while saving energy.

Figure 9: Nantum OS Showing the Related Occupancy Pattern and Electricity Demand of a Building



End-of-the-Day Ramp-Down

The same occupancy-based control also allows for the end-of-the-day ramp-down to occur as soon as the occupancy level starts to decrease. Figure 9 shows the multiple steps of the end-of-the-day ramp-down in the building's energy consumption. Immediately after the occupancy peaked following lunchtime, a steady stream of occupants began to leave the building (starting in the middle of the afternoon), allowing the building plant to scale back capacity, again lowering energy consumption. The precipitous drop in occupancy later in the afternoon permitted the further reduction of plant capacity accordingly.

Figure 9 also clearly demonstrates Rudin's well-orchestrated operational practices. The direct effect of occupancy on the building's energy consumption is made possible because Rudin executives have invested in meters, sensors and the integration of all major building systems into Nantum OS. The short intervals between changes in the building's energy consumption and the occupancy level demonstrate an understanding of a building's thermal characteristics. This is achieved because algorithms within Nantum OS access a wealth of data, enabling the accurate prediction of changes in the internal environment as a function of time of day, occupancy level, weather and building plant responsiveness.

As a result, building operators can be proactive in allocating their time and attention to system monitoring and maintenance, as the building is being monitored continuously by an intelligent system.

Quantifying Energy Savings

This section quantifies the savings from Rudin's use cases for Nantum OS. Calculations are simplified so the results may be broadly applied.

At a quick glance, potential energy reduction from delaying start-up, employing occupancy-based control during the lunch hours, and implementing end of day ramp down may seem small compared to the effort expended. Skeptical building owners and operators may surmise that concerns over the risk of failing comfort settings obligated in tenant leases are not justified.

What is missing is an understanding that the savings from Nantum OS use cases described in the previous sections are grounded in science and engineering principles. The uncertainty is mostly derived from the lack of insights into the physical properties of a building in obtaining a desired thermal state, and the time it takes to deviate from the achieved state when the energy introduced by mechanical conditioning is removed or reduced.

A competent RTEM system, such as Nantum OS, is designed to integrate existing data from the various building systems. The algorithms, residing in the cloud, have access to practically unlimited resources to "crunch" the data in real time and deliver a continuous stream of consumable information (recommended actions), enabling building operators to regulate building mechanical plants proactively. Most of the comfort concerns described in the use-cases that resulted from optimizing control can be anticipated and resolved before their impacts are noticed by the tenants.

Optimizing Start-Up

Start-up electricity consumption profiles (Figures 6 and 9) reflect real-world variations in small time increments as the mechanical plant and equipment respond to BAS control. Consequently, calculating savings is unnecessarily complicated, especially when a good approximation is all that is needed to quantify savings. The use of approximations and simplifications are common in energy engineering and have been well accepted in the industry.

Figure 10 shows a simplified profile of a mechanical plant's electricity (kW) consumption profile over 24 hours. This plant is started at 3 a.m. and ramps up to full consumption within half an hour. The assumption is the plant was started based on a fixed schedule, or the start-up was determined by the responsible engineer on duty conservatively to ensure the building would be within comfort settings before the occupied time obligated in the lease. In many existing practices, a start-up time of 3 a.m. is not uncommon to condition the building by 8 a.m.

The plant is shut off in Figure 10 at 6 p.m., which is when the building is anticipated to be unoccupied. The consumption decreases within half an hour. Some AHUs/MAUs may continue to operate to keep the air circulating for after-hour activities until midnight, such as when the cleaning crew is working in the building.

The simplified profile in Figure 10 is used as a baseline to calculate relative savings as the start-up time is delayed.

The total electric energy measured in kWh is equal to the area contained within the kW profile over the operating hours. Using Figure 10 as the baseline, delaying the start-up time by one hour from 3 a.m. to 4 a.m. would reduce kWh consumption by 6.48%; all other factors would remain unchanged (according to Figure 10). Delaying the start-up time by another hour to 5 a.m. would increase savings to almost 13% compared to the baseline. If the start-up is eventually delayed to 6 a.m., as shown in Figure 11, savings in electricity jumps to 19.4%.

Figure 10: Baseline HVAC Plant Consumption Profile

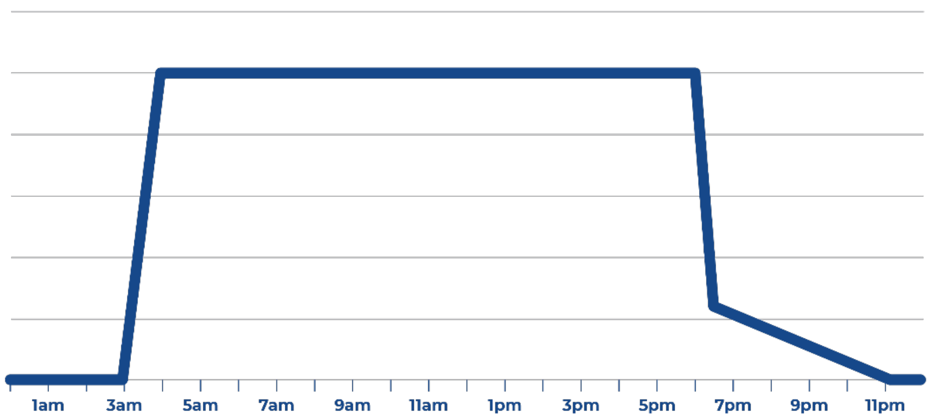


Figure 11: Delay In HVAC Plant Start-Up Time

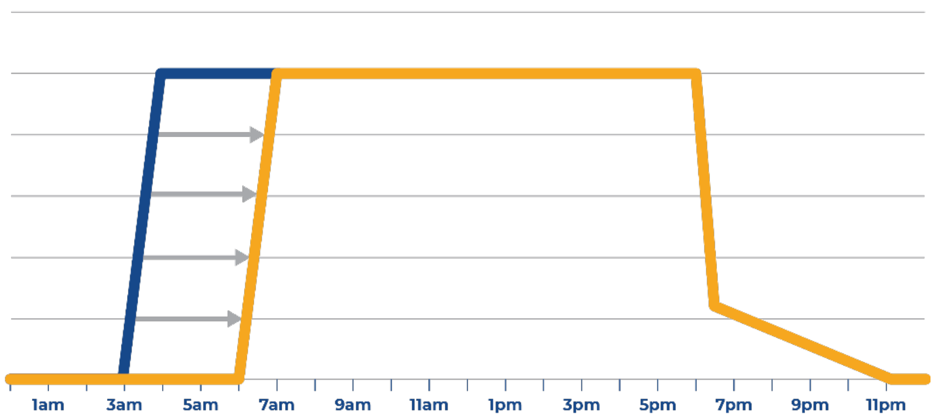


Table 2 summarizes the savings for delaying start-up from 3 a.m. to 4 a.m., 5 a.m. and 6 a.m., respectively. The savings is reported in percentages compared to the consumption of the baseline profile.

Table 2: Energy Savings Compared to Figure 9 Baseline

	Savings	Hours
3AM Start-Up	Baseline	15
4AM Start-Up	6.48%	14
5AM Start-Up	12.96%	13
6AM Start-Up	19.43%	12

Knowledge of the rate at which the building's various interior environments respond to mechanical cooling or heating is necessary to confidently optimize start-up. Rudin's management has invested in installing additional sensors in representative spaces within the building to supplement readings provided by the BAS. The monitoring of the actual space environment allows for a reduction in operating hours, with each hour of reduction providing corresponding savings.

This strategy is readily available to commercial buildings where the building plant is not operating 24x7. Operators and consultants can quickly evaluate the level of savings possible for any building by analyzing existing data and historical records. It may require a straightforward retrofitting of sensors and fine-tuning of the existing BAS to implement this strategy. An optimized start-up should be considered for every major BAS or building plant renovation project. NYSERDA encourages building owners and operators to revisit the start-up process of their buildings to identify optimization opportunities.

Automatic Capcity Control Modulation - Lunch Hour Ramp-Down

The information collected by a building's security turnstile system is very useful for estimating the number of building occupants for the purpose of HVAC control. Also, using these data, the relationship between the temperatures in various spaces and occupant levels can be understood.

Once this relationship is understood, the building operator can confidently scale back the building plants and save energy as building occupancy decreases. A building plant with variable-frequency drives provides the adjustment mechanism to scale the mechanical conditioning capacity.

Figure 12 shows the baseline and two scenarios in which the building plant is ramped down for 90 minutes during the lunch hour period, with a reduction in plant consumption of 10% and 20%, respectively.

Figure 12: Lunchtime Occupancy Adjustment

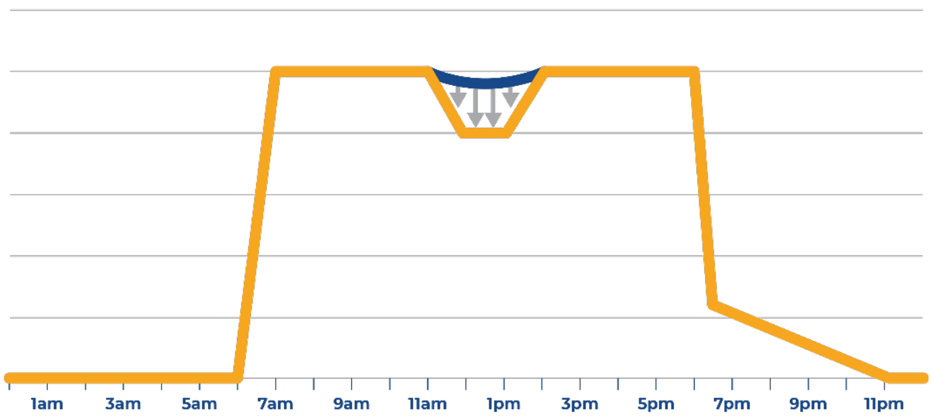


Table 3 summarizes the savings for the two lunch period ramp-down scenarios. A reduction of 10% during the lunch period provided a daily energy savings of 1.6%, compared to the baseline case without lunchtime control. A reduction of 20% provides daily energy savings of 3.2% compared to the baseline. In these scenarios, the baseline is shown in Figure 11, where the plant was started up at 6 a.m.

Table 3: Energy Savings Based on 1.5 Hours of Lunchtime Control

Lunchtime Control	Savings
No Adjustment	Baseline
10% Adjustment	1.61%
20% Adjustment	3.22%

Automatic Capacity Control – End Of Day Ramp Down

As a thermal storage medium, a building does not lose conditioned thermal energy quickly. There is an opportunity for energy savings by using a building's actual occupancy level to determine when the building plant should ramp down while maintaining comfort levels.

Figure 13 compared end of day ramp down at 6 p.m. with two scenarios of early occupancy-based ramp down: one ramp down at 5 p.m. and the other at 4 p.m. In both scenarios, the ramp down times were based on occupants leaving the building, which decreases the building load. The earlier ramp down would avoid the wasting of energy in zones that are lightly occupied.

Figure 13: Occupancy-Based Early Ramp down

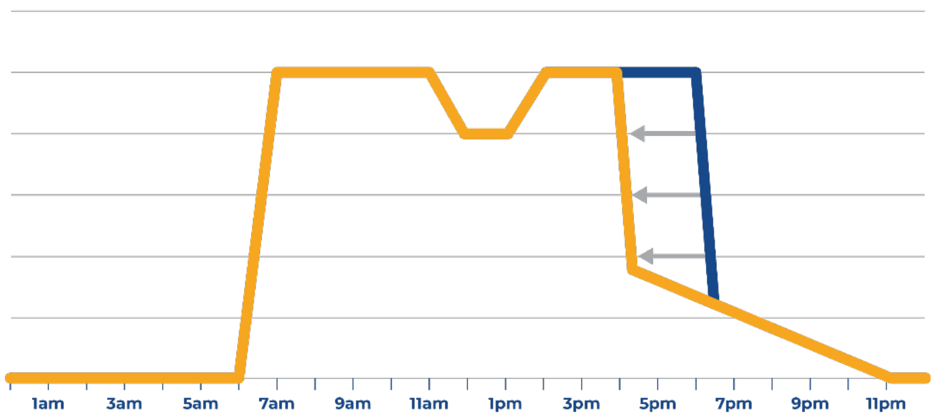


Table 4 summarizes the energy savings of the early ramp down. Shutting down earlier by one hour can save energy by almost 6%. Shutting down earlier by two hours provides savings of 11.4%.

Table 4: Energy Savings of Early Ramp down Using the Building's Actual Occupancy Level

	Savings	Hours
6 p.m. Ramp down	Baseline	12
5 p.m. Ramp down	5.92%	11
4 p.m. Ramp down	11.42%	10

Aggregated Savings Opportunity

By aggregating all three use cases, optimizing start up, ramping down during the lunch hours and shutting down the building plant early, almost 31% of savings is available, as summarized in Table 5.

Table 5: Energy Savings Comparing Figure 13 to Figure 10

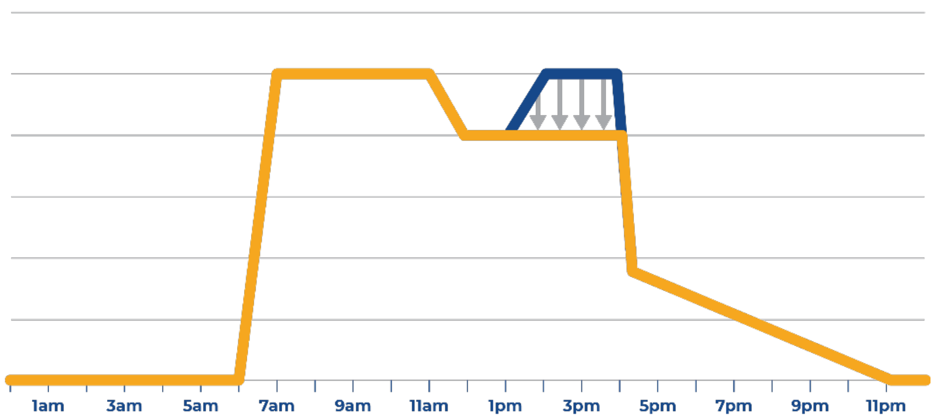
	Savings
Figure 10	Baseline
Figure 13	30.93%

Totaling the three use cases, the mechanical plant's daily consumption of electricity can be reduced by 31% through the judicious use of the RTEM system. Rudin has demonstrated these savings can become routine and has trained their operators to watch for deviations when these savings are not realized.

Additional Opportunities

There are additional novel opportunities where creative building operators can exploit the strategies described in the three uses cases. Figure 14 shows a savings strategy that is available when occupancy levels depart from normal patterns, such as Fridays during the summer and just before major holidays.

Figure 14: Friday Consumption Profile



Rudin noticed that on many Fridays, building occupancy levels never returned to the morning peak after the lunch hour lull. The same profile also occurs just before major holidays.

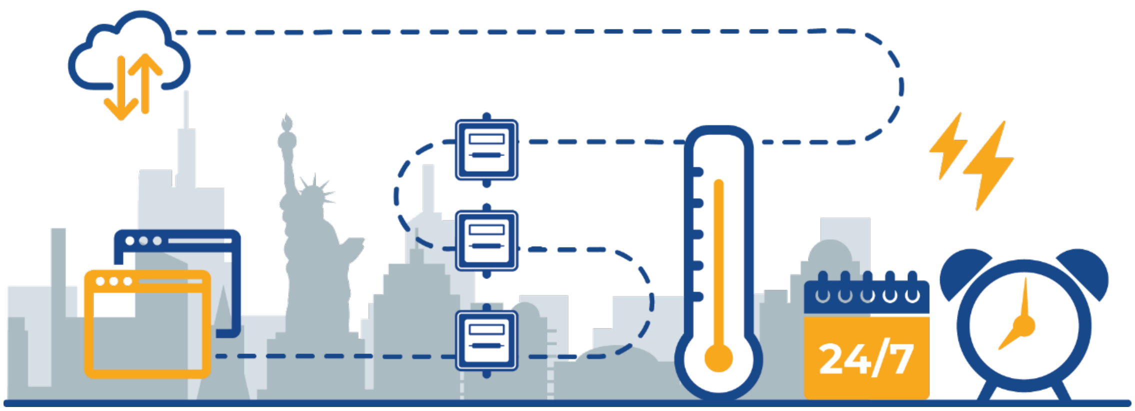
The occupancy-based ramp-down strategy would automatically detect the reduction in building occupancy and scale back the mechanical plant capacity. Figure 14 shows significant savings are available with the building operating at 80% capacity for the afternoon period.

Nantum OS as a Competitive Differentiator

Rudin employs Nantum OS as a differentiator in New York City's competitive Class-A commercial real-estate market.

Rudin's commitment to energy management is embraced at all levels of the corporation, from engineers working in a building to the most senior executive officer. Everyone NYSERDA has interacted with at Rudin has demonstrated an understanding that implementing an energy-efficient approach to building operation brings greater value to the organization than simply reducing utility bills. Rudin's buildings are operated at maximum efficiency, with staff anticipating and addressing routine weather variations and occupancy changes. This approach has freed the Rudin property managers and engineers to focus proactively on increasing tenant satisfaction, improving maintenance, and identifying continuous improvement opportunities.

As an enabling technology, Nantum OS is integrated into the management process of every Rudin building addressed in this study. Rudin has invested substantial engineering and executive expertise in refining the building thermodynamic modeling and how information is presented in actionable recommendations. Rudin refers to this as "total situational awareness." Additional sensors, meters, and systems are integrated to supplement data from the BAS to optimize all building energy use and automate the fine-tuning of the central plant capacity.



As more and more RTEM systems have incorporated advanced data analytics and refinement, using machine learning and artificial intelligence to develop an accurate "digital twin" for a building, the dependability of prediction dramatically improves overtime as real-world data are analyzed. Regardless of the sophestication of the RTEM algorithms, modeling a building's thermodynamic behavior begins when RTEM is installed in the building. Rudin's years of experience refining Di-BOSS and Nantum OS have resulted in RTEM systems that are now capable of outputting predictions that accommodate unique building characteristics across their entire portfolio. The procedures followed by the property manager and engineering staff are consistent across Rudin's portfolio, resulting in a largely common and repeatable management process for every building.

Weather-Normalized Whole Building Analysis

This study independently verified additional electricity savings with Nantum OS using whole-building, weather-normalized analysis. As expected, the savings varied between the buildings, due to the differences in the building systems, schedules, square footage, and other characteristics.

The savings summarized in Tables 6 and 7 separated savings between occupied days (non-holiday weekdays) and non-occupied days (weekends and holidays).

Nantum OS upgrades at the eight Rudin properties analyzed in this study were initiated in mid-2016 and the upgraded systems were fully commissioned by early 2017. NYSERDA selected the 12 months immediately before the start of the installation as the baseline period and the 12 months immediately following the start of the installation as Nantum OS installation period. Also, the 12 months after commissioning of Nantum OS were selected as the performance period of the analysis.

- **Baseline Period:** May 2015 – April 2016
- **Nantum OS Installation Period:** May 2016 – April 2017
- **Performance Period:** May 2017 – April 2018

The baseline period has already benefited from all the improvements Rudin has accrued from the Di-BOSS deployment since 2012. The upgrade to Nantum OS introduced capabilities not available in Di-BOSS, with additional sensors for the expanded monitoring of tenant spaces, and additional variable-frequency drives installed to maximize controllability of the plants and equipment. Tables 6 and 7 summarize the savings for six of the eight participating buildings where NYSERDA was provided with uninterrupted interval meter data from 2012/2013 to 2018.

Table 6: Nantum OS Relative Savings

Property Address	Normalized Savings for Occupied Days (%)	Normalized Savings for Non-Occupied Days(%)
41 Madison Avenue	4.2%	11.7%
40 East 52nd Street	4.3%	11.4%
1675 Broadway	8.2%	19.6%
355 Lexington Avenue	10.7%	6.0%
32 Avenue of the Americas	12.3%	10.6%
845 3rd Avenue	16.8%	22.28%

Table 7: Nantum OS kWh Savings

Property Address	Normalized Savings for Occupied Days (kWh)	Normalized Savings for Non-Occupied Days(kWh)
41 Madison Avenue	59,401	125,060
40 East 52nd Street	61,497	123,866
1675 Broadway	171,288	321,433
355 Lexington Avenue	300,875	54,918
32 Avenue of the Americas	789,975	670,588
845 3rd Avenue	671,998	444,337

As noted earlier, the buildings in this study were already well-orchestrated buildings, having benefited from Rudin's commitment to energy management and the building staff's experience with machine learning. Nonetheless, this study verified the additional savings summarized in Tables 6 and 7. This is a clear demonstration that opportunities for savings are still available even after having harvested the "low-hanging fruits."

NYSERDA used the average daily wet-bulb temperature from the Central Park Weather Station in New York City as the common independent variable for the regression analysis. Each building's interval data were also averaged from hourly intervals into daily averages. A step-wise linear regression technique was employed, with the breakpoints identified by building. Separate equations were developed for the occupied days and non-occupied days. The baseline energy consumption of each building was recalculated using the linear regression equations based on the wet-bulb temperatures of the performance period.

It is interesting to note the R^2 values of the residuals with a three-step linear regression showed that, beyond wet-bulb temperature and occupied and non-occupied days, there are additional factors influence consumption with a pattern that is more or less random. For example, the Central Park weather data do not reflect the variations of the micro-climate patterns in the immediate location of the buildings, such as heat gain from solar exposures or shadowing by neighboring properties that have to be compensated. Additionally, the dynamic adjustments that Rudin practiced during the lunch hours and end-of-the-day ramp down were also contributing to the higher R^2 value of the regression. Considering the additional factors identified, NYSERDA is confident that the analysis is a valid comparison of the Rudin buildings' energy performance between the baseline and the performance periods.

Figures 15 to 26 graphically illustrate a comparison of the normalized baseline and performance period consumption, by occupied days and unoccupied days.

Normalized Baseline   Performance

Figure 15: 41 Madison Avenue Occupied Period

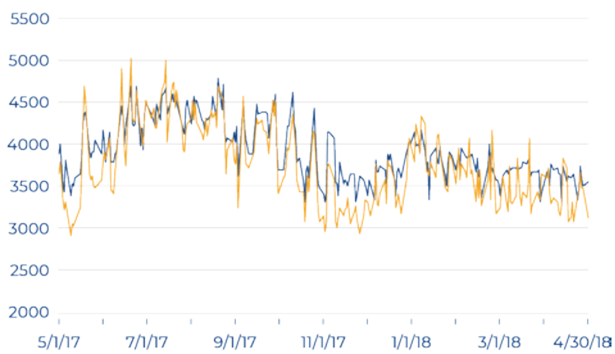


Figure 16: 41 Madison Avenue Non-Occupied Period

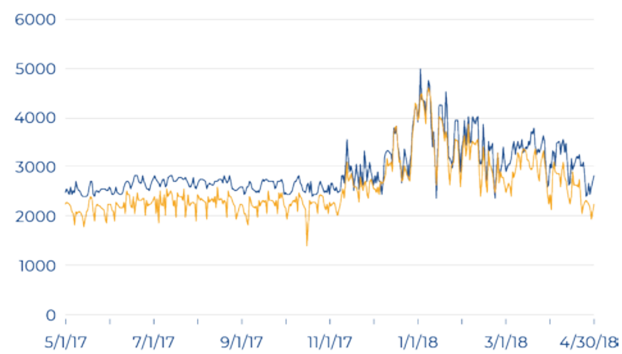


Figure 17: 40 East 52nd Street Occupied Period

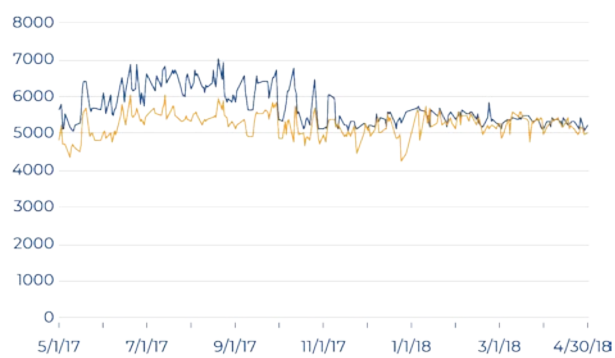


Figure 18: 40 East 52nd Street Non-Occupied Period

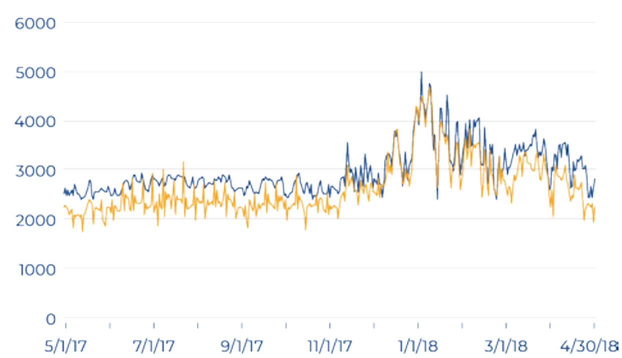


Figure 19: 1675 Broadway Occupied Period

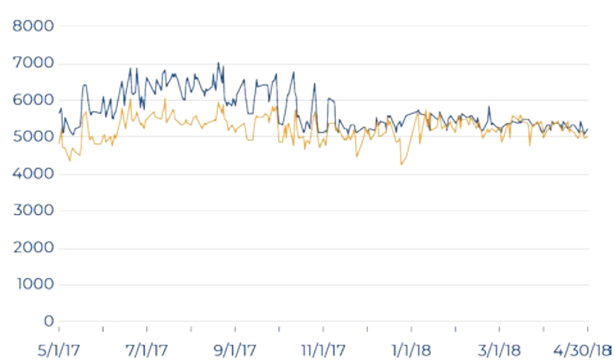
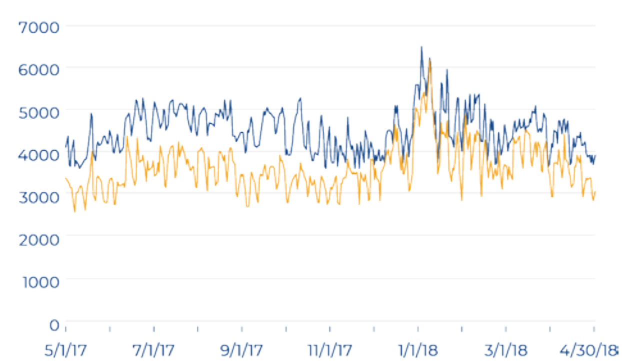


Figure 20: 1675 Broadway Non-Occupied Period



Normalized Baseline Performance

Figure 21: 355 Lexington Avenue Occupied Period

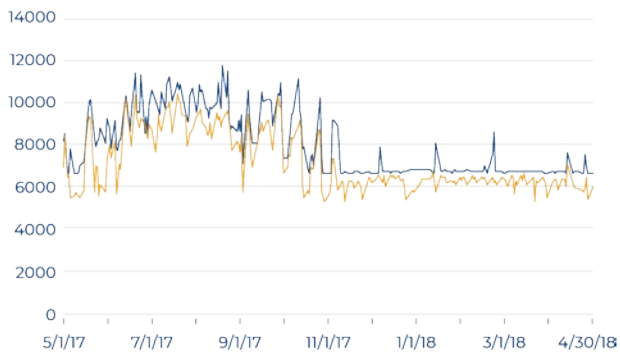


Figure 22: 355 Lexington Avenue Non-Occupied Period

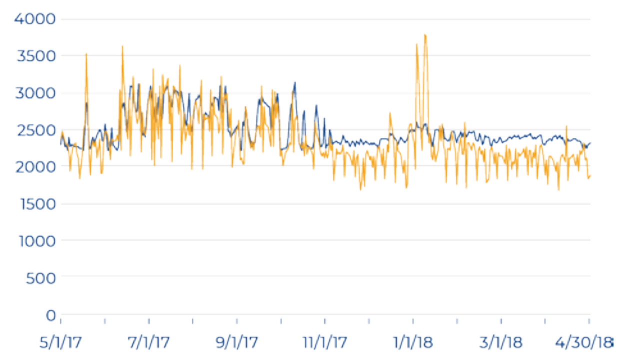


Figure 23: 32 Avenue of the Americas Occupied Period

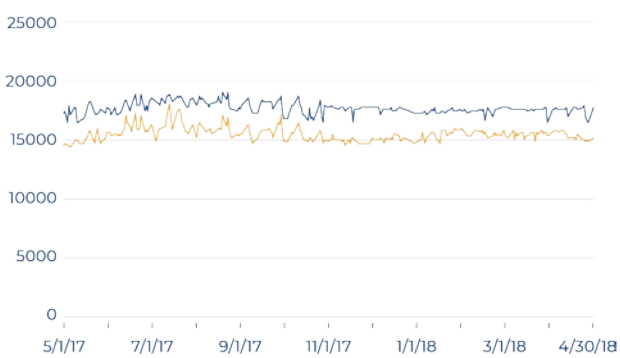


Figure 24: 32 Avenue of the Americas Non-Occupied Period

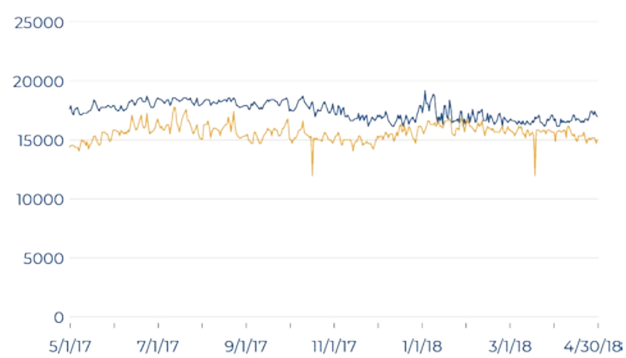


Figure 25: 845 3rd Avenue Occupied Period

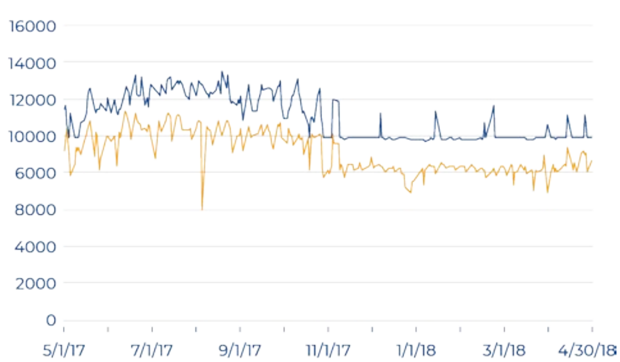
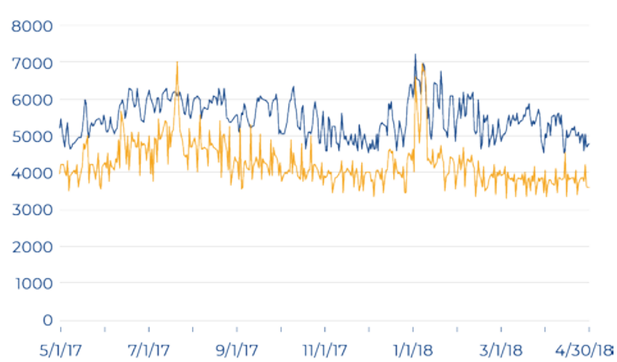


Figure 26: 845 3rd Avenue Non-Occupied Period



Introduction

This appendix to the NYSERDA-sponsored "Rudin Management Case Study – Using Real-Time Management to Optimize Building Operations" provides additional technical details supporting the case study findings.

Overview of Building Systems

Table 1 summarizes the manufacturers of the building automation systems (BAS) installed at the eight Rudin buildings and presents the estimated annual occupied hours (non-holiday office hours: 8:00 a.m. through 7:00 p.m., Monday through Friday; and 8:00 a.m. through 1:00 p.m. on Saturday).

Table 1: Building BAS and Annual Occupied Hours

Property Address	Building Automation	Annual Occupied Hours
3 Times Square	Siemens	3940 Office + 8760 Tenant Services
32 Avenue of the Americas	Johnson Controls	3940 Office
40 East 52nd Street	Andover Controls	3940 Office
41 Madison Avenue	Siemens	3940 Office
355 Lexington Avenue	Andover Controls	3940 Office
1675 Broadway	Johnson Controls	3940 Office
80 Pine Street	Andover Controls	3940 Office + 8760 Tenant Services
845 3rd Avenue	Andover Controls	3940 Office

The buildings at 3 Times Square and 90 Pine Street are responsible for supplying chilled water and condenser water 24x7x365 to the tenants' equipment housed at the building.

Heating and cooling plants are the major energy consumers in the buildings. Table 2 summarizes the main heating and cooling plants used to condition the building core and common areas. These systems are maintained and operated by Rudin engineers; tenant systems are not included in Table 2.

The building systems analyzed in the study deliver comfort heating using steam provided by Consolidated Edison (Con Edison). The steam pressures are lowered and sent to heat exchangers to generate heating hot water (HHW), which is pumped to the heating terminals. Most of the heating terminals are located at the building perimeters.

Table 2: Core Heating and Cooling Plants

Property Address	Core Heating	Core Cooling
3 Times Square	Steam/HHW Fin-Tube Radiators	2 Gas Absorption Chillers (650 Tr) 2 Centrifugal Chillers (1350 Tr)
32 Avenue of the Americas	Steam/HHW Perimeter Radiators	4 Carrier Chillers (800, 3x500 Tr)
40 East 52nd Street	Steam/HHW Baseboard	Package DX Units on Floors
41 Madison Avenue	Steam/HHW Perimeter Induction	2 Steam Absorption Chillers (1075 Tr)
355 Lexington Avenue	Steam/HHW Perimeter/Interior	2 Centrifugal Chillers (800 Tr Total)
1675 Broadway	Steam/HHW Baseboards	Package DX Units on Floors
80 Pine Street	Steam/HHW Perimeter/Interior	2 Steam Turbine Chillers (1600 Tr)
845 3rd Avenue	Steam/HHW Perimeter Induction	2 Steam Turbine Chillers (795 HP)

Three buildings rely on chillers that are not electrically operated – 41 Madison Avenue, 80 Pine Street, and 845 3rd Avenue. At these buildings, the savings derived from the Nantum OS use cases presented in the case study would largely be in lowered steam or gas consumption not in the scope of this study. Electricity savings are secondary benefits at these buildings.

Two of the buildings are air-conditioned using packaged DX units located on the floors – 40 East 52nd Street and 1675 Broadway.

Impacts of Outside Temperature on Electricity Usage

The analysis of kW usage as a function of outside temperature is a common method employed by energy engineers to characterize building energy consumption. This section compares the impact that wet-bulb temperature in Manhattan, NY has on the kW usage profile of the Rudin buildings for the periods before and after the installation of the Nantum OS. The analysis was performed for the six buildings where Rudin provided NYSERDA with uninterrupted Con Edison interval meter data from 2012 to April 2018.

The historical daily dry-bulb and dew point temperatures from the Central Park Weather Station were used to compute the daily average wet-bulb temperatures from 2012 through April 2018. The hourly interval kW data for each building from Con Edison was also averaged into daily kW values for the same periods.

The analysis investigated the impacts of dry-bulb and wet-bulb temperatures on kW usage. Wet-bulb temperatures were used due to better correlations to daily kW usage. The regression equations with wet-bulb temperature as the independent variable and the daily kW as the dependent variable were developed to normalize the baseline period to the performance period. For each building, a set of regression equations were developed for the occupied days, and another set of regression equations were developed for the non-occupied days. The difference between a building's actual kWh consumption during the performance period and the normalized consumption using the regression equations from the baseline period were calculated as kWh savings.

To further illustrate the impact the Nantum OS has on the building kW profiles, Figures 1 through 12 depict daily kW versus wet-bulb temperatures of the occupied days and non-occupied days. The charts demonstrate that all six buildings had lowered kW consumption after the installation of the Nantum OS and indicate the relative magnitude of the savings. The kW usages are also more closely clustered after the Nantum OS installation.

The differences in each building's heating and cooling plants, control strategies, occupancy, and non-HVAC electricity usages are reflected in the daily kW versus wet-bulb temperature profiles.

For example, the Rudin building located at 32 Avenue of the Americas showed that the majority of the building's electricity usage does not change dramatically with outside temperatures. Also, kW consumption does not vary significantly between non-occupied days and occupied days. For comparison purposes, the profiles of the Rudin building at 355 Lexington Avenue showed large differences of kW usage between occupied days and non-occupied days, and the occupied days further showed a distinct increase in electricity consumption with wet-bulb temperatures above the building's balance point temperature.

The balance point temperature (also balance temperature or base temperature) is the temperature at which the building does not need to provide additional heating or air conditioning. When the outside temperature drops below the balance temperature, the building has to be heated; when the outside temperature rises above the balance temperature, the building has to be air conditioned. By convention, the dry-bulb temperature is most commonly used as the balance temperature; as stated previously, wet-bulb temperatures were used in this study due to better correlations to daily kW usage.

Although Figures 1 through 12 use wet-bulb temperatures, it is nevertheless clearly shown that the six Rudin buildings have balance temperatures that are different from the conventional 65 °F when cooling degree days (CDD) and heating degree days (HDD) data are used from weather stations. A building with a lower balance temperature has to expend more energy for air conditioning. The tradeoff is that less heating energy is required to warm the building.

This observation affirms the use of directly measured hourly temperature and humidity for this analysis and not relying on CDD and HDD data.

● Baseline Occupied Actual ◆ Performance Occupied Actual ▬ Predicted < 47 ▬ Predicted > 47

Figure 1: 32 Avenue of the Americas kW Profile of Occupied Days

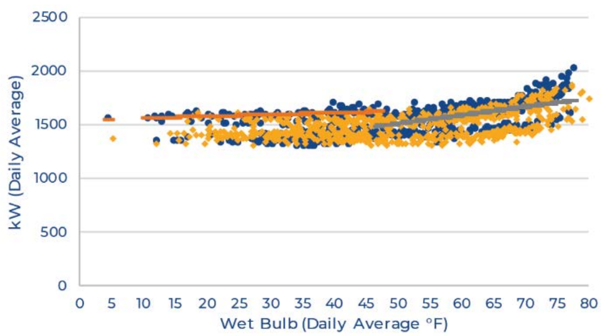


Figure 2: 32 Avenue of the Americas kW Profile of Non-Occupied Days

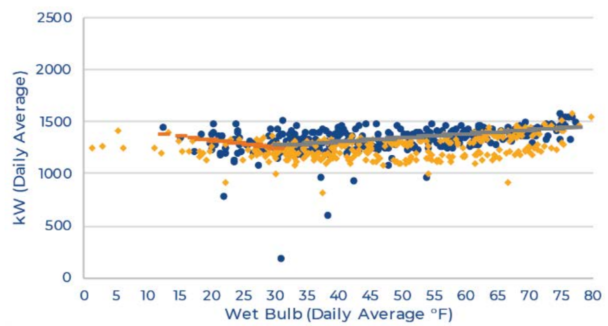


Figure 3: 40 East 52nd kW Profile of Occupied Days

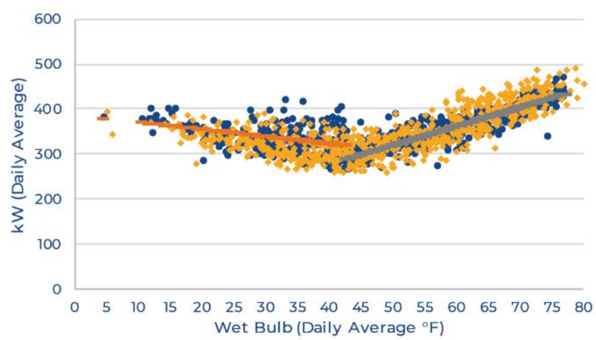


Figure 4: 40 East 52nd kW Profile of Non-Occupied Days

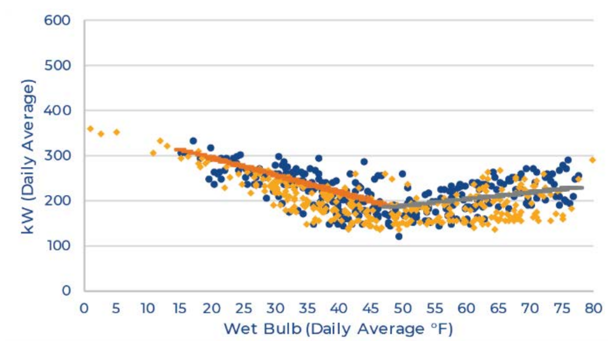


Figure 5: 41 Madison Avenue kW Profile of Occupied Days

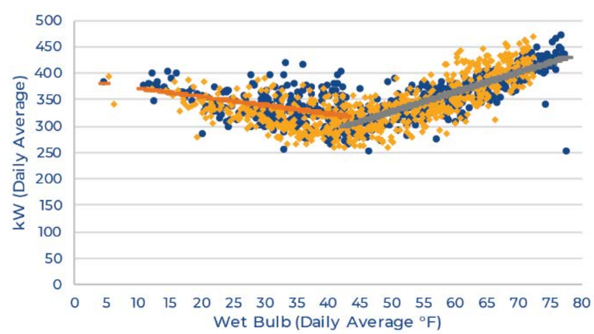
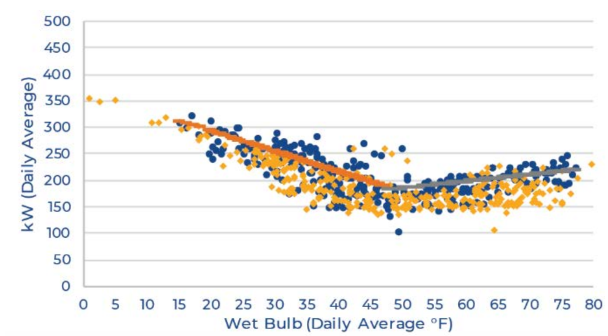


Figure 6: 41 Madison Avenue kW Profile of Non-Occupied Days



● Baseline Occupied Actual ◆ Performance Occupied Actual — Predicted < 47 — Predicted > 47

Figure 7: 355 Lexington Avenue kW Profile of Occupied Days

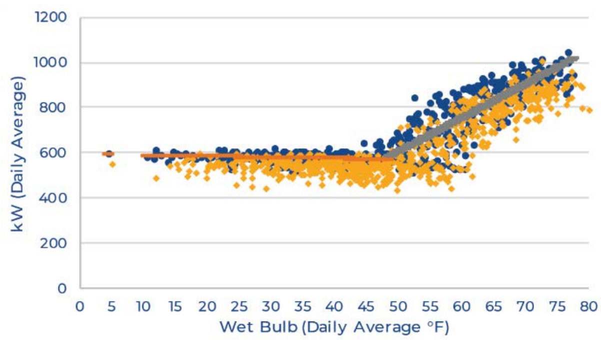


Figure 8: 355 Lexington Avenue kW Profile of Non-Occupied Days

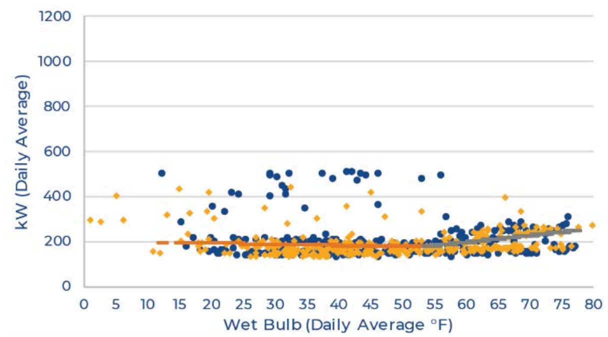


Figure 9: 845 3rd Avenue kW Profile of Occupied Days

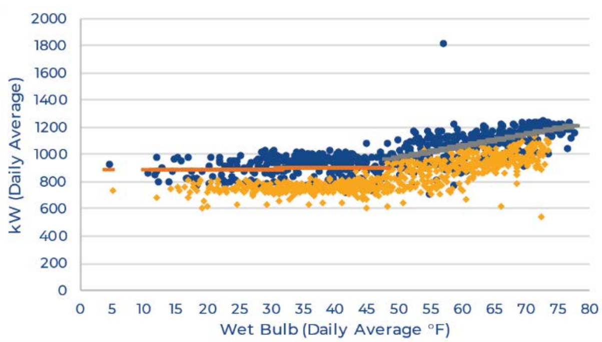


Figure 10: 845 3rd Avenue kW Profile of Non-Occupied Days

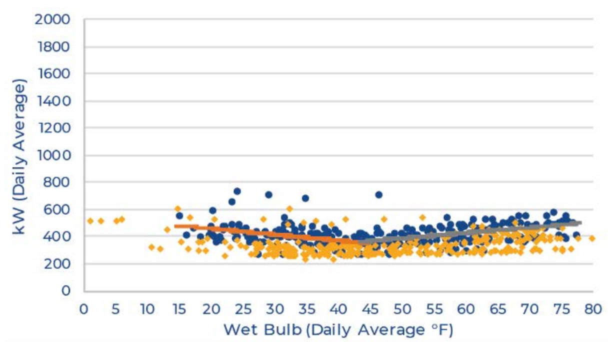


Figure 11: 1675 Broadway kW Profile of Occupied Days

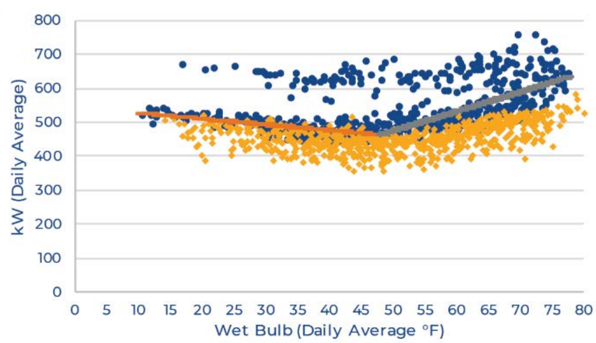
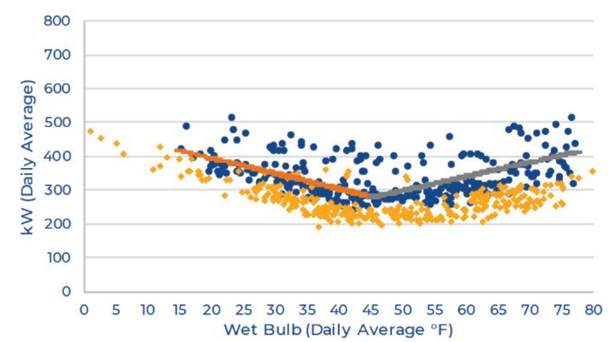


Figure 12: 1675 Broadway kW Profile of Non-Occupied Days



Daily kW Usage Profiles

This section compares the daily electricity usage patterns of six Rudin buildings before and after the installation of the Nantum OS.

Figures 13 through 36 show the hourly kW usage over 24 hours. For each building, two representative days were selected each year from 2012 through 2017 – the day with the year's highest kWh consumption and an average kWh day for the year (average of the occupied days). Unlike the previous kWh savings calculations, the analysis did not perform weather normalization and, consequently, reflects the actual hourly patterns for each building.

The day with the highest kWh consumption of each year was identified and the hourly kW intervals were plotted. As expected, all buildings had the highest kWh days on an occupied day. From a building operations perspective, the highest kWh day represented the highest air conditioning load of the year for each building, and tended to exaggerate the improvements introduced by the Nantum OS. Data from 2018 was not included in this analysis because only four months of data from that year was provided at the time of the study.

Because the kW values were not weather normalized, kWh savings cannot be calculated accurately from the day of the year with the highest kWh, as weather conditions for that day may vary from one year to another. The analysis identifies changes in hourly profiles (Figures 13, 14, 17, 18, 21, 22, 25, 26, 29, 30, 33 and 34).

It is noticeable that the hourly profiles become more differentiated over the hours in a day from 2012 to 2017, showing transitioning from unoccupied hours to occupied hours, and reflecting the later start-up and earlier ramp down times of the building's plants and equipment after the installation of the Nantum OS. Even without weather normalization, it is still possible to observe a decreasing trend of the building's maximum kW usage over this timeframe.

Figures 13, 17, 21, 25, 29 and 33 superimpose the profiles from 2012 through 2017 over each graph. Figures 14, 18, 22, 26, 30 and 34 only superimpose the profiles from 2014 and 2017, which are the years immediately before and after the installation of the Nantum OS, to highlight its contribution.

Unlike a single day of the year with the highest kWh consumption, the annual average temperature only varies by a few degrees from year to year. Table 3 shows the annual and monthly temperatures from the Central Park Weather Station from January 2008 to June 2018 (dry-bulb Fahrenheit (°F) readings). The largest difference between 2012 and 2017 is less than 3 °F, while the difference between 2014 and 2017 is less than 2 °F. The relatively small variations in the annual average temperature allow for reasonable accuracy while directly comparing average daily kWh.

Table 3: Average Annual and Monthly Temperatures at Central Park (Updated 7/8/2018)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	Annual
2008	36.5	35.8	42.6	54.9	60.1	74.0	78.4	73.8	68.8	55.1	45.8	38.1	55.3
2009	27.9	36.7	42.4	54.5	62.5	67.5	72.7	75.7	66.3	55.0	51.2	35.9	54.0
2010	32.5	33.1	48.2	57.9	65.3	74.7	81.3	77.4	71.1	58.1	47.9	32.8	56.7
2011	29.7	36.0	42.3	54.3	64.5	72.3	80.2	75.3	70.0	57.1	51.9	43.3	56.4
2012	37.3	40.9	50.9	54.8	65.1	71.0	78.8	76.7	68.8	58.0	43.9	41.5	57.3
2013	35.1	33.9	40.1	53.0	62.8	72.7	79.8	74.6	67.9	60.2	45.3	38.5	55.3
2014	28.6	31.6	37.7	52.3	64.0	72.5	76.1	74.5	69.7	59.6	45.3	40.5	54.4
2015	29.9	23.9	38.1	54.3	68.5	71.2	78.8	79.0	74.5	58.0	52.8	50.8	56.7
2016	34.5	37.7	48.9	53.3	62.8	72.3	78.7	79.2	71.8	58.8	49.8	38.3	57.2
2017	38.0	41.6	39.2	57.2	61.1	72.0	76.8	74.0	70.5	64.1	46.6	33.4	56.3
2018	31.7	42.0	40.1	49.5	66.9	71.7	-	-	-	-	-	-	-

The analysis calculated the average daily kWh for the occupied days of every year from 2012 through 2017 and identified the dates with the closest daily kWh consumption to the annual daily average. Fridays and days before major holidays were avoided in determining the average kWh day, since these days typically have lower building occupancy levels.

From a building operations perspective, the average kWh day represented the specific building's typical daily air conditioning load for the year. The hourly profile illustrates the most likely contributions by the Nantum OS.

Figures 15, 16, 19, 20, 23, 24, 27, 28, 31, 32, 35, and 36 show the hourly kW profiles over 24 hours for the average kWh day spanning the years 2012 through 2017. Figures 15, 19, 23, 27, 31 and 25 superimpose the profiles from 2012 through 2017 over each graph. Figures 16, 20, 24, 28, 32 and 36 only superimpose the profiles from 2014 and 2017 over each graph, which are the years immediately before and after the Nantum OS installation, to highlight its contribution.

The hourly profiles are similar from 2012 through 2017, with later start-up and earlier ramp down times of building plants and equipment. Also, in some buildings, the mid-day profile with the "double humps" shape becomes more pronounced after the installation of the Nantum OS. The figures that superimpose the profiles from 2014 and 2017 also clearly show the savings introduced by the Nantum OS.

2012 2013 2014 2015 2016 2017

Figure 13: 32 Avenue of Americas Highest kWh Days 2012-2017

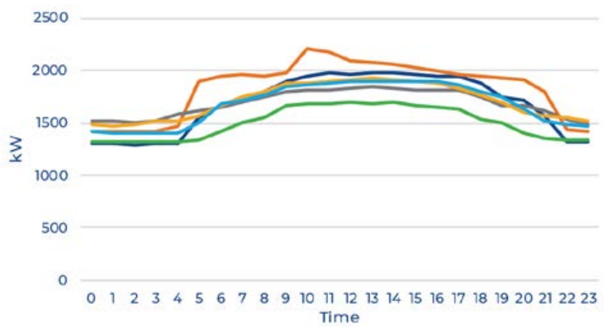


Figure 14: 32 Avenue of Americas Highest kWh Day for 2014, 2017

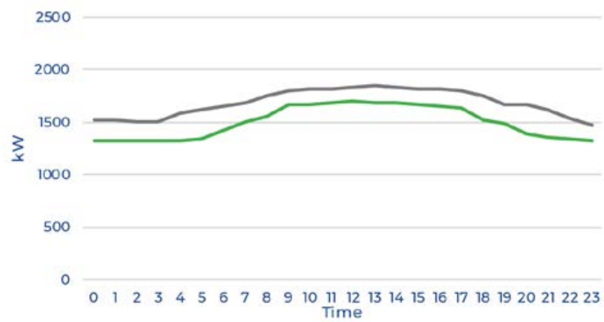


Figure 15: 32 Avenue of Americas Average kWh Days 2012-2017

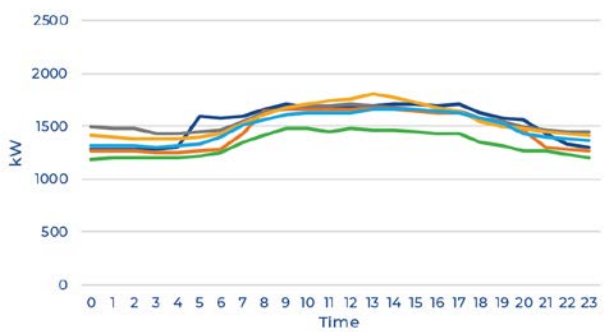
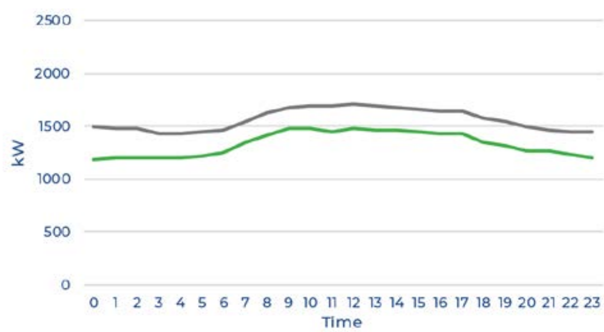


Figure 16: 32 Avenue of Americas Average kWh Day for 2014, 2017



2012 2013 2014 2015 2016 2017

Figure 17: 40 E 52nd Highest kWh Days 2012-2017

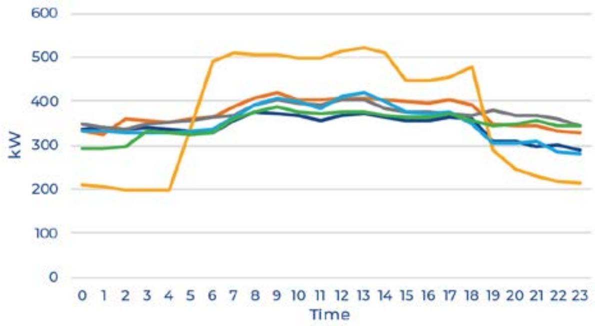


Figure 18: 40 E 52nd Highest kWh Day for 2014, 2017

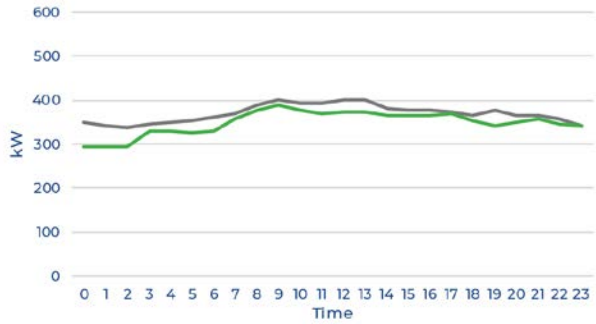


Figure 19: 40 E 52nd Average kWh Days 2012-2017

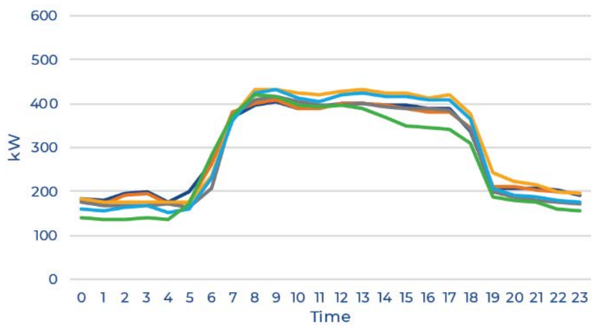
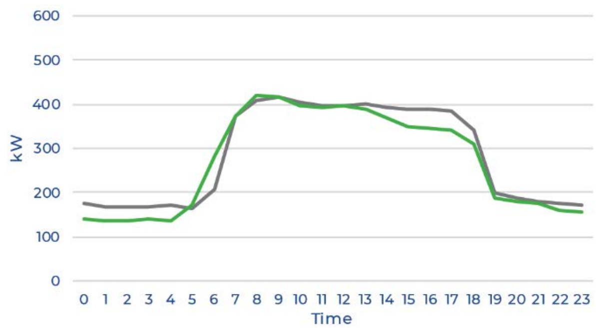


Figure 20: 40 E 52nd Average kWh Day for 2012-2017



2012 2013 2014 2015 2016 2017

Figure 21: 41 Madison Highest kWh Days 2012-2017

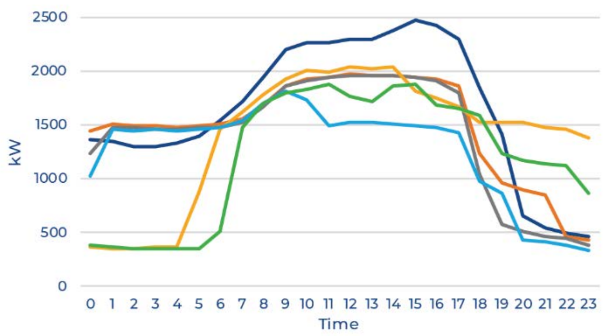


Figure 22: 41 Madison Highest kWh Day for 2014, 2017

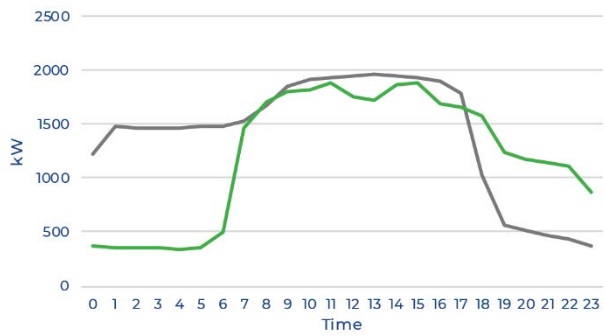


Figure 23: 41 Madison Average kWh Days 2012-2017

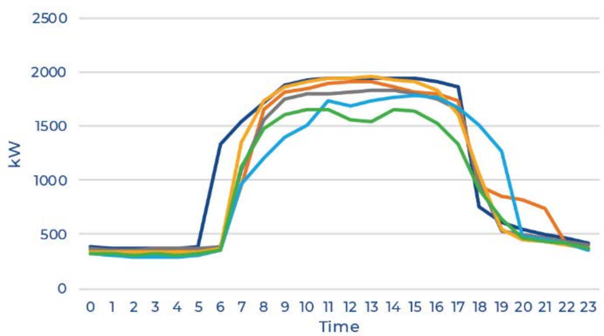
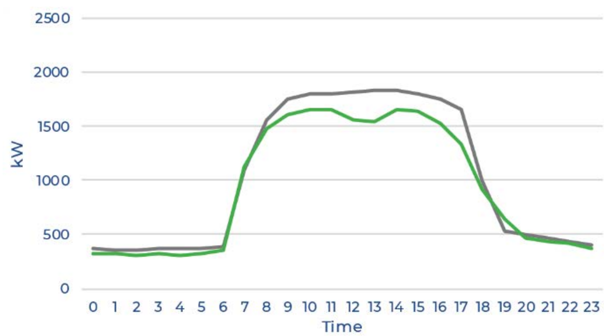


Figure 24: 41 Madison Average kWh Day for 2012-2017



2012 2013 2014 2015 2016 2017

Figure 25: 355 Lexington Highest kWh Days 2012-2017

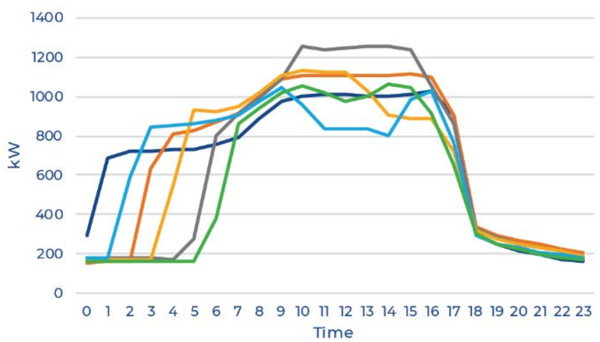


Figure 26: 355 Lexington Highest kWh Day for 2014, 2017

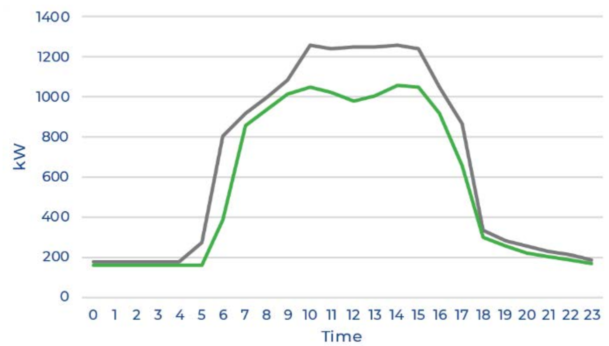


Figure 27: 355 Lexington Average kWh Days 2012-2017

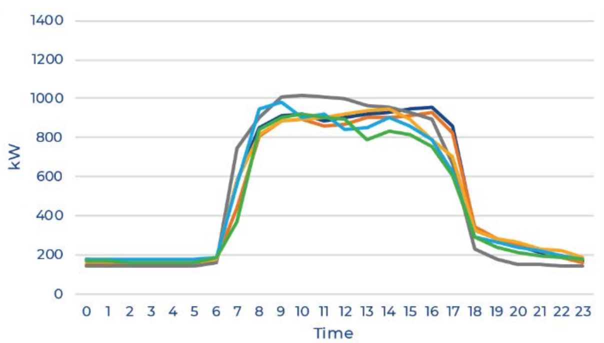
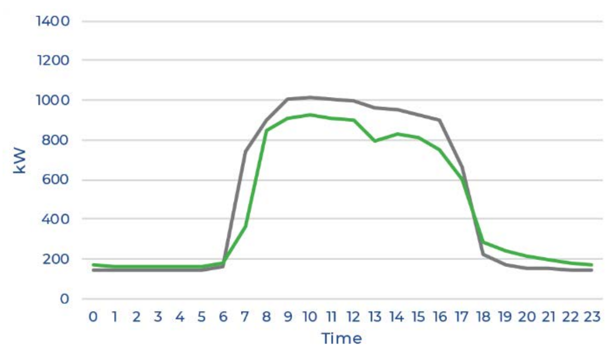


Figure 28: 355 Lexington Average kWh Day for 2014, 2017



2012 2013 2014 2015 2016 2017

Figure 29: 845 3rd Highest kWh Days 2012-2017

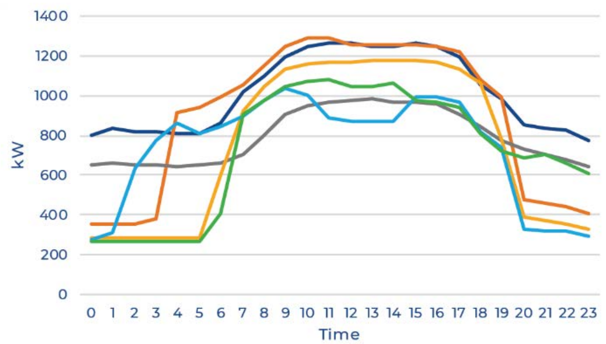


Figure 30: 845 3rd Highest kWh Day for 2014, 2017

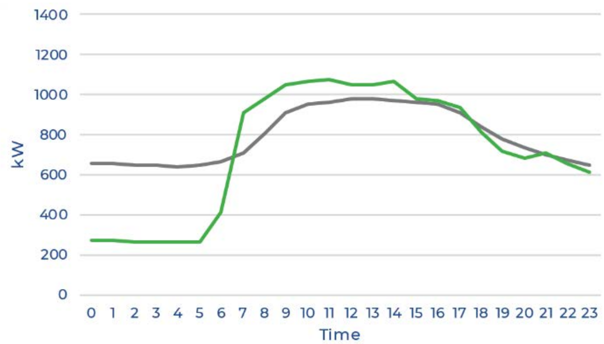


Figure 31: 845 3rd Average kWh Days 2012-2017

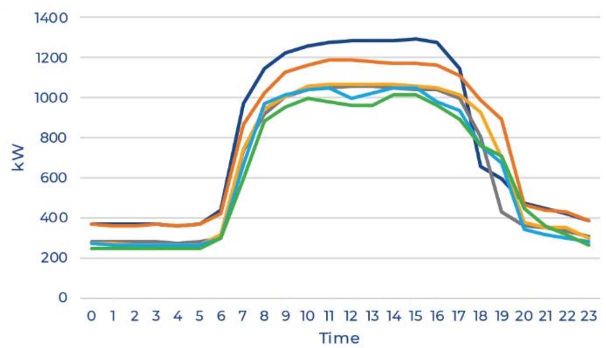
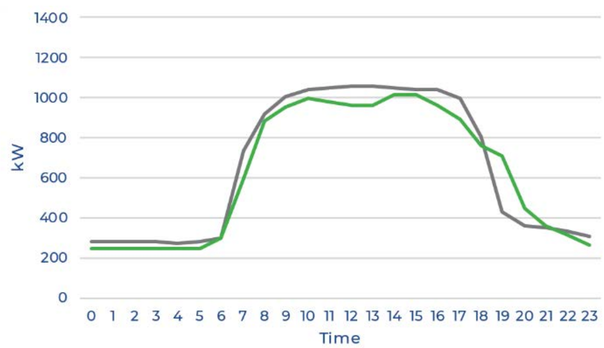


Figure 32: 845 3rd Average kWh Day for 2014, 2017



2012 2013 2014 2015 2016 2017

Figure 33: 1675 Broadway Highest kWh Days 2012-2017

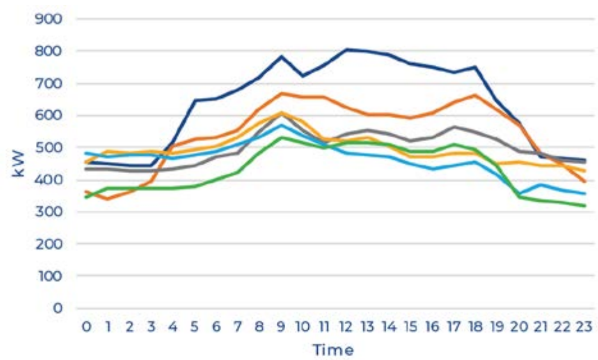


Figure 34: 1675 Broadway Highest kWh Day for 2014, 2017

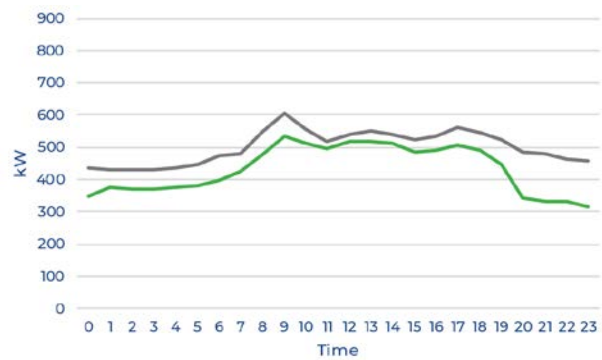


Figure 35: 1675 Broadway Average kWh Days 2012-2017

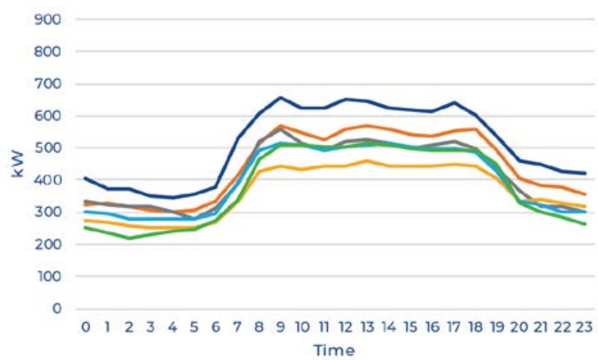


Figure 36: 1675 Broadway Average kWh Day for 2014, 2017