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The genesis of PlaNYC, New York City's ambitious sustainability agenda, was the need to accommodate an estimated one million more people by 2030 within the existing urban fabric. First released in 2007 with an update in 2011, PlaNYC sets its sights on what New York City needs to accomplish by 2030 to reduce greenhouse gas emissions, protect the quality of drinking water, and reduce wastewater outflows while improving the quality of life for 9.1 million inhabitants.

The 2011 PlaNYC update underscores both the urgency of the City's sustainability issues and the opportunities these efforts represent:

- Climate change poses acute risks to the city. By 2030, average temperatures could rise by as much as 3 °F in New York (City of New York 2011: 10).
- The once-innovative energy infrastructure needs to be modernized; buildings are full of outdated equipment (City of New York 2011: 104).

A core question posed by PlaNYC is whether or not the city can support more people without placing additional burdens on the already stressed water and energy infrastructure. The purpose of the following paper is to investigate the role of 1950–1970s era office buildings in meeting this challenge.

Background

New York City's building stock is exceptionally diverse. It has many of the world's first modern skyscrapers and a rich lineage of architectural and historic landmarks; indeed, the fight to save many of these buildings in the 1960s helped launch the modern preservation movement. Today, members of New York's architectural community are vocal, parallel participants in historic preservation and environmental sustainability – movements that are growing around the country, thanks to a lively coalition of planners, advocates, architects, researchers, and building owners.

There is considerable potential to re-purpose existing structures to meet the demands of the 21st century. In particular, buildings with high ceilings and the potential for effective daylighting and natural ventilation make excellent candidates for retrofitting efforts. Recent work on the Empire State Building is a good example (NIBS 2012). Much can be learned from mass-wall buildings like this – their small, high windows present good opportunities for natural ventilation, and their energy performance may be better than that of postwar buildings.

However, the focus of this study is a subset of Manhattan office buildings, representing the first generation of single-glazed curtain-wall buildings in New York City such as 675 Third Avenue (see Figure 1). Prior to the 1950s, curtain-wall construction was very rare, and it was not until after the 1973 energy crisis that double-glazed windows became prevalent.

Some early curtain-wall buildings are spectacular architectural and historic assets, such as the 1952 Lever House and the 1958 Seagram Building. Along with many other variables relevant to the character of urban spaces and the operation of buildings, historic preservation is important to consider closely when evaluating the future of a structure. This study considers only the energy and water implications of potential changes to this building stock, and does not aim to determine the architectural significance of any particular building. While some of the office buildings from this era should arguably be preserved purely for their architectural merit, there are many that are commonplace and have been rendered obsolete by changes in the marketplace. Modern Class "A" office space – the target market of most new office development – requires an adaptability of space, safety, and longevity that many of these buildings cannot provide.

Figure 1. 675 Third Avenue, New York. © Tectonic Photo

While single-glazed curtain walls were considered innovative at the time, these enclosures generally do not meet current wind code requirements and are at high risk of failure in a serious hurricane. Mid-century code required meeting wind loads of 20 lb/ft^2 (and only for floors above 100 feet), whereas today façades in the region can experience loads above 70 lb/ft^2. Curtain walls from this era were intended to be as thin as possible; they utilized non-load-bearing systems hung on the exterior of a building's structural frame. Consequently, most of these buildings make poor candidates for straightforward façade retrofits, as their structures cannot bear the weight of a modern, double- or triple-glazed curtain wall or a double-wall system.

Floor structures in these buildings tend to be a composite of concrete-encased steel girders, beams, and filler beams, between which are thin, low-strength reinforced concrete "goulash" slabs. Incapable of supporting any concentrated point loading, they are generally limited to the barest of code-minimum distributed loadings. These buildings also feature tight column spacing, typically 20-by-20-foot bays, versus the 40-by-45-foot bays used today. This column spacing is problematic for Class "A"-type tenants' space planning. They have low floor-to-ceiling heights of eight feet or less, a strategy to squeeze as many floors as possible into then-regulated height and setback limitations. Many do not offer adequate handicapped accessibility, and in some cases do not meet current life-safety codes.

Most of these buildings have heating, cooling, and ventilation systems optimized for an era in which natural resources were cheap and plentiful. The preferred cooling system was the Constant Volume Reheat (CVR) system, where a constant volume of air is cooled and distributed throughout the building. In areas where thermostats sense a need for less cooling, the air-conditioned supply air is reheated with electrical-resistance or steam/hot water coils. While such systems generally have a low first cost, they are doubly inefficient, analogous to driving a car with the accelerator pushed to the floor and controlling one's speed with the brakes. These buildings also consume significant quantities of potable water that evaporates through their overactive cooling towers.

As these buildings have aged and architectural standards have changed, many cannot attract Class "A" tenancy. In particular, low ceiling heights seriously limit daylight and views in interior spaces. Also, a desirable density of workspaces is difficult to achieve with 20-foot column bay spacing. While control strategies can help increase vertical transportation, adding elevators is almost impossible. There are at least 107 office buildings from the 1958 to 1973 era in Midtown Manhattan alone, many of which have become Class "B" or "C" properties (Permasteelisa 2012).

Why have these outdated buildings not been replaced? The reason in many cases is that they are "overbuilt," containing more floor area than current zoning code permits. Many were built with FARs of 15 or greater; current zoning allows only 15 FAR in C5-3 and 12 FAR in most commercial zones (generally located along major avenues in Midtown). Demolishing these buildings and replacing them with less rentable square footage would be difficult or impossible to finance.

Figure 2. The charrette teams review the 675 3rd Avenue's retrofit potentials.

Given the pressure to improve the energy performance of New York's building stock, this report asks two main questions:

1. For the target group of early curtain-wall buildings, how much energy can theoretically be saved through retrofitting the envelope and mechanical systems?
2. How does a deep retrofit program compare to replacement with a new, high-performance green building?

Design Case Study

The authors identified a specific building as representative of the 1950s–1970s single-glazed Manhattan archetype. The target building was chosen based on several factors, including design elements typical of the period and access to reliable energy and water data. Drawings and operational data were gathered and analyzed, and a façade expert undertook site investigation to explore possibilities for retrofitting the envelope. The authors hosted a design charrette to evaluate a retrofit for advanced energy efficiency against designing a replacement building on the site.

The charrette team included architects, engineers, contractors, building experts, equipment manufacturers, and building owners, all with deep experience in high-performance buildings in the Manhattan market (see Figure 2). Teams made recommendations on qualitative aspects of state-of-the-art office buildings, including specifics related to the details of the façade, mechanical systems, and quality of the indoor environmental quality. Integral Group was hired to develop computer simulations of the baseline building and each retrofit option.

“Low ceiling heights seriously limit daylight and views in interior spaces. Also, a desirable density of workspaces is difficult to achieve with 20-foot column bay spacing. While control strategies can help increase vertical transportation, adding elevators is almost impossible.”

Both the retrofit and replacement designs were intended to exemplify current best practices and prototypical performance-focused solutions to improve these sites using modern building technologies. The significant expertise on hand in the design charrette established a level of confidence that the design solutions considered reflect current best practices. While no specific economic analyses are included in the report, many rough financial calculations helped shape the design decisions of these scenarios. Long-time practitioners in the New York real estate development market were consulted or included in the charrette to ensure the solutions reflected realistic incentives and market-viable options.

The baseline building: 675 Third Avenue

Rather than study the worst of the cohort of potential candidates, the team intentionally chose a building that has been well cared-for, and for which good operating data could be obtained. The selected building, 675 Third Avenue, is owned by the Durst Organization, which has a history of implementing energy efficiency and other high-performance building measures.

Where possible, enhancements have been installed, such as variable-frequency drive fans for the central fan rooms, giving the building an approximation of Variable Air Volume (VAV) distribution, but at a more manageable cost than that of a total replacement. The air distribution still works through induction units (see Figure 3), which require significant fan power. Induction units use high-pressure air flow to mix air from within the room and blow it across a heating coil. Additionally, bronze tint film was applied to the original green-tinted single glazing to reduce heat gain, which also reduces daylight to the interior.

Outside air is provided by the central air distribution system. Although the building's curtain wall contains operable window sections, these are solely for the purpose of allowing window washing, and have become a constant source of air-balancing problems, as leaks around the aluminum awning increasingly occur and add to ventilation imbalance. Tenants occasionally open windows for more outside air when cooling is insufficient in a space.

The building has a minimal amount of exterior insulation: one inch of rigid insulation in the form of mineral wool board, mounted inboard of the anodized aluminum spandrels. V-shaped column covers that run the height of the tower are somewhat insulated by honeycomb aluminum backing, which also serves to defeat "oil-canning" of the surfaces.

Through these measures, including retrofitting window films, caulking the façade, installing variable speed drives on mechanical systems and maintaining rigorous maintenance standards, this building consumes significantly less energy than many of its cohort.

The team energy-modeled the building's existing condition and occupancy, coming within 6% of the actual historic energy records of the building – a highly accurate figure. The model resulted in a site Energy Use Intensity (EUI) of 101 kBTU/ft^2, a total site energy use of 28,221,013 kBTU, a source EUI of 209.7 kBTU/ft^2, and a total source energy use of 58,538,084 kBTU. This weather-normalized result was almost identical to data reported by the City's energy benchmarking initiative. This set of numbers was used as the baseline for comparing options for retrofit and replacement.

Figure 3. Existing perimeter induction units used to distribute air from the central fan rooms.

For another point of comparison, the baseline model was modified to simulate the building's performance at 100% occupancy (its actual occupancy rate is about 80%), at the use density that would be expected with Class "A" office tenants. As expected, the current occupancy pattern requires considerably less energy than it would if the building were 100% filled with Class "A" tenants. For purposes of this study, all comparisons were done against the current use case.

Deep retrofit

The team modeled alternatives for improving major building systems, focusing first on feasible retrofits to the building façade, with the aim of improving daylight penetration and thermal performance. This was followed by improvements to energy efficiency in lighting and air-conditioning. Features included in the energy model of this retrofit included:

- Glazing upgrades (Pilkington and Viracon low-*e* glazing model)
- Upgraded lighting and perimeter daylight controls
- Additional insulation under the spandrel and column covers

- Reduced piping pressure
- HVAC upgrade (high-efficiency electric chillers)

Glazing Upgrades. It was determined that the existing structural spandrel beam system could not bear the weight of a modern, thermally-broken, double-glazed window. Therefore, replacement of all vision glass was recommended, with two different high-performance single glazing options studied. The team also looked at upgrading lighting and installing perimeter daylighting controls.

The glazing study focused on the best combination of visible light transmittance, shading coefficient, and thermal performance, focusing on two low-*e* glass options from Pilkington and Viracon. The Pilkington glass has the more favorable Solar Heat Gain Coefficient (SHGC), due to a lower Visual Light Transmittance (VLT).

HVAC Upgrades. Replacement of the 46-year-old steam-driven turbine chillers with high-efficiency, electrically-driven chillers was studied. Energy use was modeled for replacement chillers in combination with each of the above-referenced glass types, still in single-glazed configuration, adding spandrel or column covers for insulation.

With the adoption of these additional energy efficiency measures, the resulting source EUI is 116.9 and the total projected source energy use is 32,634,844 kBTU, a reduction of 44% from the building baseline. While reducing energy use by 44% would be a tremendous achievement, this result should be taken with a grain of salt. The modeling and engineering team investigated a best-practicable energy retrofit of the building, without considering implementation cost. In reality, many retrofit options will not provide sufficient payback to justify the initial investment. Additionally, while the existing building is a well-run property, its small floor plates and eight-foot ceilings make it unrentable as a Class "A" property in the current market. The owners would find it very difficult to justify the increased rents necessary to cover the expense of the modeled energy upgrades.

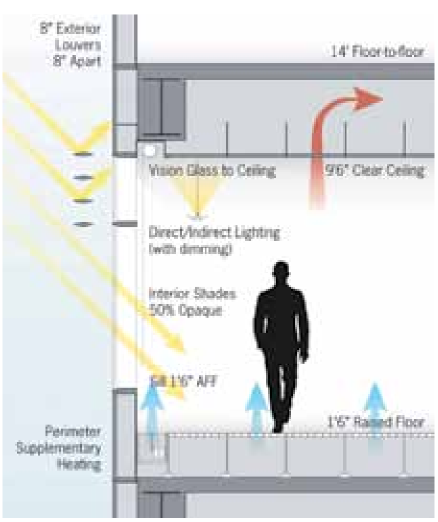

Figure 4. Design features of ideal 21.6 FAR building.

It would take 44 years to pay back the energy upgrades – five to six times the payback normally deemed acceptable for property retrofits. This calculation also leaves out expenses such as lost rents from disruption and improvement soft costs. Certain improvements, such as replacing glazing units and adding insulation to the perimeter, could be implemented while the building is occupied, but others would require significant disruption to tenancy in the building. As with many buildings of this era, the chillers are essentially entombed in the building, so that replacing them would require opening up the structure of the building and vacating the bottom two floors of the building for an extended period, which would prove expensive in terms of lost rent.

New High-Performance Building

The team charrette also produced a design study for a hypothetical new building on the site. To address the economic challenges of full replacement, the team modeled a building with more zoning floor area than the existing structure, increasing its size from a 15 FAR to a 21.6 FAR building (a two-step incremental improvement of 20%, as is typical in New York City zoning density increases). The city regularly awards upzoning for features such as public plazas. Without this upzoning, it would likely be difficult for a developer to commit to full replacement.

The prototype high-performance building would occupy the same footprint as the existing building and reflect current best practices in high-performance design as determined by the charrette participants and consultants. The design parameters of this prototype included (see Figure 4):

- Floor-to-ceiling height: 9'6"
- 40-foot clear bay spans
- Concrete core, steel structure
- Building-integrated green spaces
- Daylighting and lighting efficiency strategies
- Triple-glazed, low-*e*, and low-iron glass
- Plug load: 1.4 Watts per square foot

Based on this conceptual design, the modeling team simulated various façade and glazing options, to determine an optimal combination of enclosure, light transmittance, daylighting, and thermal performance. Following this façade configuration, the team then modeled four mechanical strategies:

1. Advanced variable air volume (VAV)
2. Under-floor air delivery (UFAD)
3. Passive chilled beam with UFAD
4. Overhead active chilled beam

The most energy efficient of the options was the passive chilled beam with UFAD and a 30-inch sill height for glazing. However, this would be the most expensive option to build. Brokers/owners expressed concern about rentability due to the high sills and relatively fixed grid of overhead chilled beams. The option of UFAD with 18-inch sill height was the second-most energy efficient, met market expectations better, and was used as the prototype replacement building. The source-energy intensity of this building was modeled at 138 kBTU/ft^2 – a 35% reduction from the baseline. The team also studied measures to reduce the new building's peak load on the city's electricity infrastructure, including ice storage and co-generation. The highest-performing options with on-site generation and load shifting resulted in an EUI of 126 kBTU/ft^2.

In addition to these modern environmental control systems, the team modeled improvements in indoor air quality, reductions in on-site stormwater loads, reductions in potable water demand, and made overall

		Building	Modelled Area (sf)	Peak Electric (kW)	Source Energy Use					Site Energy Usage				
					Electricity (MBtu)	Gas/ Steam (MBtu)	Total (MBtu)	Source EUI (kBTU/sf)	% EUI Relative Existing	Electricity (MWh)	Electricity (MBtu)	Gas/ Steam (MBtu)	Total (MBtu)	Site EUI (kBTU/sf)
Existing 15 FAR Building	Existing	Existing building, modelled, 80% occupancy	279,159	-	38,246	20,292	58,538	209.69	100.0%	3,356	11,451	16,770	28,221	101.09
		Existing building, by utility data, 80% occupancy	279,159	844.8	39,777	15,577	55,354	198.29	94.6%	3,490	11,909	12,873	24,783	88.78
		Existing building at full occupancy, Class "A"	279,159	-	46,119	22,409	68,528	245.48	117.1%	4,047	13,808	18,520	32,328	115.81
Existing 15 FAR Retrofit	Retrofit	Existing building w/ electric chiller & Viracon glazing, 80% occupancy	279,159	-	29,094	3,542	32,636	116.91	55.8%	2,553	8,711	2,927	11,638	41.69
		Existing building w/ Viracon glazing upgrade, 80% occupancy	279,159	-	31,248	23,656	54,904	196.67	93.8%	2,742	9,356	19,550	28,906	103.55
		Existing building w/ electric chiller, 80% occupancy	279,159	-	41,139	4,329	45,467	162.87	77.7%	3,610	12,317	3,578	15,894	56.94
Replacement 21.6 FAR Building	Ideal	21.6 FAR tower, UFAD, 18" sill, 100% occupancy	401,979	1,728	53,926	1,545	55,472	138.00	65.8%	4,732	16,146	1,476	17,622	43.84
	Peak	21.6 FAR tower, UFAD, 18" sill + 100 MBtu ice storage	401,979	1,139	54,177	1,545	55,722	138.62	66.1%	4,754	16,221	1,476	17,697	44.02
	Control	21.6 FAR tower, UFAD, 18" sill + 580 kW Cogen	401,979	1,159	24,404	26,196	50,600	125.88	60.0%	4,791	16,347	25,020	41,367	102.91
	Options	21.6 FAR tower, UFAD, 18" sill + 100 MBtu ice storage + 385 kW Cogen	401,979	1,161	27,529	24,762	52,291	130.08	62.0%	4,933	16,831	23,650	40,481	100.71
		21.6 FAR tower, at 90.1 ASHRAE baseline	401,979	2,154	82,371	2,204	84,575	210.40	100.3%	7,228	24,662	2,105	26,767	66.59
		24 FAR Tower, based on ideal 21.6 Tower	455,110	-	59,155	1,759	60,914	133.84	63.8%	5,191	17,711	1,680	19,391	42.61

Figure 5. Energy model result – summary.

improvements in occupant comfort. Calculations applied to the resulting Class "A" office building showed a near doubling of capacity and less than half the potable water use of the existing building,

The results of running more than 20 energy models are presented in Figure 5. The best case from this group of modeling scenarios is compared against the national average, existing, and energy code compliant buildings (see Figure 6). Note that while the best retrofit model produced a lower EUI than the best replacement model, it did so with eight-foot floor-to-floor and 80%, Class "C" occupancy.

Discussion

In concept, we have shown that a hypothetical deep retrofit of an inefficient 1960s office building could significantly reduce its energy use. Starting with a relatively well-maintained building means this improvement is a conservative estimate; the savings would be even greater for a more inefficient, single-glazed curtain wall building. In practice however, as noted above, the technical and financial barriers to achieving these savings are so great as to make them practically unattainable.

To put the analysis of 675 Third Avenue into context, we can compare the source EUI to two sources of commercial office building performance data.

The Commercial Buildings Energy Consumption Survey, published by the US Department of Energy's Energy Information Administration, is the main national source for comparing energy performance by building type and age. This data was last compiled in 2003, but the summary is still very informative. There are noticeable differences in source energy use per square foot by age of buildings (see Figure 7).

It should be noted that the older, pre-war buildings, designed to be daylit and naturally ventilated, are more likely to have thicker walls constructed of masonry and stone, as well as high windows. This partly accounts for their lower energy use, although it can also be attributed to the fact that these buildings are less likely to be densely occupied or to have intensive users like financial trading floors and data centers. The cohort of buildings we focus on here, dating from 1958 to 1974, span the two highest periods of energy use per square foot.

The second data set is compiled by the City of New York, which now requires building owners to submit energy use data as part of a citywide benchmarking system, as part of the PlaNYC effort. The building data is recorded in the US Environmental Protection Agency's EnergyStar Portfolio Manager system. In the first round of submittals there were 811 office buildings, representing 283.3 million square feet of space.

David Hsu of the University of Pennsylvania used this data to divide the buildings into source-energy quartiles (Hsu 2012):

- 0% quartile registering at 95.1 EUI
- 25% quartile registering at 169.6 EUI
- 50% quartile registering at 212.8 EUI
- 75% quartile registering at 268.5 EUI
- 100% quartile registering at 424.9 EUI

As with the CBECS data, there is no compensation for the density of occupancy, and the intensity of plug loads is not expressed

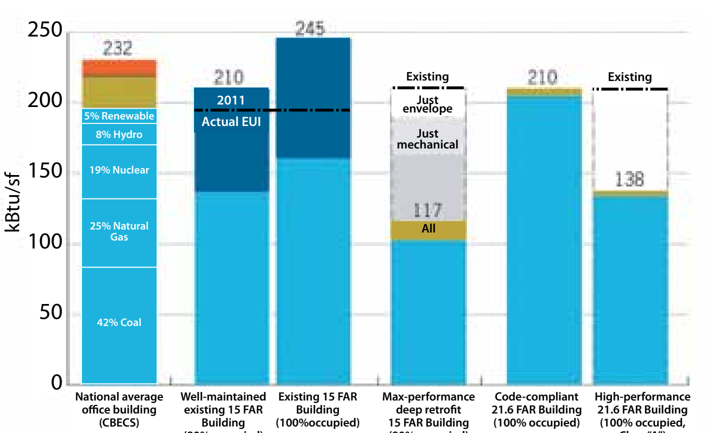

Figure 6. Comparison of source energy use.

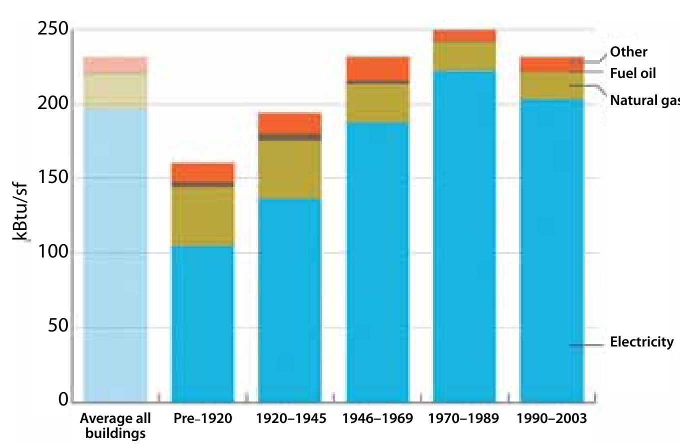

Figure 7. National Average EUI by vintage source energy – fuels.

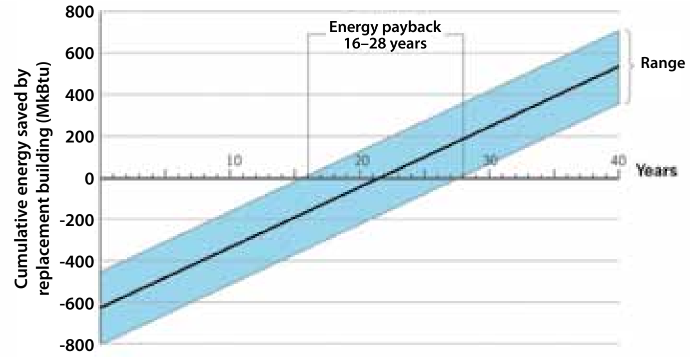

Figure 8. Cumulative energy savings.

in the EUI. So, despite being very efficient, a building with trading floors or a data center would have a high EUI. As it exists today with 80% occupancy, 675 Third Avenue has a source EUI of 209.7, which would put it into the 50% quartile for benchmarked buildings in New York City, and below the national average source EUI of 232 for office buildings constructed from 1946–1969. The hypothetical 21.6 FAR building with a source EUI of 131.6 would be in between the 0% and 25% quartile for benchmarked buildings in New York, and is significantly below the national average source EUI of 232 for recently built office buildings.

Operational energy vs. embodied energy

The analysis of energy use presented up to this point focuses on annual operating energy. Looking at a building's total energy impacts from a lifecycle perspective, however, leads to the question of how to properly account for the initial investment of energy expended during construction. Since much of this energy is "embodied" in the materials used to construct a building, the concept of embodied energy (EE) is key to the evolving discussion on how to improve existing buildings.

It is often argued that the embodied energy in existing buildings is so high, that replacing them with a more efficient structure would result in a net increase in energy consumption. Using data from a report by Richard Stein (Stein et al. 1981) – the authors calculated that the building consumes an equivalent amount of energy to that embodied in its construction every eight years (Maddex 1981). Furthermore, embodied energy of an existing building is a sunk cost, and should not be included when analyzing alternatives for future action. It is critical, however, to consider the energy required to tear down the structure and the embodied energy of a new building on the site.

Using the Stein data and more contemporary sources, the authors estimated the replacement 21.6 FAR building would have a one-time energy cost of 391–693 MkBTU embodied energy. Subtracting the operational energy savings of an equivalent square footage of the replacement building from the existing building, and dividing the embodied energy of the new building by this result, produces an energy payback period of between 16 and 28 years (see Figure 8). After this period of time, the high-performance replacement building will have saved more net energy over the existing building than was required for the new building's construction.

Conclusion

Using a representative building as a case study, we have demonstrated that it is possible to increase commercial occupancy in Manhattan while using less energy on an absolute basis. The example analyzed here suggests that significant energy savings are locked up in a segment of obsolete office buildings, which are not only inefficient but also have lost commercial value in the last 50 years.

The barriers to realizing these savings are not primarily theoretical; the high-performance building modeled for the site utilizes commercially available systems and standard construction practices. The bigger barriers are financial and regulatory, which suggests that effective solutions will need to consider such issues. While replacing an older building is not always the answer, neither should we dismiss new construction as an alternative strategy for early curtain-wall office towers. ■

The full copy of this report may be found at: **www.terrapinbrightgreen.com**

Unless otherwise noted, all photography credits in this paper are to Bill Browning.

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