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Efficient Energy Production for High-demand Tenants of Tall Buildings

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Abstract

Tall Buildings in urban landscapes present a unique challenge in the field of sustainable building. These structures tend to attract a tenant base of dynamic industries such as financial services, communications, technology and digital media. Such workforces demand intensive energy usage, sometimes around the clock, and consequently the energy use intensity (EUI) of the buildings they inhabit is consistently higher than EUIs of commercial buildings with other tenants. The mandate of the sustainable builder of tall buildings is to deliver this energy as efficiently as possible. Large-scale natural gas-fueled cogeneration facilities are potentially the most efficient means of producing onsite energy, although the successful and safe operation of such facilities depends upon the cooperation of local public utility companies. This paper examines the successes and failures of onsite energy production in a select group of buildings built and managed by The Durst Organization in New York City.

Keywords: Energy Efficiency; Sustainability

Overview

Despite substantial innovation in sustainable building and renewable technologies in recent years, New York City's large buildings remain the City's largest energy consumers, accounting for some 45% of the City's total energy usage (PlaNYC, 2012). The heaviest concentrations of high-demand tenants occur in the skyscraper-dominated commercial districts of downtown and midtown (Howard et al., 2012) (see Figure 1). Tall buildings continue to attract commercial tenants with high energy demands. Providing energy in an efficient manner to such intensive-demand tenants could significantly reduce New York's energy consumption and carbon emissions in the immediate future.

Older buildings have consistently lower EUI ratings than new large buildings, despite the fact that newer buildings are generally designed with more energy efficient technologies and construction principles. With limited workable occupancy data available, analysts suggest that this apparent discrepancy can be explained by the greater building population density and more extreme energy demands of commercial tenants in modern skyscrapers, which result in greater economic output (Aboff, Baumgartner & Coleman, 2014). Tenant bases comprised of such dynamic industries as financial services, communications, and digital media typically require 24-hour activity, open "bullpen" layout plans for large workforces, and heavy plug loads for multiple computers, monitors, and other technological equipment. In particular, trading floors may have such extreme energy demands as to require a unique categorization. Thus, high demand tenants pose a particular challenge, as well as a unique opportunity for the sustainable builder.

Certainly, much good in the way of conservation can be achieved when a building remains committed to energy efficient operations. Energy reduction programs such as daylight dimming and occupancy sensing have achieved modest success in reducing wasteful use. Further, by conscientiously monitoring tenant needs and adapting protocols beyond benchmarking and commissioning stages, a building's management can achieve optimal HVAC, lighting, and plug-load use. Such measures, however, should be considered best practices to limit excessive consumption: they do not solve the problem of finding an efficient means of delivering energy to heavy users.

The essential metric when assessing a building's efficiency of energy delivery is Source Energy Use Intensity (Source EUI). The Environmental Protection Agency's EnergyStar program identifies weather-normalized source EUI as the critical measurement for analyzing energy efficiency because it accounts for the total energy required to produce the power consumed by a building, and it reflects onsite efficiencies or waste. The EPA indicates that the national average source-site ratio for electricity purchased from the grid is 3.14; i.e., every unit of electricity consumed at a building requires more than three times as much electricity (primarily from fossil fuels) to be consumed for the generation at the plant or plants. This is largely due to the inefficiencies of the power plants as well as losses during transmission. Natural gas, on the other

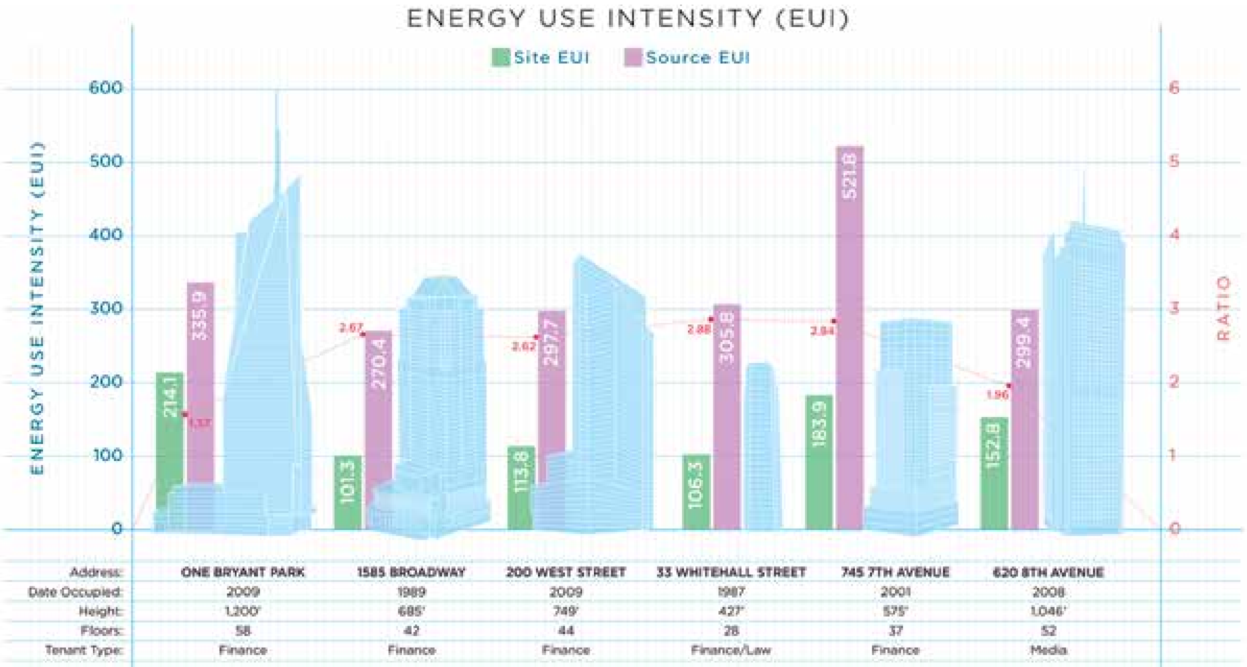

Figure 2. 2012 & 2013 Energy and Water Data Disclosure for Local Law 84. (Source: The Durst Organization)

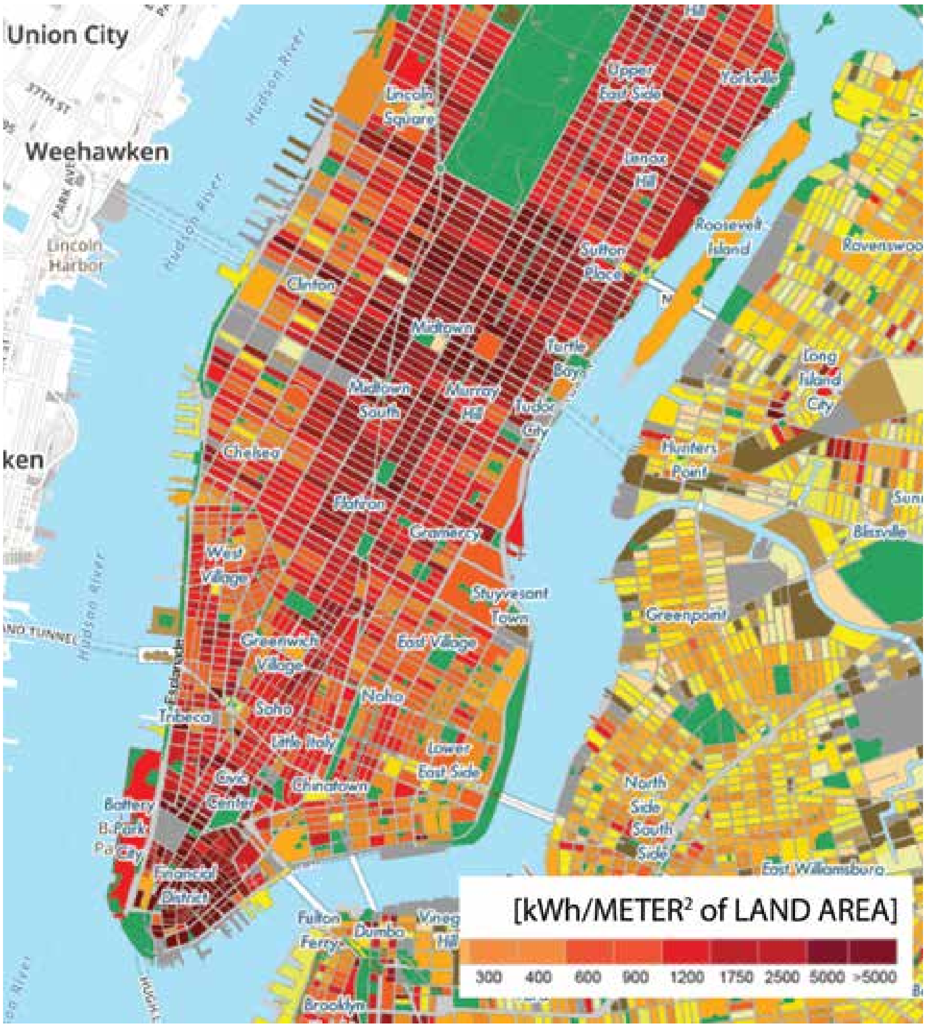

Figure 1. An interactive online map by the Modi Research Group details New York City's highest energy demand areas. (Source: Modi Research Group/Sustainable Engineering Lab, Columbia University)

hand, maintains a much more efficient ratio of 1.05; i.e., 1.05 units of natural gas leave a storage facility for every unit of natural gas consumed at a building site (EnergyStar, 2015). Naturally, electricity generated onsite has a site-source ratio of very close to 1.0, as there are negligible transfer, conversion, or distribution losses.

To understand the efficiency of buildings in New York City it is helpful to review some examples of buildings built in the last twenty-five years. Figure 2 demonstrates that while One Bryant Park has a high site EUI compared to similar buildings in Manhattan, it also has the lowest ratio of source EUI to site EUI (i.e., its source EUI is a smaller multiple of its site EUI) because it produces energy, heating, and cooling onsite. Buildings that are able to reduce their demand for electricity from the grid using onsite generation are able to achieve a more favorable source-to-site EUI ratio, and greater efficiency. It follows that companies with intensive energy demands will be attracted to buildings that supply efficient energy for simple economic reasons: buildings that can supply energy efficiently to top consumers will be able to offer greater bottom-line savings to those tenants. Meanwhile, as long as public utilities designed to generate electricity from fossil fuels remain the sole or primary source of electricity, energy supply will remain exceptionally inefficient while producing substantial greenhouse gasses.

The most efficient way to supply electricity to a large building with minimal loss is through onsite generation. Generally, electricity can be produced onsite either from renewable sources such as solar and wind power, or from fuel cells and generators relying on utility steam, natural gas, etc. Unfortunately, the vast majority of available data and anecdotal evidence suggests that onsite renewable energy sources will not be sufficient to meet high energy demands in tall buildings for the foreseeable future. Nor is it clear that any such technologies will ever be feasible for large buildings in an urban setting. This paper will briefly survey onsite wind, solar, and geothermal energy and heat production, and will document The Durst Organization's recent efforts to incorporate renewable energies into its building projects in New York City.

The most promising experience with onsite generation to date has been with large-scale cogeneration facilities. While such facilities rely on nonrenewable fuels such as natural gas, they are able to power buildings far more cleanly and efficiently than with energy transferred from a local grid. Cogeneration engines (Combined Heat and Power, or CHPs) also handle heating and hot water demands while recovering waste heat. They become even more efficient when combined with cooling mechanisms that reduce the electric load associated with the building's central chilling systems—absorption chillers, for example, and thermal storage systems that allow ice produced during non-peak hours to provide more economical cooling of the building during peak hours (sometimes referred to as tri-generation, or Combined Cooling, Heat and Power). A study undertaken at Columbia University in 2013 indicates that there currently exists the opportunity to develop systems supplying approximately 1580 MW of CHP electricity in New York City buildings, resulting in a 47% average greenhouse gas reduction per building site (Saba et al., 2013).

To allow onsite cogeneration facilities to populate buildings on a large scale, however, local utility companies must become willing partners. Without the cooperation of local electric companies, onsite cogeneration plants can be rendered inoperable by regulation or cost-prohibitive by excessive tariffs and standby charges. When builders are able to work effectively with public utilities to introduce maximal energy efficiency, they can together initiate a large-scale program of distributed natural gas cogeneration that will reduce buildings' fossil fuel consumption and greenhouse gas emissions, thereby making cities more resilient and sustainable.

Renewable Onsite Energy Production

Wind

Wind power might initially seem a promising technology by which tall buildings could produce renewable energy. Of all renewable energy sources, wind is the cheapest when harvested efficiently, and once a turbine is built and installed, it creates no greenhouse gasses during energy generation. Because wind speed typically increases at higher altitudes, the roof of a skyscraper could appear to a developer as an ideal location at which to place a wind turbine. Yet multiple factors diminish the practicality and value of wind as an onsite energy source for tall buildings.

Wind turbines are maximally effective in laminar wind, i.e., wind that flows in smooth, fluid streams. However, wind in most urban environments is turbulent because of the many obstructions disrupting airflow. Moreover, the size of a wind turbine is necessarily limited by the building's size, function, and engineering. Buildings must take measures to mitigate the noise and vibration produced from effectively operating large-scale wind turbines, further increasing capital expenditure and limiting return on investment. Finally, in an urban environment, safety is also a concern. Turbine blades can fail and break, or amass ice formations that become exceptionally hazardous when falling from the roof of a tall building.

The three most notable attempts to incorporate wind turbines into a high-rise's fundamental design have not succeeded in generating sufficient electricity to offset each building's demand. The Bahrain World Trade Center (2008, 50 floors) in Manama, Bahrain (Figure 3), the Strata SE1 in London, UK (2010, 43 floors) and the Pearl River Tower (2011, 71 floors) in Guangzhou City, China (Figure 4) were among the first tall buildings in the world to use commercial-scale wind turbines for onsite energy production. They were sited and designed to maximize wind exposure and minimize impact on tenants and neighbors. During development, each building hoped to generate approximately 10% of its energy needs from the wind turbines. However, available evidence suggests that the Bahrain World Trade Center and Strata SE 1 turbines remain inoperable most of the time, and that the Pearl River Tower has yet to be occupied.

The Durst Organization seriously weighed options for installing a wind turbine on the roof of One Bryant Park. In the building's design phase, the company installed an anemometer on the roof of nearby 4 Times Square to collect wind data for a 12-month period at a comparable height and location. Data showed that the wind in this location was far too turbulent and inconsistent to be a reliable source of energy production. Cut-in speeds were rarely reached, and estimates indicated that the turbine would remain unproductive more than 80% of the time. The amount of energy it would produce when operational would be negligible and

Figure 3. The wind turbines of the Bahrain World Trade Center. (Source: Ciacho5 (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons)

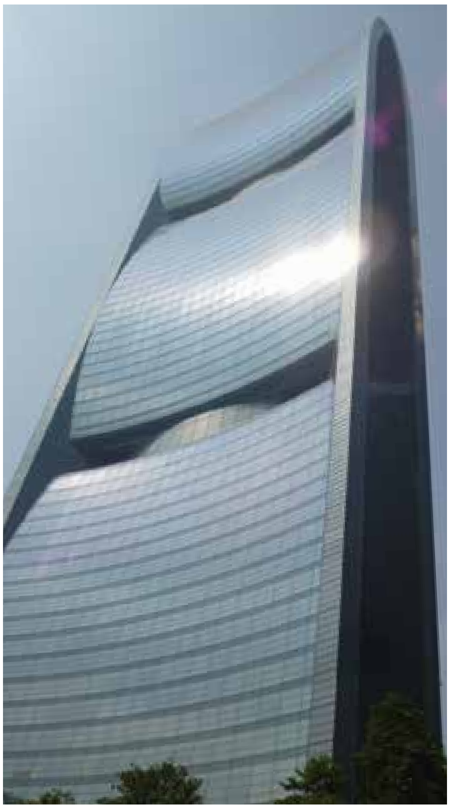

Figure 4. The Pearl River Tower in Guangzhou, China. The openings in the building's face funnel winds into vertical-axis wind turbines. (Source: IndexxRus (Own work) [CC BY-SA 3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons)

Figure 5. The photovoltaic cells at 4 Times Square. Arrows indicate approximate location of building-integrated photovoltaics. (Source: The Durst Organization)

could never justify the expense of installation. Rather than install an ineffectual wind turbine as a purely symbolic token of sustainable building (that would ultimately communicate a negative message about the futility of such efforts), The Durst Organization elected to forego this technology at One Bryant Park. Nevertheless, builders did install a wind turbine footing into the roof of One Bryant Park to avail future development, should wind turbine technology become better suited for the type of wind in this location.

Solar

On tall buildings, the roof represents a tiny fraction of the structure's overall square footage. In New York City in particular, where site area is so constricted, available roof space is a premium. Typical horizontal solar panels—with their optimal exposure and angling—are generally not an option for tall buildings with high-energy demands in high-density cities. Even when adequate roof space is available, the structural bracing required by significant wind loading makes horizontal panels difficult to justify. Typical flat plate photovoltaic panels are rated for around 35 pounds per square foot of wind loading, which is not sufficiently secure at heights above 10 stories. More promising for tall buildings are vertical panels, windows, and other building-integrated photovoltaic cells (BIPV) that could provide an alternative form of onsite solar energy.

When The Durst Organization designed 4 Times Square (1999, 48 floors), its explicit intention was to build an office tower that incorporates as many sustainable features as reasonably possible. Site-sourced solar energy formed an important component of this objective. Photovoltaic solar panels were installed from the 38th to the 46th floors on the southern- and eastern-facing façades (Figure 5). These photovoltaic cells are embedded in a thin film that was laminated to 4 Times Square's curtain wall panel.

The cost of installation of the photovoltaic cells was expected to be around $80,000, with an installed capacity of 5 kW, and an estimated efficiency of 6–8%. Presented with these Figures, The Durst Organization felt that installing BIPV panels would be a worthwhile experiment even if the cost savings proved to be nominal. However, installation was far more costly than expected, as the cells required interior wiring within the ceilings of tenant office space. Additionally, accounting for ongoing unanticipated maintenance issues, the total expenditure turned out to be approximately $500,000, with an annual power generated of only 3600 kWh. To place this output in context, 3600 kWh provides sufficient power only for the lights in the elevator lobby of a single mechanical floor, and the payback period for this renewable investment is now estimated at approximately 500 years (whereas the expected life of the BIPV panels is 40–50 years). Even taken as an experiment, it would be difficult to characterize the BIPV panels at 4 Times Square as a success.

Nevertheless, failed experiments can provide an important model for future endeavors. The lessons learned at 4 Times

Figure 6. Roof installation of building-integrated photovoltaic solar panels at The Helena. (Source: The Durst Organization)

Figure 7. Historic Front Street, where a geothermal heat pump system was installed. (Source: The Durst Organization)

Figure 8. Installing the combined heat and power plant at One Bryant Park. (Source: The Durst Organization)

Figure 9. Installed cogeneration plant with onboard gas compressor. (Source: The Durst Organization)

Square were applied at the residential development Helena (2005, 38 floors), where The Durst Organization combined horizontal solar panels and BIPV. At the time of the development of Helena, government incentives for investing in renewable energy had improved, as had the technology itself (to an estimated 14–16% operating efficiency). Solar panels at Helena promised a more robust installed capacity of 17.1 kW, with an installation cost of about $270,000 mitigated by green building incentives of approximately $100,000. With an actual operating capacity of 16,000 kWh generated annually, the solar panels at Helena will become cost neutral in around 35 years (Figure 6).

While this certainly indicates an improvement over the payback period of the BIPV at 4 Times Square, it does not represent a strong financial or practical incentive for most building developers. Still, if current pricing trends continue—that is, if available rebates and renewable energy credits offer compelling incentives for solar installations, and photovoltaic energy costs drop as fossil fuel costs rise—BIPV solar energy could represent a fiscally attractive source of onsite renewable energy in the near future. For example, if the existing spandrels at 4 Times Square were simply replaced with the most up-to-date monocrystalline "X-series" silicone paneling from Sunpower (with a 21.5%

efficiency) they could produce as much as 11,000 kWh annually. While this operation is not mechanically or economically feasible in an existing high-rise, it might make sense for a newly constructed skyscraper.

2.3 Geothermal

Another alternative is for buildings to use geothermal technologies onsite to manage their heating and cooling needs, thereby reducing their overall power demands. Geothermal heat pumps can be installed in most geographic regions, as they rely on the relatively constant temperatures of the earth for heating and cooling liquid in an open or closed pipe circuit. However, the space required for installation of a geothermal heat pump loop or well is a factor of the square footage of the building itself. There are two practical spaces for the pipes needed for the system to function: in the ground (or a body of water) adjacent to the building, or directly below the building itself. The less site area available, the deeper the wells must be dug. Not surprisingly, then, there are no current examples of a high-rise building that has successfully integrated a geothermal heat pump system into its operations to supply all, or even most of its HVAC demands. Tall buildings generally have neither the near-surface site space, nor the resources or permissions to drill deep enough below the building, to install sufficient piping for an efficient geothermal heating loop. Given their unique load profile and limited site area, tall buildings in Manhattan are generally not considered feasible for large-scale geothermal heating and cooling facilities (see MOS, 2015 & Rhyner, 2015).

In 2004, an open-loop, single column well geothermal heat pump system was installed at Historic Front Street—a modern restoration, retrofitting and build-out development of a block of waterfront buildings more than 200 years old (Figure 7). While the buildings are not tall, they do form a robust mid-size multiuse development, comprised of 95 residential apartments and 15 retail spaces. The system was commissioned in 2005. Even though the construction materials were appropriately specified for the local brackish groundwater, the stainless steel piping became corroded. The well pumps often failed while the open loop caused the condenser coils of the individual units' heat pumps to corrode and leak. When Superstorm Sandy hit in 2012, flooding compromised the well and incapacitated the heat pumps. At that time, The Durst Organization took the geothermal pump system offline and replaced it with a Variable Refrigerant Flow system on the buildings' roofs.

Onsite cogeneration

The Durst Organization first explored cogeneration with the installation of two 70 kW microturbines at Helena. Designed to run on compressed natural gas, these microturbines were installed during the original construction of the building. Heat rejection from the units was intended to be directed through an exchanger to heat domestic hot water in storage tanks (with direct-fired gas burners as backup). In 2005, however, at the time of installation, the New York City Fire Department had jurisdiction over any equipment with a working natural gas pressure of more than 15 psi, and there were no established guidelines for turbines with onboard gas compressors. The FDNY disallowed operation of the microturbines. It took four years for the Department of Buildings to write regulations for natural gas-fired microturbine systems (DOB Rule 50), which required additional safety features such as a master fuel trip, gas detection systems, and redundant ventilation. Once these upgrades had been installed at Helena, the mircoturbines began operating at an electrical efficiency of 29%, and heating at a thermal efficiency of 30%. Unfortunately, in 2012, the system experienced catastrophic failure and could not be repaired or replaced in an economical manner. Nonetheless, that short window of successful operation convinced The Durst Organization that an effective cogeneration system could greatly improve building energy efficiency.

The Bank of America Tower at One Bryant Park was designed to run a 4.6 megawatt combined heat and power plant that was installed during initial construction (Figures 8 & 9). It runs on high-pressure natural gas, and the waste heat generates steam to heat the building in the winter, and (by way of an absorption chiller) chilled water for air conditioning in the summer. While power produced at a conventional utility plant where heat is not recovered is around 35% efficient, and power produced at a combined cycle plant where heat is recovered to run a steam turbine is approximately 50% efficient, the CHP plant at One Bryant Park approaches 70% efficiency, providing more than two-thirds of the building's energy.

One potential drawback with cogeneration facilities is that they operate at maximum efficiency when run around the clock without shutdown (though this feature may in fact recommend them for high-demand tenants with round-the-clock work schedules). The chilled water plant design allows for waste heat absorption cooling to ensure that gas turbine thermal production is base-loaded for 24/7 operation year-round. Meanwhile, a thermal storage system allows ice to be produced during the night and stored at an ice tank farm (Figure 10) for air conditioning use during the day, further reducing the building's electric demands during peak hours.

Figure 10. One Bryant Park's ice storage facilities allow the plant to run 24/7 while saving on energy costs. (Source: The Durst Organization)

Figure 11. An image of the cogeneration plant proposed for installation at the Hallets Point development. (Source: MWM/The Durst Organization)

One Bryant Park's CHP plant required a capital investment of more than $30 million, a forbidding price tag to consider in the early stages of development. Yet it performs beyond expectation, such that the building's engineers have been able to focus on other aspects of operations, such as ventilation, for further energy-saving best practices (Donnolo, 2013). With the efficiencies introduced by onsite electricity generation, heating and cooling, observers might expect One Bryant Park to be an unqualified success, an enormous cost savings, and a model for sustainable builders everywhere. Yet in an unexpected development, Consolidated Edison drastically increased tariffs when the cogeneration facility became operational, raising electric standby charges by approximately 50% and steam standby charges by approximately 125%. As a tariff for operating an onsite CHP, Con Ed charges One Bryant Park nearly $2.5 million a year in standby charges for steam and for grid-connectivity should the onsite system go down, in what effectively amounts to a penalty for running a more efficient energy system. This Figure is only moderately less than what electricity and steam would cost without a cogeneration facility, severely compromising the plant's otherwise viable economics. This severe levying of tariffs and standby charges represents an enormous disincentive against cogeneration facilities for builders of tall buildings looking to increase the energy efficiency of new constructions.

Very few commercial buildings in New York City have attempted to install a large-scale cogeneration facility since the completion of One Bryant Park. Although many developers would be eager to capitalize on the significant savings delivered by efficient onsite energy production, the savings are effectively negated by the arbitrary application of tariffs and standby charges, and therefore developers are unlikely to implement CHPs (Saba et al., 2013). This untenable situation in fact mirrors the experience of the Pearl River Tower development in China, which was conceived to be the world's first carbon-neutral skyscraper. Architects had originally intended to install a chain of 50 microturbines that, when combined with the wind turbines, would supply more power than the building consumed. However, because the local power utility refused to allow the turbines to be grid-connected or to buy back excess energy from the building, the microturbines were considered cost-prohibitive and scrapped from the project (Frechette & Gilchrist, 2008). We live in an era in which there is near universal agreement that humankind must urgently reduce its energy consumption and greenhouse gas emissions, and the need for actionable solutions grows increasingly more pressing every year. In this context, it seems unconscionable that a safe and effective means of producing efficient energy and reducing carbon pollution should be rendered unfeasible.

In one of its latest developments, The Durst Organization will attempt to construct an independent micro-grid, at its Hallets Point development on the Halletts Peninsula in Astoria, Queens. With three proposed CHPs servicing 2.1 million square feet over five residential buildings, the plants would have a combined capacity of 6.8 megawatts (featuring n + 2 redundancy in capacity and 2n redundancy in the distribution between buildings) (Figure 11). This system would provide electricity and hot and chilled water for the entire facility, resulting in a building development completely disconnected from the electricity grid and municipal standby steam piping, requiring only natural gas at an estimated 1.05 source-site ratio. The estimated $23 million capital investment in the system should be recovered within the first nine years of operation, with the plant converting every $0.06 of natural gas into $0.30 cents worth of utility electricity.

Conclusion

Wind, solar and geothermal energies all have their efficient uses in particular applications and locations. These technologies can and should be incorporated into building design or offsite applications where appropriate to bring energy production and consumption closer to carbon neutrality. Onsite renewable sources of electricity, heat, and cooling can be regarded alongside and on par with conservation measures—important steps in the direction of maximal energy efficiency, but insufficient on their own to address the intensive energy demands of newly constructed tall buildings. Onsite cogeneration can have the most significant impact in reducing a building's demand for grid-purchased electricity, and thus its source EUI and its carbon footprint.

Public utilities are critical partners in the push for sustainable building, and CHPs are ultimately in the best interests of builders, their tenants, the power companies and the cities in which these entities work. Yet just as the utilities must cooperate to make CHPs economically feasible, they should also work to make electricity produced offsite more efficient. CHPs that operate on natural gas will remain the most efficient energy source for tall buildings only as long as power companies remain dependent on fossil fuels for energy production. If power companies, municipalities, and federal governments were to initiate an aggressive build-out of renewable production capacity and infrastructure, the electricity supplied by power plants could conceivably be derived primarily or entirely from clean, renewable sources. If and when this occurs, the significant loss of heat in the production of electricity from fossil fuels will diminish or disappear entirely, along with the incumbent production of greenhouse gasses, and the source-site EUI ratios will greatly improve. There may indeed come a "breakpoint" at which offsite renewable energy generation will supersede onsite generation in terms efficiency and carbon reduction. Liberation from dependence on fossil fuels is a universal aspiration; the great question is when in our global economy such a green dream might become a prevailing reality.

The fact remains that most areas in which the demand for tall buildings is greatest —Western capital cities, Asia, the Middle East— remain heavily dependent on fossil fuels. Furthermore, taking account of the emerging and increasingly prevalent impetus to decommission nuclear power, the breakpoint recedes ever further into the horizon. In the meantime, onsite cogeneration can be regarded either as a "bridge" technology to carry us to that era when clean, renewable energies are readily available from public utilities, or as the most efficient means of energy delivery for most tall buildings for the foreseeable future. In either case, the most immediate and effective means by which a tall building in development can reduce its operational energy consumption and source EUI right now is to install onsite cogeneration facilities during construction.

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