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The Folly of Building-Integrated Wind

An **Executive Summary** is available for this article.

The appeal of integrating wind turbines into our buildings is strong. Rooftops are elevated above ground, where it's windier; the electricity is generated right where it's needed; and wind energy can make a strong visual statement. Dozens of start-up wind turbine manufacturers have latched onto this idea since it fits well with a strong public sentiment to shift from fossil fuels to renewables. The 30% tax credit for the technology (that's 30% *without a cap*) provides a strong financial incentive. A year ago, Mayor Michael Bloomberg even suggested building-integrated wind as a greening strategy for New York City's many tall buildings. What's not to like about it?

The Bahrain World Trade Center, with three 225 kW turbines on bridges spanning the twin towers, is the first building to integrate commercial-scale wind turbines into a building.

It turns out that, despite some benefits, building-integrated wind doesn't make much sense as a renewable-energy strategy. In this article, we'll examine both the pros and cons of this technology, look at some examples of how it's been tried, and explain why it's usually a bad idea.

Context for Building-Integrated Wind

The wind power industry has gone through a steady evolution since the 1970s, when interest in generating electricity from the wind was reawakened. Wind turbines from the early 1970s were generally small, a few kilowatts (kW) in rated output, and most were for residential applications. Aided by significant research support from the U.S. Department of Energy, the wind industry pursued the significant economies of scale with larger turbines, leading to machines with output in the tens of kW, then hundreds of kW, then in the megawatt (MW) scale.

Another major shift, starting in the 1980s, was to aggregate wind turbines into *wind farms*. By situating multiple wind turbines close to each other on windy ridges, such as Altamont Pass and Tehachapi Pass in California, maintenance could be more efficient, and power could more easily be fed into the utility grid.

Some suggest that a third shift is underway today: putting wind turbines on top of buildings or integrating them into buildings in other ways.

The Case for Building-Integrated Wind

Wind speed typically increases with height, as it is less affected by trees and surrounding topography. Putting wind turbines on top of buildings—especially tall buildings—should allow them to take advantage of height without an expensive, full-size tower.

In some cases, building geometry can enhance wind turbine performance. Several manufacturers of building-integrated wind turbines are taking advantage of the increased wind velocities at building parapets—where the wind rises up the façade of a large building and curls over the edge. Some architects are designing wind scoops right into the structures of buildings or situating building towers to funnel wind into turbines.

Most of our electricity is used in buildings, and generating the electricity on site reduces the need for transmission. This in turn reduces transmission losses as well as the materials needed for wiring and poles. In addition to this practical benefit, wind turbines spinning on a building provide a visible testament to a building owner's commitment to the environment. While building-integrated photovoltaics (PV) can make a similar statement, the modules just sit there; we don't see them generating electricity.

Finally, many consider wind turbines to be beautiful. The graceful AeroVironment wind turbines that top an office building at Logan International Airport are an aesthetic feature. Architects and building owners spend a lot of money on non-functional, decorative elements of buildings; why not install decorative elements that actually do something?

Facing Up to Reality

Unfortunately, building-integrated wind often doesn't live up to its promise. The turbines must overcome several challenges to meet performance expectations and be cost effective.

Turbulent Air Flow

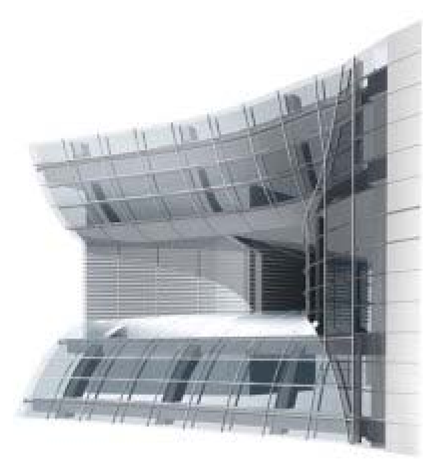
The best wind-turbine performance happens with strong *laminar* wind, in which all of the air flows in a single direction. But on top of even very tall buildings, wind flow is highly turbulent. Bob Thresher, director of the National Wind Technology Center at the National Renewable Energy Laboratory (NREL) in Golden, Colorado, explains that as wind flow comes over the edge of a roof or around a corner, it separates into streams. "Separating the flow creates a lot of turbulence," he told *EBN*.

According to Ron Stimmel, the small wind technology expert at the American Wind Energy Association (AWEA), this turbulent flow confuses a wind turbine, affecting its performance. "Even if it feels really windy [on top of a building], it's probably more turbulent than steady wind," he said. A common rule of thumb, according to Stimmel, is to elevate a wind turbine at least 30 feet (9 m) above anything within a 500-foot (150 m) radius, including the building itself.

What about the increased wind velocity at building parapets that manufacturers like AeroVironment use? Although AeroVironment's turbines successfully harvest this band of higher-velocity wind, they do so only in a fairly narrow band, which limits the potential size and output of wind turbines. Because the turbines are small, the economics are not as attractive as with larger wind turbines.

Noise and vibration

Noise and vibration from wind turbines are among the greatest obstacles to integrating them into buildings. Based on the recent surge in building-integrated wind, one might think that engineers had beaten this problem. In truth, some wind turbines are a lot quieter than others—vertical-axis machines among them—but managing noise and vibration remains a huge challenge. Roger Frechette, P.E., of Skidmore, Owings & Merrill (SOM) in Chicago, who led the engineering team on the Pearl River Tower, opted for vertical-axis turbines to minimize noise and vibration but still put them in unoccupied "technical floors" to isolate them from occupants in the building.



This opening in the face of the Pearl River Tower will funnel wind to a vertical-axis wind turbine.

Engineer Paul Torcellini, P.E., Ph.D., of NREL points out that the vibration from wind turbines is variable. He said that with HVAC fans on buildings, where the frequency of the fan is known, controlling the vibration and noise requires carefully engineered housings and mounting systems to isolate that vibration from the building—and it's still a problem.

In one of the only extensive surveys of actual performance of building-integrated wind turbines (the Warwick Wind Trials Project, the only turbines able to generate close to their projected electricity output were mounted on high-rise apartment buildings. And these wind turbines remained *switched off* throughout most of the test period because of complaints from the residents about noise.


The Pearl River Tower will include four vertical-axis turbines located in penetrations through the face of the building.

If you try to put a turbine on a tower on top of a building—to get away from the turbulent flow and into the most productive wind—the stresses on the building are magnified. Randy Swisher, the past executive director of AWEA, notes that wind turbines are subjected to a great deal of stress, and if installed on a building, “that stress can be transmitted to the building structure, creating substantial problems.”

Experts *EBN* interviewed explained that turbulent flow creates stress on the drive gear in a turbine, creating vibrations. These vibrations can, in turn, create harmonic resonances within a building structure. Metal roof decks made from thin roll-formed steel sheet, common in commercial buildings, can act like drumheads and amplify these resonances. In fact, AeroVironment, the building-integrated wind energy company that has done more than any other to understand the aerodynamics of wind around buildings, suggests in its sales literature that their turbines are only appropriate for buildings constructed of concrete.

Safety

One of the inherent fears aroused by installing wind turbines on buildings is that blades might fly off and injure people or property. It is not unheard of for large, free-standing wind turbines to occasionally shed a blade. On a ridgetop or in a large field, these accidents are unlikely to cause serious damage, but on a tall building in a city or even on a house, they could be a real problem. Even if the building owner is willing to accept that risk, the insurance company may not be.

Though *EBN* found no evidence of injury or damage from building-integrated wind turbines, a building such as the Bahrain World Trade Center, with its 95-foot-diameter (29 m) rotors, might not be insurable in the risk-averse and litigious North American market.

Poor measured performance

Despite the growing number of building-integrated wind turbine installations around North America and the rest of the world, obtaining actual *measured* performance data is like pulling teeth. Most manufacturers of these wind systems either claim not to have such data or are unwilling to share it. The reason for this reluctance may be that actual electricity production is much worse than expected.

Manufacturers publish *power curves* for their turbines that show projected electricity outputs at different wind speeds.

There is also a *rated power output* at a specific wind speed, though the wind speed used for this rated output differs among manufacturers. Referring to small-scale, rooftop wind turbines, Ron Stimmel of AWEA said that "it's very, very difficult to get them to perform at anywhere near their rated capacities." He told *EBN* that he has yet to find one that achieves its expected performance.

The municipal utility company Madison Gas and Electric, in Wisconsin, set out last year to find out for itself whether small-scale, building-integrated wind made sense. The company installed a vertical-axis wind turbine made by the Finnish company Windside, whose turbines are widely installed on rooftops in Europe. Madison Gas and Electric installed a turbine on a pole, with the top at 42 feet (13 m)—about the height it would be on a one-story commercial building—and has been tracking performance continually since November 2008.


This Windside turbine is being tested by Madison Gas and Electric is nominally rated at 10 kW AC but has never produced more than 600 watts. It is installed at a height that might be typical for a rooftop application.

According to senior engineer David Toso, P.E, the 12-foot-tall (3.7 m) by 3-foot-diameter (0.9 m) WS-4C turbine is rated at 10 kW AC power output, but he has never seen it produce more than 600 watts—6% of its rated output—even on a very windy day. The turbine cost $40,000 and was purchased from Bright Idea Energy Solutions in Evansville, Indiana (which is no longer distributing the Windside product, although the company does offer a similar, U.S.-made product). When *EBN* checked the real-time cumulative electricity production from the wind turbine in early April 2009 (go to www.mge.com and click on "Our Environment"), we found that it had produced only 33 kWh total in four months—about a quarter kWh per day. "Either someone was too aggressive with their projections, or they missed a decimal point," Toso told *EBN*. "They're not quite ready for prime time."

Power generation systems are typically rated by a *capacity factor*, which is the percent of electricity generated compared with the output if the system were operating at the rated capacity over that time period (although with wind turbines there is no standard for the wind speed on which the rated capacity is based). Freestanding wind turbines in good wind sites typically operate at a 10% to 30% capacity factor—the better the site, the higher the capacity factor. By this analysis, the Madison Gas and Electric wind turbine is operating at a capacity factor of just 0.11%. Fixed-pitch PV systems in selected cities, by comparison, have capacity factors ranging from 11% in Seattle to 18% in Tucson, according to data supplied by Steven Strong of Solar Design Associates.

The previously mentioned Warwick Wind Trials Project in the U.K. measured turbine performance of 26 building-mounted wind turbines from October 2007 through October 2008 and found an average capacity factor of 0.85%. All were very small ("microwind," defined as less than 2 kW) turbines, including the Ampair 600 (600 W), Zephyr Air Dolphin (1,000 W), Eclectic D400 StealthGen (400 W), and Windsave WS1000 (1,000 W). For each installation, measured electricity production was compared with predicted production based on the manufacturers' supplied power curves and both predicted and measured wind speeds. The study found that predicted performance exceeded actual performance by a factor of 15 to 17. With the worst-performing systems, the electricity required to run the electronics exceeded the electricity production, so the wind turbines were net consumers of electricity!

A 2008 report on 19 small wind turbines installed in Massachusetts, written by the Cadmus Group with support of the Massachusetts Technology Collaborative, found far lower performance than expected. While these were freestanding rather than building-integrated turbines, the measured capacity factor was just 4%, versus the projected 10%. In other words, the performance was 60% worse than predicted. Various reasons were given as to why this large discrepancy may exist, including inaccurate wind speed estimates, incorrect power curves, inverter inefficiencies, and greater losses due to site conditions (turbulence and wind shear) than expected.

Even AeroVironment's wind turbines, are not performing at the level the company had originally hoped for. Since 2006, when their parapet-optimized wind turbine was introduced (see *EBN* Aug. 2006), the company has adjusted downward its expectations of energy production, according to Paul Glenney, director of AeroVironment's Energy Technology Center, though installations are matching their predicted power curves.

The Adventure Aquarium in Camden, New Jersey, features eight 400-watt and four 1000-watt AeroVironment turbines.

Cost-effectiveness

Perhaps the greatest impediment to building-integrated wind energy is the economics. While large free-standing wind turbines provide the least expensive renewable electricity today, small wind turbines are far less cost effective, and when small turbines are put on buildings, the costs go up while the production drops.

How does building-integrated wind compare with PV? AeroVironment installations have been running at $6,500–$9,000 per kW of installed capacity, which is fairly close to the cost of PV installations, which averaged $7,600 in 2007, according to a February 2009 report from Lawrence Berkeley National Laboratory. An AeroVironment wind system will deliver, according to Glenney, 750–1,500 kWh annually per kW of rated capacity (depending on the wind resource), while a fixed-pitch, commercial-scale PV system will deliver annually 1,100–1,200 kWh/kW of rated capacity in Boston and 1,400–1,560 kWh/kW in Tucson, according to data provided by Strong.

When you factor in the fact that the PV system is likely to deliver closer to its rated output on a building than the building-integrated wind system, while costing less to maintain, PV is just a better deal. According to Paul Gipe, a leading advocate of wind power for 30 years and author of numerous books on the topic, if you're looking to put renewable energy on buildings, "there's nothing better than photovoltaics."

Wind turbines as advertising

Putting wind turbines on a building to advertise the greenness of a company or organization is a compelling idea—as long as those turbines spin most of the time. In Golden, Colorado, a Southwest Windpower Skystream turbine was installed at a dental office to make a statement about renewable energy and demonstrate wind energy. The problem, according to a few residents of the area, is that it's hardly ever spinning, especially during the morning rush hour when commuters are driving by. A lot of commuters who pass this turbine may conclude that wind energy doesn't work very well.

Products

Quite a few manufacturers offer wind turbines for rooftop installation. The following is a small sampling of what's available today.

AeroVironment AVX1000

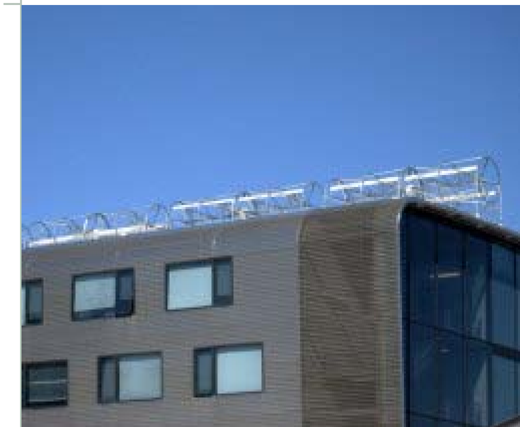
Arguably, the world leader in rooftop wind technology today is AeroVironment and its Architectural Wind division, based in Monrovia, California. In 2006, the company introduced a 400-watt wind turbine designed to take advantage of concentrated wind at the parapets of commercial buildings. That initial model has been replaced by the AVX1000, an elegant, lightweight, 1 kW turbine that bends gracefully from a mounting base on a building's parapet. The turbines are designed to be installed in a row; 20 grace a Massachusetts Port Authority (MassPort) administrative office building at Logan Airport in Boston.

AeroVironment has pursued horizontal-axis, rather than vertical-axis, wind turbines. Vertical-axis machines "are inherently less efficient by a wide margin," according to Glenney. "Our patent for leveraging the accelerated wind flow includes vertical-axis wind turbines, but we've never pursued them simply because the lower efficiency significantly increases turbine size and, thus, material costs," he said.

The 400-watt AVX400 turbine from AeroVironment, released in 2006 and shown

Aerotecture International helical rotor wind turbines

here, has since been replaced by the 1-kilowatt AVX1000.



These helical Aerotecture turbines on a building in Chicago have been operating only sporadically.

Aerotecture founder Bill Becker, a professor at the University of Illinois, invented this unique wind turbine, described on the company website as a "helical rotor and airfoils housed within … a steel cage." The lightweight, 10-foot-tall by 5-foot-diameter (3 x 1.5 m) 510V turbine is designed for vertical mounting and rated at 1 kW output—at 32 miles per hour (14 meters per second). While the 510V turbine is rated at 32 mph, the power curve for the unit shows less than 200 watts of output in 20 mph (9 m/s) wind. The cut-in windspeed (when the turbine begins generating electricity) is listed as 6.3 mph (2.8 m/s). The slightly modified 520H is made up of two 510V turbines that are installed horizontally; it is rated at 1.8 kW at 32 mph.

Eight 520H Aerotecture wind turbines were installed on a Mercy Housing Lakefront single-room occupancy building in Chicago in May 2007. Each of these was rated at 1.5 kW (somewhat lower than the currently listed rated output for the 520H)—for a total rated capacity of 12 kW. Unfortunately, there is no data available on the actual performance of these turbines. Aerotecture would not return *EBN*'s calls, referring us to a public relations agency, which told us by e-mail that "the company is focused on internal development not media coverage at this point, so it's frankly just not possible to get your query on the agenda."

Larry McCarthy, the vice president for property management at Mercy Housing Lakefront, told *EBN* that the turbines "are not all working at this time," adding that a couple of the alternators are frozen up. A Chicago resident *EBN* spoke with said he has "rarely seen more than one of the turbines rotating and often not even one."

Windside and GUS vertical-axis wind turbines

Made in Finland by Oy Windside Production, Windside turbines are Savonius-style, vertical-axis turbines made by forming two spiral vanes (photo page 15). The design was developed in 1979 by Risto Joutsiniemi, and the turbines have been on the market since 1982. Used for charging batteries in harsh, cold climates (they are manufactured just 250 miles, or 400 km, south of the Arctic Circle), some of the turbines are designed for operation in winds up to 130 mph (60 m/s). It is a Windside turbine that is being tested by Madison Gas & Electric in Wisconsin, and these turbines are planned for the Pearl River Tower. The turbines are claimed to be virtually silent: less than 2dB at two meters, according to Raigatta Energy, the Canadian distributor.

The installer of the Wisconsin turbine, Bright Idea Energy Solutions of Evansville, Illinois, no longer carries the Windside products, having replaced them with remarkably similar-looking turbines made by the Flagtown, New Jersey company Tangarie Alternative Power. Creede Hargraves of Bright Idea Energy Solutions says the Tangarie turbines (referred to as Greenpower Utility System or GUS turbines) cost half as much as Windside products—though are still far more expensive than the line of free-standing horizontal-axis turbines that the company sells. They are also larger for the same rated output, which should help to avoid the problems being experienced by Madison Gas and Electric. Hargraves said that he will be replacing that Windside turbine with a GUS model in the summer of 2009.

Quiet Revolution QR5 vertical-axis wind turbine

Currently available only in the U.K, Quiet Revolution's QR5 is an elegant, eggbeater-style (Darrieus) wind turbine with blades and spokes made from carbon and fiberglass. The 16-foot-tall (5 m) by 10-foot-diameter (3.1 m) turbine is designed for mounting on a mast that is installed either stand-alone or on top of a building. The peak DC power output in 31 mph (14 m/s) wind is 6.2 kW, with the British Wind Energy Association (BWEA) rated power output at 24.6 mph (11 m/s) is 3 kW DC. Power generation can begin at 10 mph (4.5 m/s), and the turbine cuts out at 36 mph (16 m/s). Data from the company on noise production from the turbine shows about 50 dB(A) at 13 mph (6 m/s) and 58 dB(A) at 22 mph (10 m/s). The company's website lists the price for the turbine and control electronics at 29,600 British Pounds (about $43,000), plus mast and installation.

To date, more than 65 Quiet Revolution turbines have been installed in the U.K., and expansion to other countries is anticipated in 2010 or 2011, according to Phillipa Rogers of the company.

Swift Wind Turbine

These Swift wind turbines are made of nano-fiber-reinforced polymer. The 1.5 kW turbines start up in 5 mph (2.3 m/s) wind and are claimed to be the quietest horizontal-axis wind turbines on the market, producing just 35 dB of noise.

Designed and developed by the Scottish company Renewable Devices, the unique carbon-fiber rotor is now being manufactured by Cascade Engineering in Grand Rapids, Michigan. Cascade Engineering will be manufacturing all Swift rotors worldwide and assembling all components of the Swift turbine for the U.S. market. The 7-foot-diameter (2.1 m), five-blade turbine with a distinctive outer rim and twin angled positioning fins, is designed for rooftop mounting using an aluminum mast with a minimum clearance from the roof of two feet (0.6 m). The manufacturer claims its operation to be nearly silent (less than 35 dB in all winds). The turbine is rated at 1.5 kW in 31 mph (14 m/s) wind, and annual production is estimated at “up to 2,000 kWh.” The average cost is $10,000 to $12,000, according to the company.

These graceful U.K.-manufactured Quiet Revolution turbines produce 3 kW of power in 25 mph (11 m/s) wind.

Final Thoughts

I want to like building-integrated wind. There’s a wonderful synergy in the idea of combining form and function by generating electricity with turbines that reach into the sky on the buildings they will help to power. But in most cases, at least with today’s technology, it just doesn’t make sense.

There is a huge economy of scale with wind power. This has fueled the evolution of ever-larger wind turbines from a few kW of capacity in the 1970s to a few MW today. Small turbines, even stand-alone, pole-mounted turbines, are not very cost-effective. When we put those small turbines on top of buildings, the costs go up and the performance goes down.

Rooftop installations—even the best of them—are too small to be cost-effective, and the air flow too turbulent to be effectively harvested—whether vertical-axis or horizontal-axis. The truly integrated installations that are large enough to generate significant power will be too hard to permit or insure in North America to become a serious option, even if the vibration and noise concerns are successfully addressed.

Paul Gipe vociferously discourages building-integrated wind. Wind just isn’t a good fit, he argues. Cost-effective wind turbines are “too big for the structure of buildings.”

Wind energy has a very important role to play in our energy future, but it is with large, freestanding wind turbines, located on ridgelines, in Midwestern agricultural fields, or in offshore wind farms. The bottom line regarding cost is that while large stand-alone wind farms provide the least expensive renewable electricity today, small, building-integrated wind turbines provide electricity that is more expensive than that produced by PV, while the turbines are more costly to maintain and less dependable.

By all means, power your buildings with wind energy, but do it on a larger scale, remotely, where the turbines can operate in laminar-flow winds and where their vibrations and noise won’t affect buildings and building occupants.

– Alex Wilson

For more information:

American Wind Energy Association
www.awea.org

National Wind Technology Center
National Renewable Energy Laboratory
www.nrel.gov/wind

Warwick Wind Trials Project
www.warwickwindtrials.org.uk

Aerotecture International, Inc.
www.aerotecture.com

AeroVironment, Inc.
www.avinc.com

Quiet Revolution, Ltd.
www.quietrevolution.co.uk

Norwin A/S
www.norwin.dk

Swift Wind Turbines
www.swiftwindturbine.com

Tangarie Alternative Power
www.tangarie.com

Windside Turbines
www.windside.com

Sidebar: Integrating Wind Turbines Directly Into Building Architecture

The Bahrain World Trade Center and China's Pearl River Tower provide examples of how building-integrated wind is being used in high-profile green projects.

Bahrain World Trade Center

The dramatic, 50-story, sail-shaped twin towers of the Bahrain World Trade Center (BWTC) in Manama, Bahrain, designed by the U.K.-based Atkins Design Studio (photos main story), features the first commercial-scale, building-integrated wind-energy system in the world. Three modified, 225 kW turbines made by the Danish company Norwin A/S are mounted on bridges spanning the two towers. In this configuration, the turbines are stationary, oriented to capture the prevailing winds coming off the Arabian Gulf.

Initial testing of the BWTC turbines started in April 2008, and the turbines began regular operation in December 2008, according to Ole Sangill, executive director of Norwin. While Sangill could not provide actual measured output, Atkins estimates that the system will generate 1,100–1,300 MWh annually, or 11%–15% of the building's electricity needs. Each of the turbines is designed to achieve the full 225 kW output at wind speeds of 35–40 mph (16–18 m/s), according to Sangill, and they begin generating power at wind speeds of about 9 mph (4 m/s). According to Atkins, the geometry of the towers funnels wind into the turbines and should amplify wind speeds by up to 30%.

Having such large turbines—each is 95 feet (29 m) in diameter—so close to occupied space raises concerns about noise and vibration. This is not a problem, according to Sangill. "We absolutely do not have problems with noise or vibration transferring into the buildings," he said. *EBN* was not able to independently confirm this statement.

Pearl River Tower

While the Bahrain World Trade Center is the first large building to be completed with an integrated wind system, the dramatic, 71-story, 2.3 million square-foot (210,000 m^2) Pearl River Tower in Guangzhou, China, designed by Skidmore, Owings & Merrill (SOM), has received almost as much attention. The building, currently under construction, will have four openings that extend through the broad face of the building, two about one-third of the way up and the other two about two-thirds of the way up. At these openings, prevailing winds will be funneled into vertical-axis wind turbines, generating electricity.

According to Roger Frechette, who led the engineering team at SOM, “Based on our CFD [computational fluid dynamics] modeling and wind tunnel testing, we will be able to more than double the velocity [of the wind].” The actual turbines being used are made by Windside. Compared with those at the Bahrain World Trade Center, however, these turbines will be quite small, generating at most a few kW of electricity and satisfying no more than 2%–3% of the building’s electricity demand.

Noise and vibration are being addressed in several ways. For starters, the turbines are very quiet. The turbines will be located on unoccupied floors, and Frechette doesn’t expect any noise transferring into occupied floors. Further acoustic control will be provided by the double-envelope design—a layer of insulated glass on the exterior and a single layer of glass on the interior separated by 12 inches (300 mm), with air moving through the cavity.

Surprisingly, Frechette said that the building-integrated wind system actually benefits the structure. He told *EBN* that the openings for the turbines create a “pressure release valve” that “actually relieved some of the wind forces on the building.” He thinks that the savings in steel and concrete realized by reducing the loading might actually pay for the turbines—though the turbines are a relatively small part of the cost of this building-integrated wind design.

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