NREL is a national laboratory of the U. S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Deployment of Wind Turbines in the Built Environment: Risks, Lessons, and Recommended Practices

Ian Baring-Gould, Jason Fields, Frank Oteri, and Robert Preus

Introduction

Built-environment wind turbine (BEWT) projects are wind energy projects that are constructed on, in, or near buildings, as shown below. These projects present an opportunity for distributed, low-carbon generation combined with highly visible statements on sustainability, but the BEWT niche of the wind industry is still developing and is relatively less mature than the utility-scale wind or conventional ground-based distributed wind sectors.

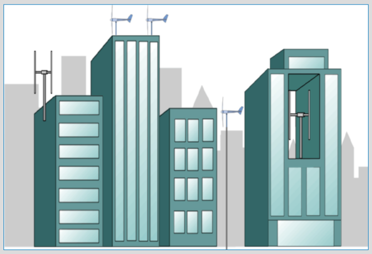


Illustration of turbine installations in the built environment

This poster and the accompanying paper investigates the current state of the BEWT industry by reviewing available literature on BEWT projects as well as interviewing project owners on their experiences deploying and operating the technology. The authors generated a series of case studies that outlines the pertinent project details, project outcomes, and lessons learned. This paper integrates those information sources into recommended practices that can be utilized by future stakeholders to evaluate the feasibility of BEWTs for their unique applications and sites. It should be noted that due to the lack of available information, the case studies were limited to building-mounted designs with limited coverage of building-integrated turbines (in which the architectural structure is shaped to support wind generation). The recommended practices are still largely applicable to any built-environment technology or approach.

Methods

NREL researchers generated a series of practical case studies with a goal of creating an informative product that accurately portrays the experiences of current built-environment wind projects from concept through installation. The case studies were selected based on the availability of public information on the projects and the identification of project representatives who could be interviewed. With the exception of the National Air and Space Administration (NASA) Building 12 installation, NREL researchers did not directly measure project data; all pre- and post-construction energy estimates were provided by project owners. The following table provides a summary of these projects.

Lessons Learned

Based on a review of the case studies, including detailed interviews with the developers of those projects, the following lessons are widely applicable to projects in the built environment:

Project planning

- Project feasibility and planning processes are insufficient and not well defined. A few project developers undertook rigorous pre-construction planning, and those projects tended to have more positive outcomes.

Project costs

- Additional expenses related to installation and operations in the built environment can create high-cost projects.

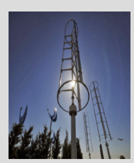
Project performance and reliability

- Consolidation of small turbine manufacturers has been common and can lead to loss of warranty and difficulty in service and parts availability.
- BEWT project performance is often overestimated when compared with actual production. None of the case study projects met their energy production estimates, largely due to the complexity of conducting accurate resource and production assessments in complex built environments. Onsite atmospheric measurements are recommended, along with detailed loss calculations to account for real-world operating conditions.
- In general, the BEWT industry has experienced mixed results, with some positive project outcomes and several negative outcomes for stakeholders.

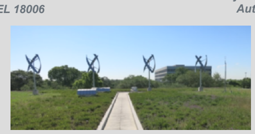
Based on several key factors (i.e., wind speeds are typically lower and costs for implementing projects are typically higher), projects in the built environment can be difficult to justify on a cost of energy or energy offset basis.

Understanding the expected production of a wind turbine in the built environment is a very complex undertaking; the use of onsite resource measurements combined with high-fidelity models is likely the only way to understand the expected turbine production.

Boston Museum of Science (MA). Photo from Boston Museum of Science, NREL 18006



Detroit Metro Airport (MI). Photo from Wayne County Airport Authority



NASA Building 12 (TX). Photo by Dave Jager, NREL 42474

Project Name	Twelve West	Detroit Metro Airport	Museum of Science	Brooklyn Navy Yard	Pearson Court Square	NASA Building 12
Location	Portland, OR	Romulus, MI	Boston, MA	Brooklyn, NY	Long Island City, NY	Houston, TX
Turbine Type	Skystream 3.7 (4)	Windspire (6)	Windspire (1) Skystream 3.7 (1) Swift (1) Proven 6 (1) AeroVironment AVX1000 (5)	AeroVironment AVX 1000 (6)	VisionAIR5 (3)	Eddy GT (4)
Capacity	9.6 kW	7.2 kW	15.6 kW	6 kW	9.6 kW	4 kW
Year Installed	2009	2010	2009	2008	2014	2014
Operational	Operating	Operating at reduced capacity	Operating at reduced capacity	Not operating	Operating	Operating
Roof Mounted?	Yes	No	Yes	Yes	Yes	Yes
Owner View	Success	Underperform	Success	Underperform	Success	Underperform

"Successful" Projects

We see that projects with positive outcomes usually share the following commonalities:

- Project goals have been well developed and quantified. These goals typically include some education or marketing component and do not rely solely on energy production.
- BEWT project developers conducted rigorous due diligence and devoted time to planning before deployment.
- BEWT projects are placed on taller buildings relative to surrounding obstacles.
- Project developers selected certified horizontal-axis wind turbines with a strong track record of previous deployments.

In addition to the value of the energy generated, some of the other possible benefits identified by project developers included:

- Leadership in Energy & Environmental Design (LEED) certification credits
- Marketing or public relations value for a commercial building
- Meeting carbon reduction targets or renewable energy targets
- Supporting local and/or onsite generation
- Utilizing federal, state, and utility incentives
- Conducting education and outreach.

Recommended Best Practices

Although the development of turbines in the built environment is not likely to pencil out from an economic or power production standpoint, if a BEWT project is developed for other reasons, NREL recommends that the following key steps be incorporated when planning:

- Establish baselines and develop project goals
- Perform a detailed technical evaluation including site evaluation, turbine selection, resource assessment, and production estimate
- Estimate project costs and conduct a cost/benefit analysis.

The built environment adds new dimensions, costs, and challenges to these planning process phases. Although relevant to the installation of all small wind turbines, the following parameters must be considered more carefully when siting BEWT projects:

- Wind resource, including frequency distribution, predominant direction, turbulence intensity, and inflow angles
- Building characteristics and geometry, including building shape, roof shape, building orientation with respect to predominant winds, and building structural considerations
- Turbine technology with a focus on turbine safety limits, turbine orientation, and planned tower height
- Installation and maintenance, including assessing initial construction costs and ongoing operations and maintenance costs
- Building occupant comfort and safety, specifically around noise emissions, vibration emissions, and turbine failure projectile zone.

Production can be even lower than conservative estimates, as shown from measured data taken at the NASA project from March 2016, when compared to estimated power based on collected data and manufacturers' power curve (as shown in the following table).

Turbine	Energy (Wh)	Capacity Factor (%)	60-W Light Bulb Duration (Hours)
1	16.54	0.0022%	0.28
2	59.10	0.0079%	0.99
3	33.12	0.0045%	0.55
4	8.16	0.0011%	0.14
Estimate	7810.0	1.05%	130.17

References

J. Fields, F. Oteri, R. Preus, and I. Baring-Gould. (2016). *Deployment of Wind Turbines in the Built Environment: Risks, Lessons, and Recommended Practices* (Technical Report). NREL/TP-5000-65622. National Renewable Energy Laboratory, Golden, CO.

Boston Museum of Science Wind Lab. (2015). Energized! Exploring Renewable Energy. http://legacy.mos.org/energized/museum-wind.php

Detroit Metro Airport. (April 22, 2010). "Earth Day Breezes into Detroit Metro Airport -- Airport Authority Begins Testing New Wind Energy Technology." News release. http://www.wcaa.us/Portals/WCAACorp/WCAA%20Documents/PDFs/NR_Windspire_Event_22APR2010_POST.pdf

Dopp, T. "NYC Opens 1st Building-Mounted Wind Turbines at Brooklyn Yard." Bloomberg, April 9, 2009. http://www.bloomberg.com/apps/news?pid=newsarchive&sid=aOiCpp9Xi1pk

Tomusiak, M. (July 26, 2011). "Museum of Science Analyzes Rooftop Turbines." Interstate Renewable Energy Council. http://www.irecusa.org/2011/07/19769/

This work was supported by the U.S. Department of Energy (DOE) under Contract No. DE-AC36-08GO28308 with the National Renewable Energy Laboratory (NREL).

AWEA WINDPOWER 2017
Anaheim, CA
May 22-25, 2017
NREL/PO-5000-68423