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**Appended June 2010: Addendum dated 3 June 2007**
1 Executive Summary

This study analyzes the feasibility of installation of wind turbine electric generators at the MoS, Inc.’s (MOS’s) world headquarters located at Science Park in Cambridge and Boston, Massachusetts. The study reviews several types of rooftop mounted wind turbines and both small (less than 10 kW) and large utility-scale wind turbines. The mission of the MoS is to stimulate interest in and further understanding of science and technology and their importance for individuals and for society. The MoS realizes that that the use of renewable energy is important as a means of serving as an example of precisely the kinds of critical thinking skills that its employees and volunteers work hard to teach, and of being responsible toward the public that they serve, and the environment.

The MoS site possesses moderate wind resources (an average of 5.4 m/s at 30 m and 6.0 – 6.5 m/s at 70 meters) according to AWS Truewind estimates, and, based on preliminary site specific anemometer measurements, 5.1 m/s at 43 m (approximate height of rooftop tower-mounted turbines) and 3.9 m/s at 30.5 m (height of Central Building 6th floor roof). The MoS also has sufficient roof area to place turbines, and more than enough electricity consumption (~9,000,000 kWh / year) to make the installation of either small or large wind turbines a viable project. This project has the potential to be a beacon to demonstrate the benefits renewable wind energy and of advanced green building design in Massachusetts.

Roof-mounted wind turbine generators of 26.5 kW capacity in total are proposed to be installed on the Penthouse #2 roof, the Blue Wing roof, the Omni Theatre roof, and the Central Building – Level 6 roof. The total estimated installed cost is $258,557 including structural tie-ins and electrical interconnection and will produce 43,182 kWh / year.

1.1 Conclusions

Some highlights of issues and our findings follow:

Site Layout

- MoS has sufficient roof area and structural elements to place and support both rooftop wind and small pole mounted wind turbines on various building wings.
• The MoS site does not possess significant real estate thereby limiting the placement, staging, installation and operation of utility-scale wind turbines.

• The MoS site is in an existing helicopter flyway and approach for the adjacent Massachusetts General Hospital and the nearby Coast Guard Station in the North End among others that navigate along the Charles River.

• The MoS site is constrained by the number of relatively tall structures in the general vicinity that will create wind turbulence that adversely affects the operational efficiency and maintenance requirements of utility-scale machines.

• The site is easily accessible via major state and federal highways for turbine and tower shipment.

• The site is located in both Cambridge and Boston. In Cambridge, it is in a Planned Unit Development overlay and is a residentially zoned area. In Boston, the site is zoned Residential Apartments. There are no residential properties directly bordering the MoS site though there are many high rise apartments and condominiums in a direct line of site of their property.

• The MoS is constructed on the Charles River Dam and is bounded to the southwest by the Charles River basin and surrounded by various parklands and pedestrian/bike paths. This area is highly trafficked by cars and trucks, public train transportation, pedestrians, bikes, rollerbladers, joggers etc. and will make for a highly visible wind turbine project.

Energy Infrastructure & Consumption

• MOS’s annual electricity consumption totaled approximately 9,000,000 kWh between 2005-06 (thru July) which will translate into total charges of approximately $1,500,000.

• Consumption peaks during the summer months, coincident with cooling load.

Engineering and Interconnection Requirements

• Roof-mounted wind turbine generators of 26.5 kW capacity in total are proposed to be installed on the Penthouse #2 roof, the Blue Wing roof, the Omni Theatre roof, and the Central Building – Level 6 roof.
• The wind turbine generators to be installed on the Penthouse #2 roof and the Blue Wing roof will be interconnected to 480 volt distribution panel inside Penthouse #2. The wind turbine generators to be installed on the Omni Theatre roof and the Central Building – Level 6 roof will be interconnected to 480 volt distribution panel located inside Penthouse #3.

• The total installed cost estimate for the interconnection work described in this report is $79,000. This is a planning accuracy (plus or minus 25%) cost estimate for all materials, installation labor, and engineering.

Solar Cells

While outside of the scope of this study a spare panel board circuit breaker exists in Penthouse #2 that is available to run the appropriate cables and conduits to repower the disconnected 1970's vintage PV panels on the Blue wing roof.

• The interconnection costs would be approximately $12,600.

• A 2.7 kW system could be installed based on the existing dimensions of the solar racks. We did not obtain capital costs estimates for new PV panels. Typically these panels are 10 W/ft² of panel and about $10/W installed (rough estimate ~$27,000 + $12,600 = $39,600).

Environmental Resource Assessment

• Shadowing and flicker impacts to the Charles River basin are not expected to be of concern for the roof-mounted units due to the small blade diameter and low relative height.

• The developed, urban setting of the MoS and the small swept area of the wind turbines will minimize or avoid any potential impact to Federal and State threatened, endangered or proposed listed species if these are present at the MoS site. No formal review is recommended.

• A regional air emission benefit of a reduction of approximately 23.8 tons per year of carbon dioxide emissions can be achieved by the installation of the 26.5 kW of roof-mounted wind turbine capacity.

Permitting

Cambridge:
- A written determination is required by the Cambridge Planning Board relating to development in the East Cambridge Riverfront area for compatibility.

- Cambridge does not define wind turbines in their zoning bylaws. However, if the electricity is consumed on-site, it will most likely be considered an allowed accessory use.

- A zoning exemption for height in Cambridge may be applicable as well under the bylaws for the architectural wind turbine units.

- A special permit may be required in Cambridge's Planned Unit Development Overlay Zone relating to noise impacts. Further review by an attorney and noise consultant is recommended (see also Noise Assessment section 3.3.3).

- A special permit may be required by the Cambridge Zoning Board of Appeals if the wind installation is defined or intended for scientific research.

- Power generation may be prohibited in Cambridge at the MoS site based on its residential zoning designation under the Zoning Ordinances. Further review by an attorney is recommended but a special permit may override this prohibition.

**Boston:**

- Boston does not define wind turbines in their zoning bylaws. However, if the electricity is consumed on-site, it will most likely be considered an allowed accessory use.

- Most likely, the Boston Zoning Board of Appeals would issue a Special Permit for accessory use (or potentially an extension of a non-conforming use) for wind turbines. Further review by an attorney is recommended.

- There is no defined height limit in the City of Boston’s Zoning Ordinance for this site’s zoning classification.

- The Massachusetts noise guideline (a change in sound not exceeding 10 dB at the property line) most likely will be met due to the existing high ambient sound
levels and the innovative design of the architectural wind turbines. The noise levels from the state-of-the art turbines is acceptable both at the property line and within the MoS itself.

- The Federal Aviation Administration (FAA) determined that the tower and blade height of large utility scale turbines would pose a “Presumed Hazard to Air Navigation” at two potential sites on the MoS property. The FAA limited wind turbine height to not to exceed 213 ft. To go beyond this height, additional FAA study, regulatory review and public participation would be required without guarantee of success.

- If the MoS proceeds with the wind turbine installation, formal notification is recommended to the U.S. Department of the Interior’s Fish and Wildlife Service and the Massachusetts Natural Heritage Program for a review of the presence of any listed threatened, endangered or proposed species.

Recommended Configuration

- Given the desires and substantial constraints of the MoS site and rooftop we have recommended a total installed system of 26.5 kW configuration with:
  
  - 6 AeroVironment AVX 400 (0.4 kW each)
  - 1 WES Tulipo (2.5 kW each)
  - 3 Proven WT 6000 (6.0 kW each)
  - 2 Southwest Skystreams (1.8 kW each)

- The total estimated installed cost is $258,557 including structural tie-ins and electrical interconnection.

Economic Feasibility Analysis

- MoS has a combination of moderate wind resources, high electric consumption, and high electric rates.

- For most turbines, economic returns are not positive until offsetting grants reach above 90%. It may be possible to combine grants to reach this level of support.

- The total estimated installed cost of roof-mounted small scale wind turbines is $258,557 including structural tie-ins and electrical interconnection and will produce 43,182 kWh / year.
- With no offsetting grants this translates into a nominal cost of $0.35 / kWh over a 20 year project life. In contrast the MoS currently pays approximately $0.12 / kWh. The project does not become cashflow positive within 20 years.

- The project still will not be cashflow positive within 20 years with a 75% grant

- With a 90% grant the project will be cashflow positive within 7 years, and provide an internal rate of return of 23% over the 20 year project life.

- While economic returns are not generally positive due to the inability of this site to utilize large, utility-scale turbines, the MoS’s benefits to society via the demonstration of renewable energy production from wind turbines for the purpose of educating the public would be invaluable.

**Other**

- Continue to track the commercial availability of the Swift and Airdolphin turbine, two innovative designs not yet available in the US.
2 Introduction

Stimulated by the pursuit of renewable energy to help offset traditional electricity supply while providing environmental benefits, this report provides a feasibility analysis of installing wind turbines at the Museum of Science (MoS) in Boston, MA. In addition to the economic and other considerations, the MoS has explicit and important educational, science and technology goals for a renewable energy project. The mission of the MoS is to stimulate interest in and further understanding of science and technology and their importance for individuals and for society. The MoS realizes that that the use of renewable energy is important as a means of serving as an example of precisely the kinds of critical thinking skills that its employees and volunteers work hard to teach, and of being responsible toward the public that they serve, and the environment.

The potential for wind energy development at the MoS site is identified primarily from the southwest prevailing winds and the open exposure of the building to these winds across the expanse of the Charles River basin in this direction. Within the context of the MoS’s mission statement and interest in renewable energy, the Boreal team was asked to undertake a feasibility study of three main types of wind turbine systems for application at the MoS; utility-scale wind turbines and two types of architectural turbines.

One architectural turbine design is intended to benefit from both the prevailing wind and the increased wind velocity (and associated pressure ridge) located where a building wall meets the roofline (parapet edge). These designs mount on the top of the windward edge of a building’s parapet or on the roof. The second type of architectural wind turbines examined are mounted on steel poles and are attached to the roof of a building by various means. Also, more traditional, free-standing, utility-scale tower-mounted turbines are considered in the analysis.
3 Site Evaluation

History

The MoS was established in 1830 as an organization through which scientific interests and natural history could be explored. First located on Berkeley and Boylston Streets in the Back Bay, the MoS opened at its current location on the Charles River Dam in 1951. Since that time, the MoS has taken on a number of facility and exhibit expansions to enhance the overall quality and experience offered. With over 550 interactive exhibits, the MoS remains on the cutting edge of science education and entertainment. More than 1.6 million students, teachers, and adults visit the MoS each year, making it Boston’s most-attended cultural institution.

3.1 Site Layout

3.1.1 Property Boundaries, Topography
Spanning the Charles River with its physical layout straddling the borders of Boston and Cambridge, the MoS is a landmark of the community. The facility consists of eight buildings, including three wings of museum space, the Charles Hayden Planetarium, Mugar Omnimax Theater, rooftop Gilliland Observatory, Theater of Electricity, two other theaters, cafes, a gift shop, conference rooms and educational facilities that total over 400,000 square feet. A large parking garage also sits adjacent to the MoS to the northwest. The site itself, known as Science Park, spreads northwest to southeast, paralleling the Monsignor O’Brien Highway (Route 28) and sitting directly atop the Charles River Dam, which was completed in 1910. It is accessible by car from Route 28 or by foot from the Science Park MBTA stop on Boston’s Green Line, located about 200 yards away.

The MoS site elevation is roughly 10-20 feet above mean sea level. To the north is Route 28, the Charles River, and North Point Park. Directly to the east, is a narrow channel of the Charles River for boat passage (boat locks are located further downstream), the Charles River Reservation, and Storrow Drive. Beyond Storrow Drive to the south and east are tall urban residential and office buildings located in the city of Boston proper and a Coast Guard Station in the North End with helicopter access. Massachusetts General Hospital (and a helipad) also is nearby to the southeast. To the
south is the Charles River, and to the west is Cambridge. The Cambridge Galleria Mall and hotel buildings are the nearest abutters in Cambridge.

While the MoS is located in a busy section near downtown Boston, it is somewhat isolated by its primary abutment with the Charles River and the heavily trafficked Rte 28. There are no residential neighbors directly adjacent to the site. City traffic and other associated sounds are the predominant sources of noise.
Figure 3-1
Site Locus¹

Reference: Google Maps 2006
3.1.2 **Wind Resources**

A wind resource assessment was performed at the MoS for two purposes: 1) to predict wind resources at the parapet edge of the various MoS’s roof surfaces (located on the prevailing wind side) for better estimation of the performance of architectural wind turbine devices and, 2) to investigate wind resources at higher elevations for the evaluation of small rooftop pole or freestanding utility-scale tower mounted wind turbines. According to modeled wind speeds by AWS Truewind, the MoS location has
an average annual wind speed of 5.4 m/s at 30 meters elevation. The annual averages are predicted to be 5.7 m/s and 6 m/s at 50 and 70 meters elevation (above ground level), respectively. Given local climatic variations in wind speed and direction that may not be accounted for properly in the Truewind model (due to nearby buildings, the Charles River, and other influences), it was necessary to install anemometers at the MoS location.

To confirm and/or refine the Truewind estimates, Boreal installed five anemometers at various locations and heights accessible from the rooftops of the MoS (see Figure 2-3 for locations and reference numbers). Given the potential for architectural wind turbines to be incorporated into a future design scheme, three anemometers were installed on tripod mounts and placed directly on the roof itself, facing upriver on the Charles (southwest direction). Two other anemometers were installed on two separate monopoles that extend from the east (oceanside) and west (riverside) corners of the MoS’s central tower, which is the highest point of all the MoS buildings. The pole mounted anemometer data also is utilized for the rooftop tower-mounted wind turbine analysis. These two anemometers, as well as one rooftop mount, feature a Nomad 2 datalogger manufactured by SecondWind and a removable memory storage chip. Hobo is the manufacturer of the other two anemometers that utilize independent dataloggers at each of these locations. An additional wind speed measurement location was considered such as the large parking garage roof but due to its open access to the general public, and that the garage itself does not have a solid vertical wall to create a wind pressure wave at the parapet, this potential location was eliminated.

Data were downloaded on a monthly basis from each of the instruments. Data were imported into Excel spreadsheets and statistically analyzed to determine average and gusting wind speed, duration, direction, turbulence (calculated) and temperature. Approximately three months of wind data were analyzed and correlated to long-term weather data sources from Logan Airport and from a “Weatherbug” meteorological station on the MoS roof. From the correlation, the MoS data were adjusted according to historical wind speed values.
Figure 3-3
MoS Aerial Photo with Anemometer Locations

Table 3-1
Description of Anemometer Locations²

<table>
<thead>
<tr>
<th>Anemometer #</th>
<th>Location / Mount</th>
<th>Elevation – Above Ground Level</th>
<th>Make</th>
<th>Vane</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Rooftop / Tripod</td>
<td>50 ft. (15.3 m)</td>
<td>Hobo</td>
<td>No</td>
</tr>
<tr>
<td>2</td>
<td>Rooftop / Tripod</td>
<td>100 ft. (30.5 m)</td>
<td>Nomad</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Rooftop / Tripod</td>
<td>54 ft. (16.5 m)</td>
<td>Hobo</td>
<td>No</td>
</tr>
<tr>
<td>4</td>
<td>Riverside MoS Tower / Pole</td>
<td>170 ft. (51.9 m)</td>
<td>Nomad</td>
<td>Yes</td>
</tr>
<tr>
<td>5</td>
<td>Oceanside MoS Tower / Pole</td>
<td>170 ft. (51.9 m)</td>
<td>Nomad</td>
<td>Yes</td>
</tr>
</tbody>
</table>

² Ground level is 19 feet above sea level.
Figure 2-4
Tower-Mounted Anemometers (#'s 4 and 5)

Figure 2-5
Tripod Anemometer (#3)
At the time of this report, we have received three and one half months of site-specific wind data from April 2006 to mid-July 2006. Average winds speeds of the raw data are in the Table 3-2.

<table>
<thead>
<tr>
<th>Instrument Name</th>
<th>Location</th>
<th>April Average (m/s)</th>
<th>May Average (m/s)</th>
<th>June Average (m/s)</th>
<th>July 1-July 11 Average (m/s)</th>
<th>Average (m/s)</th>
<th>Ratio MoS Site to Logan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Anemometer 1</td>
<td>Beehive Roof</td>
<td>1.91&lt;sup&gt;3&lt;/sup&gt;</td>
<td>1.99</td>
<td>2.26</td>
<td>3.34</td>
<td>2.38</td>
<td>47.5%</td>
</tr>
<tr>
<td>Anemometer 2</td>
<td>Central Bldg. Roof</td>
<td>3.68</td>
<td>3.30</td>
<td>3.45</td>
<td>4.35</td>
<td>3.70</td>
<td>73.8%</td>
</tr>
<tr>
<td>Anemometer 3</td>
<td>Blue Wing Roof</td>
<td>2.37</td>
<td>2.224</td>
<td>2.51</td>
<td>3.26</td>
<td>2.59</td>
<td>51.7%</td>
</tr>
<tr>
<td>Anemometer 4</td>
<td>Riverside Tower</td>
<td>4.48</td>
<td>4.85</td>
<td>4.32</td>
<td>4.55</td>
<td>4.55</td>
<td>90.9%</td>
</tr>
<tr>
<td>Anemometer 5</td>
<td>Oceanside Tower</td>
<td>4.88</td>
<td>4.93</td>
<td>4.52</td>
<td>5.15</td>
<td>4.87</td>
<td>97.3%</td>
</tr>
<tr>
<td>Logan</td>
<td>Logan Airport</td>
<td>5.36</td>
<td>5.36</td>
<td>4.43</td>
<td>4.35</td>
<td>5.01</td>
<td>n/a</td>
</tr>
</tbody>
</table>

To be useful these data must be adjusted to take into account two major factors:

i) The hub height of the potential turbine installation: Rooftop tower-mounted turbines range in hub height from 6 to 12 m. Parapet mounted turbines are mounted less than a meter from the roof surface, so no adjustment for height is necessary.

ii) Long-term weather patterns: The amount of wind can and does vary significantly month-to-month and year-to-year. As the raw data may

---

<sup>3</sup> Partial month beginning 4/8 at this location

<sup>4</sup> Missing data from 5/21 to 6/4 at this location due to battery failure
reflect higher or lower wind speeds than the historical average, an adjustment is made to account for long-term trends.

Below we describe how these two adjustments are performed:

3.1.2.1 Methodology

3.1.2.1.1 Adjustments of Wind Resources to Long Term Trends.

In order to predict the long-term wind resources with a greater degree of certainty it is necessary to correlate short-term on-site wind records with nearby weather stations that have long-term records. Three criteria are considered in selecting a weather station for this adjustment: 1) long-term measurement of wind resources, 2) available data, and 3) a good correlation between the weather station and MoS data. Table 3-3 displays the correlation of hourly average wind speeds. A review of the wind table for all hours show:

- The 3 roof locations are very well correlated with each other (.88, .91, .96)
- 2 tower locations are very highly correlated (.95)
- Logan Airport and towers locations are well correlated (.71 and .78)
- Logan and rooftop locations moderately correlated (.48, .42, .53)

An obvious reason why the rooftop locations and Logan are only moderately correlated is the wind shadowing of the buildings when the wind is not from the southwest. We re-ran the correlation for only those hours where Logan direction was from the southwest (see Table 3-4). As can be seen the correlation between the rooftop locations and Logan Airport increases dramatically. The correlation for the Oceanside rooftop location drops by 10%, not surprising as the spire will cause some wind shadowing. The correlation between Logan and the Riverside tower anemometer drops by 5%. This is somewhat counter-intuitive. One potential explanation is the winds from the southwest are generally lighter than other directions, so any absolute measurement differences between the two locations will negatively affect the correlation to a great degree.

Based on these criteria, Logan Airport was selected as a basis for adjustment of MoS data.
Table 3-3
Correlation of Hourly Average Wind Speed for April 1 through July 11th, 2006

<table>
<thead>
<tr>
<th></th>
<th>Blue Wing Roof</th>
<th>Beehive Roof</th>
<th>Central Bldg Roof</th>
<th>Riverside Tower</th>
<th>Oceanside Tower</th>
<th>Logan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Wing Roof</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beehive Roof</td>
<td>96%</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Bldg. Roof</td>
<td>91%</td>
<td>88%</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riverside Tower</td>
<td>69%</td>
<td>61%</td>
<td>76%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oceanside Tower</td>
<td>76%</td>
<td>70%</td>
<td>86%</td>
<td>95%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Logan</td>
<td>50%</td>
<td>42%</td>
<td>55%</td>
<td>78%</td>
<td>71%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 3-4
Correlation of Hourly Average Wind Speed for April 1 through July 11th, 2006
Logan Wind Direction 180° to 270°

<table>
<thead>
<tr>
<th></th>
<th>Blue Wing Roof</th>
<th>Beehive Roof</th>
<th>Central Bldg Roof</th>
<th>Riverside Tower</th>
<th>Oceanside Tower</th>
<th>Logan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blue Wing Roof</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Beehive Roof</td>
<td>93%</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Central Bldg. Roof</td>
<td>90%</td>
<td>85%</td>
<td>100%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Riverside Tower</td>
<td>88%</td>
<td>86%</td>
<td>99%</td>
<td>100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oceanside Tower</td>
<td>86%</td>
<td>84%</td>
<td>97%</td>
<td>97%</td>
<td>100%</td>
<td></td>
</tr>
<tr>
<td>Logan</td>
<td>71%</td>
<td>75%</td>
<td>71%</td>
<td>73%</td>
<td>62%</td>
<td>100%</td>
</tr>
</tbody>
</table>

Table 3-5 displays the comparison of Logan airport during the period of data collection in Spring and Summer of 2006 as compared to the long-term historical average wind speeds for the same months. On average the wind speeds during the data collection
period were lower than the historical averages. Given the good correlation between the wind speeds at Logan and the MoS we would expect over the long-term the average wind speeds would have been 8% higher than what was measured over the April to July time period.

### Table 3-5
Comparison of 2006 Logan Wind Speed (m/s) to Long Term Logan Airport Averages

<table>
<thead>
<tr>
<th>Month</th>
<th>Long Term Historical</th>
<th>Year 2006</th>
<th>Ratio Historical to 2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>April</td>
<td>5.65</td>
<td>5.36</td>
<td>105%</td>
</tr>
<tr>
<td>May</td>
<td>5.24</td>
<td>5.36</td>
<td>98%</td>
</tr>
<tr>
<td>June</td>
<td>4.94</td>
<td>4.43</td>
<td>112%</td>
</tr>
<tr>
<td>July</td>
<td>4.79</td>
<td>4.35</td>
<td>116%</td>
</tr>
<tr>
<td>Average</td>
<td>5.15</td>
<td>5.01</td>
<td>108%</td>
</tr>
</tbody>
</table>

As more data comes becomes available, the degree of correlation and adjustments can be updated, however, the data results and conclusions that can be drawn from them are not expected to be markedly different.

3.1.2.1.2 Adjustments of Wind Speed for Hub Height

The change in wind speed with height is referred to as wind shear. The wind blows at a consistently higher velocity at higher elevations. One method of estimating wind shear is given by the following formula⁵:

\[
\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^\alpha
\]

Where:

- \( U(z) \) is the wind speed at height \( z \).

---

$U(z_r)$ is the wind speed at reference height $z_r$, and,

$\alpha$ is the power law exponent.

From this formula $\alpha$ can be determined:

A conservative over rough terrain is to $\alpha$ the value of $1/7$. Estimates of long-term wind speeds at various elevations at MoS can be made by applying the power law coefficient. We expect no shear adjustment for the parapet mounted turbines (i.e., the AeroVironment turbine), but will need to make shear adjustments for the hub height of the tower mounted turbines.

3.1.2.1.3 Estimates of Long-term Wind Resources at Hub Heights

Given the above we estimate the long-term wind resources at the MoS by the following:

1. Compute the ratio of short-term average wind speeds of MoS to Logan:
   $\text{MoS}_{ST}/\text{Logan}_{ST}$ (see Table 3-5)

2. Estimate Long-term MoS wind resources at anemometer height $\text{MoS}_{LT} = \text{Logan}_{LT}$
   *  $\text{MoS}_{ST}/\text{Logan}_{ST}$

3. Adjust to tower height $\frac{U(z)}{U(z_r)} = \left(\frac{z}{z_r}\right)^\alpha$, $U(z_r)$ is the anemometer height and $U(z)$ is the hub height of the turbine.

For the roof, tower-mounted turbines will be 6 to 12.5 meters above the roof top, but will still be lower than the central tower. We use estimates of the central tower anemometers wind resources and adjust them downward to simulate the wind resources at hub height. Table 3-6 shows the computation of estimate the average long-term hub height wind speed for a turbine on a 12.5 meter tower on from the main building roof to be 5.09 m/s. Other hub heights are computed per turbine / tower / location configuration.
### Table 3-6

**Computation of Estimate of Average Long-Term Hub Height Wind Speed on 12.5 Meter Tower from Main Building Roof**

<table>
<thead>
<tr>
<th>Attribute Description</th>
<th>Adjustment Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Long Term Logan Annual Average Wind Speed</td>
<td>5.37 m/s</td>
</tr>
<tr>
<td>Ratio MoS Oceanside Tower / Logan</td>
<td>0.9726</td>
</tr>
<tr>
<td>Long Term MoS @51.9 meters</td>
<td>5.23 m/s</td>
</tr>
<tr>
<td>Wind Shear Adjustment from 51.9 to 43 meters</td>
<td>0.9736</td>
</tr>
<tr>
<td>Long Term MoS @43 meters</td>
<td>5.09 m/s</td>
</tr>
</tbody>
</table>

#### 3.1.3 Stakeholder Identification

Besides the elected officials and immediately adjacent property owners, other likely concerned entities in the area include:

- Charles River Watershed Association
- Charles River Recreation
- Charles River Conservancy
- City of Cambridge
- Cambridge Sustainable City
- Cambridge Climate Action Network
- City of Boston
- Boston Climate Action Network
- Boston Scenarios Project – Envisioning a Sustainable Boston (Tellus Institute)
- Boston Redevelopment Authority
- Green Boston Initiative
- Green Building Roundtable
- Massachusetts Audubon Society
- Environmental League of Massachusetts
• Esplanade Association
• Boston Duck Tours
• U.S. Environmental Protection Agency – Charles River Initiative
• U.S. Army Corps of Engineers (Charles River Dam)
• Massachusetts Department of Conservation and Recreation
• Massachusetts Department of Watershed Initiative
• Massachusetts Riverways
• MASS PIRG

3.2 Energy Infrastructure & Consumption

3.2.1 Existing Electrical Supply and Distribution System

The existing electric supply to the MoS is a three phase supply from the NSTAR 13.8 kV system. The 13.8 kV supply is connected to several 13.8 kV – 480 volt power transformers and to a 13.8 kV – 4.16 kV transformer within the MoS. The 13.8 kV – 480 volt transformers supply multiple 480 volt electrical distribution panels within the MoS. The 13.8 kV – 4.16 kV transformers supply several 4.16 kV – 120/208 volt transformers and associated 120/208 volt electrical distribution panels within the MoS. There also are several standby electrical generators within the MoS.

The existing electrical distribution system was surveyed to identify locations where the proposed wind turbine generators could be interconnected. The wind turbine generators are proposed to be located on the roof of the MoS and the survey focused on the existing MoS 480 volt electrical distribution panels within Penthouse #2 and Penthouse #3. Specifically, 480 volt distribution panel PPC located inside Penthouse #2 and 480 volt distribution panel PPH-3A located in Penthouse #3 have been selected for the wind turbine generator interconnection. Each panel contains a spare, three pole, 480 volt circuit breaker that can be utilized for the interconnection of the proposed wind turbine generators.
3.2.2 Electricity Consumption

Monthly kWh consumption data are displayed for MoS from August 2005 through July 2006 in Figure 3-3 and average and peak kW draw are shown over the same period in Figure 3-4. As with many occupancy driven loads, the MoS’s peak electricity consumption is in the summer months coinciding with air conditioning use.

Figure 3-3
MoS 2005-2006 Monthly Electricity Consumption (kWh)
3.2.2.1 *Daily and Hourly Patterns*

MoS daily and hourly electricity draw are always significantly higher than what has the potential to be generated by the roof mounted wind turbines. Thus any roof-mounted turbines always will be avoiding retail sales, and no electricity will be exported to the grid\(^6\).

\(^6\) In addition, the installed capacity of rooftop units will be under the 60 kW threshold and thus eligible for net metering in Massachusetts. Net metering allows for 100% of the behind the meter generation to “spin back” the meter if at some times the renewable energy project is producing more than is being consumed on-site. As the MoS consumption is so large this will never happen, net metering is irrelevant for this analysis.
3.2.3 Potential Wind Turbine Configurations

Rooftop Wind Systems:

The MoS presents a unique opportunity for rooftop wind turbine installations due to its flat, expansive roof exposed to the prevailing winds across the Charles River Basin and its relatively unobstructed location without adjacent buildings. A relatively new technology, rooftop wind turbines are becoming increasingly popular for residential and commercial grid-connected use in Europe and the US. Turbines available for rooftop mounting typically range from 0.4 to 2.5 kW in peak capacity (400 to 2500 Watts). There also are limited examples of buildings using a 6 kW capacity roof-mounted wind turbine. While an individual turbine will make little impact on the electricity supply for a site such as the MoS, an array of turbines can be used to have a cumulative effect. The MoS roof offers potential for constructing such an array.

In the interest of exploring multiple rooftop turbine technologies and the educational mission of the MoS, which supports the installation of multiple turbines for comparative study and research, Boreal selected six manufacturers (eight turbines total) that have turbines for potential rooftop application at the MoS. Many turbine configurations are possible with these systems. The manufacturers are chosen due to their demonstrated operation in the industry and willingness to support rooftop mounting of their turbines. Further, all turbines listed are or will be commercially available in 60 Hz for grid connection in the US (see dates listed in Table 3-7). Economic analysis is limited to manufacturers who currently have commercially available models. Table 3-7 provides a technical description of each of the turbines, and Table 3-8 provides indicative prices and important economic considerations. Based on these considerations, a ranking scheme is developed and provided in Table 3-9. A critical review of each manufacturer and turbine is also presented below. Boreal has copies of the original turbine brochures from most of the manufacturers that are available upon request. A contact listing of wind turbine vendors is included as Appendix D.

It should be noted that Bergey, an Oklahoma-based world leader in small wind turbines, is not included among the reviewed manufacturers. Boreal considered Bergey for the MoS, but learned that their 1 kW turbine is only available in a battery-charging model (not for grid-connect) and their 10 kW model is likely too large and heavy for rooftop mounting.
Vertical axis wind turbine systems also were considered, including TMA Global Wind Energy Systems, Mag-Wind, Wind Harvest, and Quietrevolution. As the TMA and Mag-Wind systems are still in development stage with no specified target date for availability, they are deemed unlikely candidates for the MoS. Wind Harvest has a recent model called the Windstar 1400. However, with a cut-in speed of 4.4 m/s, it would not be suitable given wind speeds experienced at the MoS. Additional information on Quietrevolution can be found later in this report.

**AeroVironment (AVX400):**

AeroVironment (AV) was founded in 1971 and is based in California (their energy center is in Austin, TX). AV has a strong corporate history of innovation in the field of aeronautics and aerodynamics. AV is unique among the selected systems in that turbines are specifically designed for mounting in a linear fashion along the parapet of a building, with multiple turbines included in the arrangement. They are an American manufacturer.

The idea behind their design is that wind is channeled as it passes up and over the side of a building, creating an air mass of greater density and velocity at the leading edge of the roof. The turbines have a slight downward angle and are aligned in a row to harness the wind’s kinetic energy as it passes (see Figure 3-5 for an installed AVX 400 unit and for a proposed depiction on the MoS by AV). This style of mounting has been termed “architectural wind,” as it not only uses the structure of a building to enhance power output but is also thought to add to the overall architectural appeal of a building. While the system is comprised of individual turbines, its cumulative output is measured by linear foot. Since the turbines are aligned closely in a row, performance depends on being perpendicular to a strong prevailing wind direction. In the case of the MoS, rooftops exposed to the Charles River Basin are perpendicular to a SW wind. Data collected from the MoS demonstrate that wind blows from directions between South and West about 40-45% of the time. The turbines are able to yaw 30° from center in each direction, which would capture most of the wind between South and West. When wind direction is not between South and West, turbine performance would be significantly diminished, if not completely inhibited.

As AV’s turbine is just recently developed, no long-term experience exists to analyze its performance in actual applications. Likewise, while the idea and design behind architectural wind turbines may be good, little information is available to support their
practical validity. In light of these limitations, it is difficult to accurately predict the performance of AV’s turbine at the MoS. The MoS has a stated concern about installing a rooftop system that does not perform well (i.e., does not spin). Therefore, Boreal would like to see more supportive data about AV’s turbine, especially from real-life experience, if possible. Some of our additional specific concerns about AV’s equipment can be found in Appendix A:
Wind Energy Solutions (Tulipo):

Wind Energy Solutions (WES) is a Netherlands based manufacturer of small and medium sized wind turbines including roof-mounted systems. Founded in 2003, WES incorporated turbine technology originally developed by Teamwork Technology. WES has a record of successful turbine installations over the past three years. Their smallest turbine, the Tulipo, is fully endowed with safety (IEC 61400-2) and green building
(LEED) certificates. In June 2006, Boreal met with a Canadian based representative from WES. He toured the MoS’s rooftop locations and was optimistic about the potential of mounting several WES Tulipo turbines at various points.

The Tulipo has the largest weight of any rooftop turbines analyzed for the MoS. With a power rating of 2.5 kW, the turbine and tower package weighs almost 800 kg (~1,750 lbs.). The WES representative did mention a 6-meter tower could be used on the MoS roof, instead of the normal 12-meter tower. This reduces the overall weight of the turbine / tower package to 550 kg (not including the 80 kg control cabinet usually placed at the base of the turbine). However, due to unpredictable effects on turbine performance from building turbulence, WES strongly favors the 12 m tower for rooftops over the 6 m. While WES claims the Tulipo and 12 m tower can be mounted on most buildings, the structural implications for mounting such a heavy turbine on the MoS roof will need to be addressed to ensure its applicability. Preliminary structural design based on the Tulipo’s specifications suggests it should be mounted only where steel I-beams are present in the roof structure. For additional technical information regarding turbine mounting systems and costs, please refer to structural engineer Paul Phelan’s (P.E.) review found in Appendix B.

The Tulipo shares many features of a modern, large-scale wind turbine. The components necessary for these features explain the system’s overall weight. One important feature of the Tulipo that sets it apart from other turbines in its class is a 360° active yaw capability. The Tulipo uses real-time measurements to turn itself perpendicular to the direction of the wind. This ensures maximum collection of wind energy. The active nature of the yaw is typically more efficient than passive yaw designs of other small wind turbines.
Proven (WT 2500 & WT 6000):

Proven Energy Ltd. is a Scottish manufacturer of small-scale wind turbines, ranging from 600 Watts to 15 kW. They are well established in the global marketplace for small turbines, with over 10 years of experience with their initial design and over 700 installations in 30 countries. They make two turbines that would be appropriate for rooftop mounting at the MoS: the WT 2500 (2.5 kW) and WT 6000 (6 kW).\(^7\) All Proven turbines employ a downwind design. This design is characterized by a 360° passive yaw capability (with a downwind rotor, the turbine will turn away from and perpendicular to the wind, much like a wind vane). In high winds, the blades bend and pitch away from the wind but continue to produce power at maximum capacity. This protects turbine equipment in high winds while preserving power output.

\(^7\) Proven also makes a smaller 600 Watt turbine, but it is primarily intended for battery charging and requires a separate inverter for grid connection. This inverter is not currently sold in the US.
As wind is somewhat impeded by the rotor before striking the blades, a downwind design is typically slightly less efficient than an upwind design. However, overall efficiency also is improved by the Proven turbines’ ability to bend away from the wind while still producing power during periods of high wind speeds (other turbines simply shut down as an emergency safety mechanism). A downwind design also requires less mechanical components, and therefore may require less maintenance throughout its lifetime. A Proven distributor informed Boreal that the WT2500 and WT6000 are durable and reliable machines with a strong record of performance and experience. Typically, they require servicing (greasing) only once a year. At a rated capacity of 6 kW, the WT6000 is the largest turbine considered for the MoS. Its turbine and tower package weight is 860 kg, roughly the same weight as the WES Tulipo on a 12 m tower. Thus, structural implications are important to its applicability. Like the Tulipo, mounting of the WT6000 will likely require a roof structure with steel I-Beams. The WT2500, at 431 kg, weighs much less, but also will produce about a third of the power of the WT6000.
Renewable Devices (SWIFT):

Renewable Devices, based in Edinburgh, Scotland, recently developed the 1.5 kW SWIFT turbine. Boreal was intrigued by the SWIFT design for the MoS, as it is intended primarily for rooftop applications. It has features to specifically address the complexity of mounting wind turbines on roofs, including a lightweight design, tripod mounting scheme, and anti-vibration controls. The outside fiberglass ring is intended to reduce vibration and noise and also act as a flywheel (see Figure 3-10 and Figure 3-11).

Boreal contacted representatives of the SWIFT turbine in Scotland and at the American Wind Energy Association (AWEA) annual conference held in June 2006 in Pittsburgh. While the system is being marketed in the US, distribution is currently limited to the UK. No target date for commercial availability outside the UK has been set, though representatives claim that an international market will be pursued if initial distribution in the UK is successful. Beyond the basic specifications listed in Table 3-7, Boreal was unable to provide further information on this system, including any indication of capital
costs. As the SWIFT system appears to be a promising small turbine technology and would likely be appropriate for the MoS, Boreal recommends that the MoS continues to track the progress of commercial availability.

Figure 3-10 - SWIFT 1 kW

Figure 3-11 - SWIFT Array at UK Grocery Store

Zephyr (Airdolphin):
Zephyr Corporation is a Japanese manufacturer of small wind turbines. Their Airdolphin model is targeted for commercial availability in the US in late 2006 / early 2007. It is the lightest of all of the units reviewed and would likely pose the least challenge structurally. Depending on the chosen tower height, structural tie-ins to the MoS roof may not be necessary (the picture below on the right in shows weighting and mounting on cinder blocks placed onto a roof membrane surface). The passive 360° yaw design employs a rudder to keep the turbine facing upwind. The rotor itself operates at variable speeds based on wind velocity. Power output varies from 1 kW to 3.2 kW with changes in wind speed between 12.5 and 20 m/s. Of all the systems analyzed, the Airdolphin spins the fastest at 1,250-1,600 rpm. This may have noise implications, as turbines with higher operating rpms tend to generate more sound. However, Zephyr claims the Airdolphin produces very little noise due to the Silent Disrupter design of the blades.

As with the SWIFT turbine, the Airdolphin is not currently available in the United States. Boreal contacted a representative from Zephyr who informed us that no cost information was available at this time. Consequently, an economic analysis of this system was not performed. Boreal recommends that the MoS continues to track the progress of this system as it most likely will be commercially available by the time the MoS moves forward with turbine construction.

Figure 3-12 - Airdolphin ~1 – 3.2 kW
Southwest Windpower (AIR X & Skystream 3.7):

Southwest Windpower (SW) is based in Flagstaff, AZ. Founded in 1987, SW has manufactured small wind turbines for over 15 years. Widespread distribution of their turbines began in 1994 with the AIR series, which had a small power output (~300-400 Watts) and were intended for battery charging. The AIR series has enjoyed tremendous popularity since 1994. With the same power output as the AeroVironment turbine, the 400-Watt AIR X is SW’s current battery charging model. It is most commonly used in marine or other remote settings with very modest power requirements. A salesperson from SW mentioned that an inverter is available to make the AIR X suitable for grid-connection. While the AIR X could be utilized for grid-connection, a large number would be required to have any significant impact on offsetting electricity consumption at the MoS. Because of its small kW output (< 1 kW) and its design is not intended for multiple, modular installations as is AeroVironment’s unit, we do not perform any substantial analysis on the AIR X.
In addition to battery-charging models, SW also manufactures turbines specifically for grid-connection. Their Whisper series have been in operation for several years, mainly for residential purposes. In June 2006, SW announced a new turbine for grid-connection. Working in conjunction with the National Renewable Energy Laboratory, SW developed the 1.8 kW Skystream 3.7. Still in beta testing around the US, the Skystream will be commercially available in August 2006. It features a lightweight, downwind design with 360° passive yaw capability. Though the Skystream operates at high rpms, the noise level has been measured at 40 dBA at the base of the tower.

Boreal spoke with a SW salesperson in July 2006 about the potential for rooftop mounting of the Skystream at the MoS. She was very excited about this prospect, and mentioned that SW could possibly offer cost reductions given the exposure the MoS will bring to their new turbine. She also noted that SW currently has no rooftop mounting schemes for any of their turbines, though in some cases owners have designed rooftop schemes for SW products on their own. SW is interested in developing a rooftop mount for the Skystream 3.7, and will provide engineering assistance should one be pursued at the MoS. Boreal has been in contact with several SW engineers, who are excited about rooftop prospects for the Skystream. A rooftop mount for the Skystream is currently being explored at the University of California at Davis, where a rooftop guy-wire system for a 1 kW Bergey was recently developed. No date for expected completion of this project was given.
Figure 3-14
- SW Skystream 1.8 kW (foreground)
  AirX 400 W (background)

Figure 3-15 - Skystream 1.8 kW
<table>
<thead>
<tr>
<th>Manufacturer / Nation</th>
<th>Aero-Vironment / USA</th>
<th>Wind Energy Solutions / Netherlands</th>
<th>Proven / Scotland</th>
<th>Renewable Devices / Scotland</th>
<th>Zephyr / Japan</th>
<th>Southwest Windpower / USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model(s)</td>
<td>AVX400</td>
<td>Tulipo</td>
<td>WT2500 / WT6000</td>
<td>SWIFT</td>
<td>Airdolphin</td>
<td>AirX / Skystream 3.7</td>
</tr>
<tr>
<td>Power Rating</td>
<td>.4 kW/unit (66.67 Watts/linear ft.)</td>
<td>2.5 kW @ 9 to 20 m/s</td>
<td>2.5 kW @ 12 m/s / 6 kW @ 12 m/s</td>
<td>1.5 kW @ 12.5 m/s</td>
<td>1 kW @ 12.5 m/s, 3.2 kW @ 20 m/s</td>
<td>.4kW @ 12.5 m/s / 1.8 kW @ 9 m/s</td>
</tr>
<tr>
<td>Type</td>
<td>Horizontal axis, upwind, angled toward roof to catch wind</td>
<td>Horizontal axis, upwind</td>
<td>Horizontal axis, downwind</td>
<td>Horizontal axis, upwind</td>
<td>Horizontal axis, upwind</td>
<td>Horizontal axis, upwind / horizontal axis, downwind</td>
</tr>
<tr>
<td>Cut-in Speed (m/s)</td>
<td>3</td>
<td>3</td>
<td>2.5</td>
<td>2.3</td>
<td>2.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Cut-out Speed (m/s)</td>
<td>16.5</td>
<td>20</td>
<td>None</td>
<td>No response</td>
<td>50</td>
<td>30</td>
</tr>
<tr>
<td>Survival Speed (m/s)</td>
<td>47</td>
<td>59</td>
<td>65</td>
<td>No response</td>
<td>65</td>
<td>49.2 / 63</td>
</tr>
<tr>
<td>Rated rpm</td>
<td>1600</td>
<td>140</td>
<td>300 / 200</td>
<td>No response</td>
<td>1,250-1,600</td>
<td>1000 / 50:325</td>
</tr>
<tr>
<td>Blade Diameter (m)</td>
<td>1.2</td>
<td>5</td>
<td>3.5 / 5.5</td>
<td>2.1</td>
<td>1.8</td>
<td>1.15 / 3.72</td>
</tr>
<tr>
<td>Power Curve Available</td>
<td>Yes, see appendix</td>
<td>Yes, see appendix</td>
<td>Yes, see appendix</td>
<td>No response</td>
<td>Yes, see appendix</td>
<td>Yes, see appendix</td>
</tr>
<tr>
<td>Yawing Mechanism</td>
<td>60° passive (30° from center each direction)</td>
<td>360° active (backup power necessary)</td>
<td>360° passive</td>
<td>360° passive w/ twin rudder</td>
<td>360° passive w/ rudder</td>
<td>360° passive w/ rudder / 360° passive</td>
</tr>
<tr>
<td>Mounting Options</td>
<td>Parapet edge of building w/ structural tie-in brackets</td>
<td>Steel base plate, structural tie-in to building</td>
<td>Tower and base frame w/ structural tie-in to building</td>
<td>Bespoke aluminum mast, rigged to building or tripod</td>
<td>Mast w/ tripod support, tie-in may not be necessary given weight</td>
<td>To be developed</td>
</tr>
<tr>
<td>Likely Height Above Roof (m)</td>
<td>1.27</td>
<td>6.5 or 12.5</td>
<td>6.5 or 11 / 9 or 15</td>
<td>≥ .5</td>
<td>~5</td>
<td>~Dependent on mounting scheme</td>
</tr>
<tr>
<td>Turbine Weight (kg)</td>
<td>29.5 (incl. mounting stand)</td>
<td>~550 or 800, control cabinet 80</td>
<td>190 / 500</td>
<td>No response</td>
<td>17.5</td>
<td>5.85 / 70</td>
</tr>
</tbody>
</table>
Table 3-8 lists a range of cost values for the different turbine options under consideration for the MoS. Capital costs for the turbine and tower configurations are taken from manufacturer representatives. Rooftop installation estimates are provided by structural engineer Paul Phelan (see Appendix B) assuming a steel material cost of $5,000 / ton.
Interconnection estimates are provided by electrical engineer Richard Gross, P.E. in section 3.4.

### Table 3-8
Turbine Costs

<table>
<thead>
<tr>
<th>Manufacturer / Nation</th>
<th>Aero-Vironment / USA</th>
<th>Wind Energy Solutions / Netherlands</th>
<th>Proven / Scotland</th>
<th>Renewable Devices / Scotland</th>
<th>Zephyr / Japan</th>
<th>Southwest Windpower / USA</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AirX $550 (inverter addtl $2,600) / Skystream $5,400</td>
</tr>
<tr>
<td>43 units (17.2 kW) for</td>
<td>$33,615</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$163,149</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WT2500 = $12,334</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WT6000 = $24,179</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unavailable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Unavailable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tower Cost</td>
<td>N/A</td>
<td>12.5 m included in turbine cost</td>
<td></td>
<td></td>
<td></td>
<td>Valmont 10 m ~$1,000</td>
</tr>
<tr>
<td>Unavailable</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mounting Frame and</td>
<td>Included</td>
<td>$7,500</td>
<td></td>
<td></td>
<td></td>
<td>Skystream $3,125</td>
</tr>
<tr>
<td>Estimated Rooftop</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installation Cost</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Included</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interconnection</td>
<td>Included</td>
<td>$14,300 – Blue Wing</td>
<td></td>
<td></td>
<td></td>
<td>2* Skystream $11,100</td>
</tr>
<tr>
<td>Estimate for</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Recommend Configuration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Included</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

8 The costs and payback for Southwest Air X was not fully analyzed for it would not be even as close to as economic as the other Southwest unit, the Skystream. The Air X’s cost per kW to purchase before installation is calculated to be $10,375 / kW higher than the Skystream’s $8,375 / kW fully installed cost. Further, including turbines less than 1 kW is out of scope of this analysis (as it was presumed before hand that such small machines would not have the economies of scale, nor enough output to be of interest). An exception to analyze the 0.4 kW AeroVironment AVX 400 was made, as the AVX 400s are configured to be installed in an array, which will in aggregate have a capacity far above 1.0 kW.
<table>
<thead>
<tr>
<th>Total Installed Cost / Unit</th>
<th>Dependent on # units $22,765+ for 6 unit installation&lt;sup&gt;9&lt;/sup&gt;</th>
<th>$55,415</th>
<th>WT2500 n/a WT6000 $50,076</th>
<th>Unavailable</th>
<th>Unavailable</th>
<th>Skystream $15,075</th>
</tr>
</thead>
<tbody>
<tr>
<td>Levelized Cost ($ / kW)</td>
<td>$9,485</td>
<td>$22,166</td>
<td>WT2500 $11,814 WT6000 $9,668</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>Skystream $8,375</td>
</tr>
<tr>
<td>Annual O&amp;M Cost / Unit</td>
<td>$125</td>
<td>$650</td>
<td>$500</td>
<td>Unavailable</td>
<td>Unavailable</td>
<td>$500</td>
</tr>
</tbody>
</table>

Table 3-9
Turbine Ranking Analysis

<table>
<thead>
<tr>
<th>Manufacturer / Rank Attribute</th>
<th>Rank Value [1 worst - 5 best]</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Aero-Vironment</td>
</tr>
<tr>
<td>Cut-in Speed</td>
<td>3</td>
</tr>
<tr>
<td>Survival Speed</td>
<td>3</td>
</tr>
<tr>
<td>RPM</td>
<td>2</td>
</tr>
<tr>
<td>Yawing Ability</td>
<td>1</td>
</tr>
<tr>
<td>Height Above Roof</td>
<td>(3)</td>
</tr>
</tbody>
</table>

<sup>9</sup> The cost estimate for the AVX 400 is calculated as the per unit cost of a 43 unit installation without canopies. The costs for a smaller installation will be higher, as fixed costs will be spread over fewer units, but how much higher is unclear. For the balance of the analysis we use the per unit cost estimate, keeping in mind that more definitive costs will be required for a final design.
### Rank Value

**[1 worst - 5 best]**

<table>
<thead>
<tr>
<th>Manufacturer / Rank Attribute</th>
<th>Aero-Vironment</th>
<th>Wind Energy Solutions</th>
<th>Proven WT6000 / WT2500</th>
<th>Renewable Devices</th>
<th>Zephyr</th>
<th>Southwest Windpower AirX / Skystream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weight</td>
<td>4</td>
<td>3</td>
<td>3 / 3</td>
<td>(5)</td>
<td>5</td>
<td>5 / 5</td>
</tr>
<tr>
<td>Control System</td>
<td>4</td>
<td>5</td>
<td>4 / 4</td>
<td>4</td>
<td>5</td>
<td>4 / 4</td>
</tr>
<tr>
<td>Noise</td>
<td>4</td>
<td>3</td>
<td>5 / 4</td>
<td>5</td>
<td>4</td>
<td>5 / 5</td>
</tr>
<tr>
<td>Safety / Certification</td>
<td>3</td>
<td>5</td>
<td>3 / 3</td>
<td>5</td>
<td>3</td>
<td>3 / 4</td>
</tr>
<tr>
<td>Commercial Availability</td>
<td>4</td>
<td>5</td>
<td>5 / 5</td>
<td>1</td>
<td>3</td>
<td>5 / 5</td>
</tr>
<tr>
<td>Vibration Control</td>
<td>(4)</td>
<td>5</td>
<td>5 / 5</td>
<td>5</td>
<td>5</td>
<td>5 / 5</td>
</tr>
<tr>
<td>Cost</td>
<td>2</td>
<td>2</td>
<td>5 / 3</td>
<td></td>
<td></td>
<td>/4</td>
</tr>
<tr>
<td>TOTAL</td>
<td>36</td>
<td>50</td>
<td>51/49</td>
<td>45*</td>
<td>45*</td>
<td>43*/51</td>
</tr>
</tbody>
</table>

( ) refer to uncertainty

* - No cost ranking included in total

Table 3-9 reflects a simple weighting of factors if the MoS wants to examine individual units and manufacturers. Boreal's recommended configuration was in part prompted by the MoS’s interest in diversity of different wind turbine types and manufacturers versus the comparison of these factors.

### 3.2.4 Location Choice and Conceptual Layout

The MoS has several rooftop locations that are appropriate for erecting small wind turbines. Choosing an optimal location and turbine size depends mainly on 1) the practicality of construction based on location-specific structural considerations for mounting, 2) location-specific wind resources and 3) weight capacity of a given roof location (the larger roof-mounted wind turbines are heavier and need greater structural support). These factors are used in Boreal’s recommendations for locating a range of
both parapet and tower-mounted turbines of different output capacity at the MoS, as discussed below and shown on Figure 3-19.

**Parapet-Mounted (AeroVironment):**

Wind data from April-July clearly demonstrate that higher, more exposed sections of roof yield greater average wind speeds. Highest of all points of measurement, the Tower locations not surprisingly yielded the greatest average wind speeds. Likewise, wind speeds at the Central Building rooftop were at least 1 m/s greater than those at the Blue Wing and Beehive locations in each month of study. As the highest length of rooftop exposed to the south/southwest, the Central Building is the best location for parapet-mounted turbines. The leading edge of the seventh floor Central Building roof is 47 feet long (a recessed edge continues for another 25 feet). Thus, with a blade diameter of six feet, an estimated six AeroVironment units could be placed on the leading roof edge of the Central Building. Two to three more units could be placed on the recessed edge. However, turbines should only be placed on the recessed edge if their performance is not negatively affected by wake effect from turbines on the leading edge. Based on the wind direction measured, we believe there would be a negative impact on performance that would not justify AV’s placement on the recessed portion of the rooftop edge.

From a structural standpoint, the Central Building is also a good location based on the mounting requirements of the AeroVironment turbines. Based on preliminary analysis, structural engineer Paul Phelan believes AV’s mounting bracket can be tied into the roof structure of the Central Building.

**Rooftop Tower-Mounted:**

Since all tower-mounted rooftop turbines can capture wind energy from 360°, it is important to locate them not only as high as possible but also as far as possible from obstacles that impede wind movement or create turbulence. The MoS Central Tower is the largest impediment to wind speeds on-site. Boreal believes the greatest wind resources at the MoS to exist atop the Omni Theater and Penthouse 2 roofs, as both locations are relatively high points furthest from the Central Tower. Above the Blue Wing roof (location of existing solar panels) may also have suitable wind resources, though being lower than both the Central Building and Central Tower a turbine at this location likely will suffer from some wind shade effect, especially when the wind is from an easterly direction. Other rooftop locations that are closer to the Central tower will
result in poorer turbine performance when the tower is between the source wind
direction and the turbine itself (a result of wind shade). Data recorded from the MoS site
and from Logan Airport confirm a strong southwesterly prevailing wind (winds originate
from between South and West roughly 45% of the time, see wind rose Figure 3-16).
However, there is enough variability in wind direction to suggest that turbine
performance would suffer considerably if they were placed close to the central tower.

The structure of the Penthouse 2 and Blue Wing roofs is such that the heavy weights
and large loads associated with the Proven and WES Tulipo turbines will be difficult to
support. Paul Phelan suggests that these locations are limited to construction of the
much lighter Southwest Skystream. The structure of the Omni Theater roof is stronger
likely will accommodate heavier loads. Therefore, a combination of 2-3 (total) Proven
and/or WES turbines is proposed [Figure 3-20].

The lighter smaller scale, tower mounted turbines will utilize stands that have a greater
degree of portability. The heavier larger-scale units are less portable. Both sizes will
necessitate roof penetrations to tie into the buildings structural members.
Figure 3-16
Wind Rose for MoS Site Through July 11, 2006

MoS Wind Rose

Note: The inner circle represents the frequency (amount of time) with which winds blow from a given direction. The small histograms represent the distribution of wind speeds that occur from each wind direction. From the histograms, it is possible to infer what direction the most energetic winds originate from. The data demonstrate that southwest winds are both the most frequent and energetic of all directions.

Decorative Wind Systems: Quietrevolution

Quietrevolution, a UK-based company, offers a vertical axis turbine that is currently available, incorporates LEDs (UK patent pending), and would otherwise be suitable for rooftop mounting at the MoS. However, with a cut-in speed of 4.5 m/s, the Quietrevolution turbine would not perform (spin) well at the MoS location, and thus is not included in further analysis.
Quietrevolution also offers a smaller, horizontal axis unit known as the Windlight. The Windlight has full range of color LEDs built in to the rotor blades that, when spinning, have color and/or image display capabilities that can be seen even in daylight (depending on wind speed). Information can be downloaded to the machine so images are continuously updated. This turbine is rated at 400 Watts and power output is used for the LED’s embedded in the blades. It is typically connected to the grid and/or batteries, which provide power to spin the blades and create a display when wind speeds are not sufficient. Thus, performance and use of the turbines are independent of actual wind speeds. The units are designed to mount onto a pole and require structural or other attachment to the roof. However, they are light and installation is assumed to pose no significant challenge. The capital costs are estimated to be £5,000/unit ($9,210.00/unit). Though not currently commercially available, the Windlight is scheduled for release in the Fall, 2006 in London with commercial manufacture beginning soon thereafter.

We recommend the MoS consider the installation of at least two and ideally six Windlight units primarily for educational and advertising purposes. At a minimum, two of the small LED Windlight units would be well suited for the central tower of the MoS.
Figure 3-17 - Quietrevolution 6 kW Vertical Axis Turbine

Figure 3-18 - Quietrevolution 400 Watt Windlight unit
3.2.4.1 Visual Performance of Proposed Turbine Configuration

A rooftop wind turbine project at the MoS will garner a great deal of public attention due to the high visibility of the MoS site as well as its standing as a premier institution and visitor attraction in the Boston area. It is our opinion that there will be a high degree of public acceptance and excitement relating to the aesthetics of the roof-mounted wind turbine system. To convey an appropriate public message about the potential benefits of wind energy, and to maintain the high quality educational significance of the MoS’s exhibits, it is important that rooftop wind turbines spin a significant portion of the time.
This is especially true for periods of the day when visibility will be highest (i.e. normal working hours).

To predict the amount of time and when the proposed turbines will spin, Boreal has combined specific cut-in speeds and hub heights for the various turbines with predicted average hourly wind speeds based on long-term data correlated to Logan Airport. Hub heights were calculated from the specific tower heights of the various turbines plus 30.5 m, which is the height of Central Building Floor 7 roof (above ground level). Figure 3-16 demonstrates the time of day wind speeds can be expected to be highest and lowest. On average, wind speeds at the MoS will begin to increase around 8:00 AM and peak between about 1:00 PM to 4:00 PM, then decrease again and remain calmer through the night. Thus, peak wind speeds (on average) will occur in the late afternoon, when visibility is assumed to be high.

Based on data in Figure 3-16, Boreal estimated the amount of time each turbine will be spinning and not spinning. These times are expressed as percentages in Table 3-10. It should be noted that downtime due to maintenance or service is not included in these
results, as it likely will occur only occasionally throughout any given year. These results also do not reflect actual power output from the turbine, but are only a prediction of the amount of time the turbines will be spinning or not spinning. For further analysis of turbine production in terms of kWh, please refer to Table 3-11.

Table 3-10
Turbine Cut-in Speed and Spin % of Time\textsuperscript{10}

<table>
<thead>
<tr>
<th>Turbine / Attribute</th>
<th>Proven 2.5 kW</th>
<th>Proven 6 kW</th>
<th>WES Tulipo 2.5 kW</th>
<th>Southwest Skystream 1.8 kW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut-in Speed (m/s)</td>
<td>2.5</td>
<td>2.5</td>
<td>3</td>
<td>3.5</td>
</tr>
<tr>
<td>% of Time Spinning</td>
<td>89</td>
<td>89</td>
<td>82</td>
<td>74</td>
</tr>
<tr>
<td>% of Time Not Spinning</td>
<td>11</td>
<td>11</td>
<td>18</td>
<td>26</td>
</tr>
</tbody>
</table>

3.2.4.2 From Wind to Electricity

The kinetic energy in the wind is a linear function of the air density, and a cubic function of the wind speed. So a doubling of the wind speed increases potential power output from a turbine by a factor of eight. In practice a wind turbine is not 100% efficient and cannot extract and convert all the kinetic energy into electrical energy. The industry standard is to provide power curves in order to estimate energy production (or efficiency) for a particular wind turbine model. The standard power curve shows the estimated electricity production at sea level air density of 1.225 kg/m\textsuperscript{3} at 15° C (59° F), at low levels of surface roughness and turbulence. Figure 3-17 provides power curves for the AV, Zephyr, Proven, Southwest, and WES turbines.

\textsuperscript{10} The AeroVironment AVX 400 was not included in the calculation as their level of output and percent of time spinning is a function of both wind speeds and wind direction. The AVX 400’s production and dependence on wind direction is attributable to the AVX 400’s limited yawing capability of 60° rather than 360° for the more traditional turbines. Because of the this significant complication AeroVironment provided their own estimates of annual kWh production based on wind speed data provided to them, but were not asked to produce percent of time spinning.
It is industry standard to describe output in terms of capacity factor, which summarizes the site-specific wind resources combined with the turbine configuration. Capacity factor is defined as the actual (or predicted) kWh production divided by theoretical peak kWh production. The peak nameplate output for the Tulipo in an hour is 2.5 kWh (or 2500 Watt-hours). So the annual maximum electricity output for a Tulipo is 21,900 kW (2.5 kW * 8760 hours in a 365 day year).

For a typical year, we estimate a Tulipo on a 12.5 meter tower would have produced 5737 kWhs or have had a net capacity factor of 26.2% (5,737 kWh / 21,900 kWh). This is considered good by comparison to most sites in Massachusetts. The average annual capacity factors, are provided for four turbines at the appropriate hub height are displayed in Table 3-11. Note that these are net capacity factors that take into account line losses, surface roughness, availability, and air density.
Table 3-11
Annual Estimated Energy Production for Turbines on Main Building Roof

<table>
<thead>
<tr>
<th>Turbine</th>
<th>Nominal kW</th>
<th>Capacity Factor (Net)</th>
<th>Annual kWh Production (Net)</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVX 400 0.4 kW</td>
<td>0.4</td>
<td>12%(^{11})</td>
<td>420</td>
</tr>
<tr>
<td>WES Tulipo 2.5kW</td>
<td>2.5</td>
<td>26.2%</td>
<td>5,737</td>
</tr>
<tr>
<td>Proven WT2500 2.5kW</td>
<td>2.5</td>
<td>16.7%</td>
<td>3,654</td>
</tr>
<tr>
<td>Proven WT6000 6kW</td>
<td>6.0</td>
<td>18.4%</td>
<td>9,657</td>
</tr>
<tr>
<td>Southwest Skystream 1.8kW</td>
<td>1.8</td>
<td>18.9%</td>
<td>2,986</td>
</tr>
</tbody>
</table>

3.3 Environmental Impact Analysis

3.3.1 Threatened and Endangered Species

The developed, urban setting of the MoS and the small swept area of the wind turbines will most likely minimize or avoid any potential impact to Federal and State threatened, endangered or proposed listed species if these are present at the MoS site. If the MoS chooses to proceed with the wind turbine installation, formal notification is recommended to the U.S. Department of the Interior’s Fish and Wildlife Service and the Massachusetts Natural Heritage Program for a review of the presence of any threatened, endangered or proposed listed species.

3.3.2 Avian Impacts

A formal avian impact analysis was not performed as part of this study. Due to the small swept area of the architectural wind turbines and their lack of demonstrated avian impacts at other installed locations, the turbines are presumed represent a very low or non-quantifiable risk to birdlife in the vicinity of the MoS. However, it should be noted that there are relatively few installations of this scale of equipment worldwide so its operational history is still being established. One system, AV’s AVX400 has on optional canopy to prevent any possibility of bird strikes. The other units do not provide this type of bird safety system.

\(^{11}\) Estimates calculated by AeroVironment
3.3.3 Noise Assessment

A formal noise assessment for each of the turbines considered was not performed as part of this study. Each turbine manufacturer has listed specific decibel (dB) levels for their equipment, as provided in Table 3-7. For each manufacturer, measurements were taken directly adjacent to the tower or turbine where noise impact is greatest. The highest dB level for any of the turbines at the base of the tower is 72 dB (WES Tulipo). For context, this level is the equivalent to what can be expected inside an average office. At 20 m distance, this level drops to about 35 dB, or the equivalent of an average living room or bird-call. Given the urban setting of the MoS, with heavy traffic, helicopters and other equipment, and, general city noise, it is unlikely that any of the proposed turbines will pose a significant noise impact to MoS employees, visitors, or passersby. From street level, it likely will be very difficult to hear the turbines at all. For dB levels of everyday settings, please refer to Table 3-12.
### Table 3-12

**Common Noise Decibel levels**

<table>
<thead>
<tr>
<th>Noise</th>
<th>Average decibels (dBA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Leaves rustling, soft music, whisper</td>
<td>30</td>
</tr>
<tr>
<td>Average home noise</td>
<td>40</td>
</tr>
<tr>
<td>Normal conversation, background music</td>
<td>60</td>
</tr>
<tr>
<td>Office noise, inside car at 60 mph</td>
<td>70</td>
</tr>
<tr>
<td>Vacuum cleaner, average radio</td>
<td>75</td>
</tr>
<tr>
<td>Heavy traffic, window air conditioner, noisy restaurant, power lawn mower</td>
<td>80–89</td>
</tr>
<tr>
<td>Subway, shouted conversation</td>
<td>90–95</td>
</tr>
<tr>
<td>Boom box, ATV, motorcycle</td>
<td>96–100</td>
</tr>
<tr>
<td>School dance</td>
<td>101–105</td>
</tr>
<tr>
<td>Chainsaw, leaf blower, snowmobile</td>
<td>106–115</td>
</tr>
<tr>
<td>Sports crowd, rock concert, loud symphony</td>
<td>120–129</td>
</tr>
<tr>
<td>Stock car races</td>
<td>130</td>
</tr>
<tr>
<td>Gun shot, siren at 100 feet</td>
<td>140</td>
</tr>
</tbody>
</table>

Source: [www.WebMD.com](http://www.WebMD.com)

### 3.3.4 Potential Impacts and mitigation

**3.3.4.1 Reduced Regional Air Pollution from Wind Power**

An estimate of air pollution reductions that would be created based on the installation of 26.5 kW of roof-mounted wind turbines was performed at the MOS. The analysis based on the New England Power Pool's (NEPOOL's) aggregated air emissions from their fleet of power plants for the air pollutants sulfur dioxide (SO$_2$), nitrogen oxides (NO$_x$) and carbon dioxide (CO$_2$) for the calendar year 2004. NEPOOL provides average emission rates for these pollutants that represent the emissions from the last 500 MW of power added to the grid, known as the marginal unit. This power dispatched is typically from
the least economic and most polluting units. Since the wind turbine uses air to generate electrons versus the predominately fossil-fuel based generation capacity of the NEPOOL’s system, each electron generated by a renewable energy system can be viewed as displacing from the grid an electron that would otherwise be created by the existing system’s fossil fueled marginal power plant.

The 26.5 kW wind turbines are estimated to generate an output of approximately 43,182 kWh/yr.

Table 3-13 provides the anticipated benefit to regional air emissions from the MOS’s wind turbines.

The renewable electricity from clean fuel (air) that will be produced will displace fossil-fueled generation capacity and their resultant air pollution emissions from the grid, therefore, creating regional air quality benefits.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>lb/yr</th>
<th>ton/yr</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>47,587</td>
<td>23.8</td>
</tr>
<tr>
<td>SO₂</td>
<td>88</td>
<td>0</td>
</tr>
<tr>
<td>NOx</td>
<td>23</td>
<td>0</td>
</tr>
</tbody>
</table>

### 3.4 Engineering and Interconnection Requirements

#### 3.4.1 Electrical Interconnection Plan

Wind turbine generators are proposed to be installed on the Penthouse #2 roof, the Blue Wing roof, the Omni Theatre roof, and the Central Building – Level 6 roof. The wind turbine generators to be installed on the Penthouse #2 roof and the Blue Wing roof will be interconnected to 480 volt distribution panel PPC located inside Penthouse #2 as shown below:

---

12 Source: 2004 NEPOOL Marginal Emission Rate Analysis – May 2006
The details of the interconnection for the wind turbine generators to be installed on the Penthouse #2 roof and the Blue Wing roof are as follows:
Penthouse #2 Roof: Two (2) Southwest Windpower wind turbine generators rated 1.8 kW each. The Southwest Windpower generators include an inverter to convert the output power to 60 Hertz, 240 VAC, single phase. The wind turbine generators will be connected to a single phase, 480 volt – 120/240 volt, outdoor, dry type transformer that will be installed on the Penthouse #2 roof. The transformer will be connected to a 15 ampere, 2 pole circuit breaker within a new 480 volt distribution panel inside Penthouse #2. The new 480 volt panel will be connected to the existing 20 ampere 3 pole circuit breaker within panel PPC.

Blue Wing Roof: One (1) WES Tulipo wind turbine generator rated 2.5 kW. The WES generator has a 60 Hertz, 400 VAC, three phase output. The wind turbine generator will be connected to a three phase, 480 volt – 400 volt, outdoor dry type transformer that will be installed on the Blue Wing roof. The transformer will be connected to a 15 ampere, 3 pole circuit breaker within the new 480 volt distribution panel to be installed inside Penthouse #2 for the interconnection of the wind turbine generators on the roof of Penthouse #2.

In general, all interconnection circuits will be installed in rigid galvanized steel conduits. For planning and cost estimating purposes, a ¾ inch conduit will be used. From the existing panel PPC to the new 480 volt panel inside Penthouse #2, the conduit/wire may be run along the inside wall of Penthouse #2 at a distance of 60 feet. The new 480 volt panel will be a main lug type panel and include two (2) branch circuit breakers; one (1) 15 ampere, 2 pole breaker and one (1) 15 ampere 3 pole breaker. A conduit will penetrate the wall of Penthouse #2 from the new 480 volt panel to a new junction box installed on the west exterior wall of Penthouse #2. Dedicated conduit/wire runs will be routed from the new junction box to the new roof-top transformers.

The distance from the junction box to the transformer on the Blue Wing roof is estimated to be 130 feet. The transformer will be located in close proximity to the wind turbine generator. The transformer will include a 480 volt, 20 ampere, 3 pole circuit breaker to protect the circuit between the transformer and the wind turbine generator. A 480 volt, fused safety switch will be installed at the base of the wind turbine generator.

The distance from the junction box to the transformer on the Penthouse #2 roof is estimated to be 50 feet. The transformer will be located equidistant to the two (2) wind turbine generators and will include a 240 VAC distribution panel and two (2), 20 ampere, 2 pole circuit breakers to protect the circuit between the transformer and each wind
turbine generator. A 240 volt, fused safety switch will be installed at the base of each wind turbine generator.

Appropriate warning signs will be required at all affected distribution panels to indicate that the wind turbine generators are interconnected to the circuits. The signs shall be permanent, clearly legible, and have the following words or equivalent: WARNING. ELECTRIC SHOCK HAZARD. DO NOT TOUCH TERMINALS. TERMINALS ON BOTH THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.

The wind turbine generators to be installed on the Omni Theatre roof and the Central Building – Level 6 roof will be interconnected to 480 volt distribution panel PPH-3A located inside Penthouse #3 as shown below:
ELECTRICAL INTERCONNECTION PLAN
WIND TURBINE GENERATORS ON OMNI THEATRE ROOF AND CENTRAL BLDG. – LEVEL 6 ROOF

13.8 kV Supply to Penthouse #3

Penthouse #3
Power Transformer
750 kVA
13.8 kV – 480 V

Penthouse #3
Power Transformer
500 kVA
13.8 kV – 480 V

200 A Circuit Breaker to
Panel PPH-3A

Panel PPH-3A
(located inside
Penthouse #3)

Existing Facilities

New Facilities

30 A Circuit Breaker
3 pole

New 480 V Panel
(located on wall of Penthouse #3)

15 A Circuit Breaker
2 pole

15 A Circuit Breaker
2 pole

20 A Circuit Breaker
2 pole

20 A Circuit Breaker
2 pole (Qty. 2)

240 VAC Safety Switch

Wind Turbine Inverter
240 VAC output

7.5 kVA
480 V – 120/240 V
Dry Type Transformer
(on Central Bldg. roof)

20 A Circuit Breaker
2 pole

240 VAC Safety Switch

Wind Turbine Inverter
240 VAC output

Turbine Safety Switch
(non-fused)

Six (6) AeroVironment Wind Turbine Generators
Rated 400 watts each (2.4 kW Total)

(AeroVironment Turbines on
Central Bldg. – Level 6 Roof)

7.5 kVA
480 V – 120/240 V
Dry Type Transformer
(on Omni Theatre Roof)

20 A Circuit Breaker
2 pole (Qty. 2)

240 VAC Safety Switch

Wind Turbine Inverter
240 VAC output

(Quantity 2)

10 kVA
480 V – 120/240 V
Dry Type Transformer
(on Omni Theatre Roof)

40 A Circuit Breaker
2 pole

240 VAC Safety Switch

Wind Turbine Inverter
240 VAC output

(Proven turbines on roof of Omni Theatre)

Proven WT2500
2.5 kW Wind Turbine Generators (Qty. 2)

Proven WT6000
6 kW Wind Turbine Generator
The details of the interconnection for the wind turbine generators to be installed on the Omni Theatre roof and the Central Building – Level 6 roof are as follows:

**Omni Theatre Roof:** Two (2) Proven WT2500 wind turbine generators rated 2.5 kW each and one (1) Proven WT6000 wind turbine generator rated 6 kW. The Proven generators include an inverter to convert the output power to 60 Hertz, 240 VAC, single phase. The wind turbine generators will be connected to single phase, 480 volt – 120/240 volt, outdoor, dry type transformers that will be installed on the Omni Theatre roof. The 10 kVA transformer associated with the WT6000 wind turbine generator will be connected to a 20 ampere, 2 pole circuit breaker within a new 480 volt distribution panel located on the interior wall of Penthouse #3. The 7.5 kVA transformer associated with the WT2500 wind turbine generators will be connected to a 15 ampere, 2 pole circuit breaker. The new 480 volt panel will be connected to the existing 30 ampere 3 pole circuit breaker within panel PPH-3A.

**Central Building – Level 6 Roof:** Six (6) AeroVironment wind turbine generators rated 400 watts each for a total installed capacity of 2.4 kW. The AeroVironment generators provide a dc output voltage. The output of the six (6) generators will be connected together and interconnected to a dc safety switch. The safety switch will be connected to a common inverter to convert the output power to 60 Hertz, 240 VAC, single phase. The common inverter output will be connected to single phase, 480 volt – 120/240 volt, outdoor, dry type transformers that will be installed on the Omni Theatre roof. The transformer will be connected to a 15 ampere, 2 pole circuit breaker within the new 480 volt distribution panel to be installed on the interior wall of Penthouse #3 for the interconnection of the wind turbine generators on the Omni Theatre roof.

In general, all interconnection circuits will be installed in rigid galvanized steel conduits. For planning and cost estimating purposes, a ¾ inch conduit will be used. From the existing panel PPH-3A to the new 480 volt panel on the interior wall of Penthouse #3, the conduit/wire may be run along the inside wall of Penthouse #3 at a distance of 30 feet. The new 480 volt panel will be a main lug type panel and include three (3) branch circuit breakers; two (2) 15 ampere, 2 pole breakers and one (1) 20 ampere 2 pole breaker. A conduit will penetrate the wall of Penthouse #3 from the new 480 volt panel to a new junction box installed on the east exterior wall of Penthouse #3. Dedicated conduit/wire runs will be routed from the new junction box to the new roof-top transformers.
The distance from the junction box to the transformers on the Omni Theatre roof is estimated to be 360 feet. The 10 kVA transformer will be located in close proximity to the WT6000 wind turbine generator. The transformer will include a 240 volt, 40 ampere, 2 pole circuit breaker to protect the circuit between the transformer and the wind turbine generator. A 240 volt, fused safety switch will be installed at the base of the wind turbine generator. The 7.5 kVA transformer will be located equidistant to the two (2) WT2500 wind turbine generators and will include a 240 VAC distribution panel and two (2), 20 ampere, 2 pole circuit breakers to protect the circuit between the transformer and each wind turbine generator. A 240 volt, fused safety switch will be installed at the base of each wind turbine generator.

The distance from the junction box to the transformer on the Central Building – Level 6 roof is estimated to be 240 feet. The transformer will be located in close proximity to the common inverter and will include a 240 VAC distribution panel and one (1), 20 ampere, 2 pole circuit breaker to protect the circuit between the transformer and the common inverter. A 240 volt, fused safety switch will be installed at the 240 VAC output terminals of the inverter. Appropriate warning signs will be required at all affected distribution panels to indicate that the wind turbine generators are interconnected to the circuits. The signs shall be permanent, clearly legible, and have the following words or equivalent: WARNING. ELECTRIC SHOCK HAZARD. DO NOT TOUCH TERMINALS. TERMINALS ON BOTH THE LINE AND LOAD SIDES MAY BE ENERGIZED IN THE OPEN POSITION.

3.4.2 Cost Estimate

The total installed cost estimate for the interconnection work described in this report is $79,000. This is a planning accuracy (plus or minus 25%) cost estimate for all materials, installation labor, and engineering.

3.5 Permitting

Boreal reviewed the various regulatory implications of roof and tower-mounted wind turbines at the MoS location. As previously mentioned, the MoS straddles both the Cities of Cambridge and Boston, therefore dual approvals may be necessary depending on the location of the wind turbine installation. Boreal contacted planning and zoning
officials in both Cambridge and Boston to better understand the local regulatory approval process for both tower mounted and roof-mounted wind turbines.

**Cambridge:** The MoS location is zoned C-3A (residence) and Planned Unit Development overlay PUD-2 (an overlay zone for East Cambridge Riverfront). A written determination by the Planning Board that a proposed use is compatible with the development policies for “The Front” district specified in the East Cambridge Riverfront Plan is necessary for certain projects in this district.

![Cambridge District Zoning Map](image)

On June 12, 2006, Boreal spoke with Les Barber, the Director of Land Use and Zoning in the City of Cambridge. Mr. Barber noted that to his recollection, no tower-mounted wind turbine project has been proposed within Cambridge. However, he understood that wind energy is growing in popularity, and that his office likely will need to take steps in the near future to make specific provisions to provide for the development of wind turbines within city limits.

With regard to specific articles in the current Zoning Ordinances for Cambridge, Mr. Barber mentioned height (Article 5.23) and the ordinances relating to Project Review for Special Permit concerning noise (Article 19.24 paragraph 7, and 19.33 concerning aesthetics) as primary issues. He also noted that while wind energy is not listed as a
specific accessory use option in Cambridge, it would likely be considered an accessory use if power generation was targeted primarily for on-site consumption.

In terms of height, Article 5.23 (b) does provide some exceptions for all zoning districts for features including “domes, towers, or spires above buildings if such features are not used for human occupancy and occupy less than ten (10) percent of the lot area.” This most likely would allow the installation of the rooftop style turbines without a height variance.

Project Reviews for Special Permit are intended to ensure construction projects or changes of use in existing buildings are consistent with the urban design objectives of the City. The process is controlled by the Planning Board, who make findings regarding the project. This process applies in any PUD district and Residence district C-2A. The noise provision (if applicable) requires a noise study be performed. However, thresholds for this Article may not be triggered and further review by a zoning legal expert is recommended.

Article 19.33 involves mitigating adverse environmental impacts of a development upon its neighbors including:

“ (a) Reasonable attempts have been made to avoid exposing rooftop mechanical equipment to public view from city streets. Among the techniques …are the inclusion of screens or a parapet around the roof to shield low ducts and other equipment on the roof from view. [Note: If architectural wind is perceived as having adverse environmental impacts, this provision is in direct conflict with the goals of the project.]

(d) Tall elements…are carefully designed as features of the building, thus creating interest on the skyline.

Responding to how the Cambridge Planning office may react to a wind turbine project at the MoS, Mr. Barber stated appearance and general aesthetics would be of primary concern. While admitting that these are subjective criteria, he confessed that the Zoning Board would probably be more concerned with a larger-sized turbine than with a collection of smaller, either rooftop or tower-mounted turbines. He noted that rooftop turbines likely would not be of much concern to the Zoning Board.
The Zoning Ordinance refers to Useable Open Space requirements for PUD-2 districts. While tower mounted turbines utilize a small area, land is very limited on these parcels and it is expected that the MoS lot is currently non-conforming (e.g., see section 13.35 requiring a 25% useable open space).

**Boston:** The MoS location is zoned H-3 (Residence District - Apartments). No specific height limit is defined in H-3. The City of Boston confirmed that it is not considered to be in the Downtown Interim Planning Overlay District (IPOD). The IPOD would have suspended all or a portion of the underlying zoning requirements at the MoS site.

On June 22, 2006 Boreal spoke with Jeff Hampton, Senior Planner in the City of Boston and additional conversations with the Planning Office occurred in July. Mr. Hampton noted that Boston, like Cambridge, has yet to list wind turbines as a specific use within city limits, but the city is currently negotiating how to write them into their zoning bylaws. Mr. Hampton explained that the Boston Zoning Board of Appeals (ZBA) typically interprets proposals for uses that are not defined as forbidden. However, in his opinion, if the electricity produced from the turbines was primarily used on-site at the MoS, it would likely qualify as an accessory use and thus would be subject to special permit approval from the ZBA.

Alternatively, an extension of a non-conforming use may apply, as was the case for the wind turbine at the International Brotherhood of Electrical Workers (IBEW) Local 103 (also within city limits). In this case, a variance for height or setback may be needed. Ultimately, the IBEW project was successful with their permits, and can thus be used as a guide for MoS permitting in Boston. Mr. Hampton directed Boreal to Articles 8, 9, and 10 of Boston’s zoning bylaws, as they deal specifically with use, non-conforming use, and accessory use in the city, respectively.

In further inquiries with the Cities Planning Office, it is recommended that the MoS prepare and application for a building permit for the ISD office. The ISD will provide a summary review of the Zoning requirements. Since the MoS’s site zoning is considered a H-3 unoccupied conforming use, the wind turbine project will most likely be considered
a conforming use. This most likely means that there will not be height restrictions nor roof structure requirements.

Boreal and the City recommends that the MoS obtain assistance from experienced legal council familiar with both Boston and Cambridge zoning requirements to facilitate all local approvals during the design phase of the wind energy project.

**Chapter 91, Mass DEP Waterways:**

At the end of our conversation, Mr. Hampton mentioned the Massachusetts Department of Environmental Protection Chapter 91 law that applies to structures in or near selected waterways in Massachusetts is applicable to the MoS location. Among the limitations imposed on structures is a 55 ft. height limit. A quick tour around Boston’s waterfront suggests this height limit is not often followed. In a follow-up conversation, Boreal spoke with an environmental lawyer who implied that Chapter 91 likely would not be a barrier to a wind turbine project at the MoS. Still, Chapter 91 will be an important part of the permitting process. A determination of what tidal districts the MoS resides in, if any, will be necessary, as this dictates what regulations apply and how stringently they may be followed (Commonwealth tidelands carry stricter regulations than private tidelands).

The DEP suggests clients have an initial meeting with a DEP contact to discuss the project and what will be required through Chapter 91. A lawyer familiar with Chapter 91 statutes should also be present at this meeting. Following the meeting, a permitting application can be filed with the DEP. According to the Boston City Planning office, the City of Boston will require a sign-off on the Chapter 91 application.

**Federal Aviation Administration (FAA)**

Boreal notified the FAA and applied for a determination of air hazard assessment in May, 2006 as it related to large utility-scale wind turbines. The application proposed a tower height of over 400 feet at two locations, one north of the parking garage and the other, southwest in the area fronting the Charles River where there is a turnaround.

The FAA provided their determination on August 31, 2006 that the tower and blade height of large utility scale turbines would pose a “Presumed Hazard to Air Navigation” at two potential sites on the MoS property. The FAA limited wind turbine height to not to
exceed 213 ft. To go beyond this height, additional FAA study, regulatory review and public participation would be required without guarantee of success. See Appendix C for copies of these determinations.

**Permitting Summary Tables:**

Boreal prepared permitting tables to identify the local, State and Federal requirement, the authority and citation, and permit approval timeframe. See Table 3-14, Table 3-15, Table 3-16, and Table 3-17 for a summary of these findings.

In terms of state permitting, no wetlands, coastal resources or areas of critical habitat are impacted by the proposed development. It is possible for utility-scale tower mounted turbines that work in a riverbank may occur. These permitting constraints were not fully evaluated due to the critical flaw associated with the Federal Aviation Administration air hazard review.

### Table 3-14

**Local Applicable Regulations – City of Cambridge Zoning Ordinance**


<table>
<thead>
<tr>
<th>Regulation/Permit</th>
<th>Authority</th>
<th>Citation</th>
<th>Approval Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Section 4.21(2)</td>
<td>Board of Zoning Appeals</td>
<td>2.3.7 (77)</td>
<td></td>
<td>Accessory Use is allowed for scientific research with a Special Permit; Wind turbine installation may be defined as installed for scientific research.</td>
</tr>
<tr>
<td>Scientific Research – Special Permit</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Transportation, Communication &amp; Utility Uses</td>
<td>Zoning Ordinance</td>
<td>4.32 (g.) in zoning district Residence 3-A</td>
<td></td>
<td>Power plant for the non-nuclear production, generation and distribution of electricity or steam is prohibited; It is possible that since no “distribution” is occurring this</td>
</tr>
<tr>
<td>Regulation/Permit</td>
<td>Authority</td>
<td>Citation</td>
<td>Approval Time</td>
<td>Comments</td>
</tr>
<tr>
<td>------------------</td>
<td>-----------</td>
<td>----------</td>
<td>---------------</td>
<td>----------</td>
</tr>
<tr>
<td>Planned Unit Development Unit -2</td>
<td>Planning Board</td>
<td>Article 13.32.5 – Other Uses</td>
<td></td>
<td>Planning Board approval required for compatibility with East Cambridge Riverfront Plan.</td>
</tr>
<tr>
<td>Sunlight</td>
<td></td>
<td>Article 13.34.3</td>
<td></td>
<td>Building planes facing or generally oriented toward the riverfront should be stepped back to minimize shadows that are cast on the river side of the Cambridge Parkway.</td>
</tr>
</tbody>
</table>

### Table 3-15

*Local Applicable Regulations – City of Boston Zoning Ordinance*


<table>
<thead>
<tr>
<th>Regulation/Permit</th>
<th>Authority</th>
<th>Citation</th>
<th>Approval Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Building Permit</td>
<td>Inspectonal Services Department</td>
<td></td>
<td></td>
<td>A building permit will be required for the installation</td>
</tr>
<tr>
<td>Article 16.2 – Building Heights</td>
<td>Height exception for windmills</td>
<td></td>
<td></td>
<td>. The provisions of Section 16-1 shall not apply to, ..., radio towers, transmission towers, windmills, ... or other structures normally built above the roof and not devoted to</td>
</tr>
</tbody>
</table>
human occupancy, but such structures shall be erected only to such heights, ... as are necessary to accomplish the purpose they are intended to serve.

<table>
<thead>
<tr>
<th>Regulation/Permit</th>
<th>Authority</th>
<th>Citation</th>
<th>Approval Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Article 13 Table B</td>
<td></td>
<td></td>
<td></td>
<td>No height limit Zone H-3</td>
</tr>
<tr>
<td>Article 27D IPOD overlay district</td>
<td></td>
<td></td>
<td></td>
<td>Not applicable. Verified via conversation with Boston City Planning Dept.</td>
</tr>
</tbody>
</table>

**Table 3-16**  
**State Applicable Regulations**

<table>
<thead>
<tr>
<th>Regulation/Permit</th>
<th>Authority</th>
<th>Citation</th>
<th>Approval Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEPA Determination: Notice of Intent and Environmental Notification Form (ENF)</td>
<td>Executive Office of Environmental Affairs</td>
<td>MEPA Regulations, 301 CMR 11.00</td>
<td>Jurisdictional authority occurs if there is State financial assistance; No thresholds are met requiring an Environmental Impact Report (EIR); No ENF filing required; EOEA notice will occur.</td>
<td></td>
</tr>
<tr>
<td>Notice of Intent</td>
<td>Mass. Natural Heritage and Endangered Species</td>
<td>321 CMR 10:00</td>
<td>Not recommended – developed urban site.</td>
<td></td>
</tr>
</tbody>
</table>

Notes: Portions adapted from Renewable Energy Research Laboratory, University of Massachusetts at Amherst - Community Wind Power Fact Sheet #7;
<table>
<thead>
<tr>
<th>Program</th>
<th>Massachusetts Department of Highways</th>
<th>Permits</th>
<th>Massachusetts Department of Highways</th>
<th>Route approval required; Road limits may require funding of separate road survey by a Civil Engineering firm.</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Access Permits</td>
<td></td>
<td>Needed if road modifications to State roads must occur</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Wide Load Permits</td>
<td></td>
<td>Route approval required; Road limits may require funding of separate road survey by a Civil Engineering firm.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Project Notification Form</td>
<td>Massachusetts Historical Commission (MHC)</td>
<td>Any new construction projects etc. that require funding, licenses, or permits from any state, federal agencies must be reviewed by MHC for impacts to historic and architectural properties. Purpose is to protect important historical and architectural assets of Commonwealth.</td>
<td>MGL Ch. 9 Sections 27-32</td>
<td>30 days</td>
</tr>
<tr>
<td>Noise control policy</td>
<td>Massachusetts Department of Environmental Protection</td>
<td>At nearest property line or residence: No increase by more than 10 dB(A) above ambient; or No “pure tone” condition.</td>
<td>MGL 310 CMR 7.09 -7.10</td>
<td>criteria</td>
</tr>
<tr>
<td>Request for Airspace Review</td>
<td>Mass Aeronautics Commission</td>
<td>Not applicable – no formal permit required</td>
<td>MAC should be notified if projects are over 200ft tall</td>
<td></td>
</tr>
<tr>
<td>NEEPOOL Interconnection System Impact Study &amp; Facility Study</td>
<td>RTO-NE (a/k/a ISO-NE)</td>
<td>None – informational only</td>
<td>For projects under 5 MW the submittal of form 18.4 does not trigger a system impact study. It</td>
<td></td>
</tr>
</tbody>
</table>
provides information to RTO-NE for system planning purposes.

### Table 3-17
**Federal Applicable Regulations**

<table>
<thead>
<tr>
<th>Regulation/Permit</th>
<th>Authority</th>
<th>Citation</th>
<th>Approval Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Notice of Proposed Construction or Alteration</td>
<td>Fed Aviation Admin.</td>
<td>14 CFR Part 77</td>
<td>At least 30 days</td>
<td>Required for crane erection and tower structure. All structures above 199 ft will need lighting. Determination found Presumed Hazard to Air Navigation above 213 ft – See Appendix C</td>
</tr>
<tr>
<td>Habitat Conservation &amp; Incidental Take Permit</td>
<td>Fish &amp; Wildlife Service</td>
<td>Endangered Species Act</td>
<td></td>
<td>No endangered species identified</td>
</tr>
<tr>
<td>Migratory Bird Treaty Act</td>
<td>Fish &amp; Wildlife Service</td>
<td>Migratory Bird Treaty Act</td>
<td>Prohibits the taking, killing possession etc. of migratory birds</td>
<td>Enforcement potential</td>
</tr>
<tr>
<td>Golden Eagle Protection Act</td>
<td>Fish &amp; Wildlife Service</td>
<td>Golden Eagle Protection Act</td>
<td></td>
<td>Enforcement potential</td>
</tr>
</tbody>
</table>

---

14 Notes: Portions adapted from Renewable Energy Research Laboratory, University of Massachusetts at Amherst - Community Wind Power Fact Sheet #7;
<table>
<thead>
<tr>
<th>Regulation/Permit</th>
<th>Authority</th>
<th>Citation</th>
<th>Approval Time</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Commission</td>
<td></td>
<td></td>
<td>fac.asp</td>
</tr>
</tbody>
</table>
4 Economic Feasibility Analysis

This section provides analysis on the economic viability of installing rooftop turbines at the MoS site. First it will describe the costs, and then the benefits of installing wind turbines on-site. These factors are combined to analyze scenarios and provide the realistic net financial benefits for a wind turbine installation, concluding with recommendations of next steps.

4.1 Summary Installation Costs

From the information presented in the Sections above, Table 4-1 provides a summary of installation costs and cost effectiveness (in $/kWh) for the five turbines where we have sufficient information on a per turbine basis.\(^\text{15}\) On a first year installed basis the SW Skystream is estimated to be the most cost-effective installation at $5.05/kWh. On a 20 year nominal dollar\(^\text{16}\) basis it is estimated that the Proven WT6000 is the most cost-effective at $0.35/kWh (versus $0.42/kWh for the Skystream). To provide some context, the MoS is currently paying ~$0.12/kWh.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>AVX-400</th>
<th>WES - Tulipo</th>
<th>Proven WT2500</th>
<th>Proven WT6000</th>
<th>SW Skystream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbine Cost</td>
<td>$3,794</td>
<td>$33,615</td>
<td>$12,334</td>
<td>$24,179</td>
<td>$5,400</td>
</tr>
<tr>
<td>Tower Cost</td>
<td>included</td>
<td>included</td>
<td>$3,700</td>
<td>$6,680</td>
<td>$1,000</td>
</tr>
<tr>
<td>Mounting Frame &amp; Est. Installation Cost</td>
<td>included</td>
<td>$7,500</td>
<td>$5,000</td>
<td>$6,750</td>
<td>$3,125</td>
</tr>
<tr>
<td>Interconnection Cost</td>
<td>included</td>
<td>$14,300</td>
<td>$8,500(^\text{18})</td>
<td>$12,467</td>
<td>$5,550</td>
</tr>
</tbody>
</table>

\(^\text{15}\) There was not sufficient cost information for the Zephyr AirDolphin and Renewable Devices machines.

\(^\text{16}\) More sophisticated estimates of payback using net present value is provided below.

\(^\text{17}\) Costs were allocated on a per unit basis based upon the recommended configuration.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>AVX-400</th>
<th>WES - Tulipo</th>
<th>Proven WT2500</th>
<th>Proven WT6000</th>
<th>SW Skystream</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Cost</td>
<td>$3,794</td>
<td>$55,415</td>
<td>$29,534</td>
<td>$50,076</td>
<td>$15,075</td>
</tr>
<tr>
<td>$/kW</td>
<td>$9,485</td>
<td>$22,166</td>
<td>$11,814</td>
<td>$8,346</td>
<td>$8,375</td>
</tr>
<tr>
<td>$/kWh - First Year</td>
<td>$9.02</td>
<td>$9.66</td>
<td>$8.08</td>
<td>$5.19</td>
<td>$5.05</td>
</tr>
<tr>
<td>O&amp;M / Year</td>
<td>$125</td>
<td>$650</td>
<td>$500</td>
<td>$500</td>
<td>$500</td>
</tr>
<tr>
<td>$/kWh - 20 Years</td>
<td>$0.75</td>
<td>$0.60</td>
<td>$0.54</td>
<td>$0.31</td>
<td>$0.42</td>
</tr>
</tbody>
</table>

Table 4-2 display the summary costs for the recommended configuration of a wind garden. The combined estimated cost is $258,557 with a nominal cost over 20 years of $0.42 / kWh.

Table 4-2
Summary Costs and Cost Effectiveness for Recommended Configuration

<table>
<thead>
<tr>
<th>Attribute</th>
<th>AVX-400</th>
<th>WES - Tulipo</th>
<th>Proven WT2500</th>
<th>Proven WT6000</th>
<th>SW Skystream</th>
<th>Recommended Configuration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Turbines</td>
<td>6</td>
<td>1</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>12</td>
</tr>
<tr>
<td>Nominal kW</td>
<td>2.4</td>
<td>2.5</td>
<td>n/a</td>
<td>6</td>
<td>3.6</td>
<td>26.5</td>
</tr>
<tr>
<td>Annual kWh</td>
<td>2,523</td>
<td>5,735</td>
<td>n/a</td>
<td>28,949</td>
<td>5,976</td>
<td>43,182</td>
</tr>
<tr>
<td>Total Cost</td>
<td>$22,765</td>
<td>$55,415</td>
<td>0</td>
<td>$150,227</td>
<td>$30,150</td>
<td>$258,557</td>
</tr>
<tr>
<td>$/kW</td>
<td>$9,485</td>
<td>$22,166</td>
<td>n/a</td>
<td>$8,346</td>
<td>$8,375</td>
<td>$9,757</td>
</tr>
<tr>
<td>$/kWh - First Year</td>
<td>$9.02</td>
<td>$9.66</td>
<td>n/a</td>
<td>$5.19</td>
<td>$5.05</td>
<td>$5.99</td>
</tr>
<tr>
<td>O&amp;M / Year</td>
<td>$750</td>
<td>$650</td>
<td>n/a</td>
<td>$1,500</td>
<td>$1,000</td>
<td>$2,000*</td>
</tr>
<tr>
<td>$/kWh - 20 Years</td>
<td>$0.75</td>
<td>$0.60</td>
<td>n/a</td>
<td>$0.31</td>
<td>$0.42</td>
<td>$0.35</td>
</tr>
</tbody>
</table>

---

18 Interconnections costs assume 2 WT2500 installed and 1 WT 6000 installed

19 Costs were allocated on a per unit basis based upon the recommended configuration.

20 The combined O&M costs is assumed to be considerably lower than sum of the individual O&M estimates as there will be great efficiencies.
4.2 Benefits of Electricity Production

There are three types of energy revenue and/or avoided costs resulting from an on-site wind turbine project. First, and generally most valuable, is to avoid paying utility bill energy charges[^21]. Second is to sell part or all of the production of a project into the wholesale market. Third is to capture revenue from selling renewable energy certificates (RECs) that are available from wind projects in some New England states, including Massachusetts (more on this later).

The balance of this section describes these revenue streams.

4.2.1 Benefits of Avoiding Utility Bill Charges

An electric bill from NSTAR consists of four types of charges:

- Customer Charges
- Demand (kW) Charges
- Energy (kWh) Charges
- Other (e.g., metering, interconnection study)

Customer, demand, and “other” charges all are considered purely utility “wire charges”. The energy charges are a mixture of “wire” and “generation” charges. The above charges are assessed for various “services” and include:

- Generation. Generation services currently can be purchased two different ways. They are:
  i) Basic Service is available who choose not for whatever reason not to procure electricity from a competitive supplier; and,
  ii) Competitive supply service. Hess currently serves MoS as its competitive supplier (at a rate of 7.251 ¢/kWh); and,

[^21]: Customers that sign-up for competitive generation supply (e.g., Constellation Energy, Trans Canada) can get two bills one from Cambridge Electric Company (a NSTAR subsidiary) and one from their competitive generation supplier. For simplicity’s sake we assume, regardless whether MOS procures generation from a competitive supplier or default service, it will receive only one bill from NSTAR, and that that bill includes generation and all other charges.
• Distribution;
• Transmission;
• Competitive transition (i.e., stranded costs);
• Energy efficiency; and,
• Renewable energy fund.

Unless a customer opts to totally disconnect from the grid and rely on a combination of wind turbines and other sources of electricity (e.g., photovoltaics, banks of batteries, micro-turbines), they can not avoid monthly customer charges nor demand (kW) charges.

What certainly can be avoided (in part) by the installation of a wind turbine are energy charges. The amount of energy charges a customer pays on the utility bill varies by, their location, rate class and consumption patterns. MoS is appropriately on the Cambridge Electric tariff class 70 (Large General Time-of-Use). The computation of the “wire charges” (all the charges with the exception of the generation charges) are defined in Cambridge Electric’s tariff22. Energy charges constitute a very large share of MoS’s electric bill (currently ~ 9 ¢/kWh), though the actual size will depend on a particular month’s consumption size and pattern.

4.2.1.1 No Implementation of “Standby” Generation Charges

NSTAR does not impose Standby Generation Charges on customers that install on-site renewable energy generation projects., 23

4.2.2 Protection from Volatile Electric Rates

For as long as the wind turbine is utilized, its fuel costs will be zero. This is in contrast to very volatile natural gas, fuel oil and electricity prices. While a DG wind turbine will only provide a fraction of the energy consumed on-site (the most likely sizing will be only a


23 Renewable energy projects in the NSTAR service territory are exempt from standby charges per a Settlement until at least August 1, 2008. See http://www.mass.gov/dte/catalog/7206.htm. Non-renewable projects are not exempt from standby charges.
small fraction of MoS’s consumption), even this proportion will slightly dampen the risk associated with volatile energy prices. A much larger traditional wind turbine would have a much larger impact.

4.2.3 Renewable Energy Certificates

An additional revenue stream for wind turbines in Massachusetts comes from a legislative mandate to promote renewable energy sources. The potential revenue comes from the sale of Renewable Energy Certificates (RECs), or so called “green certificates”. RECs are a tool created as a result of the Renewable Portfolio Standard (RPS) legislation adopted in some New England states, notably Massachusetts, Connecticut, and most recently Rhode Island. Maine and Vermont has a RPS, but in practice it does not promote new renewable projects to a great degree\(^{24}\).

Accounting for RECs is the method to certify compliance with an RPS. The primary purpose of the RPS legislation is to create demand for new renewable electric generation sources which have significantly fewer environmental impacts than traditional fossil fuel based generation and which help diversify the domestic electricity generation mix thereby leading to greater long-term price stability.

The Massachusetts RPS mandates that 1% of all in-state investor owned utility service territory (i.e., NSTAR, National Grid, Fitchburg Gas & Electric, and Western Mass Electric) electric consumption come from new (post-1997) renewable resources by 2004. These levels increase by 0.5% each year though 2009, and at the discretion of the DTE, 1% for each year from 2010 through 2014 for a total of 9%. Connecticut has a similar requirement for in-state electricity consumption in place, and Rhode Island, as well, has legislated a similar RPS to start in 2007.

The alternative compliance payment (ACP, i.e., penalty) for an electricity supplier (e.g., ConEd Solutions) not reaching these mandates in 2006 is $55.13 /MWh for Massachusetts served load and $55/MWh for Connecticut served load. In both cases the ACP is adjusted for inflation. An on-site turbine at FTP could be used to satisfy the

\(^{24}\) As of March 15, 2005 New Hampshire had RPS legislation pending, and Maine had changes to their RPS legislation pending as well.
Massachusetts and Connecticut\textsuperscript{25} RPSs. Output from new wind farms that sell their output into the wholesale market installed on Cape Cod and Martha’s Vineyard (or for that matter anywhere in the ISO-NE area, including off-shore locations, such as the proposed Cape Wind project) would create RECs that could be used to satisfy either the Massachusetts, Connecticut, or soon to be implemented Rhode Island RPS mandates.

4.2.3.1 REC Prices

There is significant uncertainty in the REC markets. Rules are still in flux, additionally nearby states of New York, New Jersey, Pennsylvania, Maryland and the District of Columbia also have their own RPS’s, which may increase demand and/or decrease the potential to import RECs that could supplant RECs from New England based products\textsuperscript{26}. In short-term it is safe to say that RECs (1 REC = 1 MWh of attributes of output from a renewable generation source) are in high demand as can be seen in Table 4-3.

<table>
<thead>
<tr>
<th>Term</th>
<th>Bid Price</th>
<th>Offer Price</th>
<th>Last Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calendar Year 2005</td>
<td>$52.50</td>
<td>$53.50</td>
<td>$53.50</td>
</tr>
<tr>
<td>Calendar Year 2006</td>
<td></td>
<td></td>
<td>$50.00</td>
</tr>
<tr>
<td>Calendar Year 2007-2009 Package</td>
<td>$39.00</td>
<td>$44.00</td>
<td>$42.50</td>
</tr>
</tbody>
</table>

4.2.4 Forward Capacity Market Payments

While impossible to yet quantify except in the most broadest sense, it is possible that a wind powered installation will receive payments from the newly proposed ISO-NE forward capacity market (FCM). Capacity payments are payments for kW generation installed. ISO-NE recently submitted a settlement proposal to FERC to implement a

\textsuperscript{25} Connecticut is the only New England state that allows out-of-state, behind-the-meter generation to be eligible for their RPS.

\textsuperscript{26} To be eligible for Massachusetts RECs the energy of a renewable project must be sold into the ISO-NE market. Connecticut legislation theoretically allows for RECs to be eligible for ISO-NE projects that do not deliver their energy into ISO-NE, but rules have not been finalized. Further Connecticut legislation prohibiting REC eligibility without physical import is pending.

\textsuperscript{27} United Power Renewable Energy Certificates Trade Recap For the Week Ending: 8/25/06.
forward capacity market\textsuperscript{28}. The settlement needs to be approved by FERC and specific rules hashed out. There is even more uncertainty because payments, after a transition period through 2010, will be based on a market clearing auction.

For a guess at potential parameters payments we assume capacity clearing prices after the transition period of $8.00 / kW-month and a wind turbine, as an intermittent resource, would be de-rated to its capacity factor of ~25%. Thus we guess that payments per month for a 6 kW wind turbine might be $12 ($8.00/kW * 6 kW * 25%), or $144 / year.

Because of the great uncertainty surrounding the FCM, such payments are not incorporated into a base case pro-forma..

4.3 Analyze Financing / Ownership Options

As detailed above, the cost of a single turbine can be close to $50,000. Given the small kW size we assume that third-party ownership is not viable because of high transaction costs, and so only MoS ownership is considered. As the MoS is a non-profit, no tax benefits are considered.

4.4 Analyze Project Financials

This subsection analyzes the financial payback for various scenarios of turbine configurations, ownership, costs, revenue, etc. It first describes the methodology employed, and then defines the primary base cases used in the analysis. Sensitivity to various input assumptions will be shown. The analysis establishes strong payback when assuming a high fraction of installation costs are offset with grants.

4.4.1 Methodology

4.4.1.1 Hourly Analysis Foundation

The goal of this analysis is to compute the financial payback of ownership and turbine configuration options in a realistic fashion and to confirm the suitability of utilizing on-site anemometer measurements, historic wind resource and electric use data for forward

looking projections. To replicate impacts that would have occurred in 2005 from a wind
turbine we have simultaneously taken into account:

- MOS’s 2005 monthly electricity consumption.
- Cambridge Electric Rate 70 Time-of-Use tariff structure
- The 2005 hourly wind resources at MoS, and the corresponding electricity output
from the analyzed turbines. The 2005 wind resources were estimated by:
  - Using 2005 Logan Airport hourly wind speeds as a starting point
  - Scaling 2004 Logan Airport hourly wind speed to match the long-term
    Logan average annual wind speed (a 8% increase)
  - Scaling the above to downward by the ratio of the Tower mounted
    anemometer to Logan Airport wind speeds for April through July 11, 2006
  - Adjusting the wind speeds to appropriate hub height for the specific
    turbine model.

From this information we are able to calculate the amount of electricity produced by wind
turbines, the amount and value of electricity that would have been consumed on-site in
2005. 2005 was not a typical year in terms wind resources (average wind speed was
92% of long-term average), and thus the adjustment to long-term average provides
reassurance that projecting 2005 adjusted production to future years is appropriate.

4.4.1.2 Projecting Financial Impacts to Future Years

A wind turbine has an expected 20-year equipment life. For futures years we assumed
replication of 2005 wind resources and MoS’s electricity consumption\(^{29}\). We have
increased prices by assumed inflations rates (e.g., wholesale prices), decreased prices
per tariff filings (e.g., Cambridge Electric’s transition costs are expected to decrease over
the next few years), or assumed prices would stay steady (e.g., we assumed that the
renewable energy charge, the portion of the bill that funds MTC, would stay constant at
0.05¢/kWh for the life of the wind turbine), as appropriate. Additionally we make explicit
assumptions about the cost of the wind turbine installation, O&M costs, percent of time

\(^{29}\) In reality, electricity consumption almost certainly will increase with the increases in electricity
consuming equipment (e.g., computers, monitors, etc.). This will make no difference as MoS
electric consumption will always be higher than combined output of the proposed turbine arrays.
the wind turbine is available (i.e., not undergoing repair or maintenance), line losses, REC revenue, loan terms, potential grants, and inflation rates.

All this information is combined to provide nominal costs and benefits of a wind turbine for each of the 20 years of expected life of operation. From these results cash flow, internal rate of return (IRR), and net present value (NPV) can be computed.

4.4.2 Define Major Scenarios

for each of the 20 years of expected life of operation. From these results cash flow, internal rate of return (IRR), and net present value (NPV) can be computed.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value / Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wind Resources</td>
<td>On-site wind resources adjusted to 2005 hourly and long-term trends</td>
<td></td>
</tr>
<tr>
<td>Electricity Consumption Patterns</td>
<td>2005 Historical</td>
<td>~9,000,000 kWh</td>
</tr>
<tr>
<td>Project Start Date</td>
<td>January 2007</td>
<td></td>
</tr>
<tr>
<td>Months to Complete</td>
<td>12</td>
<td></td>
</tr>
<tr>
<td>General Inflation</td>
<td>3.5%</td>
<td></td>
</tr>
<tr>
<td>Energy Inflation</td>
<td>4.5%</td>
<td></td>
</tr>
<tr>
<td>Value of Avoiding Retail Generation</td>
<td>10.0 ¢/kWh*</td>
<td>Inflation adjustment</td>
</tr>
<tr>
<td>Value of Avoiding All Wire Charges</td>
<td>1.134 ¢/kWh*</td>
<td>*First year weighted average charges. Portion scheduled to decrease over time per tariff filing. Inflation adjustment as appropriate.</td>
</tr>
<tr>
<td>All-in cost of turbine kWh output to</td>
<td>n/a</td>
<td>No inflation adjustment</td>
</tr>
<tr>
<td>REC price</td>
<td>4.00 ¢/kWh for first 3 years, 3.00 ¢/kWh thereafter</td>
<td>No inflation adjustment</td>
</tr>
<tr>
<td>Ongoing Management Fee</td>
<td>15% of RECs</td>
<td></td>
</tr>
</tbody>
</table>

30 When the current contract with Hess expires it is expected that generation costs will be 9 to 11 ¢/kWh.
<table>
<thead>
<tr>
<th>Attribute</th>
<th>Value / Description</th>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Interest Rate</td>
<td>8.0%</td>
<td>Generally not applicable to MOS as they assume to pay for project in cash.</td>
</tr>
<tr>
<td>Risk-free interest bearing rate</td>
<td>5.5%</td>
<td>Used in Net Present Value Calculation</td>
</tr>
<tr>
<td>Loan Down Payment</td>
<td>100%</td>
<td>MOS pays for project without a loan</td>
</tr>
<tr>
<td>Loan Term</td>
<td>n/a</td>
<td></td>
</tr>
<tr>
<td>Capital Costs and Operating Costs</td>
<td>See Table 4-1</td>
<td></td>
</tr>
<tr>
<td>Internal Line Losses</td>
<td>2%</td>
<td></td>
</tr>
<tr>
<td>Turbine Availability</td>
<td>98%</td>
<td></td>
</tr>
<tr>
<td>Grants</td>
<td>None</td>
<td></td>
</tr>
</tbody>
</table>

### 4.4.3 Financial Results

On a purely financial basis the rooftop wind turbines are not a good investment based on the wind resources at the MoS and other factors. Table 4-5 shows the financial returns with no subsidization. None of the turbines show a positive financial return. The same analysis is run for a grant of 75% of capital costs (see Table 4-6), and again none of the turbines show a positive financial return. Finally when the same analysis is run for a grant of 90% of the capital costs (see Table 4-7), the Proven 6 kW ekes out a positive return for the 20 year time-frame. The financial returns are weak because of:

- High capital costs
- High O&M costs (per kWh produced)
- Lack of ability to use tax incentives
- Moderate wind resources

However, the MoS’s benefits to society via the demonstration of renewable energy production from wind turbines for the purpose of educating the public, would provide a great many non-financial benefits, and directly fits into the MoS’s mission.
### Table 4-5
Financial Results on a Per Turbine Unit Basis.
No Grant Scenario

<table>
<thead>
<tr>
<th>Turbine Model</th>
<th>IRR-10 Years</th>
<th>NPV-10 Years</th>
<th>IRR-20 Years</th>
<th>NPV-20 Years</th>
<th>Years Until Cash Flow Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVX-400</td>
<td>n/a</td>
<td>($7,790)</td>
<td>n/a</td>
<td>($11,380)</td>
<td>n/a</td>
</tr>
<tr>
<td>Tulipo</td>
<td>n/a</td>
<td>($60,840)</td>
<td>n/a</td>
<td>($59,817)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT2500</td>
<td>n/a</td>
<td>($32,889)</td>
<td>n/a</td>
<td>($32,815)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT6000</td>
<td>n/a</td>
<td>($58,356)</td>
<td>n/a</td>
<td>($51,981)</td>
<td>n/a</td>
</tr>
<tr>
<td>Southwest Skystream</td>
<td>n/a</td>
<td>($17,520)</td>
<td>n/a</td>
<td>($18,252)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

### Table 4-6
Financial Results on a Per Turbine Unit Basis
of 75% Grant Scenario

<table>
<thead>
<tr>
<th>Turbine Model</th>
<th>IRR-10 Years</th>
<th>NPV-10 Years</th>
<th>IRR-20 Years</th>
<th>NPV-20 Years</th>
<th>Years Until Cash Flow Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>AVX 400</td>
<td>n/a</td>
<td>($4,608)</td>
<td>n/a</td>
<td>($8,107)</td>
<td>n/a</td>
</tr>
<tr>
<td>Tulipo</td>
<td>n/a</td>
<td>($14,356)</td>
<td>n/a</td>
<td>($13,333)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT2500</td>
<td>n/a</td>
<td>($8,107)</td>
<td>n/a</td>
<td>($8,033)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT6000</td>
<td>n/a</td>
<td>($9,695)</td>
<td>2%</td>
<td>($3,321)</td>
<td>18.9</td>
</tr>
<tr>
<td>Southwest Skystream</td>
<td>n/a</td>
<td>($4,874)</td>
<td>n/a</td>
<td>($5,606)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

31 IRR=Internal Rate of Return, NPV=Net Present Value. Unless explicitly noted elsewhere the interest rate used to compute NPV for MoS is 5.5%.
4.4.3.1 *Recommended Configuration*

If the MoS proceeds with the recommended configuration of

- 6 AeroVironment AVX 400’s (0.4 kW)
- 1 Tulipo (2.5 kW)
- 3 Proven WT 6000 (6.0 kW)
- 2 Southwest Skystreams (1.8 kW)

the total project costs is estimated to be $258,557, and will produce 43,182 kWh / year. Table 4-8 shows computation of financial results for the recommended configuration.
If the MoS can procure grants to cover 90% of the costs the project will have a positive economic return.

5 Conclusions

A roof-mounted wind turbine installation has the potential for considerable benefit for the MoS with moderate financial impacts depending upon the grant amount. Further, there appears no major technical or environmental constraints preventing the installation and operation of the project. Based on the presentation to MOS’s project manager and following revised capital and construction cost estimating, the Boreal team will implement design, and construction activities for the wind turbine installation at the MOS site during the fall of 2006- winter 2007.

Some highlights of our conclusions follow:

Site Layout

- MoS has sufficient roof area and structural elements to place and support both rooftop wind and small pole mounted wind turbines on various building wings.
- The MoS site does not possess significant real estate thereby limiting the placement, staging, installation and operation of utility-scale wind turbines.
- The MoS site is in an existing helicopter flyway and approach for the adjacent Massachusetts General Hospital and the nearby Coast Guard Station in the North End among others that navigate along the Charles River.
- The MoS site is constrained by the number of relatively tall structures in the general vicinity that will create wind turbulence that adversely affects the operational efficiency and maintenance requirements of utility-scale machines.
- The site is easily accessible via major state and federal highways for turbine and tower shipment.
- The site is located in both Cambridge and Boston. In Cambridge, it is in a Planned Unit Development overlay and is a residentially zoned area. In Boston,
the site is zoned Residential Apartments. There are no residential properties directly bordering the MoS site though there are many high rise apartments and condominiums in a direct line of site of their property.

- The MoS is constructed on the Charles River Dam and is bounded to the southwest by the Charles River basin and surrounded by various parklands and pedestrian/bike paths. This area is highly trafficked by cars and trucks, public train transportation, pedestrians, bikes, rollerbladers, joggers etc. and will make for a highly visible wind turbine project.

Energy Infrastructure & Consumption

- MOS’s annual electricity consumption totaled approximately 9,000,000 kWh between 2005-06 (thru July) which will translate into total charges of approximately $1,500,000.

- Consumption peaks during the summer months, coincident with cooling load.

Engineering and Interconnection Requirements

- Roof-mounted wind turbine generators of 26.5 kW capacity in total are proposed to be installed on the Penthouse #2 roof, the Blue Wing roof, the Omni Theatre roof, and the Central Building – Level 6 roof.

- The wind turbine generators to be installed on the Penthouse #2 roof and the Blue Wing roof will be interconnected to 480 volt distribution panel inside Penthouse #2. The wind turbine generators to be installed on the Omni Theatre roof and the Central Building – Level 6 roof will be interconnected to 480 volt distribution panel located inside Penthouse #3.

- The total installed cost estimate for the interconnection work described in this report is $79,000. This is a planning accuracy (plus or minus 25%) cost estimate for all materials, installation labor, and engineering.

Solar Cells

While outside of the scope of this study a spare panel board circuit breaker exists in Penthouse #2 that is available to run the appropriate cables and conduits to repower the disconnected 1970’s vintage PV panels on the Blue wing roof.

- The interconnection costs would be approximately $12,600.
• A 2.7 kW system could be installed based on the existing dimensions of the solar racks. We did not obtain capital costs estimates for new PV panels. Typically these panels are 10 W/ft$^2$ of panel and about $10/W installed (rough estimate ~$27,000 + $12,600 = $39,600).

Environmental Resource Assessment

• Shadowing and flicker impacts to the Charles River basin are not expected to be of concern for the roof-mounted units due to the small blade diameter and low relative height.

• The developed, urban setting of the MoS and the small swept area of the wind turbines will minimize or avoid any potential impact to Federal and State threatened, endangered or proposed listed species if these are present at the MoS site. No formal review is recommended.

• A regional air emission benefit of a reduction of approximately 23.8 tons per year of carbon dioxide emissions can be achieved by the installation of the 26.5 kW of roof-mounted wind turbine capacity.

Permitting

Cambridge:

- A written determination is required by the Cambridge Planning Board relating to development in the East Cambridge Riverfront area for compatibility.

- Cambridge does not define wind turbines in their zoning bylaws. However, if the electricity is consumed on-site, it will most likely be considered an allowed accessory use.

- A zoning exemption for height in Cambridge may be applicable as well under the bylaws for the architectural wind turbine units.

- A special permit may be required in Cambridge’s Planned Unit Development Overlay Zone relating to noise impacts. Further review by an attorney and noise consultant is recommended (see also Noise Assessment section 3.3.3).
A special permit may be required by the Cambridge Zoning Board of Appeals if the wind installation is defined or intended for scientific research.

Power generation may be prohibited in Cambridge at the MoS site based on its residential zoning designation under the Zoning Ordinances. Further review by an attorney is recommended but a special permit may override this prohibition.

Boston:

- Boston does not define wind turbines in their zoning bylaws. However, if the electricity is consumed on-site, it will most likely be considered an allowed accessory use.
- Most likely, the Boston Zoning Board of Appeals would issue a Special Permit for accessory use (or potentially an extension of a non-conforming use) for wind turbines. Further review by an attorney is recommended.
- There is no defined height limit in the City of Boston’s Zoning Ordinance for this site’s zoning classification.

- The Massachusetts noise guideline (a change in sound not exceeding 10 dB at the property line) most likely will be met due to the existing high ambient sound levels and the innovative design of the architectural wind turbines. The noise levels from the state-of-the-art turbines is acceptable both at the property line and within the MoS itself.
- The Federal Aviation Administration (FAA) determined that the tower and blade height of large utility scale turbines would pose a “Presumed Hazard to Air Navigation” at two potential sites on the MoS property. The FAA limited wind turbine height to not to exceed 213 ft. To go beyond this height, additional FAA study, regulatory review and public participation would be required without guarantee of success.

**Recommended Configuration**

- Given the desires and constraints of the MoS rooftop we have recommended a total installed system of 26.5 kW configuration with:
- 6 AeroVironment AVX 400’s (0.4 kW each)
- 1 WES Tulipo (2.5 kW each)
- 3 Proven WT 6000 (6.0 kW each)
- 2 Southwest Skystreams (1.8 kW each)

- The total estimated installed cost is $258,557 including structural tie-ins and electrical interconnection.

**Economic Feasibility Analysis**

- MoS has a combination of moderate wind resources, high electric consumption, and high electric rates.

- For most turbines, economic returns are not positive until offsetting grants reach above 75%. It may be possible to combine grants to reach this level of support.

- While economic returns are not positive, the MoS’s benefits to society via the demonstration of renewable energy production from wind turbines for the purpose of educating the public would be invaluable.

**Other**

- Continue to track the commercial availability of the Swift and Airdolphin turbine, two innovative designs not yet available in the US.

- While we recommended the above configuration for its variety, the MoS may want to focus more on the potential for economic payback. If this were the case it would be best to install only the largest turbines that could technically be installed on the rooftop because of economies of scale.
  - It should be noted the installation of the AeroVironment AVX 400’s would not interfere with the installation of any of the traditional pole mounted turbines.

**5.1.1 Next Steps**

- Apply to Kresge/MTC grant program for design and construction grants

- Refine costs based upon final configuration.
• Proceed to design, stakeholder outreach, permitting, engineering and construction following consultation with civil and electrical engineers and crane operators on final site configuration.
AeroVironment Technical Review Comments

The following provides comments relating to specific concerns with AV’s system. It is continued from the in-text narrative about AV in Section 3.2.3

1) **Limited yaw**- As wind direction can change frequently, a turbine’s performance depends strongly on its ability to capture the wind from any direction. While there may be a strong prevailing wind direction at the MoS (wind blows between South and West 40-45% of the time), it is difficult to predict the performance of AV’s turbine when wind is not blowing from the prevailing direction. We would like to see a more detailed analysis by AV of the impact of wind direction on system performance, as well as the turbine’s wake effect on one another.

2) **Vibration**- AV claims that no significant vibrations have been measured or documented during operation of their turbines. This may be a strong point of their design, however Boreal would like to see more documentation on AV’s claim based on real-life operation at different sites.

While our concerns about AV’s system are significant, we also see positive aspects relating to the following:

1) **Aesthetics**- AV’s system has a high tech, futuristic appearance. Their low mounting profile does not protrude far from the roof or into Boston’s skyline (which can be interpreted as a positive or negative aspect depending on different perspectives, i.e. from a permitting standpoint it may be easier to obtain permission for construction and thus a low profile is a positive, but from the MoS’s standpoint the inability to see the turbines from certain vantage points poses a reduction in educational/advertisement opportunity). Nonetheless, those who are in view of AV’s system (especially from the Charles River and Esplanade Parkway) will see an appealing turbine display.

2) **Modularity**- Unlike other systems, AV’s is specifically designed with modularity in mind. Depending on the length of a rooftop, multiple turbines can be constructed in an array without much further complication. Tower-mounted turbines require individual structural foundations and interconnection.
Gentlemen,

As requested, I have reviewed the information obtained concerning the proposed roof top wind turbines. Since my visits to the MOS, and the information sought, focused on goals discussed at the March meeting, I obtained structural information on the Central Building roof, East Wing roof and West Wing lower roof, related to AV installations only. I had some information on the West Wing Penthouse, but will require more along with Omni Theatre roof information before any working designs can be developed.

I’ve tabulated some of the information obtained and performed some calculations as well. I could not find the Tulipo thrust load so I estimated it.

The thrust loads generated by the AV 400 Watt turbines are relatively minor, and because the rotor is only about six feet above the roof line, the base moments are minor as well. Also, the nature of the mounting system for the AV Units keeps loads at the roof perimeter and spreads it across the roof length (see the attached TIF file for conceptual, D-1 is not included).

I recommend that we use similar horizontal X-Frame bases for the SkyStream, Proven and Tulipo as observed in the pictures you provided via email. Depending on the building frame, turbine thrust and tower height, the X-Frame can range from twelve to twenty feet long and six to twelve feet wide. The West Wing lower roof and the penthouse roof are composed of full span precast concrete T-Beams with bearing ends on the south face. If spread out sufficiently, I believe the SkyStyream 1.8s can be installed there, but the heavier units will be
a serious challenge. It would be nice to reduce the tower height of the SkyStream 1.8s to reduce the base moment and therefore the steel and overall weight.

The steel contractor I’ve spoken with stated that, fabrication, delivery and installation costs for galvanized steel components will run from $4000.00 to $6500.00 per ton depending on the amount of steel and complexity of fabrication and installation.

If I have the information on the AV turbine correct, an individual unit is approximately six feet wide and they are installed next to each other for a total length of 36’-0”. If this is the case, the weight of base steel for all six AV units is equivalent to the weight of the base steel for a single SkyStream 1.8 and should therefore cost about the same.

Turbine estimated weights, loads and costs are tabulated below (pounds, foot-pounds, feet-inches, dollars).

<table>
<thead>
<tr>
<th>Turbine</th>
<th>SkyStream 1.8</th>
<th>Proven 2.5</th>
<th>Proven 6.0</th>
<th>Tulipo 2.5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rotor weight</td>
<td>154#</td>
<td>419#</td>
<td>1102#</td>
<td>600#??</td>
</tr>
<tr>
<td>Tower weight</td>
<td>549#</td>
<td>531#</td>
<td>793#</td>
<td>1873#</td>
</tr>
<tr>
<td>Total weight</td>
<td>703#</td>
<td>950#</td>
<td>1895#</td>
<td>2473#</td>
</tr>
<tr>
<td>(less base steel)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tower Height</td>
<td>33'-6”</td>
<td>21’-4”</td>
<td>29'-6”</td>
<td>39'-36”</td>
</tr>
<tr>
<td>Shear at base</td>
<td>862#</td>
<td>1120#</td>
<td>2240#</td>
<td>1200#??</td>
</tr>
<tr>
<td>Moment at base</td>
<td>26,245 ft-lb</td>
<td>23,878 ft-lb</td>
<td>66,124 ft-lb</td>
<td>47,400 ft-lb??</td>
</tr>
<tr>
<td>Base steel weight</td>
<td>1250#</td>
<td>2000#</td>
<td>2700#</td>
<td>3000#</td>
</tr>
<tr>
<td>Base steel cost (est.)</td>
<td>$2800-$4000</td>
<td>$4500-$6500</td>
<td>$6000-$8500</td>
<td>$6750-$9750</td>
</tr>
</tbody>
</table>
Note that the Proven 6.0 and the Tulipo base moments are substantial and will therefore require more extensive base structures. As discussed earlier, the SkyStream 1.8 is relatively light. I suspect that the blade diameter is similar to the Proven 2.5. If possible, I would like to limit the Penthouse and West Wing to the SkyStream and shorten the tower which will lessen the base moment.

All design information is conceptual and costs are rough estimates at this time and subject to obtaining additional drawings and site information.

Please call with questions or comments.

Regards,

Paul A. Phelan, Jr., P.E.

2" X 4" X 1/4" TUBE STEEL (TIP)

5'-0" (H=) 2" TUBE STEEL FOR BEAM OF BASEPLATE SEE D-2

3/4" THROUGH BOLTS WITH SHOULDER NUTS 12" X 1/2" HONOR PLATE
**NOTICE OF PRESUMED HAZARD**

The Federal Aviation Administration has conducted an aeronautical study under the provisions of 49 U.S.C., Section 44718 and if applicable Title 14 of the Code of Federal Regulations, part 77, concerning:

Structure: Wind Turbine  
Location: Cambridge, MA  
Latitude: 42-22-6.00 N NAD 83  
Longitude: 71-4-24.00 W  
Heights: 404 feet above ground level (AGL)  
414 feet above mean sea level (AMSL)

Initial findings of this study indicated that the structure as described exceeds obstruction standards and/or would have an adverse physical or electromagnetic interference affect upon navigable airspace or air navigation facilities. Pending resolution of the issues described below, the structure is presumed to be a hazard to air navigation.

If the structure were reduced in height so as not to exceed 213 feet above ground level (223 feet above mean sea level), it would not exceed obstruction standards and a favorable determination could subsequently be issued.

To receive a favorable determination at the originally submitted height, further study would be necessary.  Further study entails distribution to the public for comment, and may extend the study period up to 120 days.  The outcome cannot be predicted prior to public circulation.

If you would like the FAA to conduct further study, you must make the request within 60 days from the date of issuance of this letter.

NOTE: PENDING RESOLUTION OF THE ISSUE(S) DESCRIBED ABOVE, THE STRUCTURE IS PRESUMED TO BE A HAZARD TO AIR NAVIGATION. THIS LETTER DOES NOT AUTHORIZE CONSTRUCTION OF THE STRUCTURE EVEN AT A REDUCED HEIGHT. ANY RESOLUTION OF THE ISSUE(S) DESCRIBED ABOVE MUST BE COMMUNICATED TO THE FAA SO THAT A FAVORABLE DETERMINATION CAN SUBSEQUENTLY BE ISSUED.

IF MORE THAN 60 DAYS FROM THE DATE OF THIS LETTER HAS ELAPSED WITHOUT ATTEMPTED RESOLUTION, IT WILL BE NECESSARY FOR YOU TO REACTIVATE THE STUDY BY FILING A NEW FAA FORM 7460-1, NOTICE OF PROPOSED CONSTRUCTION OR ALTERATION.
If we can be of further assistance, please contact our office at (813) 417-6429. On any future correspondence concerning this matter, please refer to Aeronautical Study Number 2006-ANR-483-OE.

Signature Control No: 461109-480456
William Merritt
Specialist
** NOTICE OF PRESUMED HAZARD **

The Federal Aviation Administration has conducted an aeronautical study under the provisions of 49 U.S.C., Section 44718 and if applicable Title 14 of the Code of Federal Regulations, part 77, concerning:

| Structure: | Wind Turbine |
| Location:  | Cambridge, MA |
| Latitude:  | 42.31-59.00 N WAD 83 |
| Longitude: | 71-4-12.00 W |
| Heights:   | 404 feet above ground level (AGL) |
|            | 422 feet above mean sea level (AMSL) |

Initial findings of this study indicated that the structure as described exceeds obstruction standards and/or would have an adverse physical or electromagnetic interference effect upon navigable airspace or air navigation facilities. Pending resolution of the issues described below, the structure is presumed to be a hazard to air navigation.

If the structure were reduced in height so as not to exceed 201 feet above ground level (219 feet above mean sea level), it would not exceed obstruction standards and a favorable determination could subsequently be issued.

To receive a favorable determination at the originally submitted height, further study would be necessary. Further study entails distribution to the public for comment, and may extend the study period up to 120 days. The outcome cannot be predicted prior to public circularization.

If you would like the FAA to conduct further study, you must make the request within 60 days from the date of issuance of this letter.

See attachment for additional information.

NOTE: PENDING RESOLUTION OF THE ISSUE(S) DESCRIBED ABOVE, THE STRUCTURE IS PRESUMED TO BE A HAZARD TO AIR NAVIGATION. THIS LETTER DOES NOT AUTHORIZE CONSTRUCTION OF THE STRUCTURE EVEN AT A REDUCED HEIGHT. ANY RESOLUTION OF THE ISSUE(S) DESCRIBED ABOVE MUST BE COMMUNICATED TO THE FAA SO THAT A FAVORABLE DETERMINATION CAN SUBSEQUENTLY BE ISSUED.

IF MORE THAN 60 DAYS FROM THE DATE OF THIS LETTER HAS ELAPSED WITHOUT ATTEMPTED RESOLUTION, IT WILL BE NECESSARY FOR YOU TO REACTIVATE THE STUDY BY FILING A NEW FAA FORM 7460-1, NOTICE OF PROPOSED CONSTRUCTION OR ALTERATION.
If we can be of further assistance, please contact our office at (813)417-6429. On any future correspondence concerning this matter, please refer to Aeronautical Study Number 2006-ANE-564-08.

Signature Control No.: 465136-198457
William Merritt
Specialist
Attachment(s)
Additional Information
D Turbine Vendor Contact List

Aerovironment
David Wold - Director, Global Business Development
w: 512-305-0660
c: 512-228-4392
wold@avinc.com
Website: www.avinc.com

Proven
Chris Worcester - USA sales rep (CA)
w: 530-582-4503
f: 530-582-4603
c: 530-488-9692
chris@solarwindworks.com
Website: http://www.provenenergy.co.uk/

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Andrew Lyle, Director
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Fax: +44 (0) 131 535 3303
info@renewabledevices.com
Website: www.renewabledevices.com

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f: 928-779-1485
miriam@windenergy.com
Website: http://www.windenergy.com/

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nakayama@zephyreco.co.jp
Website: www.zephyreco.co.jp/en
June 3, 2007

David Rabkin PhD
Museum of Science
Science Park
Boston MA 02114

Dear Dr. Rabkin:

This letter report is an addendum to the Wind Feasibility Study completed by Boreal Renewable Energy Development (Boreal) for the Museum of Science (MoS) dated October 2006. The addendum represents the completion of the long term wind speed and directional data acquisition for over a one year time period that was monitored on the MoS roofs, and an update of project financials for various roof-mounted wind turbines. In addition, we have included in this addendum report one vertical-axis bladed turbine, an Aeroturbine (1.35 kW) from Pfister Energy (see photo below) and, a new wind monitoring location, the Omni Theater Roof that was not monitored as part of the original FS study.

Also, during the intervening time period prior to this addendum, Boreal was engaged in identifying more visible locations for the roof-mounted turbines to the general public versus those recommended in the October 2006 FS. This included considering placing wind turbines on locations visible from the front of the MoS and the McGrath/O’Brien Highway and possibly on the roof of the parking garage. No additional wind monitoring was performed on the parking garage.
6 Anemometry Results

Table 9 displays the raw wind speed during the period Apr. 1, 2006 and Mar. 26, 2007 (excluding Aug. 26 to Sept. 23 because of equipment failure). The average wind speed at the Riverside Tower was 4.71 m/s. This 92.7% of the average wind speed at Logan Airport over the same time period. As described in the October 2006 report this ratio is important as we estimate long-term wind resources at the MoS by adjusting the Logan average long-term wind speeds by this ratio (92.7%). This ratio of 92.7% is lower than the 97.3% ratio than was calculated after 3.5 months of data were collected and analyzed for the October 2006 report. (see Table 3-2 of the main report)\textsuperscript{32}. Thus the predicted wind long-term wind speeds at the MoS are 95.3% (92.7%/97.3%) of what was predicted in the October FS report.

Table 9
Raw Wind Speeds and as Compared to Logan Airport

<table>
<thead>
<tr>
<th>Anemometer</th>
<th>Average Wind Speed (m/s)\textsuperscript{*}</th>
<th>Ratio to Logan Wind Speed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Central Building</td>
<td>3.36</td>
<td>66.1%</td>
</tr>
<tr>
<td>Oceanside Tower</td>
<td>4.58</td>
<td>90.1%</td>
</tr>
<tr>
<td>Riverside Tower</td>
<td>4.71</td>
<td>92.7%</td>
</tr>
<tr>
<td>Logan</td>
<td>5.08</td>
<td>100.0%</td>
</tr>
</tbody>
</table>

Table 10 displays the average and comparison of wind speeds from April 20, 2007 to May 22, 2007 of four locations: Central Building Roof, the Oceanside and Riverside Tower locations, and the Omni Theater. For this period it shows the Omni Theater average wind speed at 2.67 m/s which is 91% of the average wind speed recorded on the Central Building roof.

\textsuperscript{32} Also note the 97.3% is associated with the Oceanside anemometer. In retrospect we believe we mislabeled the anemometers in the original report.
Table 10
Wind Speeds and as Compared to Omni Theater
April 20, 2007 through May 22, 2007

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Central Building</th>
<th>Oceanside Tower</th>
<th>Riverside Tower</th>
<th>Omni Theater</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average Wind Speed m/s</td>
<td>2.94</td>
<td>4.14</td>
<td>4.46</td>
<td>2.67</td>
</tr>
<tr>
<td>Wind Speed of Omni Theater Compared to …</td>
<td>91%</td>
<td>64%</td>
<td>60%</td>
<td>100%</td>
</tr>
</tbody>
</table>

The decrease in wind resources results in less wind turbine production and has negatively impacted the financial results.

As shown in 3, the decrease in wind speeds has a dramatic effect on the estimates of energy production. Remember that the kinetic energy of the wind is a cube of the wind speed. Table shows this relationship in practice as kWh production is calculated from the power curves of the recommended wind turbines. The last row in Table shows the addition of the AeroTurbine as specified by Pfister Energy. The low capacity factor for the AeroTurbine is a function of its assumed short tower (1 meter above roof level), and the shape of its power curve (not reaching peak production until 18 m/s).

Table 3
Annual Estimated Energy Production for Turbines on Main Building Roof

<table>
<thead>
<tr>
<th>Turbine</th>
<th>Nominal kW</th>
<th>Capacity Factor</th>
<th>Annual kWh Production</th>
<th>Original Prediction</th>
<th>Ratio of Predictions</th>
</tr>
</thead>
<tbody>
<tr>
<td>WES_Tulipo_2.5kW</td>
<td>2.5</td>
<td>21.3%</td>
<td>4,666</td>
<td>5,737</td>
<td>81.3%</td>
</tr>
<tr>
<td>Proven_WT2500_2.5kW</td>
<td>2.5</td>
<td>13.8%</td>
<td>3,017</td>
<td>3,654</td>
<td>82.6%</td>
</tr>
<tr>
<td>Proven_WT6000_6kW</td>
<td>6.0</td>
<td>15.1%</td>
<td>7,959</td>
<td>9,657</td>
<td>82.4%</td>
</tr>
<tr>
<td>Southwest_Skystream_1.8kW</td>
<td>1.8</td>
<td>15.4%</td>
<td>2,421</td>
<td>2,986</td>
<td>81.1%</td>
</tr>
<tr>
<td>AeroTurbine_Twin_2.7kW</td>
<td>2.7</td>
<td>5.8%</td>
<td>1,380</td>
<td>n/a</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Table 4, Table 4-65, and Table 6 display the results in the same fashion as Tables 4-5, 4-6, and 4-7 of the October 2006 FS report. The results of the updated analysis are diminished from the prior results given the decreased in estimated wind resources. Only the Proven WT 6000 with a 90% grant has a positive financial return.
### Table 4
Financial Results on a Per Turbine Unit Basis.
No Grant Scenario

<table>
<thead>
<tr>
<th>Turbine Model</th>
<th>IRR-10 Years</th>
<th>NPV-10 Years</th>
<th>IRR-20 Years</th>
<th>NPV-20 Years</th>
<th>Years Until Cash Flow Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tulipo</td>
<td>n/a</td>
<td>($61,993)</td>
<td>n/a</td>
<td>($62,110)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT2500</td>
<td>n/a</td>
<td>($33,577)</td>
<td>n/a</td>
<td>($34,184)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT6000</td>
<td>n/a</td>
<td>($60,179)</td>
<td>n/a</td>
<td>($55,607)</td>
<td>n/a</td>
</tr>
<tr>
<td>Southwest Skystream</td>
<td>n/a</td>
<td>($18,131)</td>
<td>n/a</td>
<td>($19,469)</td>
<td>n/a</td>
</tr>
<tr>
<td>AeroTurbine Twin³³</td>
<td>n/a</td>
<td>($54,797)</td>
<td>n/a</td>
<td>($57,245)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

### Table 5
Financial Results on a Per Turbine Unit Basis
of 75% Grant Scenario

<table>
<thead>
<tr>
<th>Turbine Model</th>
<th>IRR-10 Years</th>
<th>NPV-10 Years</th>
<th>IRR-20 Years</th>
<th>NPV-20 Years</th>
<th>Years Until Cash Flow Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tulipo</td>
<td>n/a</td>
<td>($15,508)</td>
<td>n/a</td>
<td>($15,626)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT2500</td>
<td>n/a</td>
<td>($8,795)</td>
<td>n/a</td>
<td>($9,402)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT6000</td>
<td>n/a</td>
<td>($11,518)</td>
<td>2%</td>
<td>($6,947)</td>
<td>18.9</td>
</tr>
<tr>
<td>Southwest Skystream</td>
<td>n/a</td>
<td>($5,486)</td>
<td>n/a</td>
<td>($6,823)</td>
<td>n/a</td>
</tr>
<tr>
<td>AeroTurbine Twin</td>
<td>n/a</td>
<td>($15,494)</td>
<td>n/a</td>
<td>($17,941)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

³³ The cost of the AeroTurbine Twin includes the Pfister Energy estimated costs of $39,854, plus an additional $2,000 for design / PE stamp, and $5,000 for interconnection.
### Table 6

**Financial Results on a Per Turbine Unit Basis of 90% Grant Scenario**

<table>
<thead>
<tr>
<th>Turbine Model</th>
<th>IRR-10 Years</th>
<th>NPV-10 Years</th>
<th>IRR-20 Years</th>
<th>NPV-20 Years</th>
<th>Years Until Cash Flow Positive</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tulipo</td>
<td>n/a</td>
<td>($6,211)</td>
<td>n/a</td>
<td>($6,329)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT2500</td>
<td>n/a</td>
<td>($3,839)</td>
<td>n/a</td>
<td>($4,445)</td>
<td>n/a</td>
</tr>
<tr>
<td>Proven WT 6000</td>
<td>-8%</td>
<td>($1,786)</td>
<td>12%</td>
<td>$2,785</td>
<td>12.3</td>
</tr>
<tr>
<td>Southwest Skystream</td>
<td>n/a</td>
<td>($2,957)</td>
<td>n/a</td>
<td>($4,294)</td>
<td>n/a</td>
</tr>
<tr>
<td>AeroTurbine Twin</td>
<td>n/a</td>
<td>($7,633)</td>
<td>n/a</td>
<td>($10,081)</td>
<td>n/a</td>
</tr>
</tbody>
</table>

7 Turbine Placement

Most of the locations considered on the front facing side of the MoS from an energy production standpoint are not as desirable for roof mounted turbine placement primarily due to the proximity to the main tower that will create turbulence and block wind from the predominate southwest direction. In addition, some of the roof surfaces that are most visible to the general public are at lower elevation that again, will negatively impact production from the roof mounted turbines since wind speeds will be significantly lower.

The only locations on the front of the MoS that continue to merit consideration are the parking lot and Omni Theater roofs. That being said, since one of the main goals of the wind installation is education versus optimizing energy production, visibility and aesthetics can trump economics as long as the wind turbines will spin.

Sincerely,

Bob Shatten

Principal / Boreal Renewable Energy Development