Hawai‘i Energy and Environmental Technologies (HEET) Initiative

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TASK 4. ALTERNATIVE ENERGY SYSTEMS
4.5 Energy Test Platforms

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Introduction

In the fall of 2008 Project Frog and the Office of Naval Research (ONR) began discussing a research program focused on energy efficient platforms tailored to the Pacific region with the potential for mass-deployment. The program spanned several years and was broken into multiple phases – Phase I: materials and technologies research; Phase II: technology integration and deployment feasibility studies; Phase III platform deployment and field testing to explore energy generation and performance monitoring. Phases I and II were previously funded by ONR directly with Project Frog. Phase III deployment was funded through HNEI and is the subject of this report.

Project Frog

In Phase I, Project Frog performed a comprehensive study of current and emerging materials and technologies as potential components of a systematized kit-of-parts for use in the Pacific islands. The components were categorized into six general groups - structure, envelope, materials, energy generation and management, sensors and controls, and integrated building technologies, and were evaluated based on their performance as standalone parts, as well as sub-elements of an integrated building system. Through the use of computerized parametric modeling of design alternatives in different climates, Phase I of the program concluded in April, 2009 with the recommendation of a single type of pre-engineered Frog module appropriate for field-testing across the Pacific.

![Figure 4.5.1 Field Test Locations](image)

Building upon the findings of first stage, the second phase of the program focused on identifying several test locations across the Hawaiian Islands that are representative of the climate conditions of the Pacific Region. Within that context, the research further evaluated the integration of clean energy generation technology within the test platforms while taking into account the compatibility and structural requirements of the different systems. HNEI and Project Frog
selected two sites – one platform at Ilima Intermediate School and two platforms at Kawaikini School New Century Public Charter School, based on their environmental diversity and availability for timely installation, see Figs. 4.5.1 and 4.5.2. A third location considered was Hawaii Volcanoes National Park (HAVO) on the island of Hawaii. Discussed later in the report, the HAVO site was determined to be unsuitable and an alternate location was selected at the University of Hawaii at Manoa (UH).

After the completion of phase Phase II and the issuance of a key report in January 2010, Project Frog and HNEI embarked on the third segment of the research program. This stage consisted of the deployment of the test platforms on two of the selected sites, and the assessment of the structures with regards to their manufacturing and installation cost effectiveness, and logistical efficiency.

The building prototypes analyzed in phase Phase III represented the latest version of the Frog structure – Frog platform v2.2, which achieves both performance enhancements and cost savings compared to the originally proposed Frog v2.0.

Project Frog identified four different building components and analyzed their design or material applicability in different tropical climates, in contrast to the v2.0 systemized kit. These components included insulated wall panels, curtain wall system, integrated roof deck, and exterior cladding. Since the new generation Frog platform v2.2 implements a greater degree of integrated component prefabrication, the company also investigated the economic value of an increase in modularity with respect to mass-deployment in the Pacific region.

The purpose of the field tests was to establish experimental platforms in three climatically different environments with the intent to test how the platforms perform with respect to: daylighting, energy efficiency, thermal comfort, indoor air quality, material durability, and energy consumption. The research program aimed to also track the cost effectiveness of manufacturing and installing the platforms as well as the logistical efficiency of shipping the platforms. Finally, the platforms were tested for their ability to integrate energy generation and storage capabilities as net energy neutral platforms. Table 4.5.1 illustrates the basic parameters
of the platform requirements and research intent of the various sites selected to field test the platform.

<table>
<thead>
<tr>
<th>Test Site Location</th>
<th>Climate</th>
<th>Platform Design</th>
<th>Cooling Approach</th>
<th>Unit Count</th>
<th>Automation</th>
<th>PV</th>
<th>Wind</th>
<th>Storage</th>
<th>Monitoring</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ilima</td>
<td>Warm, dry, low cloud cover</td>
<td>Frog v2.2</td>
<td>2) Primary: Passive cooling &amp; natural ventilation</td>
<td>1</td>
<td>No automated controls; manually operated louvers &amp; windows</td>
<td>(1) 5 kW PV system</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>2) Fan assisted cooling/ ceiling fans</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Kawaihina</td>
<td>Warm, wet, moderate cloud cover</td>
<td>Frog v2.2</td>
<td>3) Split system: underfloor mechanical cooling</td>
<td>2</td>
<td>Some automated controls; manually operated louvers &amp; windows</td>
<td>(2) 5 kW PV systems</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UH Manoa*</td>
<td>Warm, moderately wet, high cloud cover</td>
<td>Frog “Library” modular design</td>
<td>Same as Frog v2.2 except: mechanical split system; overhead ducting</td>
<td>2</td>
<td>No automated controls; manually operated windows</td>
<td>(2) est 5 kW</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

Note: *University of Hawaii at Manoa location site was substituted for Volcano. UHM platforms under construction, to be completed spring 2016.

**Table 4.5.1 Research Platform Parameters**

The test platforms serve as the “control” in the field experiments, so the envelope, structure and mechanical specifications for the test platforms are identical across the Field Test sites. The envelope features highly reflective materials (cool roof and low-e glazing), high values of thermal insulation, large roof overhangs above the clerestories, sunshades over the lower windows, and a large open air vent for natural ventilation and cooling. The full specifications for the Frog v2.2 platform installed at Ilima and Kawaihina can be viewed in Table 4.5.2 below.
Table 4.5.2 Test Platform Frog v2.2 specifications

<table>
<thead>
<tr>
<th>Product Component</th>
<th>Sub-Component</th>
<th>Product Description / Spec</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Platform Structure</strong></td>
<td>Floor Framing</td>
<td>Cold rolled steel perimeter chassis w/ light gauge steel pultrus and structural steelVoidek. Lightweight forearm subfloor surface.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Exterior Walls</td>
<td>6&quot; EPS foam panels with light gauge steel thermally broken frame</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roof Decking</td>
<td>Epic integrated roof deck and acoustical ceiling</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Foundation</td>
<td>Insulated cold-formed steel floor framing; concrete pier footings, refer to structural details</td>
<td></td>
</tr>
<tr>
<td><strong>Platform Envelope</strong></td>
<td>Roof Insulation</td>
<td>EPS foam board: 4-1/4&quot; average wing roof, 3-3/4&quot; average plain roofs, 3&quot; spine roof</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roof System</td>
<td>Data East PVC single ply roof membrane</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stoneclad System</td>
<td>VRC thermally enhanced aluminum cortenwall system with Solarban</td>
<td></td>
</tr>
<tr>
<td></td>
<td>rainscreen system, low-E glass, integrated sunshades at wing windows</td>
<td>Anodized Aluminum</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Louvers</td>
<td>High performance operable awning</td>
<td></td>
</tr>
<tr>
<td><strong>Finishes</strong></td>
<td>Exterior Cladding</td>
<td>Frameless, Products Backboard FSC certified cedar siding</td>
<td>Clear coat finish</td>
</tr>
<tr>
<td></td>
<td>Interior Walls</td>
<td>1/8&quot; Gypsum wallboard (type IV, where required)</td>
<td>Painted</td>
</tr>
<tr>
<td></td>
<td>Floors</td>
<td>Tote raised access floor</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Carpet</td>
<td>Interface carpet tile</td>
<td>Green Label Plus Certified, at least 60% recycled content</td>
</tr>
<tr>
<td><strong>Specialties</strong></td>
<td>Resilient Wall Base</td>
<td>Wall base, 4&quot; 7/8&quot; applied resilient wall base. Wall base, Wet Area: 6&quot; integral coated laminated base</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ceiling</td>
<td>Epic integrated roof deck and acoustical ceiling</td>
<td>NRC = 0.95</td>
</tr>
<tr>
<td></td>
<td>Interior Paint</td>
<td>Low VOC interior paint by Pittsburgh Paints, Sherwin Williams, or equivalent</td>
<td></td>
</tr>
<tr>
<td><strong>Electrical</strong></td>
<td>Signage</td>
<td>Interior ADA required signage</td>
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</tr>
<tr>
<td></td>
<td>Appliance</td>
<td>NIC - By Owner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Furniture</td>
<td>NIC - By Owner</td>
<td></td>
</tr>
<tr>
<td><strong>Exterior Lighting</strong></td>
<td>Exterior Lighting</td>
<td>NIC - By Owner</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>NIC - By Owner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Lighting</td>
<td>NIC - By Owner</td>
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<td></td>
<td></td>
<td>NIC - By Owner</td>
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<td>NIC - By Owner</td>
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<td>NIC - By Owner</td>
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<tr>
<td></td>
<td></td>
<td>NIC - By Owner</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Electrical Equipment</td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mechanical</strong></td>
<td>HVAC</td>
<td>Carrier split system fan coil with condensing unit</td>
<td>R134a refrigerant (R410A)</td>
</tr>
<tr>
<td></td>
<td>Exhaust Fans</td>
<td>Greenheck roof mounted exhaust fan</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ducting</td>
<td>Underfloor plenum with floor diffusers</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ceiling Fans</td>
<td>3&quot; Diameter ceiling fans</td>
<td></td>
</tr>
</tbody>
</table>

The test platform was designed to maximize daylight autonomy – or the amount of time when there is sufficient natural daylight in the space so that electric lighting is not required. The daylighting studies indicate that daylight autonomy is expected to occur over 95% of the time (for which the buildings are occupied) at each project location. To support natural daylight the other 5% of the time, high efficiency direct/indirect lighting is used. Each light fixture is outfitted with a Lutron Ecosystem ballast that works in conjunction with daylight and occupancy sensors to automatically adjust lighting levels.

The Test Platform uses both passive and active cooling and ventilation systems to ensure thermal comfort, while using energy efficiently. The main features include:

- Operable louvers at the base of the solid wall panels
- High and low operable windows in the glazed panels
- A roof mounted exhaust fan at the highest point of the roof
- Nine ceiling fans
- A split system fan coil and condensing unit
The Test Platform offers three options for cooling and ventilation with different levels of energy intensity.

- **Least energy intense option:** uses passive systems, which is achieved by opening the louvers and both the lower and upper windows, thus creating a stack effect of air movement through the space. This option can be slightly enhanced by using the roof mounted low-energy exhaust fan.

- **Medium energy intense option:** uses the ceiling fans in conjunction with the open louvers and windows. The ceiling fans selected for this project consume approximately half the energy when operating as compared with conventional ceiling fans. In addition, these fans produce greater airflow than other similarly sized fans and are significantly quieter, which improves acoustics.

- **Most energy intense option:** close all louvers and windows and use the mechanical fan coil and condensing unit. The early design simulation models predict that the mechanical system will only be required for a few hours per year at each site due to our careful passive design strategy.

**Field Tests: Ilima Intermediate School and Kawaikini New Century Charter School**

The assembly of the Test Platform at Ilima Intermediate School was completed and ownership transferred from UH to the Department of Education on September 30, 2011. The two test platforms at Kawaikini were completed and transferred March 15, 2013 (Figure 4.5.3).

Table 4.5.3 highlights key logistical metrics, specifically an on-site completion time of 35 work days. The completed scorecard, Table 4.5.3 will serve as benchmarks to evaluate future installations. Similar metrics were not reported for Kawaikini, although Table 4.5.4 compares both fabrication and installation times between the two projects.
<table>
<thead>
<tr>
<th>Logistics</th>
<th>Metric</th>
<th>Result</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Manufacturing time</td>
<td>60</td>
<td>in working days</td>
</tr>
<tr>
<td></td>
<td>Transportation Time</td>
<td>16</td>
<td>in calendar days</td>
</tr>
<tr>
<td></td>
<td>Ease of Transportation</td>
<td>5</td>
<td># of flat racks</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5</td>
<td># of trucks to site</td>
</tr>
<tr>
<td>Installation Time</td>
<td>Platform (unload &amp; pier set)</td>
<td>4</td>
<td>days</td>
</tr>
<tr>
<td></td>
<td>Structure (incl subfloor)</td>
<td>5</td>
<td>days</td>
</tr>
<tr>
<td></td>
<td>Enclosure (roof &amp; Finish)</td>
<td>17</td>
<td>days</td>
</tr>
<tr>
<td></td>
<td>Systems (MEP)</td>
<td>9</td>
<td>days</td>
</tr>
<tr>
<td></td>
<td>Total Time</td>
<td>35</td>
<td>work days</td>
</tr>
<tr>
<td></td>
<td>Ease of Installation</td>
<td>39</td>
<td>Total # of workers</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Approx 17-20</td>
<td>Total “Requests for Information”</td>
</tr>
</tbody>
</table>

Table 4.5.3 Measures of logistics for Ilima Intermediate platform

The few hurdles Frog did encounter at Ilima were primarily due to underestimating the complexity associated with managing the logistics of the multiple parties associated with the test site and the specific requirements associated with the end use of the platform. Specifically, the overall site requirements (especially regarding permitting) and utility connections were not sufficiently vetted which resulted in significant delays to the turnover of the platform. During the process, Frog identified two ways to improve future deployments. Optimizing the packaging and shipping procedures would decrease the number of trucks and containers; and creating a certified installer network would allow us to use 100% locally sourced labor and management. For the installation of the Ilima test site, Frog hired local labor, supplementing the crew with mainland installers (Figures 4.5.4 and 4.5.5).

![Figure 4.5.4 Platform components ready for shipment](image1)

![Figure 4.5.5 Installation of steel frame](image2)

As reported in the Project Frog Phase III Update Report of March, 2011, few logistical hurdles were observed during the installation of the first test platform at Ilima Intermediate School. Similarly, the construction process at the second site, Kawaikini School, went unobstructed by
any major difficulties. A notable challenge during the construction process at the latter site was damage to a shear wall panel caused by the exposure of the panel to the elements during the prolonged period between material delivery and start of installation (due to permitting complications). Although the wall panel had to be rebuilt on-site, the work of the installation crew was minimally obstructed, and this did not result in any delays of the overall schedule. In regards to the wall, roof and curtain wall systems of the Frog v2.2 platform, Project Frog observed significant time savings during on-site installation when contrasted with an actual Frog v2.0 project of similar size (Table 4.5.4).

More specifically, the most considerable time reductions were observed in the roof-ceiling system, where the integration of the roof-ceiling assembly and the elimination of the drop ceiling system and roof deck panels, decreased on-site labor by approximately 17 days for the Ilima test platform compared to a Frog v2.0 building of similar size. In addition, the incorporation of the insulation and the steel stud panel frame reduced field installation time for the component by up to 6 days at Ilima.

Finally, the curtain wall system of the v2.0 platform was completed via traditional construction methods, where the glass procurement and sizing is carried out only after the framing installation is complete. For the two test sites, however, the curtain wall assembly arrived on-site correctly-sized and ready to be attached directly onto the structure, thus, cutting back up to 7 days from the installation schedule for that system at Ilima. Similar time reductions can be observed during the installation of Kawaikini Elementary School.

<table>
<thead>
<tr>
<th>Component</th>
<th>Task</th>
<th>Frog v2.0 Platform** (app. 1,200sf)</th>
<th>Test Platforms</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Kawaikini (2 str. x app. 1,200sf)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>Ilima (app. 1,200sf)</td>
</tr>
<tr>
<td>Wall Panels</td>
<td>Fabrication</td>
<td>60 days</td>
<td>59 days</td>
</tr>
<tr>
<td></td>
<td>Installation*</td>
<td>5 days Erection</td>
<td>8 days Erection</td>
</tr>
<tr>
<td></td>
<td></td>
<td>16 days Finishes</td>
<td>6 days Finishes</td>
</tr>
<tr>
<td>Roof - Ceiling</td>
<td>Fabrication</td>
<td>60 days</td>
<td>30 days</td>
</tr>
<tr>
<td>System</td>
<td></td>
<td></td>
<td>25 days</td>
</tr>
<tr>
<td></td>
<td>Installation</td>
<td>5 days Roof Deck</td>
<td>4 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>15 days Ceiling</td>
<td>3 days</td>
</tr>
<tr>
<td>Curtain Wall</td>
<td>Fabrication</td>
<td>40 days Framing</td>
<td>58 days</td>
</tr>
<tr>
<td>System</td>
<td></td>
<td></td>
<td>52 days</td>
</tr>
<tr>
<td></td>
<td>Installation</td>
<td>2 days Framing</td>
<td>5 days</td>
</tr>
<tr>
<td></td>
<td></td>
<td>9 days Glass Installation</td>
<td>3.5 days</td>
</tr>
</tbody>
</table>

Table 4.5.4 Comparison between the fabrication and installation schedules between Frog v2.0 and v2.2 for structures of comparable size. *Installation assumes a crew of 4
**Schedule presented as extrapolated from an actual Frog v2.0 project
The platform costs were on-budget, and through the experience of developing the initial platform, Project Frog has identified ways to decrease the future manufacturing and shipping costs by 17%-26%. With respect to installation and site costs, Project Frog did not sufficiently anticipate the total requirements and did not allocate enough of the budget to address means of egress to and from the test platform. As a result, they encountered significant cost over-runs associated with designing and building decks and stairs.

One of the objectives of the platforms was to test the ability to self-generate enough energy to offset consumption. Five kilowatt PV systems were installed on each platform mid-2013 under project funding from another HEET09 project, that compares performance of three PV materials (thin film, amorphous silicon, and monocrystalline silicon) and two inverter types (string inverters and micro-inverters) in different combinations. Monitoring of these solar systems commenced in October of 2013. Preliminary data is reported in Tables 4.5.6-4.5.8 of this report.

As discussed earlier, the objective of the field test was to evaluate the performance and applicability of the Frog platform in three different climates. The building model used in this study incorporates design changes that result in greater prefabrication scope, higher performance and quicker deployment, all at an economic advantage over the v2.0 structure (Figure 4.5.6). Among these improvements and the sustained components of the original platform, Project Frog recognized four major areas that provide valuable lessons for prospective building projects in the Pacific Region.
Due to the large impact of the building envelope on indoor quality and occupants’ satisfaction and productivity, one of Frog's primary goals during the design optimization process was the performance enhancement of the platform's wall panels. A frequently encountered problem with the insulation qualities of steel stud wall panels is the thermal bridging effect, which occurs when a material with high thermal conductivity, such as steel, creates heat flow pathways that circumvent thermal insulation. Studies have shown that the thermal performance of steel stud walls can be reduced by up to 55% due to the steel elements that serve as thermal connections. Thermal bridging is primarily a concern in cold climates, however, it leads to design inefficiency due to the additional insulation thickness, and for energy-neutral design purposes it becomes an important factor in climates similar to the environmental conditions of the Pacific Region.
Although the v2.0 wall panels provided a high overall thermal resistance value, the thermal bridging effect caused by the panel studs had to be compensated with a thick layer of insulation, which was applied on-site in the original kit version. In order to enhance the wall panel functionality, in the v2.2 platform Project Frog incorporated the thermally broken K-Tect Wall System. The stud pattern of the K-Tect panels is specifically designed to allow for a continuous cross-sectional layer of insulation in order to avoid thermal and sound pathways between the interior of the building and the outside environment (Figure 4.5.7). The pre-fabricated combination of light gauge structural steel and the expanded polystyrene (EPS) insulation foam provide the cost, time and quality benefits of factory-manufactured materials, while at the same time, the ductility of the metal allow for easy manipulation on-site.

As Phase II of the research program established, the climate zone of the Pacific is generally characterized as tropical, although some climate variations occur due to changes in landscape and trade winds. Such climate conditions dictate the need for high performance glazing, especially when energy neutrality is an objective. Since the Frog test buildings are designed for maximum daylight autonomy at each project location, glazing takes up a significant portion of the building envelope. The v2.2 platform re-evaluated the balance between the solid and glazing wall panels from the perspectives of occupants' satisfaction and energy consumption loss and gain due to the increased daylight amount and the heat conductivity of glass respectively. By incorporating the v2.2 specified glazing type, the overall heat transfer though indirect radiation exposure was reduced by 27% across the window area. While higher heat transfer control is usually achieved at the cost of visible light transmittance (VLT), the current curtain wall system admits 17% more visible light, to a total of 63%, thus, increasing the daylighting potential of the structure without compromising energy efficiency. The resulting design specifies a better performing glazing system with assured quality since the entire glass-framing assembly is prefabricated in a factory. Furthermore, the new system also minimizes field labor, particularly at the clerestory and front spine all window sections which were provided and site-built by the General Contractor in the v2.0 version (Figure 4.5.8).
Another area of major design improvement between the two Frog generations is the roof deck of the structure. The ceiling roof system of the 2.0 platform consisted of a metal deck screwed to light gauge steel roof panels, single-ply roof membrane over rigid insulation, and an acoustical drop ceiling. Albeit the roof components had been performing effectively from a thermal and acoustical standpoint, their cost and required installation time and labor put the assembly at a disadvantage compared to integrated systems. The v2.2 design comprises of an interior acoustical and exterior non-acoustical Epicore roof system with exposed bottom surface (Figure 4.5.9). The integrated assembly eliminates the roof panels and drop ceiling of the v2.0 platform, and results in material, installation and shipment cost and time savings. The light weight of the roof deck - 4.4psf, and the long clear span - up to 20ft for gauge 18, also provide design flexibility for projects of different purposes. An additional benefit is the perforation pattern of the flat ceiling surface which allows direct interaction between the sound waves and the sound absorption elements. This profile enhances the noise reduction coefficient to 95%, or 25% more than the v2.0 drop ceiling system (Figure 4.5.10).

The siding of a building plays a crucial role in the structure's cold shell protection against the elements, as well as its exterior appearance. Using a natural red cedar laminate has been one of two preferred siding materials for Frog's second-generation buildings, and
was held constant in the transition between v2.0 and v2.2. Apart from their appealing aesthetic exterior and environmental advantages of using natural wood, the treated laminate panels also exhibited durability, high quality and low need for maintenance when subjected to laboratory testing conducted by the manufacturer. Taking into consideration the theoretical performance, aesthetics and sustainability of the system, the cladding was found suitable for rain screen application across the Pacific (Figure 4.5.11).

The findings presented in this report are based on field observations during the construction process and site visits of the first two test platforms. The erection of the third test structure was scheduled for late 2010, however, due to material performance and durability concerns under the HAVO climate conditions, and more specifically, the high concentrations of sulphur dioxide in the Park, construction did not take place. Project Frog conducted material testing on a roof deck and two wall panel samples through directly exposing the samples to the local environmental conditions for approximately twelve months.

At the time of the current report, Phase IV of the research program focused on energy generation and performance monitoring has not been executed, and the theoretical performance of the two deployed test platforms has not been confirmed. It is Project Frog's understanding that HNEI will conduct this final stage of the research program under a separate contract. Project Frog carried out a comparative cost analysis of the Frog platforms on a square foot basis, and determined cost reductions across every modified component of the v2.2 kit. The data presented in Table 4.5.5 has been averaged based on the installation and material cost for the first two test sites in order to minimize sampling error. Among the three assemblies studied in this section, the most significant cost savings are achieved in the roof-ceiling system where the integrated roof deck amounts to only 71% of the v2.0 assembly economically. Similarly, the v2.2 wall panels and curtain wall result in 10% and 29% cost reductions respectively.

It is important to note that given the original contract between the company and HNEI was signed close to two years before construction, Frog experienced a significant overrun of initial cost estimates for the company's scope at the time of the two installations. In addition, Project Frog had grossly underestimated the General Contractor's costs inflicted on the company, which in KawaiKini’s case amounted to approximately 150% of initial estimates. As a result, the cost savings related to material optimization of the v2.2 platform helped compensate the company's aforementioned losses.
Frog's project management team responsible for the construction of the two test structures visited site one in January, 2012, and site two in April, 2012 to assess material performance. During the site inspections, the wall, roof and curtain wall assemblies were found to be suitable for both the warm and dry climate of Ilima, as well as the warm and wet climate of Kawaikini. In the latter case, a number of concerns were raised to Project Frog about rusting of the roof deck, as well as of the curtain wall framing, after spots in red color were observed in some regions of both components. Upon investigation, it was confirmed by the company and HNEI that the spots on the roof deck were in fact stains of dirt mistaken for rusting due to the red pigment of the local soil. Similarly, Frog examined what was thought to be rusting on the mullion of the curtain wall system, and found that the rust specs were actually rusted steel shavings which had fallen down during the attachment of the roof deck to the structure. When these shavings were removed from the mullion with a sanding sponge, it was determined that there was no impact of corrosion on the surface of the aluminum.

The exterior wood siding, however, exhibited significant weathering in both climates. Under the low cloud-cover, dry weather conditions of the first test location, the primary problem observed with the wood material was its fast and uneven fading due to the different intensity and duration of sun exposure of the four sides of the building. On the other hand, the warm and wet climate of the second location could potentially cause excessive water absorption, which may lead to delamination in natural wood laminates.

The material performance study Project Frog conducted at HAVO shows satisfactory conditions of the pre-fabricated wall panel samples, although considerable weathering has been observed on components directly open to the elements. The highly acidic nature of sulphur dioxide has accelerated the corrosion of exposed galvanized steel. Similarly, the roof deck also demonstrated extensive deterioration. The two wall panel samples include different types of exterior siding - treated and untreated natural wood laminate, and bio-composite material. As expected, the untreated laminate showed the most severe weathering, while the bio composite, made of post-consumer recycled paper and bamboo fiber, was barely affected. It is important to note, however, than the superior performance of the bio-composite siding comes at a non-trivial cost premium.

HNEI let sub-contracts to MKThink under N00014-11-1-0391 and N00014-12-1-0496 to monitor environmental and performance factors in the Kawaikini and Ilima platforms. While the details of the monitoring studies will not be discussed in this report, they are being referenced as relevant to the conclusions that may be drawn from the ongoing operation and observation of these experimental platforms.
After the first complete year of data collection in 2014, the three platforms performed as designed, achieving one of three bracketed estimates made in the Phase II report: “High Estimate”, “Anticipated Performance”, and “Optimal Performance”. The structure in the hotter Oahu microclimate performed exactly at the “High Estimate” which assumed significant dependence on air conditioning, resulting in an actual electric site EUI of 7.8 kWh/sf-yr. (excluding solar). The two predominantly naturally ventilated structures in the more temperate Kauai location produced twice as much energy than was used, realizing an average electric site EUI of about 4.7 kWh/sf-yr, achieving the “Optimal Performance” target. This difference in performance may be attributable to two factors: differences in micro-climates and difference in policies, awareness and user response to the internal environment.

In addition to evaluating annual energy flows, energy consumption was evaluated in different time frames, including school days only. Below are examples of preliminary tables of performance that will be presented in detail in future reports. Table 4.5.6 presents relative energy and environmental performance. Table 4.5.7 disaggregates energy consumption by end-use. Table 4.5.8 is a preliminary evaluation of energy consumption compared to generation for the most recent data set. The Kawaikini Frogs are net zero, they generate more than they consume. The Ilima platform, during this time frame was slightly net negative, consuming 6.5% more energy than it generated. These numbers will vary year to year depending on climatic conditions.

<table>
<thead>
<tr>
<th></th>
<th>Classroom Type</th>
<th>Total Energy [kWh/ft²]</th>
<th>Environmental Performance Criteria Score*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ilima</td>
<td>Project FROG Modular</td>
<td>5.03</td>
<td>60.7%</td>
</tr>
<tr>
<td>Kawaikini West</td>
<td>Project FROG Modular</td>
<td>2.19</td>
<td>65.0%</td>
</tr>
<tr>
<td>Kawaikini East</td>
<td>Project FROG Modular</td>
<td>2.05</td>
<td>79.0%</td>
</tr>
</tbody>
</table>

*Calculated by aggregating the following 3 percentages: (1) % of time PMV is inside the ASHRAE Comfort Zone, (2) % of time CO₂ concentration is below 1100 ppm, the ASHRAE threshold for ventilation, (3) % of time lights were off while the wall illuminance > 5 ft·cd and wall-ceiling illuminance ratio < 5

**Table 4.5.6 Preliminary energy and environmental performance, school days only**

| TOTAL NORMALIZED ENERGY USE (2013-2014 HIDOE school year, school days only) |
|-------------------------------|-----------------|-----------------|-----------------|
|                               | Ilima           | KW West         | KW East         |
| Total Energy [kWh/ft²]        | 5.03            | 2.19            | 2.05            |
| Mech. Cooling [kWh/ft²]       | 3.74            | 1.21            | 1.07            |
| Fans [kWh/ft²]                | 0.01            | 0.32            | 0.18            |
| Int. Lighting [kWh/ft²]       | 0.50            | 0.27            | 0.11            |
| Ext. Lighting [kWh/ft²]       | 0.32            | 0.49            | 0.44            |
| Plugs [kWh/ft²]               | 0.47            | 0.26            | 0.25            |

**Table 4.5.7 Preliminary energy consumption during school days only**
In its Phase II final report, Project Frog evaluated the time and cost effectiveness and the material performance of four building components as parts of a quickly-deployed, systemized kit tailored to the Pacific Region. The analysis demonstrates that an increase in the prefabricated scope of the wall panels, roof-ceiling assembly and curtain wall system results in material and installation cost reductions, and time savings during construction. These factors, as well as the implied greater ease of transportation and installation and decrease in shipping costs, give such modular assembly systems great advantage over traditional construction for the purposes of mass-deployment in various environments across the Pacific.

Project Frog also found that natural wood siding, in its role as the first line of defense against the elements, may be prone to severe visual deterioration when exposed to tropical climate conditions. Despite that weathering may not pose immediate threat to the performance of the building and the satisfaction of its occupants, such siding material requires frequent maintenance in order to sustain desirable building aesthetics.

Finally, as explained earlier, the purpose of the collaboration between Project Frog and HNEI was to develop and test a kit in various climate conditions representative for the Pacific. While the first and second test platforms performed as expected across two contrasting tropical climates, analysis of the HAVO location found the local environmental conditions to be prohibitive for the construction of a third test structure with similar characteristics. Although Project Frog does not advise against construction in areas with high concentration of volcanic air pollution altogether, it recommends extensive research of the building materials’ susceptibility to deterioration and corrosion due to meteorological factors specific to that region.

The Ilima and Kawaikini structures as commissioned and accepted are shown in Figure 4.5.12.
Crissy Field Center Wind Power Study

Under HEET 2009, HNEI was awarded funding to conduct research including the installation, testing, and evaluation of passive and active energy systems using modular test platforms fabricated by Project FROG, Inc. The test platforms incorporate advanced design elements to decrease user energy demand, thus increasing the effectiveness of integrated renewable energy generation systems. The research intent was to study the integrated performance and effectiveness of the test platforms and energy systems in relevant Pacific region environments for potential future Navy applications.

Under the same ONR award, the energy systems research, testing and evaluation were extended to take advantage of a Project Frog test platform site uniquely suited for wind energy technology research located in San Francisco, California. Under this subtask, HNEI contracted the Golden Gate National Parks Conservancy (Conservancy) to install 5 small (1 kW) wind turbines adjacent to, and connected with, Project FROG test platforms located at the Crissy Field Center (Center) in the Presidio of San Francisco, a proven wind resource for collection of comparative wind energy data.

The Conservancy, the lead organization for operation of the Center, planned, permitted, and installed five wind energy systems including connection with the test platforms. The wind turbines were located proximate to each other to ensure consistency of the wind resource and...
comparability of data. HNEI served as the technical expert for the project including data collection and analyses.

The objective of this research was to evaluate and test selected wind turbine technologies to determine the relative effectiveness of differing designs, the impact of different climatic conditions, and integration with the test platform systems toward the achievement of energy neutrality and/or net positive energy within the test site.

Turbines manufactured by Venco Power, GMBH, Windspire Energy and Tangarie Alternative Energy Power, LLC were selected after a vetting process was conducted of small, vertical axis technology. The Conservancy, with support of Project Frog and HNEI, integrated the wind energy data into a dashboard based, public monitoring system, tracking overall building performance as well as its environmental sub-systems.

The Crissy Field project site is located in the Golden Gate National Recreation Area, federal land managed by the National Park Service. Figure 4.5.13. Vertical helical turbines were selected to meet the requirements of the Center and the National Park Service for bird safety and low visual, noise and vibration impact on staff and visitors. In anticipation of wind turbines, conduit from the proposed site to the Center’s mechanical closet was installed during the Center’s construction.

![Figure 4.5.13 Crissy Field Center site location](image)

Under this project, the Conservancy commissioned a wind study specific to the location of the Center, as close to the estimated hub height of the turbines as possible. Results are represented in Figure 4.5.14. Average annual wind speeds at a height of 20 meters was calculated at 5.1 m/s +/- 1.1 m/s (10.5 miles per hour (mph)).
The Conservancy also acquired average wind speed data from project partners operating in the immediate vicinity of the project site. Four years of data (from 2007 to 2010) were provided from the Anita Rock site, a Coast Guard station located approximately 200 yards offshore near the Center. Data was provided in annual averages and in 5 minute intervals.

The wind turbine array was also subject to visual evaluation by the National Park Service in order to establish that the cultural and historical fabric of the site was not compromised by the project. For complete report detail, please see “Golden Gate National Parks Conservancy Deliverable 1: Recommendations for Wind Turbine Systems and Data Acquisition Systems”.

Design and engineering services were underway from November 2011 through January 2012. The Conservancy contracted with Luminalt Energy Corporation as the prime contractor for the design/build installation of the selected turbine array. The Conservancy provided the layout plan for the wind turbines. Tower Engineering Professionals (TEP) produced the structural analysis and foundation design for the wind turbines. Consolidated Engineering Labs (CEL) was contracted to perform compaction testing, reinforced steel inspection, anchor bolt testing and concrete testing. Amec Engineers provided geotechnical analysis and recommendations for the project footing design. Amec also reviewed the final footing design produced by TEP to ensure conformance with geotechnical requirements. Luminalt Energy Corporation provided electrical design and design-build plans for the project. For complete engineering reports, please see “Golden Gate National Parks Conservancy Deliverable 2: Report on Final Design and Permitting”.

Construction consisting of trenching, footing reinforcement, running of electrical conduit, concrete work, mast and installation of 2 turbines took place January and February of 2012, with a public opening ceremony on February 15, 2012. The remaining three turbines were installed in March and April, 2012 (Figure 4.5.15):

1. “Windspire” 1.2 kW, with integrated inverters (February 2012)
2. “Venco Twister” 1000 with Power One 3.0 kW Inverters (April 2012)
3. “Tangarie Gale” T2 with a Power One 3.6 kW Inverter (March 2012)
The turbines were all operating by April 2012, with each of the five units required varying amounts of diagnostics, field tuning and, in some cases, the replacement of specific components before they became operational. Details for each of the selected technologies follows:

**WINDSPIRE:** Over the first year the Windspire turbines had several issues regarding "wobbling" which began upon operation in February. After several adjustments to the shaft assemblies no pronounced improvement was evident. In March 2012 base and shaft assemblies were replaced, solving the wobble issues. In September 2012, a wobble was again noticed that was attributed to the anchor bolts loosening. Maintenance protocols were put in place to regularly inspect and tighten the anchor bolts with a torque wrench. In December of 2014, the North unit failed catastrophically in high wind and in order to ensure public safety, both units were taken off line. The Windspire turbines are equipped with a braking feature that is set to engage when a certain rpm limit is reached. During the first few months of operation, it was observed that the North and South units did not brake consistently in response to similar wind conditions. The Southern unit tended to brake much more frequently. Subsequently, it was determined that the “over speed” limit was set differently for the two units. The limit on the Southern unit was adjusted from 1,300 watts to 1,700 watts – thereby matching the 1,700 watt limit of the Northern unit.

**VENCO:** The Venco Twister 1000 TL units 1 and 2 were installed and began operating in April of 2012. The units were installed with Power One PVI-3.0 OUTD inverters per the recommendations of Castle Energy, the US distributor of Venco turbines. Although the Venco turbines are typically mated with SMA Windy Boy inverters, the Power One units were selected due to their potential ability to realize increased energy harvests. With the installation complete, the Venco units appeared to be operating properly but the Power One inverters gave readings indicating a ground fault error. Consultation with Venco engineers suggested several possible reasons for the error, including incompatibility between the Vencos and Power One inverters.

The Venco engineers suspected a ground fault in the eddy current brake, and instructed the installer (Luminalt) to disconnect it and take insulation resistance readings. When the current
brake was disconnected the error readings disappeared and the units started functioning properly. The disconnection of the integrated Venco current brake was deemed acceptable because the Power One units had the capacity to perform the braking function through programming of the power curve. With the electrical error solved, the Venco units were fully operational by the end of May, 2012.

Between January and March of 2014, both Venco units stopped rotating. Luminalt was contracted for a maintenance visit at the site for all of the turbines, which was conducted on March 26, 2014. Lubricating grease was added to the Venco bearing assemblies and the units were cracked loose and rotated by hand. Although the units could be manually rotated, they would not rotate on their own in the wind.

Small stress cracks were observed in the blades at some locations where they attach to the struts.

**TANGARIE:** The Tangarie Gale T2 was installed in March of 2012. Despite what appeared to be a correct installation, the Tangarie turbine never turned freely in the wind and appeared to resist rotation. In higher winds, this resistance appeared to translate into the shaking of the entire turbine’s tower. Per the manufacturer and distributor’s directions, various inverter curves were programmed without significant effect. After more than a month of operation, the Tangarie was incapable of consistently generating more than 50 Watts, even in 25 mph winds.

The performance described above persisted for the entire service life of the unit, despite repeated field adjustments made at the direction of the manufacturer.

In July, 2013, the Tangarie was inspected by Luminalt and “severe signs of failure and was removed from the tower” for service or replacement. It was determined that neither was an option, so the unit sat idle without producing energy.

For detailed reports and documentation for each of these units please refer to “Golden Gate National Parks Conservancy Deliverable 5: Wind Turbine Commissioning and Interconnection”.

The Data Acquisition System (DAS) was installed to monitor wind turbine performance as well as building performance of the Center. The components specific to monitoring the wind turbine performance include two sets of wind speed and direction sensors. These were mounted at the center of the row of wind turbines as well as on the roof of the cafe, along with power monitoring sensors mounted on each wind turbine power circuit. Hardware components of the system are indicated in the as-built system diagrams, see reference 6.

For wind speed and direction at the center turbine, the sensors are connected to a microcontroller. This microcontroller was powered through low voltage power cables from the building and communicates via ZigBee radio transmission to a receiver located near the cafe weather station. The microcontroller located at the wind instrument holds 60 1-second interval measurements in memory. When prompted by a serial call, the microcontroller calculates minimum, maximum, mean, and standard deviation of the two datasets, and returns these summary statistics via serial connection. A vector average is used for the mean of the wind direction. Data are logged in flash memory at the controller.
For power, each wind turbine circuit is monitored using current transformers and reference voltage that are wired to an electrical monitoring device to calculate power use. The controller logs these readings in its flash memory.

Data accumulated in flash memory is retrieved approximately monthly via manual File Transfer Protocol (FTP) request. Both the original data file and the consolidated ("pivoted") data file are uploaded to a web server for distribution.

The DAS for the building operates on a 10-minute interval and also reports power data for each individual turbine. These data are collected and processed automatically and are ultimately visualized using a custom dashboard interface that shows data in real time (see Appendix B, Dashboard Screenshots). This visual representation of the data has been helpful for assessing whole building performance and to identify issues with wind turbine performance. Several times during the project, the dashboard helped alert the team to issues with wind turbines.

Several issues arose in the commissioning and ongoing operation of the DAS. These include the following issues:

- Wind speed readings tended to be less than expected. Replacement of an anemometer unit at the rooftop of the café helped identify a likely issue with anemometer calibration for each original anemometer. Using a statistical analysis of anemometer readings before and after the replacement of this anemometer, we identified a correction factor that could be applied to the anemometer at the wind turbines to correct the calibration (see Appendix C, Anemometer Correction Factor memo). Even after the correction, the wind speed readings still tended to be lower than what was expected from a previously completed site survey.

- Wind turbines and inverters were expected to be producers of electricity, not consumers. The Tangarie turbine unit appeared to be producing a constant output of 20W. However, an analysis of Tangarie output revealed that this 20W was most likely 20W of electrical use on the Tangarie circuit (see Appendix D, Power Production of North Windspire and Tangarie Turbines, November 1–17, 2012). It is unclear whether the source of this 20W load was the inverter or another load on the same circuit.

HNEI was able to receive the data collected from the DAQ system. An analysis was completed of this data, during which process they collected notes on lessons learned. In particular, issues were identified as attempts were made to extract performance curves from the wind and wind turbine data. The primary issue was that the power use and wind data didn’t show a strong relationship at the level of the most detailed data collected due to the timing and nature of the readings. Instantaneous power readings and 1-minute averaged wind data demonstrated wind turbine performance over time, but the analysis team found they wanted more detailed data that showed performance at a 1-second sample interval. Other issues were identified as well, and include gaps in the data and a bug in data processing software that omits or duplicates a line of data at the edges of monthly datasets.
Recommendations for the next phase of the project to address issues identified in the first phase include:

- **Data Acquisition (DAQ)**
  - Record wind and energy data in synchronized 1 Hz intervals.
  - With 1 Hz data for wind and turbine output, we would not require additional pre-processing (min, max, ave, std dev)
  - Synchronize time stamps across all sensors in DAQ system.
  - Localize anemometers to each turbine, 1 anemometer per turbine
  - Identify sources of false signals (e.g., 10-20W signal from non-performing Tangarie)

- **Data Processing**
  - Troubleshoot sources of missing data
    - E.g., Network, internet, archiving, instrumentation, communication, inverter, connection, logging, etc.
  - Request direct access to raw data
  - Make data format consistent across sub reports (monthly)
  - Eliminate redundant reporting across sub reports (monthly); double reporting of same timestamps on different reports causes data reconciliation issues.

For detailed report and DAQ system drawings please see “Golden Gate National Parks Conservancy, Deliverable 6: Installation and Commissioning of the Data Acquisition System”6.
The five turbines were installed and commissioned by July of 2012. Simultaneous wind speed and turbine output was recorded from October 5, 2012 forward. Figure 4.5.16 illustrates power generated over the project life of each turbine. The two Windspires (T14 and T18) generated energy continuously from project beginning through Dec 31, 2014. The Venco turbines operated up to July 31, 2014, when the turbines experienced a mechanical failure. Bearing seizures were responsible for lack of production for several months in 2014. They were repaired but failed and were taken offline July 30, 2014. The Tangarie turbine experienced blade failure late June 2013 and was decommissioned shortly thereafter.

With 816 days of minute-level data, actual performance was compared to expected performance for both wind resource and turbine generation. Table 4.5.9 presents key findings from the data.

**Figure 4.5.16 Daily average power output over turbine life (Watts)**

With 816 days of minute-level data, actual performance was compared to expected performance for both wind resource and turbine generation. Table 4.5.9 presents key findings from the data.
Finding 1: Both Windspire turbines operated from October 6, 2012 through December 31, 2014, or 816 days. The Venco 1 and 2 turbines had intermittent operating issues described in other sections of this report operating for a total of 556 and 514 days respectively. The Tangarie turbine operated for only 268 days, having failed by June 30, 2013.

Finding 2: The observed average wind speed was lower than predicted from the wind study commissioned by the Parks Conservancy. The predicted average wind speed was 5.1 m/s (11.4 mph) using the data from the Anita Rock wind site. The observed average wind speed was 3.6 m/s, 70% of the projected wind speed.

Finding 3: From an observed wind velocity profile created on a minute to minute basis, the projected turbine outputs were forecasted based on the manufacturers power curves. For the Windspire turbines, the total actual generated energy was nearly twice as high as would have been forecast at the observed wind regime. The Windspire 1 and 2 generated 204% and 180% respectively, of the energy expected at observed wind regime. The Venco 1 and 2 turbines generated 70% and 52% of the expected energy, respectively, during actual periods of operation. The energy expected from the Tangarie could not be determined since there was no manufacturer’s power curve available.

Finding 4: While Finding 3 was a comparison of actual energy to the power curve, Finding 4 highlights the capacity factor at rated conditions. The Windspire rated capacity is 1200 Watts at a wind speed of 10.7 m/s. The Venco rated capacity is 1000 Watts at wind speed of 12.0 m/s. The Tangarie capacity is rated at 2000 W with no wind speed specification.

The Capacity Factor is the observed amount of energy produced relative to the amount that would have been generated if the turbine ran at rated capacity over the specified duration. For this analysis, the duration is the 816 days of measured data from October 5, 2012 through December 31, 2014.

The Windspire capacity factors were 5.09% and 4.50%. The Venco capacity factors were 1.43% and 0.99%. The Tangarie capacity factor could not be determined due to lack of manufacturer data.

There is no robust relationship between average wind speed and the power output of any of the Vertical Axis Wind Turbines (VAWT) at Crissy field on a minute-to-minute basis, as can be seen readily by examining the scatterplots in Figures 4.5.17 and 4.5.18 below.
Figure 4.5.17  Power plotted against wind indicating weak relationship

The poor relationship in the data set between wind speed and power output seems to be due to the fact that the wind turbines are sampled instantaneously every 60 seconds, whereas the wind data is an average over 60 seconds. As the output from the VAWTs varies significantly within a one minute time period, the instantaneous “snapshots” recorded every 60 seconds are not representative of the power output over the rest of the period. This idea is supported by the fact that there is significantly less scatter in the relationship between wind speed and VAWT output if one only considers “steady wind”, defined as the average of wind speed per minute, at a standard deviation of wind speed over one minute of less than 1 mph, Figure 4.5.18 below.
Effectively, the 60 second snapshots are a random sampling of the underlying probability distribution of turbine power output. In order for these random samples to be representative of the real output from the turbines, they must be averaged over a long period of time. A straightforward way to accomplish this is to examine wind speed daily averages, as can be seen in the plots in Figure 4.5.19 below, the daily averages of wind speed and power output for the various VAWTs for the year 2013. Note that we have excluded the Tangarie VAWT from the remainder of the analysis due to the short period it was operational.

In Figure 4.5.19 the relationship between wind speed and VAWT power output are much more robust on a day to day basis. However, the daily average of the wind speed rarely exceeds 8 mph, which allows for examining only the lower end of the power curves. A daily average wind profile over a 12 month period (2013) shows in Figure 4.5.20 that at Crissy Field the wind peaks in the afternoon, so we repeat the analysis using only data from between 12 – 9 pm, as shown in Figure 4.5.21.
Better representing actual short term turbine performance, the resulting afternoon averages show a similar relationship between wind speed and power output for the Windspire and Venco VAWTs at lower wind speeds, while revealing more of the relationship at higher wind speeds. Overall, it is apparent that the Windspire turbines outperform Venco turbines by a large margin. This is true both for total power output and power output relative to the rated power. The plot below in Figure 4.5.22 shows the actual afternoon averages of VAWT power output versus what would be expected given the published power curves for the respective VAWTs. Simple linear estimates of the actual versus expected power output indicate that the Windspire turbines perform at approximately 45% of their rated value at Crissy field, while the Venco turbines perform and approximately 27%.

The annual average wind speed measured at the Center is shown in Figure 4.5.23, showing observed annual averages ranging from 3.73 to 3.98 m/s for the two years with complete data. Data for 2012 was only available from October 5-December 31. By comparison, the 4 year average at Anita Rock is 4.28 m/s, with gusts to 5.25 m/s.
The histogram in Figure 4.5.2.12 illustrates the counts of one minute periods of averaged measured wind speed, in binned increments of 0.5 m/s. Much of the observed wind is less than 8.0 m/s, with the velocity ranging from 1.0 to 5.0 m/s and a mean of 3.59 m/s.

A pronounced seasonality exists with the Crissy Field wind regime, Figure 4.5.2.13, with the fall/winter average approximately 66% of the average spring/summer wind speed.

Figure 4.5.23 Average annual wind speed measured at Crissy Field. Data for 2012 was only available from October 5-December 31.

Figure 4.5.24 Histogram of Count of Average Wind Speed (one minute averages)

Figure 4.5.25 Monthly variation of wind speed (in average wind speed (m/s) from November 2012 to January 2015)
Wind is predominantly WSW, with a secondary north component as illustrated in the wind rose, Figure 4.5.26. Figure 4.5.27 adds a time dimension by indicating percent of total wind hours for each 45 degree segment.

From a request by the Conservancy, the weather tracking firm, WeatherFlow, provided 2 years of 2012-2104 data collected from Anita Rock as indicated in Figure 4.5.28. Visual inspection shows prevailing direction of approx. 240 degrees.

The wind data collected on site, and at Anita Rock conflicts with the initial wind rose provided to the Conservancy in 2010, suggesting further investigation to determine which data source accounted properly for the magnetic declination for this region. A misapplication of the
magnetic declination correction factor can make from 15 to 30 degree difference in reported wind direction in 2011 third party wind prospecting study, Figure 4.5.29.

![Wind Rose From Crissy Field Wind Prospecting Study, 2011](image)

References:
5. Golden Gate National Park Conservancy, Deliverable 5: Wind Turbine Commissioning and Interconnection. September 2015