To prepare electrical apprentices for working in the sustainable building industry in Northern California, the Zero Net Energy Center is a working example of an emerging phenomenon. The International Brotherhood of Electrical Workers Local Union 595 (IBEW) and the Northern California Chapter, National Electrical Contractors Association (NECA) created a world-class learning environment for apprentices to gain hands-on experience with cutting-edge technology and electrical systems. The ZNEC also addresses the need to repurpose the existing building stock in the U.S. by transforming a typical 1980s suburban office building into a modern net zero energy showcase.
The Zero Net Energy Center (ZNE Center) exceeded its energy goal its first year of operation, producing an excess of 69,071 kWh over modeled calculations, and realizing a net savings of more than $15,000 in energy bills. It produced 20.83 kBtu/ft² of energy in its first year, and consumed 15.32 kBtu/ft², for a net energy use intensity (EUI) of –5.49 kBtu/ft² (Figure 1).

The ZNE Center proves that retrofitting a decades-old commercial building can result in net zero energy performance with the same budget most projects use to achieve code compliance. And, it earned a dollar-for-dollar appraisal on its high performance building improvements.

**Integrative Design**

Integrative design proved to be the key strategy in achieving budget goals and the net zero energy goal. And, it allowed the required time and feedback needed to refine and tune optimal systems-based solutions. For example, a “saw-tooth” roof upgrade to improve daylight distribution into the deep floor plate met early resistance and was nearly abandoned. Eventually, the idea developed through the integrated process and resulted in one of the most significant project elements to save money, increase energy efficiency, and improve indoor environmental quality. In addition, the roof provides a signature aesthetic feature.
The ZNE Center team engaged in multiple design charrettes, considering natural resources, occupancy-specific energy design, project timeline and budget. Through analyzing the energy and construction cost impacts of many sustainability scenarios, the team gained comprehensive insight into which combination of passive/active designs and technologies would meet building performance, use type, and budgetary goals.

For instance, an analysis of typical meteorological year (TMY) data prior to design showed that the local outdoor air temperature would meet the cooling load during more than 70% of occupied hours, while also optimizing indoor air quality and comfort. In addition, during more than 30% of occupied hours, wind pressure would provide free cooling ventilation to reduce fan energy consumption.

Using the natural climate, the ZNE Center would only need to install an exterior insulation finishing system (EIFS) on the southeast façade. The ensuing HVAC selection and design were also tailored around natural ventilation and passive cooling.

An essential element of the design process was input from the general contractor, who provided early phase cost and buildability guidance. First, the builder presented a rough order of magnitude (+40%) pricing for the full project based on a code minimum scope of work. This became the cost baseline against which alternate solutions could be compared, and was used to tailor design direction for the project’s budget and performance goals.

By integrating subconsultants such as the lighting designer, mechanical engineer, structural engineer, and renewables designer early in the programming stages, the ZNE Center team identified synergistic design and construction strategies. Early integration of the builder and design consultants added slight upfront soft costs and schedule impacts.

However, these upfront costs were more than recouped through the schedule and costs savings during construction. Deep, iterative energy and financial analysis resulted in
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installing inherently simple building systems such as the roof monitors and tubular daylighting devices with solid payback periods.

**Existing Structure**

At project conceptualization the team assumed they would have to perform a roof seismic retrofit to meet code requirements for this earthquake-prone region, replace existing single-glazed windows with a dual-glazed system and install both roof and new carport-mounted solar panels to meet net zero energy standards. Fortunately, the owners built extra time into the early design phase to understand and develop optimized systems-based solutions.

As a result, the cost for the seismic retrofit became a shared cost with the building’s performance upgrades. Second, energy modeling revealed that single-glazed windows provided the ideal envelope performance solution for this building massing, climate, occupant schedule and density, saving significant replacement costs and construction time. Finally, the optimized building design reduced energy demand so significantly that PV would only be required on the roof, eliminating the costs of below-grade electrical distribution and carport structures.

**Net Zero Design**

While many active and passive systems contributed to the performance of the ZNE Center, the effective integration of systems enabled the 75% energy-use reduction (compared to similar buildings from the energy.gov Building Performance Database). Integrating HVAC, lighting and plug load solutions with envelope and renewable energy systems resulted in drastic energy cuts and savings. Ongoing commissioning is verifying the optimal functionality of each system.

**HVAC**

HVAC system selection depended on its ability to optimally integrate with the project’s need to provide heating and cooling and desire to use mixed-mode ventilation, and the building’s existing conditions, which included its wide, single-story plan and suboptimal orientation for passive conditioning.

The team selected a two pipe variable refrigerant flow (VRF) condensing unit/fan coil system (See VRF System and Figure 2). The VRF system performs better and cost $1 million less than a traditional code baseline forced-air HVAC system. Additionally, the VRF system eliminated the need for roof mounted units, which would have increased the roof retrofit cost and reduced the area available for PV.

The ZNE Center uses an active and passive mixed-mode ventilation system design and sequence of operations. The active mechanical system uses 100% outside air direct ducted supply to every fan coil zone for fan powered free cooling.

The passive strategy of direct wind space conditioning places natural...
Positive and negative air pressure natural ventilation opening modulation is also used to control ventilation air speed and volume as wind and occupancy conditions change. This design further reduces ventilation fan power and cooling demand.

The building BMS controls the interface between these active and passive systems, preventing condensing unit powered cooling from operating at the same time passive ventilation openings in relationship to building adjacent outside air pressure differentials resulting from wind direction and building mass. This strategy increases and directs natural ventilation airflow for enhanced occupant breathing zone ventilation. It also reduces the perceived air temperature and distributes cool outside air during the dominant cooling demand conditions.

**VRF HVAC System**

The two-pipe variable refrigerant flow (VRF) condensing unit/fan-coil HVAC system uses R-410A refrigerant as the cooling and heating medium. Liquid refrigerant is distributed to fan coil units in spaces that require cooling, where warmer ambient air is removed, transforming the liquid refrigerant into a hot gas.

This hot gas refrigerant is then directed to spaces in the building that require heat by way of intelligent manifolds that monitor fan coil zone demands and signal the VRF to transfer excess heat/cooling to areas of the building where it’s needed prior to powering up the condensing unit motors. The VRF system is also part of the domestic hot water (DHW) heating system as hot gas refrigerant is diverted to a secondary heat exchanger in the service equipment yard that supplements the glycol solar thermal DHW heating system (the primary source of heat for domestic hot water).

The HVAC system includes condensing units zoned specifically with fan coil sub-zones having simultaneous opposite thermal demand to optimize thermal swapping effectiveness (VRF diversity). The fan coils have individual outside air inlets, minimizing duct work cost and maximizing the zonal based ability to incorporate natural outside air temperatures and ventilation to meet specific zone needs.

**Building Envelope**

- **Roof**
  - Type: Thermoplastic polyolefin (TPO) membrane over plywood deck
  - Overall R-value: R-19
  - Reflectivity: 0.55

- **Walls**
  - Type: Existing Wall Assembly
    - Single glazed aluminum storefront transparent glazing.
  - Type: New N/S Wall Assembly
    - All new walls are dual glazed low-e aluminum storefront with tint to match existing.
  - Type: New Clerestory Wall Assembly
    - All 2×6 wood stud R-19 cavity insulated
  - Overall R-value:
    - New N/S Wall: R-14
    - New Clerestory Wall: R-19
    - Existing Wall: Not insulated except for an east-facing wall that was insulated with an exterior insulating finish system
  - Vertical Glazing Area: 29%

- **Windows**
  - Effective U-factor for Assembly
    - Fixed Monitor Window: 0.32
    - Operable Monitor Window: 0.42
  - Solar Heat Gain Coefficient (SHGC)
    - Fixed Monitor Window: 0.41
    - Operable Monitor Window: 0.32
  - Visual Transmittance
    - Fixed Monitor Window: 0.5
    - Operable Monitor Window: 0.5

- **Location**
  - Latitude: 37.69°N
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cooling is occurring. In addition, the passive ventilation system is only used incrementally with a low percentage of natural ventilation openings when zones are in heating mode, and also only when the outdoor air temperature is no greater than 5°F below heating setpoint.

BMS programming includes shoulder season night-flush precooling to increase use of free, healthy air resources. In addition, raceways are installed in walls and floors for future excess thermal mass in the form of water barrels, with a double use as structural supports for classroom desktop surfaces, have very small thermal lag due to the water’s ability to circulate within its container and quickly capture “coolth.”

These rooms—tempered by feedback from mass temperature sensors in the concrete floor and water barrels—keep the spaces from reaching dew point while increasing their “coolth” storage for use in other zones. By embedding concepts like these into the project, the design team continues to work in partnership with the operations team to optimize building performance.

Lighting. The greatest energy reduction design solution at the ZNE Center is lighting. The combination of daylighting, lighting controls, high efficacy dimmable fixtures and optimized task lighting results in 50% better lighting energy performance than similar existing buildings.

Light tubes collect daylight and provide natural light to interior spaces. Of all of the project’s energy-reducing designs, lighting strategies— involving daylighting, lighting controls and efficient artificial lighting— provide the greatest energy savings.
high white ceilings and walls minimize contrast glare and support daylight distribution. Any additional lighting needs are met via a combination of dimmable T-8 fluorescent up/down linear pendants and LED industrial area lamps.

Through detailed tuning, classrooms for reading technical documents or performing detailed handwork have 50 to 75 footcandle levels at the work height, while lecture rooms have mid-range settings. The computer lab has low lighting levels of 20 footcandles.

The abundance of natural light and ventilation integrated with the building’s electrical and mechanical systems differentiates the ZNE Center from the previous training facility. Students, employees, and guests of the ZNE Center comment on feeling more aware, energized and engaged in the building.

**Plug Loads.** Having reduced HVAC and lighting loads, plug loads rose to nearly 50% of the remaining load.

### LESSONS LEARNED

| **Assemble a Broad Design/Construction Team Early.** |
| **Perform Rigorous Site Analyses.** These improve understanding of the existing building, region and climate as precursors to the schematic design process. Developing a conceptual program that includes this analysis as well as “blue sky” sustainability goals will help a project get started on the right foot with available resources at hand. This project’s location near the San Francisco Bay with quality wind access and favorable outdoor air temperatures during occupancy periods influenced the project’s focus on natural ventilation and free cooling, which in turn drove roof penetration frequency and geometry, side window operability renovation and HVAC system selection and design. |
| **Secure Early Design Phase Building Valuation.** The ZNE Center received a dollar-for-dollar appraisal valuation on its high performance building designs, significantly improving its financing options. |
| **Engage With the Utility Company During Project Programming or Early Schematic Design Phase.** For the ZNE Center, submitting a utility incentive application and inviting program representatives to early design charrettes enabled timely net metering equipment upgrades and owner agreements. The utility financial incentive included $81,000 for the owner and $25,000 for the design team. |
| **Build a Strong Working Relationship With the Local Jurisdiction.** Doing so will ease the process of gaining entitlements and building permits. Establishing a relationship with the City of San Leandro also enabled a common vision and benefit for the ZNE Center to serve as a community focal point for education and economic vitality. |

| **Integrate Performance With Design.** Balancing sustainable aspects with aesthetics is important to create a functional and inviting space. In the case of the ZNE Center, the strength of the design solution depended on the designer’s ability to expose passive, structural and renewable energy systems as integral with the architecture. This includes allowing the existing roof structural system framing members to be exposed to view from below, while placing light reflecting insulation batts in the cavities between. This was the preferred solution over an insulated drop ceiling that would have reduced daylighting effectiveness and eliminated the opportunity for occupant exposure to the building’s structural system. The result is a highly conducive learning environment with strong architectural statements like the wind turbines that help tell the building’s story. |

| **Proper Motion Sensor Application.** The commissioning process revealed that standard dual mode motion sensors used to determine occupancy for the lighting and HVAC zone activation system were being activated by the operable windows and janitorial staff during unoccupied hours. Installing a newer passive infrared motion sensor that operates without requiring ultrasonic technology eliminated erroneous lighting system activation. Additionally, requiring manual activation of the HVAC fan control on the thermostat resolved the potential for HVAC energy waste and added fan coil runtime. |

| **Operable Window Management.** The natural ventilation provided by the operable windows is a significant benefit to providing an optimal learning environment in addition to managing energy use. The original control design of the windows allowed for an incremental stepped control process for opening and closing windows. This would allow for very accurate zone temperature control. Once implemented, it became apparent that the motor noise generated from the sturdy widow actuators during the short yet frequent movements would potentially detract from the learning process. This was resolved by increasing the delay time between window movement commands without impacting zone comfort or energy use. |

| **Wind Turbines.** Although selected for emerging technology training purposes rather than energy output potential, the turbines generated less than expected during design wind days. Further review indicated that the roof monitors were affecting wind flow to the turbines. A potential solution was to raise the installed height, which would require a special clearance from the city. Review showed that special attention must be paid on future projects to potential wind effect caused by building design. |

| **Integration Consultant.** Toward the later phases of the building and systems design, it became apparent that an integration consultant was needed to integrate stand-alone systems, such as lighting, HVAC and renewables. |

**Proper Monitoring and Alarming of All Systems.** To keep on top of the performance of the individual HVAC, lighting, submetering, renewable power and operable window systems, it is imperative that all components of these system are integrated into a higher tier monitor and control system. This system is responsible for dashboards presentations, managing integrated system rule sets as well as monitoring the status of the integrated systems. Being notified through email or text that a component from one of the integrated systems is performing inadequately is essential to optimal building operation and energy management. |
Energy modeling showed that replacing existing desktop computers with low energy mini-towers and laptops would reduce computer energy use by nearly 90%. A life-cycle cost analysis calculated a return on investment of less than 12 months, making this change an easy decision over increasing the size of the solar PV array to meet the excess load.

**Roof Monitors.** The ZNE Center’s roof monitors serve multiple purposes in the building’s energy conservation strategies. Designing the monitors required input from the energy model, airflow model, daylighting simulation, cost analysis and structural consideration.

After optimizing the size and geometry of a single roof monitor for daylight quantity, glare avoidance and internal daylight distribution, the team discovered that the series of monitors bounce added daylight into the adjacent monitor, allowing for a reduced glazing aperture and associated materials cost.

Additionally, small adjustments to the monitor rooftop/ceiling angles served the needs of optimized photovoltaic (PV) panel mounting angle with minimal daylight reduction. This eliminated the need for PV racking by mounting the panels directly to an off-the-shelf standing seam metal roofing system.

**FIGURE 3 ZERO NET ENERGY CENTER ROOF MONITORS**

**TYPICAL MONITOR SECTION**

1. **Natural Daylight/Glare Reduction:** Roof monitors distribute sunlight evenly throughout a room.

2. **Natural Ventilation/Passive Cooling:** Raised monitor geometry creates stack-effect ventilation and exhaust to help remove stale, warm air.

3. **Passive Heating:** Paired with the break room thermal mass wall, the single south-facing monitor passively captures heat to offset the building’s seasonal heating load.

4. **Mounting Surface for Solar Panels:** Angled roofing matches the optimal sun exposure angle for solar panels directly mounted to the standing seam assembly.


Figure 3 shows the multiple functions of the building’s roof monitors, including natural daylight/glare reduction, natural ventilation/passive cooling and passive heating, in addition to serving as mounting surfaces for solar panels.

Renewable Energy. To meet the remaining energy needs, the ZNE Center selected three types of on-site renewable energy technologies: three 4 kW dc wind turbines, one 11.3 kW dc Solar Tree entry canopy, and 154.8 kW dc roof-mounted photovoltaics (mono- and polycrystalline arrays). The technologies boast 178.1 kW dc and were estimated to generate 251,607 kWh per year (first year actual production was 274,582 kWh). With a 6% buffer built into the renewables sizing equation, and an exceptional year for ambient outdoor temperatures and solar availability, the combined renewable systems produced an excess of 69,071 kWh over the energy model in the first operational year.

These on-site renewable technologies were selected because apprentices could be trained on multiple live system types, and for their aesthetic statement. They have performed within 2% of designed values.

Water. The ZNE Center has lowered its indoor water use by 30% below code via finely tuned motion sensors atop efficient plumbing fixtures. Given the sensitive drought conditions in California, outdoor water used for landscaping is monitored closely and adjusted regularly. The ZNE Center has lowered its outdoor water use by 50% below code and plans to install soil moisture sensors for further conservation.

Ongoing Performance

With a modeled annual site energy use intensity (EUI) of 17.9 kBtu/ft² and an actual EUI of 15.3 kBtu/ft², the project consumes less energy than it produces, meeting its net zero energy goal. The successful integration of all the ZNE Center systems hinges upon the building automation system (BAS), which gathers data and controls and integrates otherwise non-integrated systems.

For instance, the VRF fan coils are controlled in concert with the operable windows, outdoor air temperature sensors and rain sensors to optimize their mixed-mode sequence of operations. Building tuning individually optimizes the incremental open areas of supply and exhaust vents based on wind speed and direction.

Impact

Since opening, the ZNE Center has attracted thousands of new students, admirers and guests from all over the world, reaching far beyond its energy and academic communities. The ZNE Center is an example of what can be done to improve new and existing building stock, while significantly increasing the success and satisfaction of the communities they serve.

ABOUT THE AUTHORS

Michael Hummel is a licensed architect, LEED AP+ and senior sustainability consultant with Environmental Building Strategies, based in San Francisco.

Galen Grant, AIA, is principal of FCGA Architects based in Danville, Calif.

Byron Benton is the training director for IBEW-NECA Local 595 and served as the owner’s representative for the project.

Kim Kuettel Desmond is a sustainability project manager with Environmental Building Strategies in San Francisco.