Commercially Viable Net Zero Office Building

The Sustainable Energy Fund
LEARNING OBJECTIVES

1. Understand how using systems thinking helps successfully identify qualitative project goals, centering around the context of the site and the user’s culture.

2. Explain how Net Zero Energy design and sustainability goals drove the selection of an air-source VRF system and various envelope components.

3. Analyze the role of energy modeling in the design, construction and operation of a Net Zero Energy Building. Develop an understanding of available energy modeling tools.

4. Understand the relationship between building cost and the cost of energy in creating an approach to cost-effective net zero design.
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THE SUSTAINABLE ENERGY FUND

Our mission is to promote, research, and invest in clean and renewable energy technologies, energy conservation, energy efficiency and sustainable energy enterprises that provide opportunities and benefits for PPL Electric ratepayers in Pennsylvania.

Non-Profit organization expands sustainable energy in PA through:

• Financing
• Legal Advocacy
• Public Education
• Demonstrate Commercial Viability / Prototype
• Display Conservation / Efficiency / Renewable Technologies
• Offer Healthy Motivating Work Environment
• Attract Targeted Tenants
Intro to Design Process

How we start a project?
Sustainability Framework
Defining Priorities is the key to project success
Sustainability Framework – The Living Building Challenge

What Does Good Look Like?

- **Compliance**: Business as Usual, Minimum Compliance
- **Efficiency**: ‘Doing Things Better’, Minimise Footprints
- **Net Positive**: ‘Doing Better Things’, Maximise Handprints
- **Regeneration**: Transformation, Co-Evolution
Petals Framework

LBC is used as a discussion framework for holistic sustainability.
Sustainability & Resources

- Water
- Materials
- Light
- Land
- Ecology
- Beauty
Understanding the Project Needs
“HOW BIG IS HERE?”
Topographical Map 2013
Site History

1938 1962

1981 2005
SEF Site Walkable Area
Solar Access & Resources
Essence
*Identify the essence of place*

4-Whats
*Who we are and where we’re going*
Understanding the SEF – Purpose Statement

“We will build a net zero energy building in a way that is unique, financially responsible and environmentally friendly so that it educates the community, demonstrates that net zero is economically feasible and sets a sustainable example for the region.”

• Commercially-viable Net-Zero
• Demonstrate New Technology
• Push the Market
Aesthetic Boards
Apple Tree Concept
Solar Roof Shape

- Passive House Roof Detail
- East/West Window Views (Vertical Shading Strategy)
- Solar Collection
- Southern Window Views/Solar Gains Overhang for Shading (South Facing Window)
- Passive House Wall System (Thick Insulation, Air Tightness)
- Light Shelf
- Continuous Insulation/Thermal Bridge Free
- Continuous Air Tightness Layer
- Open Ceiling Reveals Structure & Mechanical
- Increased Surface Area is Intentional
- Intentional Lighting from Clerestory (Even North Sunlight)
- Intentional Lighting/Views to North (Even North Sunlight)
- Passive House Foundation Detail (Insulation Underslab)
Apple Tree Concept
SEF Floor Plan
# Building Systems: Mechanical

<table>
<thead>
<tr>
<th>System</th>
<th>Pros</th>
<th>Cons</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Packaged Rooftop with VAV Boxes</td>
<td>- Very affordable</td>
<td>- Uses more energy</td>
<td>Excluded</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- Not as easy to zone (small tenants)</td>
<td></td>
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<tr>
<td></td>
<td></td>
<td>- All in one system</td>
<td></td>
</tr>
<tr>
<td>Mini Split System with ERVs</td>
<td>- Flexible and scalable</td>
<td>- Potential for lots of outdoor units</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Separates heat/cool from ventilation</td>
<td>- Not as energy efficient</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Saves some energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Affordable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>VRF System with Fan Coil Units and ERVs</td>
<td>- Flexible and scalable</td>
<td>- Not as affordable as Mini-Split System</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Separates heat/cool from ventilation</td>
<td>- Maintenance may be more difficult</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Saves more energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Geothermal Heat Pump System with ERVs</td>
<td>- Flexible and scalable</td>
<td>- Most expensive</td>
<td>Excluded</td>
</tr>
<tr>
<td></td>
<td>- Easy to maintain</td>
<td>- Payback not as good as other systems</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Separates heat/cool from ventilation</td>
<td>- Disruptive to install</td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Saves energy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>- Can make hot water too</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
**Building Systems: Mechanical**

<table>
<thead>
<tr>
<th>Wall-Mounted</th>
<th>Floor-Mounted</th>
<th>1-Way Ceiling Suspended</th>
</tr>
</thead>
<tbody>
<tr>
<td>6 MBH – 30 MBH nominal cooling</td>
<td>6 MBH – 24 MBH nominal cooling</td>
<td>15 MBH – 36 MBH nominal cooling</td>
</tr>
<tr>
<td>1-Way Ceiling Cassette</td>
<td>4-Way Ceiling Cassette</td>
<td>Concealed Horizontal Ducted</td>
</tr>
<tr>
<td>6 MBH – 15 MBH nominal cooling</td>
<td>8 MBH – 48 MBH nominal cooling</td>
<td>6 MBH – 96 MBH nominal cooling</td>
</tr>
</tbody>
</table>

**Outdoor Unit**

**ERV (ventilation)**

**Various Indoor Units**
Building Systems: Electrical & Lighting

- Advanced Metering and Dashboards
- LED Lighting Just Enough Light Controls
- Working with Occupants Plug Loads
- PV Panels on sloped roof
**Building Systems: Plumbing**

**WATER-SAVING FAUCETS**

Our water-saving faucets feature the quality, design and performance you expect from Kohler. So you can have a great-looking bathroom and kitchen, while also feeling great about conserving water.

*The Purist® single-handle bathroom faucet features a modern, minimalist style and uses at least 30 percent less water than standard 2.2 gpm faucets.*

- **Low Flow Fixtures**
- **Centralized Efficient Hot Water Heating**
- **Drinking Fountains Not Water Coolers**
What are the challenges and opportunities?
1. Net zero-energy building

2. Zero net site energy use

3. Net Zero Source Energy Building

4. Grid Tied Net Zero

5. Storage Net Zero

6. Off Grid Net Zero
“One hundred percent of the buildings energy needs on a net annual basis must be supplied by on-site renewable energy. No combustion is allowed.”
Generating an Energy Budget

**Energy Used < Energy Made**

### How Much Energy Will We Use?
- Building Envelope, Systems, and equipment options may result in less energy but may cost more
- Need to determine energy savings vs first cost total

### How Much Energy Can We Make?
- Space for PV panels may be a limiting factor. Sometimes energy generation sets the limit for how much energy the building can use.
- If space is not a factor, it is important to understand the first cost impacts – does an energy saving measure cost more than the amount of PV panels that it saves?
Generating an Energy Budget for SEF

Factors at play:
1. One story building
2. Lots of southern roof space
3. Owner wants PV ONLY on the roof (not over parking lot)
4. Office occupancy with standard business hours

Which factor do you think is driving the energy budget?

Energy Used or Energy that can be made?
Calculating Predicted Energy Usage

Modeling completed using DesignBuilder - an Energy Plus based software program

In the preliminary design, focus is on:

1. Building footprint, height, openings and orientation
2. Building envelope construction
3. Building Schedule
4. Building Systems
5. Occupant Equipment and behavior assumptions
1. **Energy Modeling Accuracy**: We know energy modeling is not 100% accurate and will have inconsistencies and errors in it. This is particularly true at the early conceptual model phase.

2. **Design Evolution & Implementation**: As the design evolves, performance tends to slip as cost estimates impact design choices, constructability factors impact design, and a better understand of occupant impact typically result in an increase in energy predictions.

3. **Building Construction**: The construction of the building may result additional energy usage due to material substitutions, field conditions that alter the design and the resolution RFIs. There may also be performance issues in terms of improperly installed systems and components.

4. **Occupant Behavior and Building Operations**: Actual building operations and occupancy generally vary from the projections at the start of the project.

5. **External Factors**: External factors such as weather variations from the typical year energy model basis as well as un-planned equipment outages impact performance.
Adding an Energy Contingency

AKF/In Posse Typical Recommended Contingency Value: 20%
SEF Preferred Contingency Value: 30%

Pre-contingency Energy Generation Target: 89,359 kWh Annually
Post-contingency Energy Generation Target: 116,167 kWh Annually
Tracking The Energy Budget

- Initial Budget Set Feasibility
- Preliminary SD Modeling
- Final SD Modeling
- DD ECM Modeling
- DD Final Modeling
- CD Final Modeling
- End of Construction Modeling
- Final NZE Model Comparison
Calculating Predicted Energy Generation

Starts with understanding some basic information about the building AND some assumptions about the PV panels

General Information:

- Building Campus orientation: 12 Degrees East of South
- Building Orientation: Due South and 12 Degrees East of South
- Roof Slope: 18 Degrees
- Calculations assume 340 Watt PV panels dimensions: 77.5” x 39.1”
## Calculating Predicted Energy Generation

No Standards – Makes Designing Difficult

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Model</th>
<th>Cell type</th>
<th>Rated power @ STC (W)</th>
<th>Rated power per sq. ft. (W/sf)</th>
<th>Module efficiency (%)</th>
<th>Length (in.)</th>
<th>Width (in.)</th>
<th>Depth (in.)</th>
<th>Weight (lbs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Motech</td>
<td>XS72C4-340</td>
<td>mono</td>
<td>340</td>
<td>17.1</td>
<td>17.4</td>
<td>77.4</td>
<td>37</td>
<td>1.6</td>
<td>58.9</td>
</tr>
<tr>
<td>Suniva</td>
<td>OPT340-72-4-100</td>
<td>mono</td>
<td>340</td>
<td>16.2</td>
<td>17.43</td>
<td>77.6</td>
<td>39</td>
<td>1.5</td>
<td>50.7</td>
</tr>
<tr>
<td>Sunpower</td>
<td>SPR-X21-345</td>
<td>mono</td>
<td>345</td>
<td>19.6</td>
<td>21</td>
<td>61.4</td>
<td>41.2</td>
<td>1.8</td>
<td>41</td>
</tr>
<tr>
<td>Candian Solar</td>
<td>CS6U-350P</td>
<td>mono</td>
<td>350</td>
<td>16.9</td>
<td>18</td>
<td>76.9</td>
<td>38.7</td>
<td>1.4</td>
<td>48.5</td>
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<tr>
<td>Solaria</td>
<td>XT-350R-PD</td>
<td>mono</td>
<td>350</td>
<td>18</td>
<td>19.4</td>
<td>63.8</td>
<td>43.9</td>
<td>1.6</td>
<td>46</td>
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<tr>
<td>Solar World</td>
<td>SWA-350</td>
<td>mono</td>
<td>350</td>
<td>16.3</td>
<td>17.54</td>
<td>78.5</td>
<td>39.4</td>
<td>1.3</td>
<td>47.6</td>
</tr>
<tr>
<td>Axitec</td>
<td>AC-360M/72S</td>
<td>mono</td>
<td>360</td>
<td>17</td>
<td>18.55</td>
<td>77</td>
<td>39.1</td>
<td>1.6</td>
<td>50.7</td>
</tr>
<tr>
<td>Sunpreme</td>
<td>GxB-380</td>
<td>mono</td>
<td>380</td>
<td>18.2</td>
<td>19.4</td>
<td>77.2</td>
<td>38.9</td>
<td>0.1</td>
<td>55.6</td>
</tr>
</tbody>
</table>
Solar Panel Orientation

It is possible to determine the impact at any location. However, the pattern is generally similar. South is best, but some slight deviations have minimal impact.

<table>
<thead>
<tr>
<th>West</th>
<th>120</th>
<th>105</th>
<th>90</th>
<th>75</th>
<th>60</th>
<th>45</th>
<th>30</th>
<th>15</th>
<th>0</th>
<th>15</th>
<th>30</th>
<th>45</th>
<th>60</th>
<th>75</th>
<th>90</th>
<th>105</th>
<th>120</th>
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</thead>
<tbody>
<tr>
<td>South</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>East</td>
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</tbody>
</table>

PV production losses by orientation for Cambridge, MA

- In:posse
Running Test Fits

Do we need access ways? Perimeter Space?
Budget Reconciliation

- Using Design/Build to manage costs
- Premiums for Net-Zero
- Premiums for demonstrating technology
### Cost Breakdown

<table>
<thead>
<tr>
<th>Description</th>
<th>50% DD Design</th>
<th>100% CD Bid</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Conditions</td>
<td>321,100</td>
<td>321,000</td>
</tr>
<tr>
<td>Foundations</td>
<td>535,851</td>
<td>316,800</td>
</tr>
<tr>
<td>Structure</td>
<td>483,500</td>
<td>463,000</td>
</tr>
<tr>
<td>Horizontal Envelope</td>
<td>592,389</td>
<td>156,000</td>
</tr>
<tr>
<td>Vertical Envelope</td>
<td>1,331,810</td>
<td>965,629</td>
</tr>
<tr>
<td>Finishes</td>
<td>337,939</td>
<td>430,165</td>
</tr>
<tr>
<td>Plumbing</td>
<td>158,000</td>
<td>131,000</td>
</tr>
<tr>
<td>HVAC &amp; Controls</td>
<td>439,698</td>
<td>386,000</td>
</tr>
<tr>
<td>Electrical &amp; Solar</td>
<td>783,800</td>
<td>673,600</td>
</tr>
<tr>
<td><strong>Subtotal</strong></td>
<td><strong>4,984,087</strong></td>
<td><strong>3,843,194</strong></td>
</tr>
<tr>
<td>Permit</td>
<td>15,000</td>
<td>10,000</td>
</tr>
<tr>
<td>PreConstruction</td>
<td>23,500</td>
<td>20,500</td>
</tr>
<tr>
<td>Contingency</td>
<td>200,891</td>
<td>0</td>
</tr>
<tr>
<td>Contractor’s Fee, Insurance</td>
<td>288,019</td>
<td>293,583</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>5,511,497</strong></td>
<td><strong>4,167,277</strong></td>
</tr>
</tbody>
</table>
Summary of Net Zero Strategies

- Solar/PV
- Insulation at Roof and Slab
- Reduced Air Leakage
- Fiberglass Windows
- Roof Slope
- Roof Eave Overhangs
- VRF System

NZE Cost: $395,000
9% of building cost
Solar/PV System

Goal: Produce more energy than building consumes with 30% contingency

Strategy: Use roof mounted PV array

Premium Cost: $277,000
Cost/SF: $18.47
% Cost: 6.65%
Insulation - Roof

Goal: Increase insulation in roof over code

Strategy: Use a 3 layer, R-49 system by PEMB

Premium Cost: $11,900
Cost/SF: $0.80/SF
% Cost: .29%
Insulation – Floors

Goal: Increase insulation in floor

Strategy: Floors – Used 2” rigid insulation at 6’ around perimeter as well as a skirt of 6” vertical and 4” horizontal

Premium Cost: $10,000
Cost/SF: $0.67/SF
% Cost: .25%
Reduced Air Leakage

Goal: Decrease air leakage
Strategy: Establish and test for air leakage rate of .08 cfm/sf

Premium Cost: $25,000 (TBD)
Cost/SF: $1.67/SF
% Cost: .60%
Fiberglass Windows

Goal: Combine economy with thermal break properties; ability to provide fresh air in swing seasons

Strategy: Use economical, commercially available fiberglass frames with double pane, operable windows

Premium Cost: 0
Cost/SF: $0/SF
% Cost: 0%
Roof Slope

Goal: Provide south facing sloped roof for PV array

Strategy: Used roof slope of 2:12

Premium Cost: $72,300/inch of roof slope

Cost/SF: $4.82/SF/inch of roof slope

% Cost: 1.74%/inch of roof slope
Roof Eave Overhangs

Goal: Minimize overhangs while protecting south facing openings from solar heat gain

Strategy: Use 3’ overhangs on south facing windows

Premium Cost: $14,125 ($28.25/SF of overhang)
Cost/SF: $.94/SF
% Cost: .34%
VRF System

Goal: Minimize energy use
Strategy: Use VRF system

Premium Cost: $56,500
Cost/SF: $3.77
% Cost: 1.36%
Demonstrating Sustainable Tech

- Super-Insulated Walls
- Clerestory
- Solar Hot Water
- Control System
- Window Contacts
- Lighting Controls

Demonstration Cost: $395,000
11.3% of building cost
Insulation - Walls

Goal: Increase insulation in walls over code

Strategy: Use 6” batt insulation plus 6” continuous rigid insulation on green girt system

Premium Cost: $26,500
Cost/SF: $1.76/SF
% Cost: .64%
Clerestory

Goal: Introduce natural light into space and create more pleasant work environment

Strategy: Design a single sloping roof with upper level windows on north side of building

Premium Cost: $375,000
Cost/SF: $25/SF
% Cost: 9%
Solar Hot Water Heating System

Goal: Minimize energy use

Strategy: Use solar hot water heating system

Premium Cost: $10,700 + owner supplied panels

Cost/SF: $.71/SF+

% Cost: .26%+
Building Controls

Goal: Minimize energy use
Strategy: Use building automated controls system

Premium Cost: $40,000
Cost/SF: $2.67/SF
% Cost: 1%
Window Contacts

Goal: Minimize energy use when windows are open

Strategy: Provide contacts on each operable window tied to BAS system

Premium Cost: $7,400
Cost/SF: $.49/SF
% Cost: .18%
Lighting Control System

Goal: Minimize energy use
Strategy: Use lighting control system

Premium Cost: $30,000
Cost/SF: $2.00
% Cost: .72%
Does this project prove the commercial viability of Net-Zero Energy?
Lessons Learned

What went well?

What could have been done different or better?
Combining Technology, Beauty and Meaning in the New Sustainable Energy Fund