Net-Zero Schools from Process to Impacts
Uncovering Barriers and Benefits of Net-Zero Schools – A Best Practice Pattern Book

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Building Performance Data Base
> 150 buildings >100K responses

- **BELS™:** Benchmarking & Evaluation of LEED™ Schools
- **GCT™:** Green Classroom Toolbox™
- **PROBPE™:** Post-Relocation and Occupancy Building Performance Evaluation
- **SPEQ™:** Space Performance Evaluation Questionnaire
  Adopted for LEED v.4.1 and WELL v.2.0
We are driven by green schools research, design, and delivery
Net-Zero Schools Definition

In a Typical Metrological Year:
Energy Used = Energy Produced

- **Behavior (B)**:
  - Energy Behavior
  - Occupant’s Comfort
  - Spatial Flexibility
  - Community Building

- **Process (P)**:
  - Integrated Design
  - Stakeholder Engagement
  - Incentives
  - Cultural Buy-in
  - Building as a Teacher

- **Technology (T)**:
  - Sustainable Site
  - Building Performance
  - Envelope Design & Details
  - Indoor Environmental Quality
  - Occupant’s Well-being

**NZS**
How Are Net-Zero Schools Performing?
QUESTIONS

1. What are NZS impacts on building performance and the environment?
2. What are NZS impacts on occupants and buildings operations?
3. What are successful strategies and design processes for NZS?
Methods & Research Workflow

Comparative Case Study / Survey Design
Data Mining + Interviews + Simulations + Analysis
Project Data

1- Hood River Middle School
2- Woodburn Success High School
3- Durham Education Center
4- Vernonia School
5- Locust Trace High School
6- Sandy Grove Middle School
7- Discovery Elementary School
8- Kathleen Grimm School
9- Socastee Elementary School
10- Socastee Middle School
11- Mvrtle Beach Middle School
12- St. James Intermediate School
13- Wilde Lake Middle School
14- Carolina Forest Middle School
15- Spring Creek Middle School
16- Willow School
17- Grantham Middle School
18- Da Vinci Middle School
19- Putney Field House
20- Bertschi School Science
21- Energy Lab at Hawaii
22- Sacred Heart Schools
23- Dearing Elementary School
24- Friends School of Portland
25- Bishop O'Dowd High School
26- Egan Junior High School
27- Irvine High School
28- Newcastle Elementary
29- Vista Grande Elementary School
30- Woodside Priory School
31- Mark Day School
32- OUSD Madison Middle School
33- Dr. Walter C. Ralston School
34- Santiago High School Science
35- OUSD Glenview Elementary School
36- Los Osos Middle School
37- Kay's Creek Elementary School
38- Odyssey Elementary School
39- Richardsonville Elementary School
40- Muse School
41- Dr. Martin Luther King, Jr. School
Comparatives

1- Hood River Middle School
2- Woodburn Success High School
3- Durham Education Center
4- Vernonia School
5- Locust Trace High School
6- Sandy Grove Middle School
7- Discovery Elementary School
8- Kathleen Grimm School
9- Socastee Elementary School
10- Socastee Middle School
11- Myrtle Beach Middle School
12- St. James Intermediate School
13- Wilde Lake Middle School
14- Carolina Forest Middle School
15- Spring Creek Middle School
16- Willow School
17- Grantham Middle School
Case Studies

1- Hood River Middle School
2- Woodburn Success High School
3- Durham Education Center
4- Vernonia School
5- Locust Trace High School
6- Sandy Grove Middle School
7- Discovery Elementary School
NZS – Meet Energy Predictions

Energy Utilization Intensity Predicted
Arch 2030 Benchmark EUI (80% reduction)
EPA Median Facility EUI (Traditional 100 zscore)
Expon. (Energy Utilization Intensity Predicted)
Expon. (EPA Median Facility EUI (Traditional 100 zscore))
Expon. (Arch 2030 Benchmark EUI (80% reduction))
NZS – Impact Neighborhoods Property Values

$\Delta$ PPV = Difference in property value increase over comparatives

<table>
<thead>
<tr>
<th>Location</th>
<th>PPV (%)</th>
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<tbody>
<tr>
<td>Hood River Middle School Net-Zero Addition</td>
<td>3.7</td>
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<tr>
<td>Woodburn Success High School</td>
<td>5.2</td>
</tr>
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<td>2.5</td>
</tr>
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<td>Vernonia School</td>
<td>2.1</td>
</tr>
<tr>
<td>Locust Trace AgriScience High School Campus</td>
<td>6.6</td>
</tr>
<tr>
<td>Sandy Grove Middle School</td>
<td>2.5</td>
</tr>
<tr>
<td>Discovery Elementary</td>
<td>1.7</td>
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</table>
### NZS – Increase Neighborhood Walkability

<table>
<thead>
<tr>
<th>School Name</th>
<th>Walkability Score</th>
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<tbody>
<tr>
<td>Hood River Middle School Net-Zero Addition</td>
<td>77</td>
</tr>
<tr>
<td>Woodburn Success High School</td>
<td>18</td>
</tr>
<tr>
<td>Durham Education Center</td>
<td>58</td>
</tr>
<tr>
<td>Vernonia School</td>
<td>26</td>
</tr>
<tr>
<td>Locust Trace AgriScience High School Campus</td>
<td>4</td>
</tr>
<tr>
<td>Sandy Grove Middle School</td>
<td>0</td>
</tr>
<tr>
<td>Discovery Elementary</td>
<td>14</td>
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**Source:** [HiPE](#)
NZS – Better Classroom Acoustics

<table>
<thead>
<tr>
<th>School</th>
<th>Unoccupied</th>
<th>Occupied</th>
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<tr>
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<td>0.3545</td>
<td>0.35</td>
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<tr>
<td>Durham Education Center</td>
<td>0.34</td>
<td>0.34</td>
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<tr>
<td>Vernonia School</td>
<td>0.33</td>
<td>0.326</td>
</tr>
<tr>
<td>Locust Trace AgriScience High School Campus</td>
<td>0.3</td>
<td>0.298</td>
</tr>
<tr>
<td>Sandy Grove Middle School</td>
<td>0.359</td>
<td>0.354</td>
</tr>
<tr>
<td>Discovery Elementary</td>
<td>0.39</td>
<td>0.38</td>
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</tbody>
</table>
NZS – Daylight Glare Probability

<table>
<thead>
<tr>
<th>School</th>
<th>Daylight Glare Probability</th>
<th>Recommended</th>
<th>Intolerable Glare</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hood River Middle School</td>
<td>41%</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Woodburn Success High School</td>
<td>32%</td>
<td>35%</td>
<td>45%</td>
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<tr>
<td>Durham Education Center</td>
<td>28%</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Vernonia School</td>
<td>26%</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Locust Trace Agriscience High School</td>
<td>28%</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Sandy Grove Middle School</td>
<td>26%</td>
<td>35%</td>
<td>45%</td>
</tr>
<tr>
<td>Discovery Elementary</td>
<td>27%</td>
<td>35%</td>
<td>45%</td>
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</table>
NZS – Classroom Daylighting Performance

<table>
<thead>
<tr>
<th>School</th>
<th>Spatial Daylight Autonomy</th>
<th>Useful Daylight Illumination</th>
<th>Recommended</th>
<th>Exceptional</th>
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</thead>
<tbody>
<tr>
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<td>84%</td>
<td>84%</td>
<td>55%</td>
<td>75%</td>
</tr>
<tr>
<td>Woodburn Success High School</td>
<td>54%</td>
<td>89%</td>
<td>55%</td>
<td>75%</td>
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<tr>
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<td>57%</td>
<td>90%</td>
<td>55%</td>
<td>75%</td>
</tr>
<tr>
<td>Vernonia School</td>
<td>54%</td>
<td>97%</td>
<td>55%</td>
<td>75%</td>
</tr>
<tr>
<td>Locust Trace AgriScience High School Campus</td>
<td>0%</td>
<td>36%</td>
<td>55%</td>
<td>75%</td>
</tr>
<tr>
<td>Sandy Grove Middle School</td>
<td>28%</td>
<td>57%</td>
<td>55%</td>
<td>75%</td>
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<tr>
<td>Discovery Elementary</td>
<td>31%</td>
<td>74%</td>
<td>55%</td>
<td>75%</td>
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</table>
NZS – Annual Solar Exposure

<table>
<thead>
<tr>
<th>School</th>
<th>Annual Solar Exposure</th>
<th>Allowable</th>
<th>Recommended</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hood River Middle School Net-Zero Addition</td>
<td>40%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Woodburn Success High School</td>
<td>47.7%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Durham Education Center</td>
<td>29.50%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Vernonia School</td>
<td>11.9%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Locust Trace AgriScience High School Campus</td>
<td>25.4%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Sandy Grove Middle School</td>
<td>20.5%</td>
<td>20%</td>
<td>10%</td>
</tr>
<tr>
<td>Discovery Elementary</td>
<td>18.5%</td>
<td>20%</td>
<td>10%</td>
</tr>
</tbody>
</table>
NZS – Percent of Time in Indoor Comfort Zone

<table>
<thead>
<tr>
<th>Location</th>
<th>Percent of Time in Comfort Zone</th>
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</thead>
<tbody>
<tr>
<td>Hood River</td>
<td>54%</td>
</tr>
<tr>
<td>Woodburn</td>
<td>88%</td>
</tr>
<tr>
<td>Durham</td>
<td>91%</td>
</tr>
<tr>
<td>Vernonia</td>
<td>78%</td>
</tr>
<tr>
<td>Locust Trace</td>
<td>75%</td>
</tr>
<tr>
<td>Sandy Grove</td>
<td>77.3%</td>
</tr>
<tr>
<td>Discovery</td>
<td>77.5%</td>
</tr>
</tbody>
</table>

% time in Comfort Zone

<table>
<thead>
<tr>
<th>Percentage</th>
<th>Hood River</th>
<th>Woodburn</th>
<th>Durham</th>
<th>Vernonia</th>
<th>Locust Trace</th>
<th>Sandy Grove</th>
<th>Discovery</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>54.05</td>
<td>88.26</td>
<td>90.98</td>
<td>78.04</td>
<td>75.09</td>
<td>77.25</td>
<td>77.53</td>
</tr>
</tbody>
</table>

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Net-Zero Schools Design Guidelines
NZS – School Siting & Massing

Shape Factor
Building Massing + Roof Form
South-West Isometric

Hood River: Sawtooth / Gable
Woodburn: Flat
Durham: Gable w/ Roof Monitor
Vernonia: Sloped / Flat
Locust Trace: Shed
Sandy Grove: Gable / Flat
Discovery: Flat w/ Roof Monitors

Hood River 12.13%
Woodburn 14.20%
Durham 10.72%
Vernonia 13.62%
Locust Trace 1.32%
Sandy Grove 6.82%
Discovery 15.30%

15% 14% 14% 12% 9% 2%
NZS – South Facing Classrooms Optimization

% of wall area facing south as classrooms:

- Hood River: 18%
- Woodburn: 30%
- Durham: 19%
- Vernonia: 25%
- Locust Trace: 36%
- Sandy Grove: 25%
- Discovery: 36%

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# NZS – PV Roof Areas

<table>
<thead>
<tr>
<th>Area</th>
<th>PV Area %</th>
<th>Footprint</th>
<th>Typical Floor Area</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hood River</td>
<td>37%</td>
<td>Bar</td>
<td>2,544 sf 2 Floors</td>
</tr>
<tr>
<td>Woodburn</td>
<td>0%</td>
<td>Cluster</td>
<td>11,700 sf 1 Floor</td>
</tr>
<tr>
<td>Durham</td>
<td>50%</td>
<td>L-Shape</td>
<td>7,530 sf 2 Floors</td>
</tr>
<tr>
<td>Vernonia</td>
<td>2%</td>
<td>H-Shape</td>
<td>66,141 sf 2 Floors</td>
</tr>
<tr>
<td>Locust Trace</td>
<td>34%</td>
<td>Bar</td>
<td>47,394 sf 1 Floor</td>
</tr>
<tr>
<td>Sandy Grove</td>
<td>50%</td>
<td>Finger</td>
<td>75,910 sf 1 Floor</td>
</tr>
<tr>
<td>Discovery</td>
<td>36%</td>
<td>Bar / Cluster</td>
<td>48,794 sf 2 Floors</td>
</tr>
</tbody>
</table>
NZS – Classroom Window-To-Wall Ratio

<table>
<thead>
<tr>
<th>School</th>
<th>WWR</th>
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</thead>
<tbody>
<tr>
<td>Hood River</td>
<td>29%</td>
</tr>
<tr>
<td>Woodburn</td>
<td>30.5%</td>
</tr>
<tr>
<td>Durham</td>
<td>12%</td>
</tr>
<tr>
<td>Vernonia</td>
<td>20%</td>
</tr>
<tr>
<td>Locust Trace</td>
<td>20%</td>
</tr>
<tr>
<td>Sandy Grove</td>
<td>19%</td>
</tr>
<tr>
<td>Discovery</td>
<td>38%</td>
</tr>
</tbody>
</table>

Hood River Middle School Net-Zero Addition: 29%
Woodburn Success High School: 30.5%
Durham Education Center: 11.95%
Vernonia School: 19.52%
Locust Trace AgriScience High School Campus: 19.67%
Sandy Grove Middle School: 18.76%
Discovery Elementary: 38.00%
NZS – Patterns: Design Process

**Project Statement**
The building massing and form aims to work around existing site constraints by adding value to it through formation of a social center nestled between the historic and the new classroom building.

**Response to Neighborhood Context**
The New Classroom Building is an addition to the Creekside Community High School. Its shape surrounds the existing ‘Old Schoolhouse’ on the site to define a communal courtyard meant to foster social interaction between students.

The form, elevation and footprint of the building fit in its context by responding to the shapes and sizes of surrounding buildings.

The act of connecting the building to the community through form is further pursued by the implementation of a vegetable garden near the entrance of the building. The garden is meant to bring together local community members with students to learn about growing food and culinary education.

Most buildings surrounding Durham Center Alternative School are a mix of residential homes and one to two story commercial stores and factories.

**P3 Advantages:**
- Harnessing of private sector’s expertise and efficiency
- ‘Off-balance sheet’ method of financing the delivery of public sector assets
- Speed of delivery
- Possible tax credits and breaks
- Energy tax credits
- Potential new market tax credits
- Elimination of bid day risk
- Elimination of construction risk
- Reduced risk of inflation

**An Aim To Reduce Costs And Expenses**
The school managed to reduce the cost from $53.5 million in project delivery costs to a total of $16.3 million due to the leased delivery model allowed for a public-private partnership with the design team.
NZS – Patterns: Design Strategies

Net Zero Energy Design

Discovery is an all-electric building that fully offsets its energy use through the generation of clean, renewable solar power. Achieving an EUI of 23 involved meticulous evaluation of the way Arlington Public Schools (APS) builds and operates its facilities. Discovery’s sustainable features are highlighted in the diagram to the right:

- Ideal solar orientation + shading
- 1,700 roof mounted solar panels
- Insulated concrete exterior walls with high thermal mass
- A geothermal well field
- Solar pre-heat of domestic water
- Solar pre-heat of domestic water

Balancing Net Zero Strategies

Balance between energy production, consumption, and conservation is an important design consideration when building on a budget. The fundamental approach to creating this balance when moving into net zero design is to match the goals of energy production, consumption and conservation with realistic and tangible solutions.

Architecture as a Teaching Tool

- Students have physical access to the greenhouse and its bio-filter.
- Students have visual accessibility to building’s systems.
- Students have access to the building’s geothermal and water system throughout the building.
- Wall & Floor Assemblies visible through glass for an understanding of how it works.
- Onsite Energy Diagrams as Interpretive Signage.

Resource Management

Visible Systems

Truth Windows + Interpretive Signage

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NZS – Patterns: Site Performance

Site to Building Ratio

14% built up area.
Set on corner of site due to access to nearest road. Also placed there due to it being the point of least obstruction on its landscape.

Resource Flows on Site
Resources include: rainwater, solar energy, food production, solid waste, people.

• school district area: 24 sq.mi.
• longest distance across district: roughly 6 miles.
• walk-score: 58
NZS – Patterns: Building Performance

Heat Loss and Heat Gain
Heat loss measures the amount of heat being lost by the building due to infiltration and lack of insulation. Heat gain measures the amount of heat being gained by the building due to heat gains and losses. Both heat loss and heat gain are measured in KWh per square meter.

Winter Heat
Major heat gain and loss in Winter. Surfaces are gaining above 10 KWh per sq. meter. Openings are losing roughly 17 KWh per sq. meter.

Spring Heat
Neutral heat transfer in Spring. Walls, roof and floor aren’t losing or gaining any heat. Openings are gaining over 30 KWh of heat per sq. meter.

Energy Utilization Intensity
Actual EUI: 9.9

Energy Use Intensity is a building’s annual energy consumption per unit of floor area. It’s commonly measured in thousands of BTU per square foot per year (kBTU/ft²/yr).

Energy Metrics

<table>
<thead>
<tr>
<th>Metric</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mechanical Equipment (kWh)</td>
<td>NA</td>
</tr>
<tr>
<td>Lighting/Plug Loads (kWh)</td>
<td>NA</td>
</tr>
<tr>
<td>Total Power Consumption (kWh)</td>
<td>188,600</td>
</tr>
<tr>
<td>PV Energy Production (kWh)</td>
<td>211,630</td>
</tr>
<tr>
<td>Net Power Consumption/Production (kWh)</td>
<td>+ 23,030</td>
</tr>
</tbody>
</table>

Energy Reduction Investments
Solar beyond PVs
Daylighting Controls
NZS – Envelope Performance

Overview
Typical Roof Area

Roof
Typical Roof Detail

Wall
Typical Wall Detail

Window Sill
Typical Window Detail
NZS – Patterns: Indoor Comfort

Acoustics
Reverb Time: 0.35 seconds
The desire to minimize materials and use a floor slab created an acoustical problem due to concrete’s very low Noise Reduction Coefficient (NRC). The design team solved this by using mineral wool; an insulating material that’s good for sound absorption. Additionally, the use of wood stud framed walls instead of concrete walls serves as a better noise-reducing wall element.

Thermal
Due to the inability for the central common area ceiling to hide any ductwork, the architects and engineers decided to use side-wall diffusers within the classroom walls facing the common area to pump hot and cold air to create a comfortable thermal environment within the large space.

Psychrometric Chart
Mean average of data falls just inside and to the left of the ASHRAE indoor comfort standards.
The school’s most concentrated number of hours lies at:
- Temperature: 15 C
- Relative humidity: 80-90%
- Enthalpy: 25 kg/kd
- Humidity ratio: 0.005

ASHRAE Thermal Sensation
This building is in use during the months of September to June where school activities begin around 8 AM and end at 3 PM.

Indoor Comfort Results
The percentage of the time occupants within the school are inside the comfort zone is 88.3%
NZS – Patterns: Daylight Management

Daylighting

The spaces were designed so that even amounts of daylight can penetrate deep into the space. To achieve this, daylight modeling tested various clerestory and skylight scenarios. The goal was to place less emphasis on an overall light level, and more focus on a balanced light condition to reduce glare. Lightly colored acoustic panels also help reflect daylight in the space. Electric lighting is automatically dimmed when daylight is adequate by employing a daylighting controls system.

Average Illuminance: **2017.47 lux** (annually)

Daylight Autonomy Analysis

This classroom space is **84%** for active occupant behavior.

- **Daylit Area (DA300lux50%)**: 84% of floor area
- **Mean Daylight Factor**: 4.0%
- **Occupancy**: 3650 hours per year

As an example, a point indicating semi-red color in the area means that 84% of the occupied time, that point meets the criteria of having daylight factor of 300 lux or above.

Illuminance Node Analysis

Mean illuminance: **2017.47 lux** (each point’s value is available)

Daylight Factor

Mean daylight factor – **4.12%**

- The daylight factor for 99.8% of the area is between 0 & 15% 
- The daylight factor for 0.2% of the area is above 15%

Sunlight and Disturbing Glare

For 30% of the year, the floor surface of the classroom experiences sunlight glare at the yellow, orange and red spots in the plan simulation above. Sunlight glare can significantly impact focus levels of students and teachers using the classroom space if the sunlight glare is to disturb them.

Annual Glare Analysis

This chart represents the result of annual glare simulation in which the intolerable glare, disturbing glare, perceptible glare and imperceptible glare are shown with their relative color, for the selected view in Rhino from indoor space (The false color rendering above represents this view).
NZS – Design Approach

• Integrated participatory design
• Engaging stakeholders
• Embracing passive systems
• Setting-up proper metrics
• Shoe-box performance simulations
• Feedback loops – Iterative design

Site Section
Scale: 1/32" = 1’

1. Main entry
2. Green roof
3. Skylights providing daylighting
4. South facing PV panels at optimal tilt
5. Individual reading spaces
6. Cafeteria
7. Media center/Library
8. Sunspace for heating adjacent cafeteria
9. Roof overhang shades high summer sun
10. Operable Clerestories for ventilation
NZS – Design Resources

- Early feasibility studies
- Proper benchmarks, such as net zero tool
- Early design decisions resources
- Design guides, such as HiPE lab: Net-Zero Schools from Process to impacts, ASHRAE, Energy Trust, etc.

Figure 31: Full Building Energy Analysis
Lessons Learned

1. The current status of net-zero energy schools across North America is promising. It is feasible to deliver NZS that are comfortable, cost effective, and have positive impacts on children and their communities.

2. The process of designing, constructing, and operating a school to net-zero energy is integrated and require early planning, coordination, and education of partners.

3. Resources and research findings are available and provide best design strategies and metrics to set as design targets on six major categories: Design Process, Design Strategies, Site Performance, Building Performance, Envelope Performance, and Indoor Environmental Quality/Occupant Comfort.
FOR MORE INFORMATION

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