2018 Energy Trust
Net-Zero Fellowship

HiPE
High Performance Environments Lab

Net-Zero Schools from Process to Impacts

Uncovering Barriers and Benefits of Net-Zero Schools – A Best Practice Pattern Book

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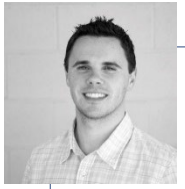

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Building Performance Data Base

> 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

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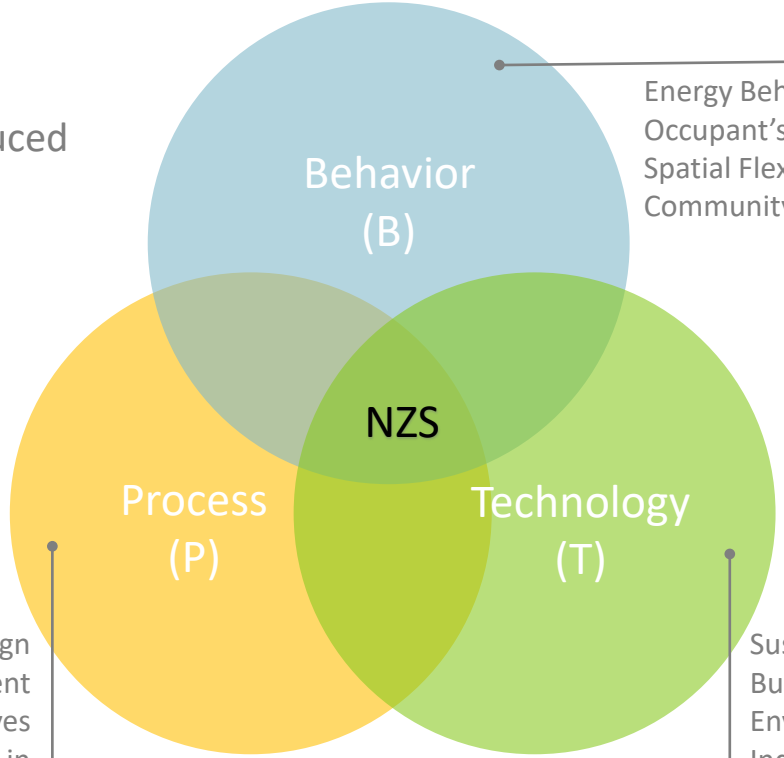
We are driven by green schools research, design, and delivery

Photo by Lorie Shaull, Washington, United States

Net-Zero Schools Definition

In a Typical Metrological Year:
Energy Used = Energy Produced



Energy Behavior
Occupant's Comfort
Spatial Flexibility
Community Building

Integrated Design
Stakeholder Engagement
Incentives
Cultural Buy-in
Building as a Teacher

Sustainable Site
Building Performance
Envelope Design & Details
Indoor Environmental Quality
Occupant's Well-being







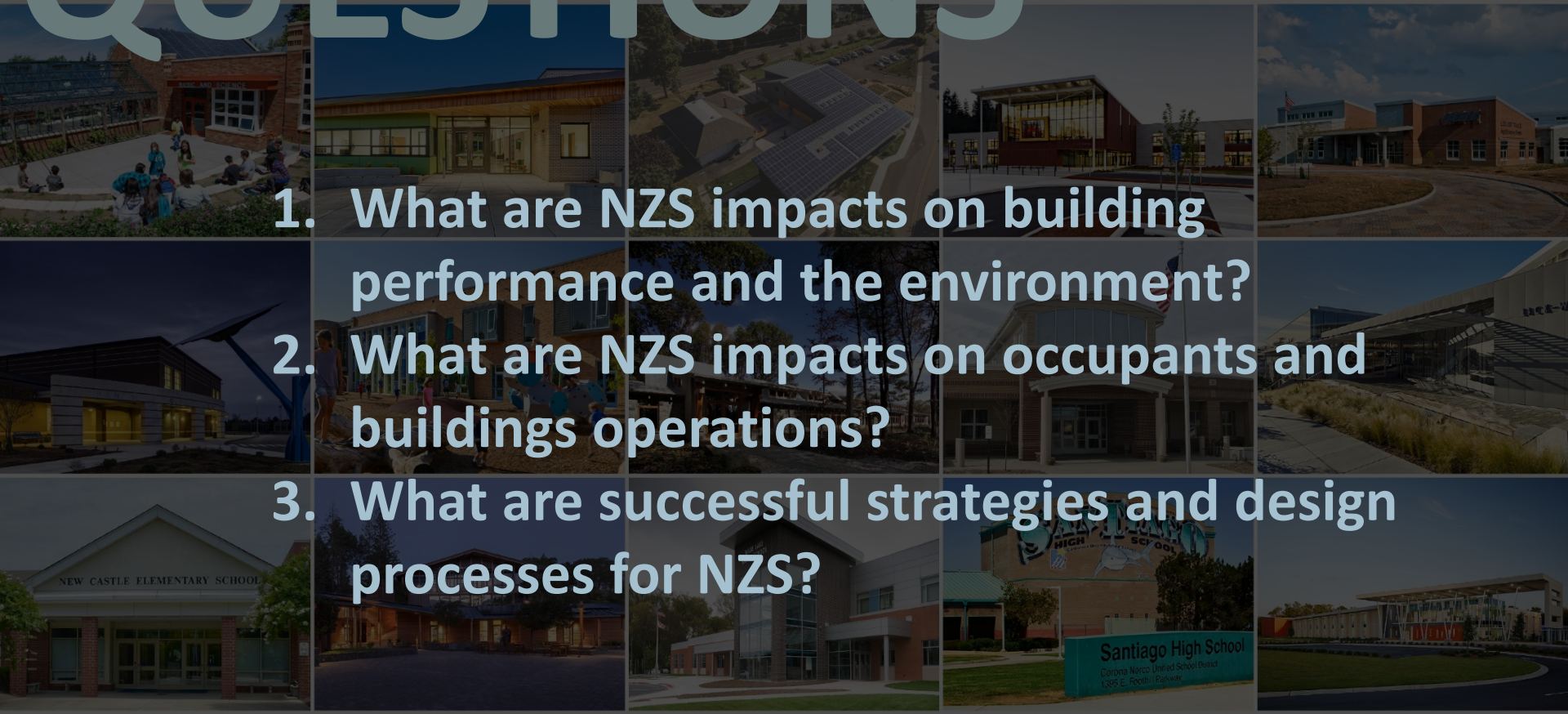







How Are Net-Zero Schools Performing?

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

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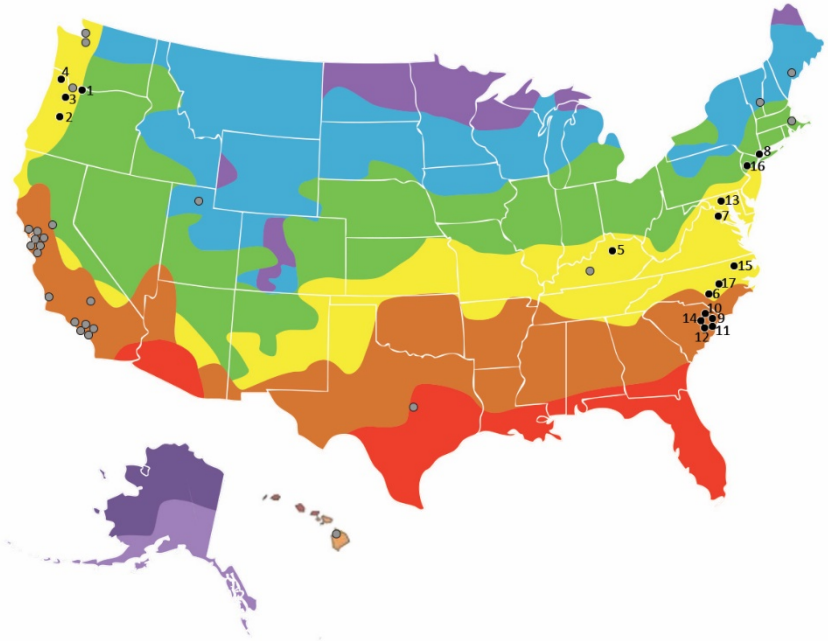
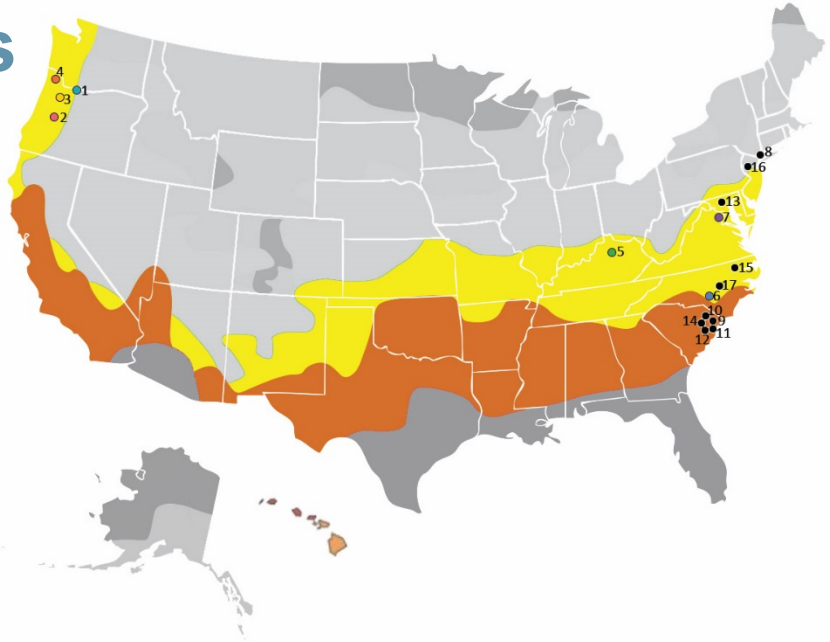
Project Data



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- 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
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- Richardsville Elementary School
40- Muse School
41- Dr. Martin Luther King, Jr. School

Comparatives



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Net-Zero Schools Impacts

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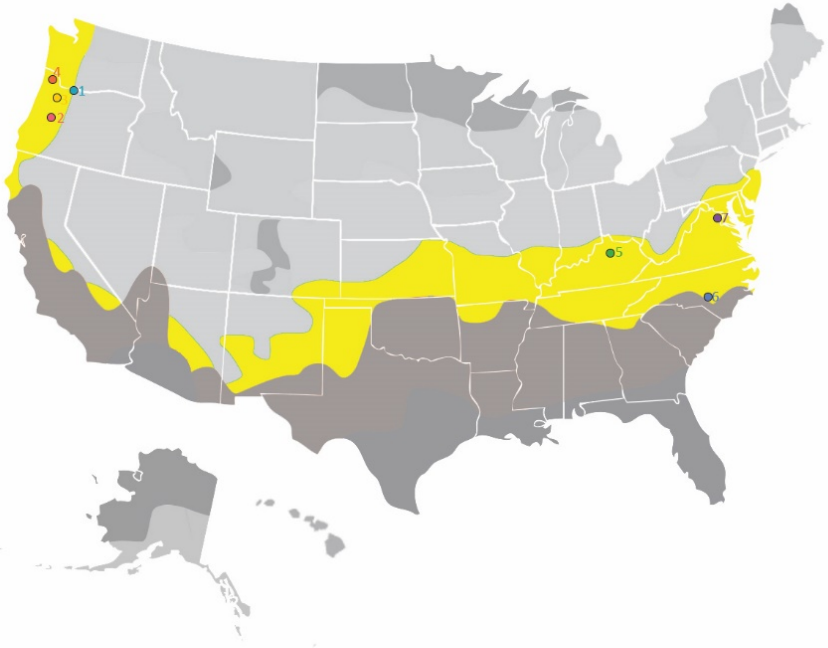
Case Studies



1- Hood River Middle School
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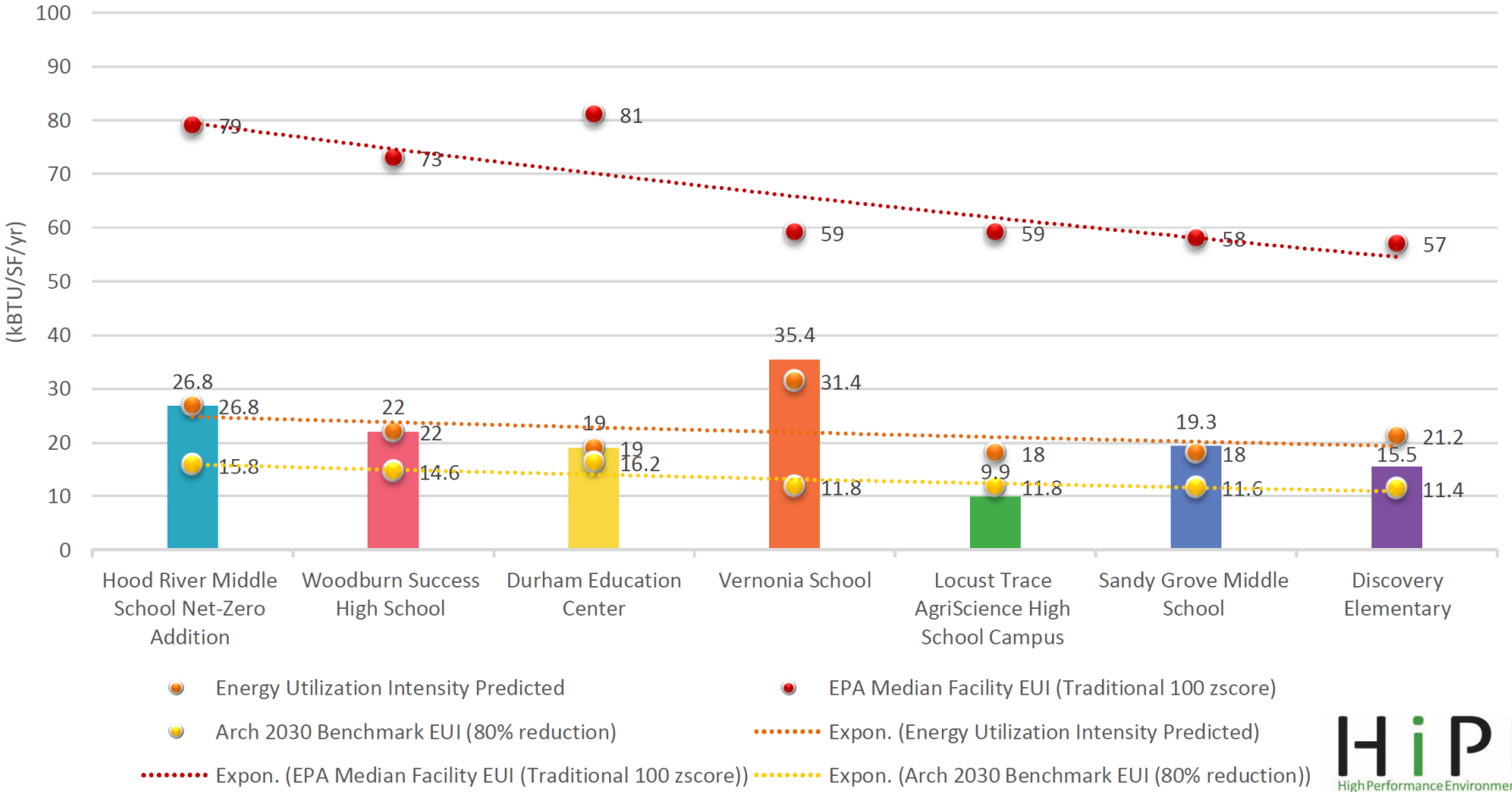
NZS – Meet Energy Predictions



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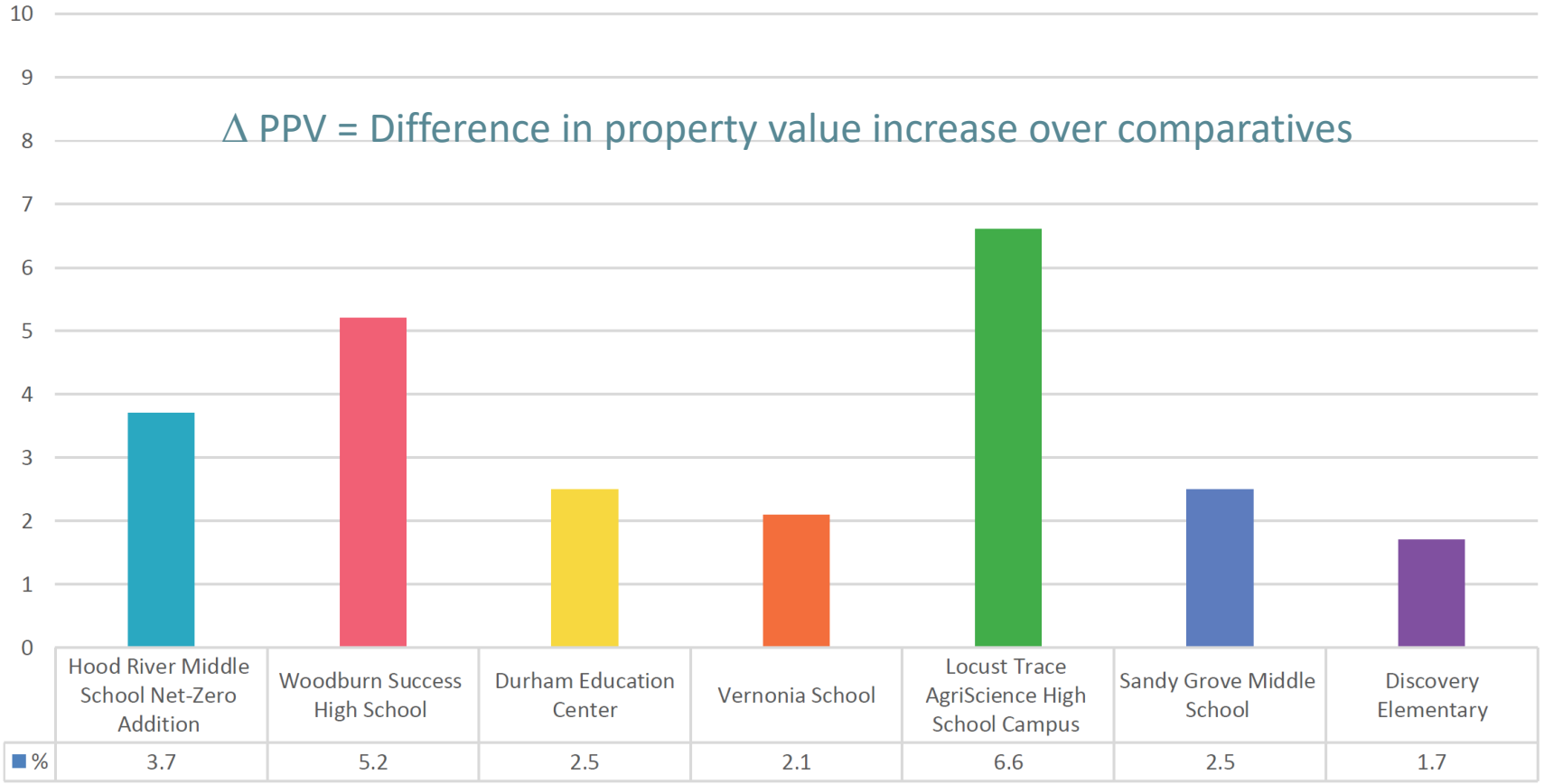
NZS – Impact Neighborhoods Property Values



	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
%	3.7	5.2	2.5	2.1	6.6	2.5	1.7

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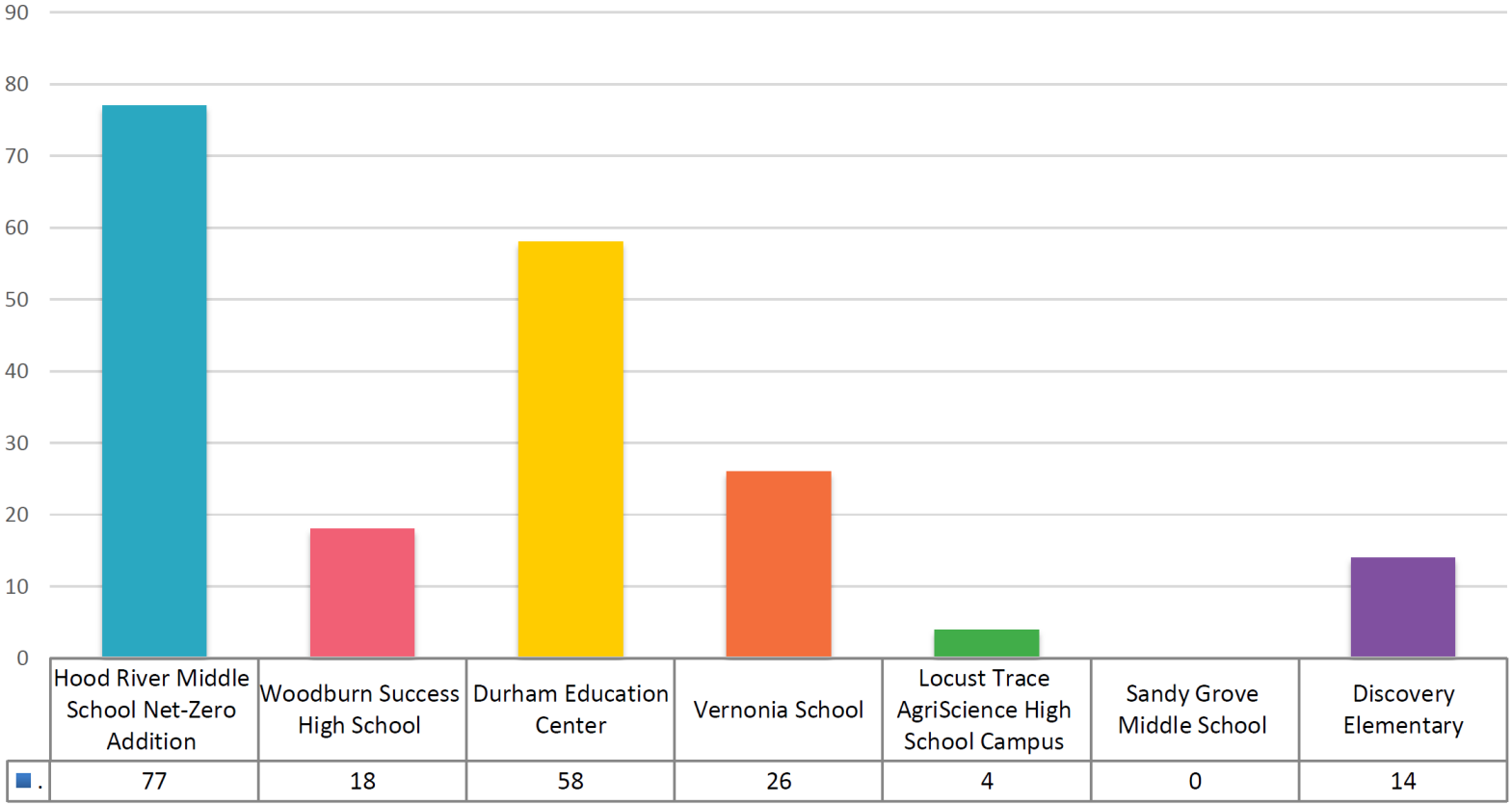
NZS – Increase Neighborhood Walkability



	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
.	77	18	58	26	4	0	14

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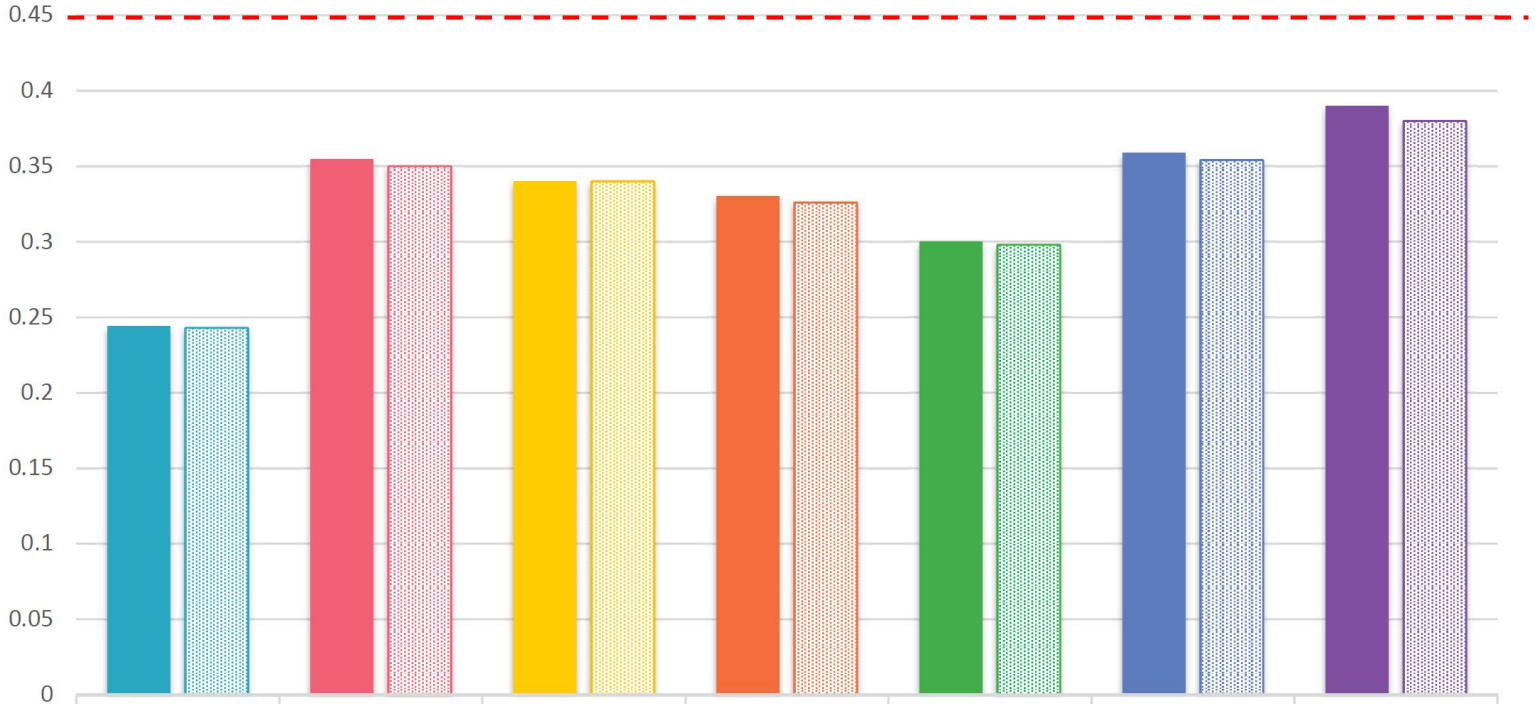
NZS – Better Classroom Acoustics



	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
Unoccupied	0.244	0.3545	0.34	0.33	0.3	0.359	0.39
Occupied	0.243	0.35	0.34	0.326	0.298	0.354	0.38

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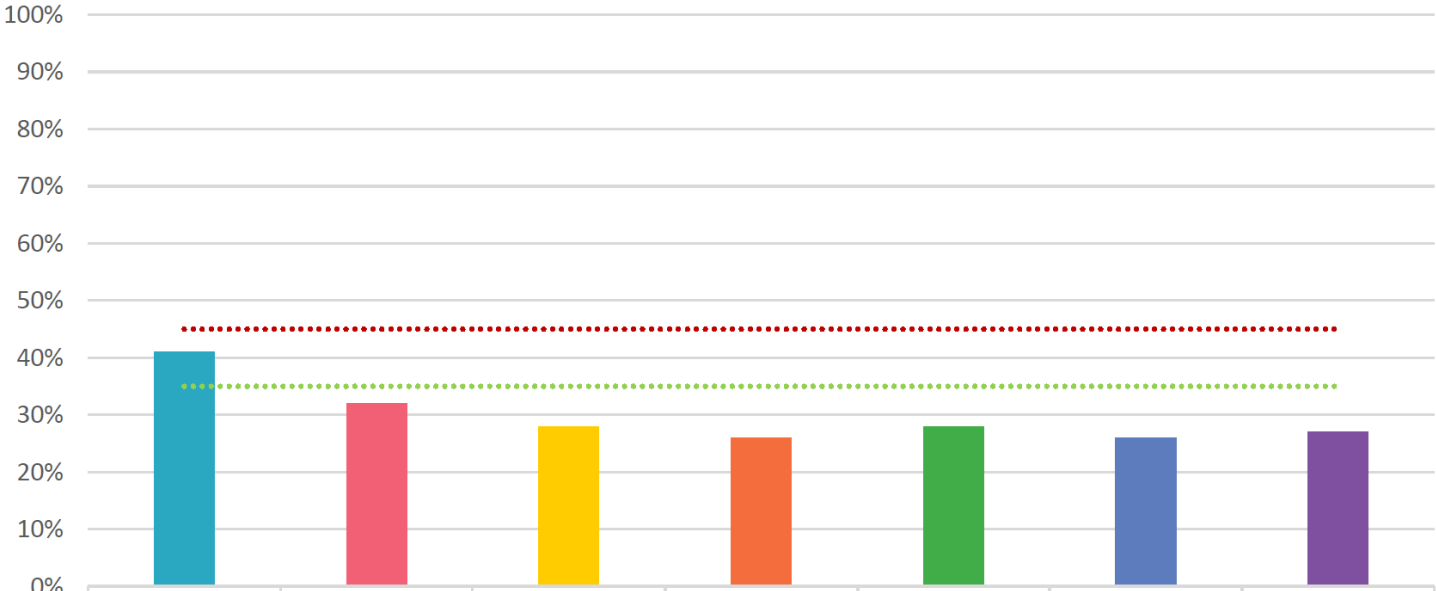
NZS – Daylight Glare Probability



	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
Daylight Glare Probability	41%	32%	28%	26%	28%	26%	27%
Recommended	35%	35%	35%	35%	35%	35%	35%
Intolerable Glare	45%	45%	45%	45%	45%	45%	45%

Daylight Glare Probability Recommended Intolerable Glare

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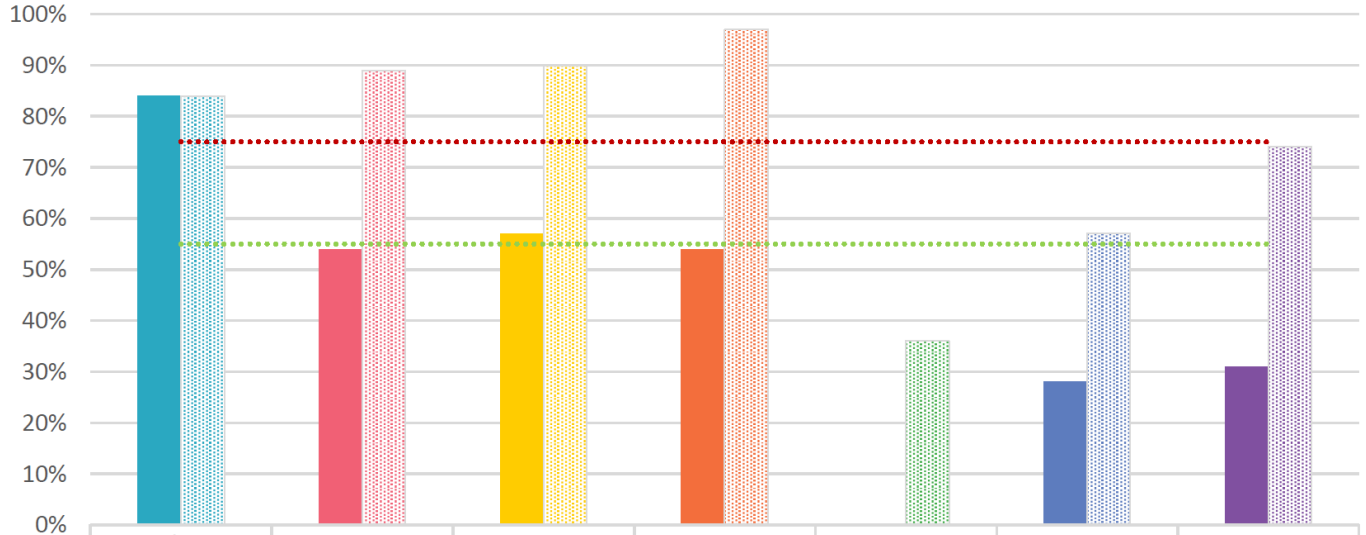
NZS – Classroom Daylighting Performance



	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
Spatial Dylight Autonomy	84%	54%	57%	54%	0%	28%	31%
Useful Daylight Illumination	84%	89%	90%	97%	36%	57%	74%
Recommended	55%	55%	55%	55%	55%	55%	55%
Exceptional	75%	75%	75%	75%	75%	75%	75%

Spatial Dylight Autonomy Useful Daylight Illumination Recommended Exceptional

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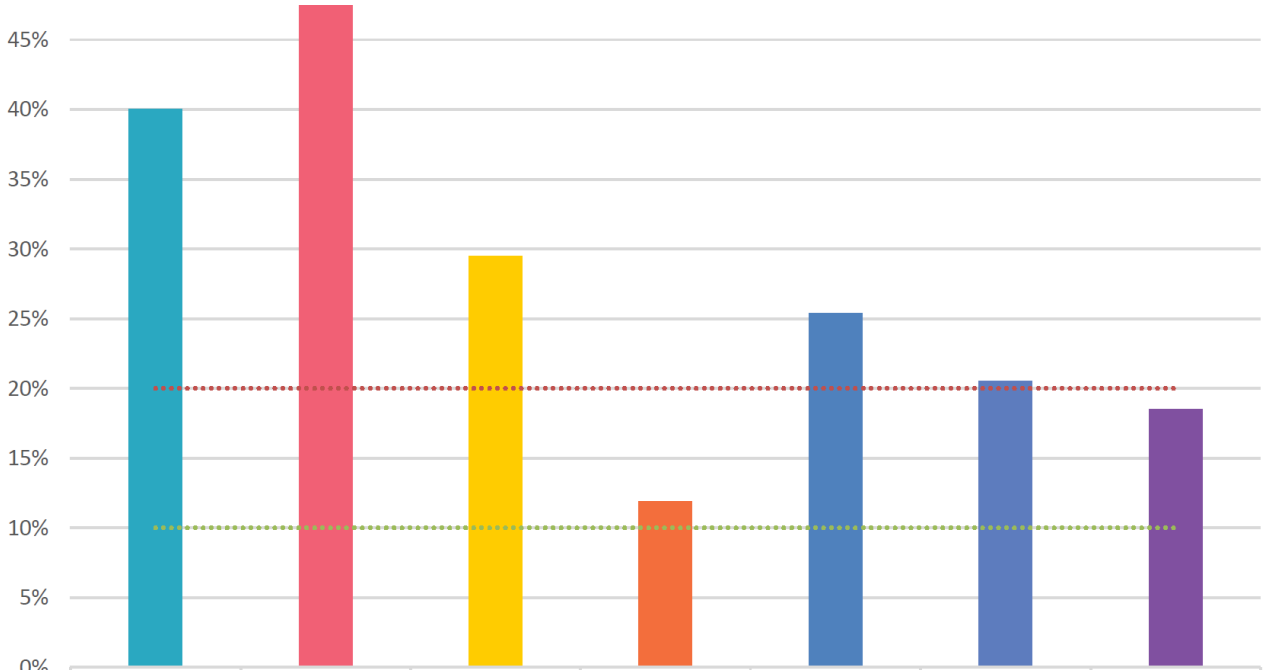
NZS – Annual Solar Exposure



	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
Annual Solar Exposure	40%	47.7%	29.50%	11.9%	25.4%	20.5%	18.5%
Allowable	20%	20%	20%	20%	20%	20%	20%
Recommended	10%	10%	10%	10%	10%	10%	10%

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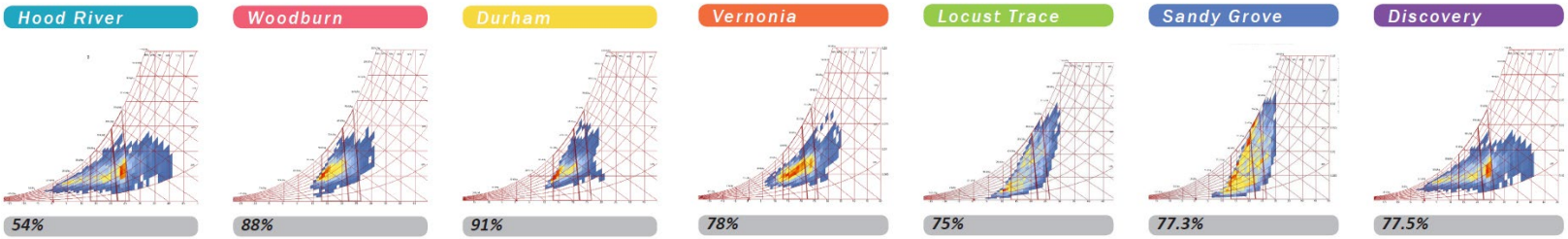
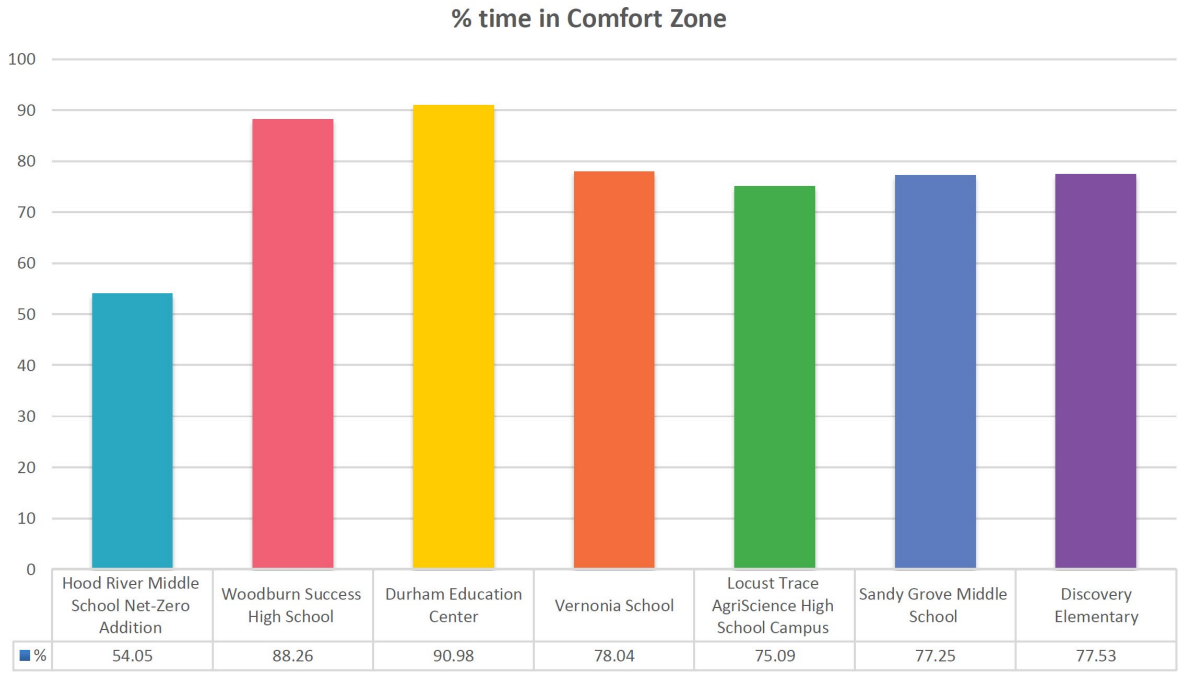
NZS – Percent of Time in Indoor Comfort Zone

Psychometric Chart

Percentage of Time in the Comfort Zone





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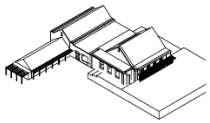
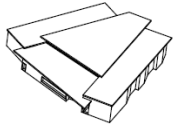
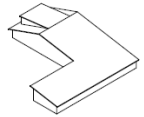
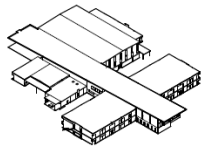
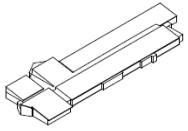
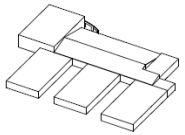
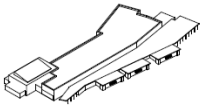
Net-Zero Schools Design Guidelines

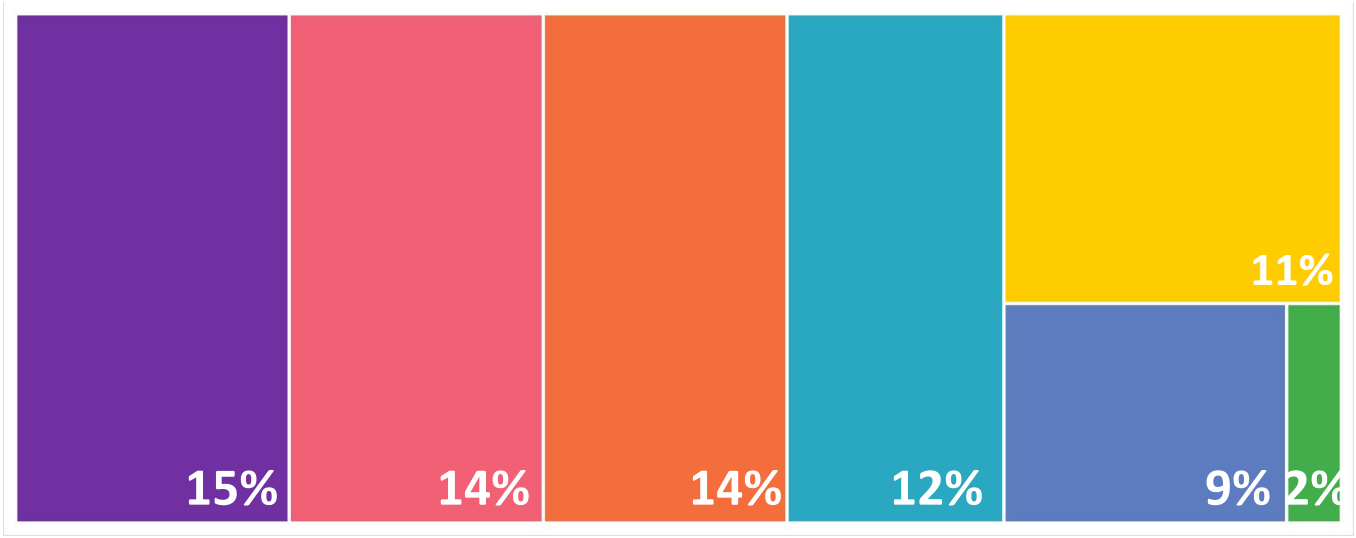
NZS – School Siting & Massing

Shape Factor

Building Massing + Roof Form

South-West Isometric

Hood River	Woodburn	Durham	Vernonia	Locust Trace	Sandy Grove	Discovery
Sawtooth / Gable	*Flat*	*Gable w/ Roof Monitor*	*Sloped / Flat*	*Shed*	*Gable / Flat*	*Flat w/ Roof Monitors*
						
2.22	*1.87*	*1.81*	*1.31*	*1.31*	*1.52*	*1.08*



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

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NZS – South Facing Classrooms Optimization

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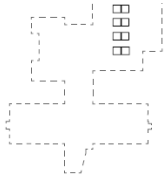
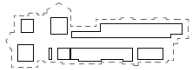
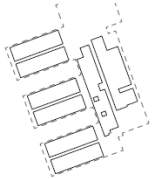
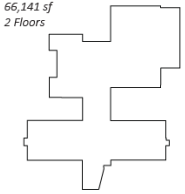
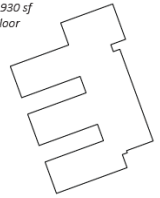
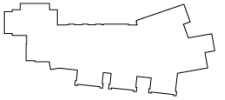
NZS – PV Roof Areas

PV Area %

Annual Electricity Produced
# of Units
PV area (% of total Floor Area)
Solar Energy Utilization Index

Footprint

Typical Floor Area

	Hood River	Woodburn	Durham	Vernonia	Locust Trace	Sandy Grove	Discovery
		 Ground Mounted					
PV Area %	42,368 kWh 1,873 sf (37%) Solar EUI: **28.16**	298,010 kWh 12,900 sf (0) Solar EUI: **86.86**	140,000 kWh 8,398 sf (50%) Solar EUI: **31.74**	41,600 kWh 2,583 sf (2%) Solar EUI: **1.07**	211,630 kWh 16,287 sf (34%) Solar EUI: **15.04**	768,972 kWh 38,328 sf (50%) Solar EUI: **34.53**	354,300 kWh 35,131 sf (36%) Solar EUI: **12.38**
	37%	**0**	**50%**	**2%**	**34%**	**50%**	**36%**
Typical Floor Area	2,566 sf 2 Floors	11,700 sf 1 Floor	7,520 sf 2 Floors	66,141 sf 2 Floors	47,994 sf 1 Floor	75,930 sf 1 Floor	48,794 sf 2 Floors
							
	Bar	**Cluster**	**L-Shape**	**H-Shape**	**Bar**	**Finger**	**Bar / Cluster**

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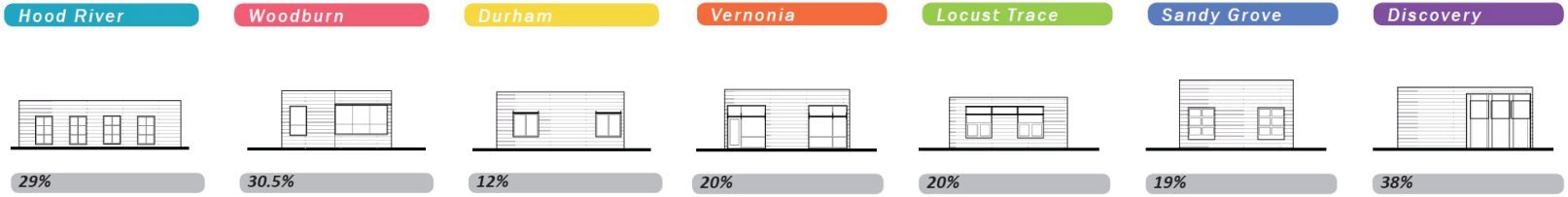
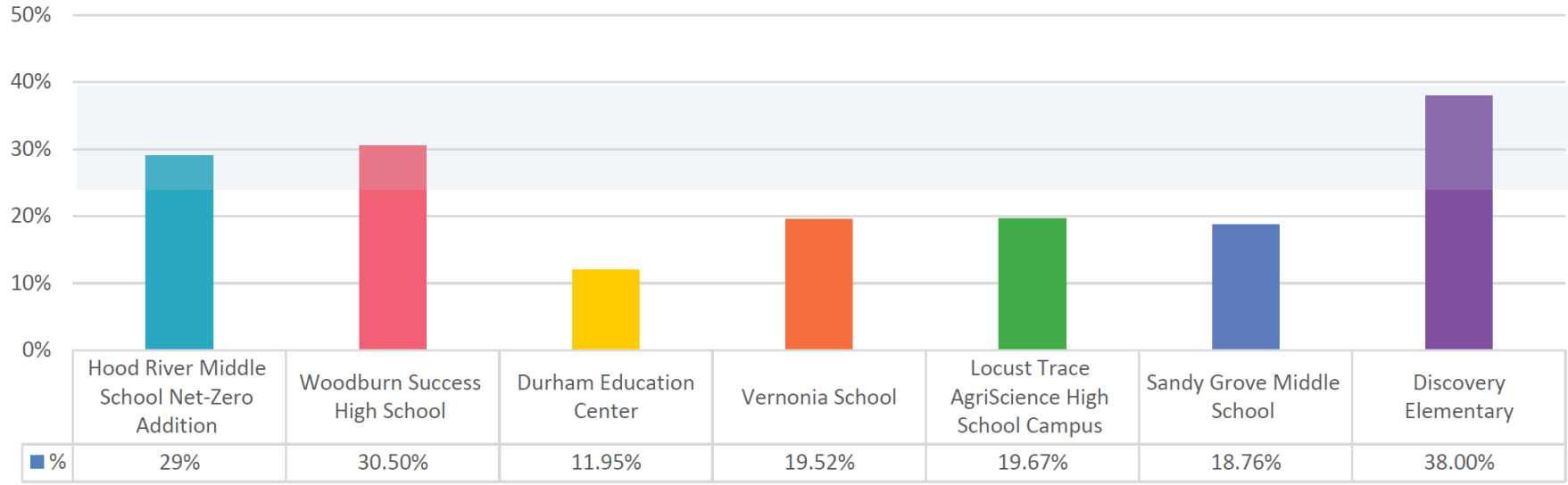
NZS – Classroom Window-To-Wall Ratio

WWR
Window-to-Wall Ratio
Typical Classroom





	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
%	29%	30.50%	11.95%	19.52%	19.67%	18.76%	38.00%

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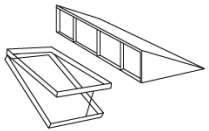
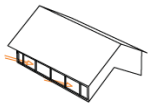
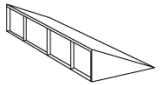
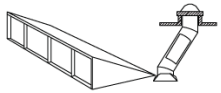
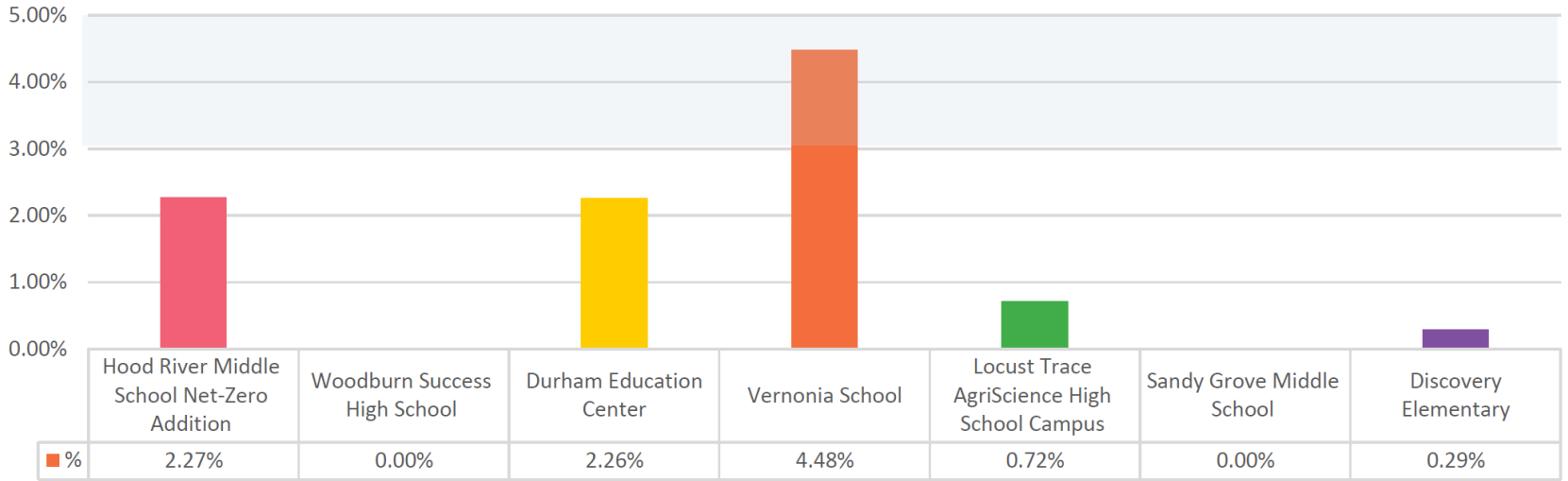
NZS – Classroom Toplight-Floor-Ratio

SFR

Skylight-to-Floor Ratio

Typical Classroom

Hood River	Woodburn	Durham	Vernonia	Locust Trace	Sandy Grove	Discovery
Clerestory + Skylights	No Classroom Toplight	Clerestories	Variety of Skylights	Clerestory + Skylights	No Classroom Toplight	Skylights
						
2.27%	0	2.26%	4.48%	0.72%	0	0.29%



	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
%	2.27%	0.00%	2.26%	4.48%	0.72%	0.00%	0.29%

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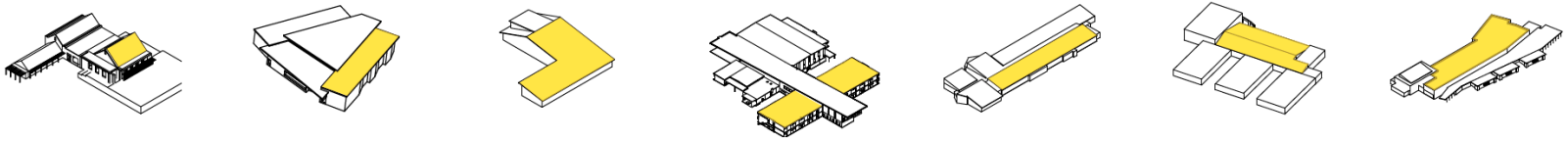
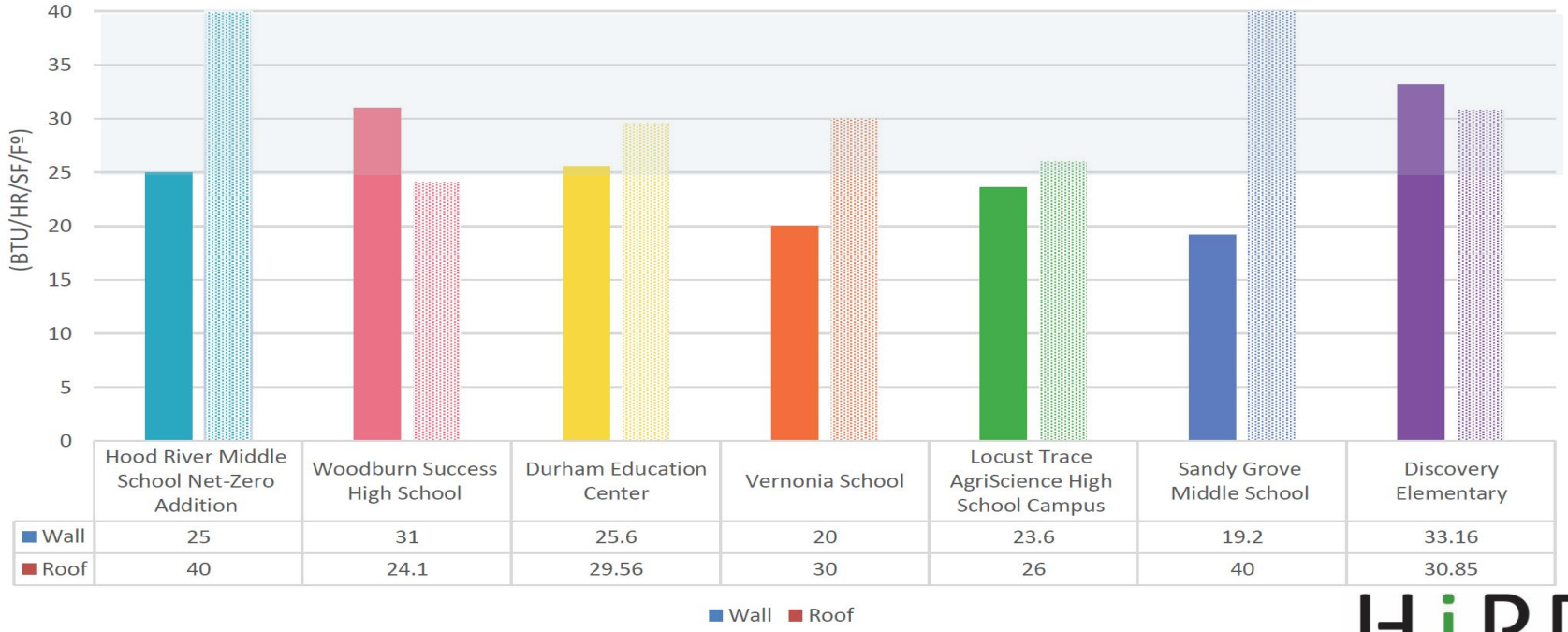
NZS – Envelope Insulation Values

Overview

Typical Roof Area

Hood River | Woodburn | Durham | Vernonia | Locust Trace | Sandy Grove | Discovery





	Hood River Middle School Net-Zero Addition	Woodburn Success High School	Durham Education Center	Vernonia School	Locust Trace AgriScience High School Campus	Sandy Grove Middle School	Discovery Elementary
Wall	25	31	25.6	20	23.6	19.2	33.16
Roof	40	24.1	29.56	30	26	40	30.85

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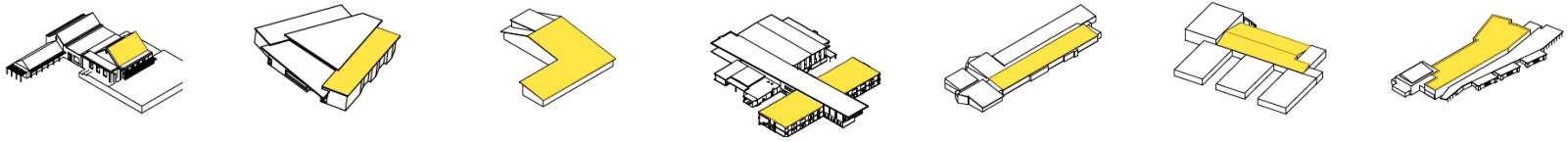
NZS – Patterns of Success

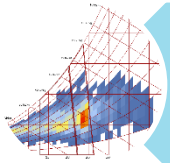


Design Process

Design Strategies

Building Performance

Envelope Performance



Indoor Comfort

Site Performance

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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.

Site Plan

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.

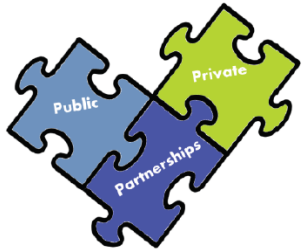
Most buildings surrounding Durham Center Alternative School are a mix of residential homes and one to two story commercial stores and factories.

Bird's Eye View of Surrounding Neighborhood. Courtesy of Google Earth.

Building Height Comparison. Courtesy of BORA Architects.

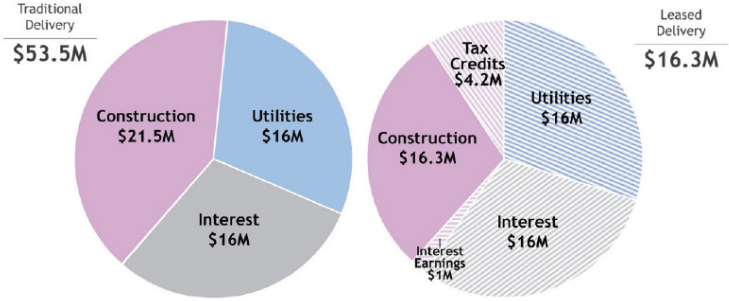
P3 Advantages:

- 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.



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NZS – Patterns: Design Strategies

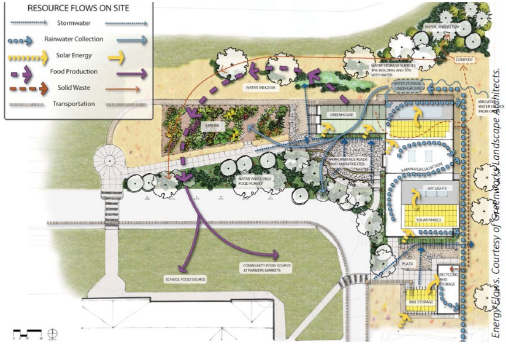
Net Zero Energy Design

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*
- *100% LED lighting*
- *1,706 roof mounted solar panels*
- *Insulated concrete exterior walls with high thermal mass*
- *A geothermal well field*
- *A geothermal well field*
- *Solar pre-heat of domestic water*
- *Solar pre-heat of domestic water*

Architecture as a Teaching Tool

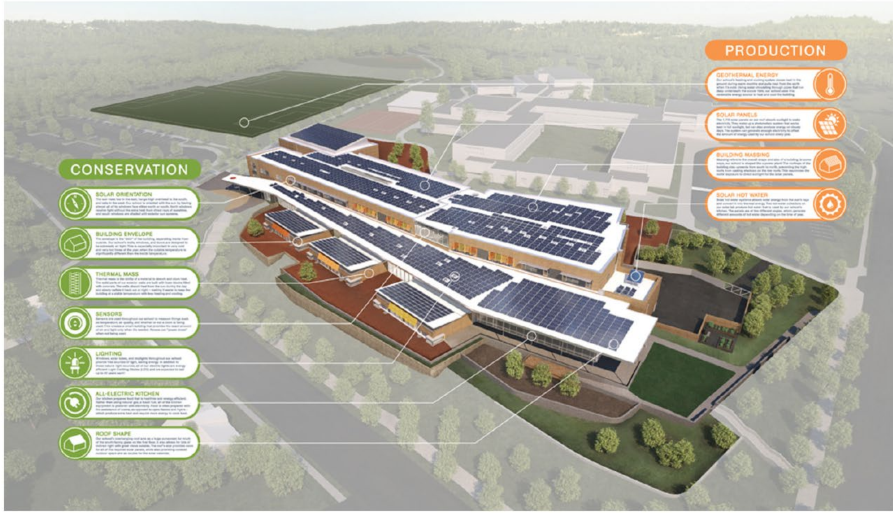
- Students have physical access to the greenhouse and its bio-filter.
- Students have visual accessibility to building's systems.
- Students have access to the building's geothermal and water system throughout the building.
- Wall & Floor Assemblies visible through glass for an understanding of how it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



Energy Flows. Courtesy of GreenWorks Landscape Architects.

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.



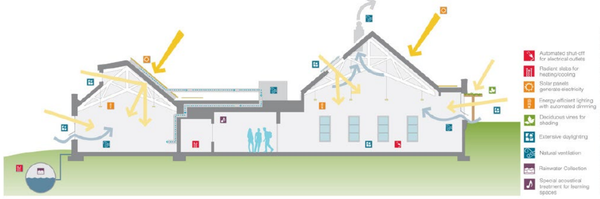
Net zero strategies Rendering. Courtesy of VMDO Architects.

Resource Management

Visible Systems

Solar Roof near

Truth Windows + Interpretive Signage



Section Drawing highlighting Passive Strategies. Courtesy of Opsis Architecture.

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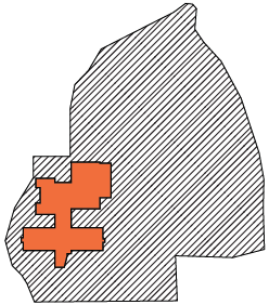
NZS – Patterns: Site Performance

- *school district area: 24 sq.mi.*
- *longest distance across district: roughly 6 miles.*
- *walk-score:* ***58***

School district boundary catchment map.

Site to Building Ratio



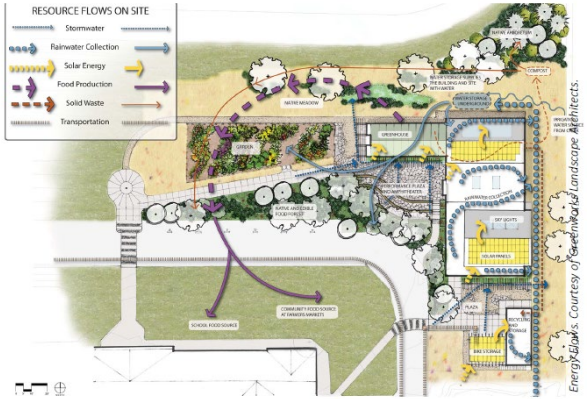
Built Up Area.

14% built up area.

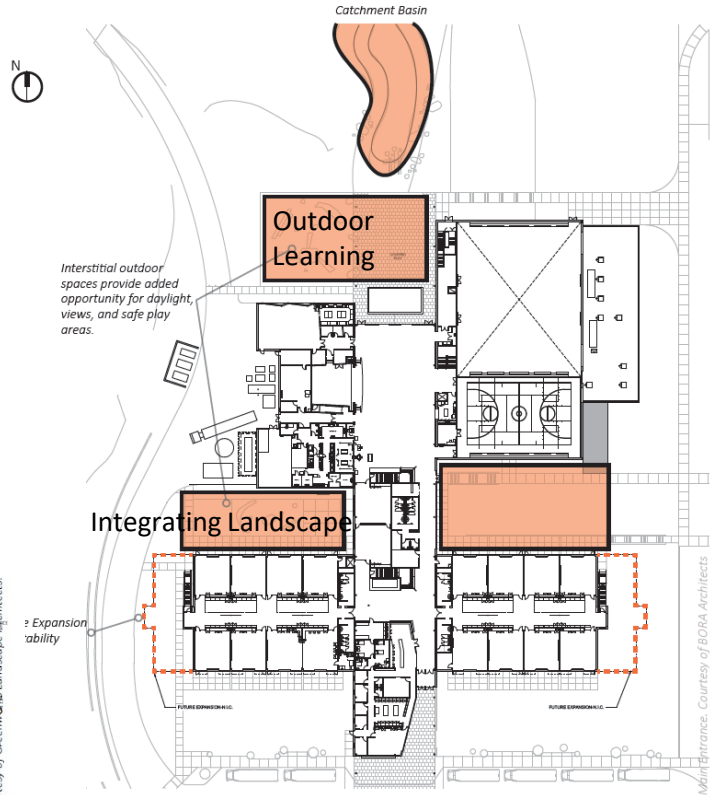
Set on corner of site due to access to nearest road. Also placed there due to it being the point of least obstruction on its landscape.

Resource Flows on Site

Resources include: rainwater, solar energy, food production, solid waste, people.



Energy Blocks. Courtesy of Sweetwater Landscape Architects.



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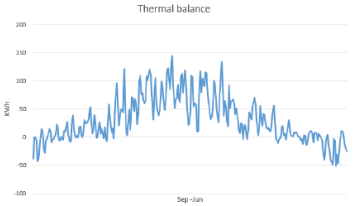
NZS – Patterns: Building Performance

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.

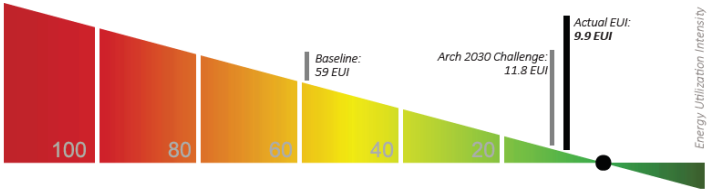


Thermal Balance Chart

Energy Utilization Intensity

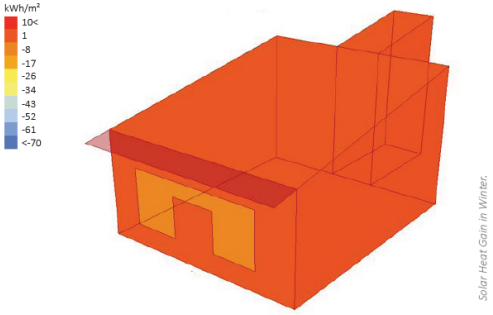
Actual EUI: ***9.9***

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).



Winter Heat

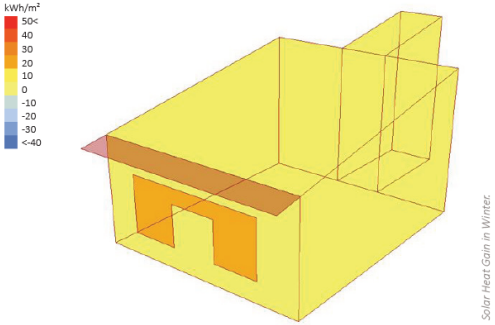
Major heat gain and loss in Winter. Surfaces are gaining above 10 KWh per sq. meter. Openings are losing roughly 17 KWh per sq.meter.



Solar Heat Gain in Winter.

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.



Solar Heat Gain in Winter.

Energy Metrics

Mechanical Equipment (kWh)	*Lighting/ Plug Loads (kWh)*	*Total Power Consumption (kWh)*	*PV Energy Production (kWh)*	*Net Power Consumption/ Production (kWh)*
NA	***NA***	***188,600***	***211,630***	***+ 23,030***

Energy Reduction Investments

Solar beyond PVs

Daylighting Controls

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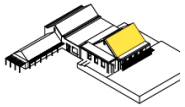
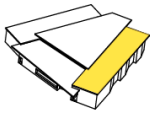
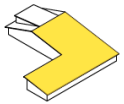
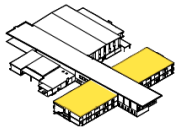
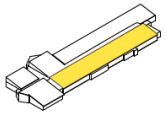
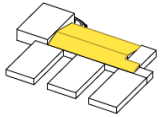
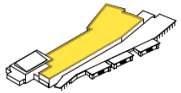
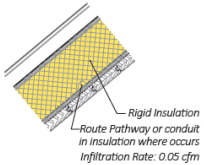
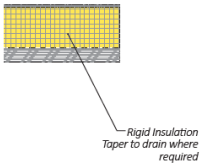
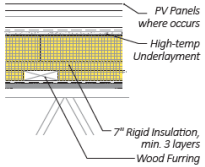
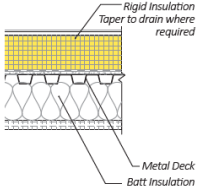
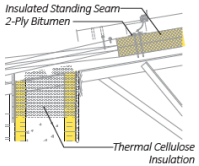
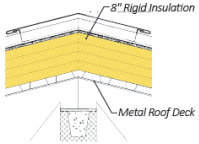
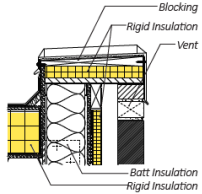
NZS – Envelope Performance

	Hood River	Woodburn	Durham	Vernonia	Locust Trace	Sandy Grove	Discovery
Overview Typical Roof Area							
Roof Typical Roof Detail							
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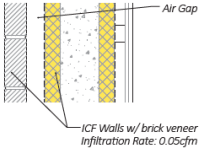
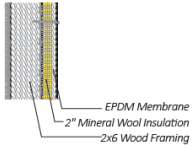
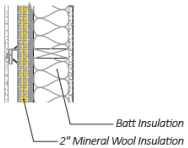
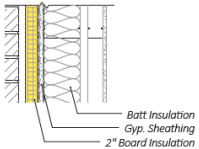
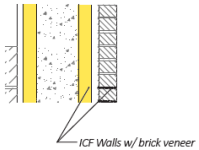
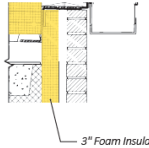
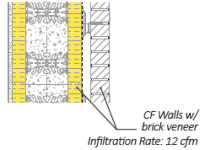
Wall Typical Wall Detail							
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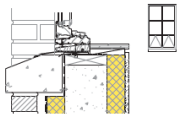
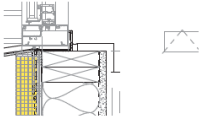
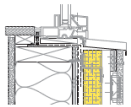
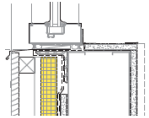
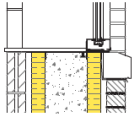
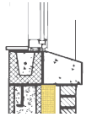
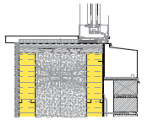
Window Sill Typical Window Detail							
	Triple Glazed Windows SHGC: 0.30 Vis. Transmittance: 0.38	SHGC: 0.27 Vis. Transmittance: 0.26	SHGC: 0.27 Vis. Transmittance: 0.65	SHGC: 0.44 Vis. Transmittance: 0.7	Triple Glazed Windows SHGC: 0.36 Vis. Transmittance: 0.65	SHGC: 0.23 Vis. Transmittance: 0.28	Triple Glazed Windows SHGC: 0.36 Vis. Transmittance: 0.65
	R 3.33	**R 6.1**	**R 3.45**	**R 3.33**	**R 3.85**	**R 3.85**	**R 2.17**

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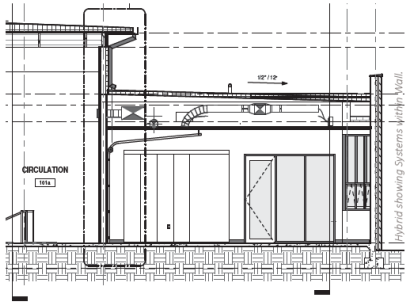
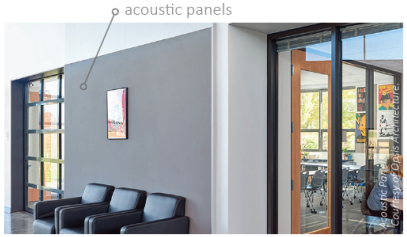
NZS – Patterns: Indoor Comfort



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; a insulation 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.

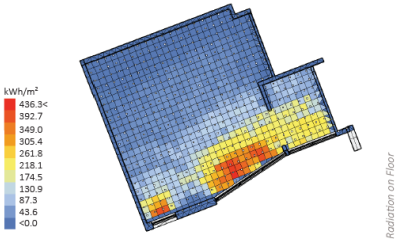


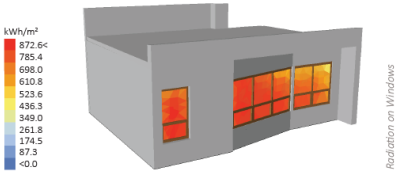
Air

The air management system works similarly to the thermal management system in this building. Side wall diffusers within the inner walls of classrooms pump air into the large common area in order to maintain steady air flow and low carbon dioxide build-up to avoid impacting the health of students in this learning environment.

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.



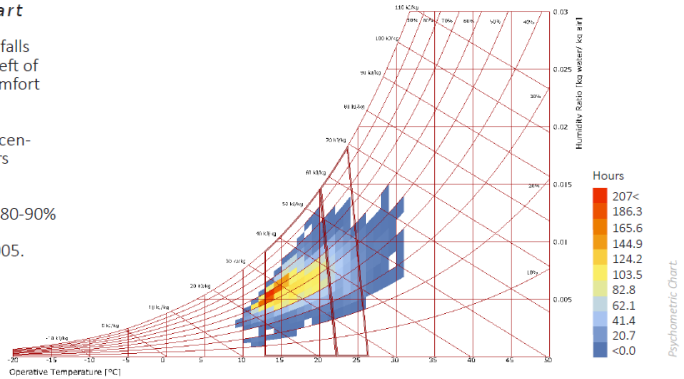


Psychometric Chart

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/kJ
- Humidity ratio: 0.005.

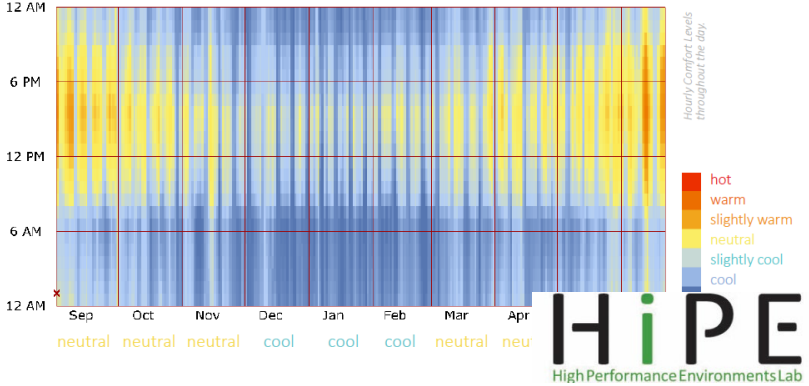


ASHRAE Thermal Sensation

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%**



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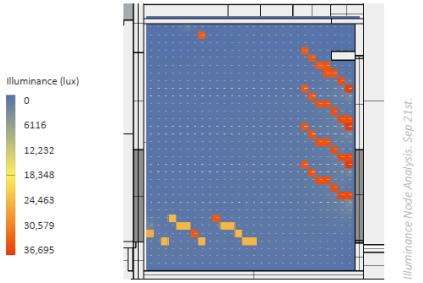
NZS – Patterns: Daylight Management

Daylighting

The spaces were designed so that even amounts of daylight can penetrate deep into the space. To acheive 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 (DA300lux[50%])	*84% of floor area*
Mean Daylight Factor	*4.0%*
Occupancy	*3650 hours per year*

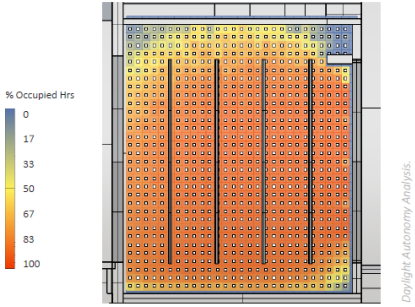
As an example, a point indicating semi-red color in the area means that 84% of the occupied time, that point meets the criteria of having daylight factor of 300 lux or above.

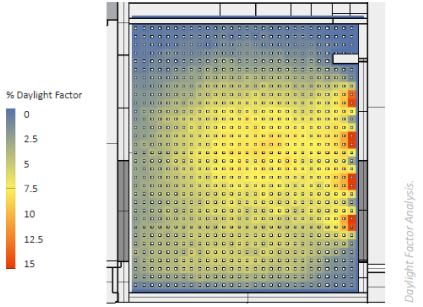
Illuminance Node Analysis

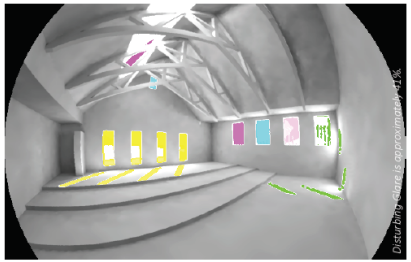
Mean illuminance: ***2017.47 lux*** (each point's value is available)

Daylight Factor

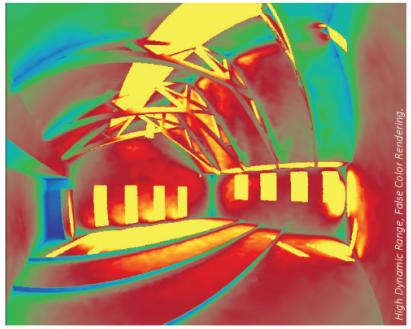
Mean daylight factor = ***4.12 %***
The daylight factor for 99.8% of the area is between 0 & 15 %
The daylight factor for 0.2% of the area is above 15%

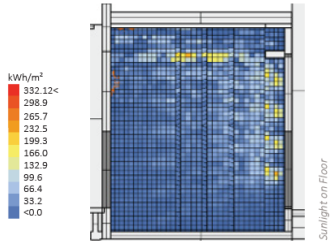






Daylight Glare Probability is approximately ***41%***.





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).

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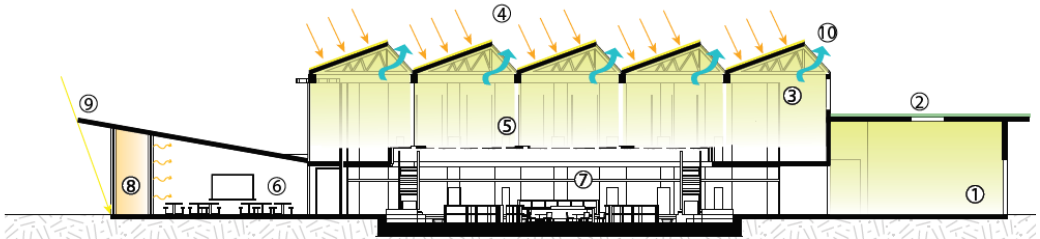
NZS – Design Approach

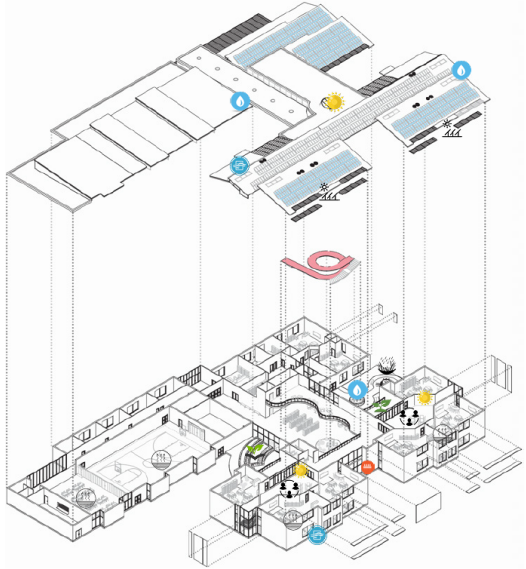
- Integrated participatory design
- Engaging stake holders
- Embracing passive systems
- Setting-up proper metrics
- Shoe-box performance simulations
- Feed-back loops – Iterative design



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

DESIGN GOALS

ECO-EDUCATION
THERMAL MASS
NATURAL VENTILATION
NATURAL DAYLIGHTING
FLEXIBLE SPACE
SOLAR SHADING
OUTDOOR CLASSROOM
RAINWATER HARVESTING
RADIANT FLOOR
BIO-SWALES



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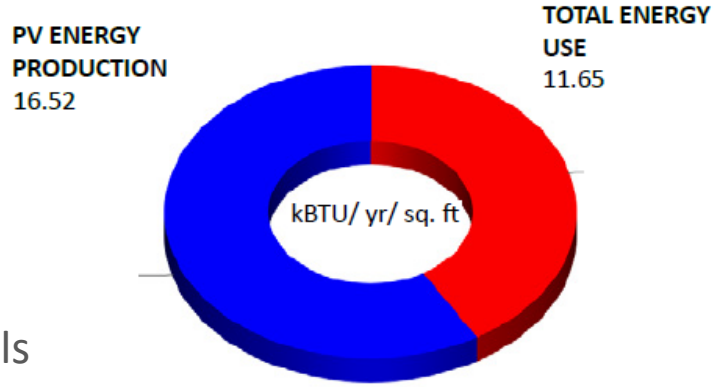
NZS – Design Resources

- 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.



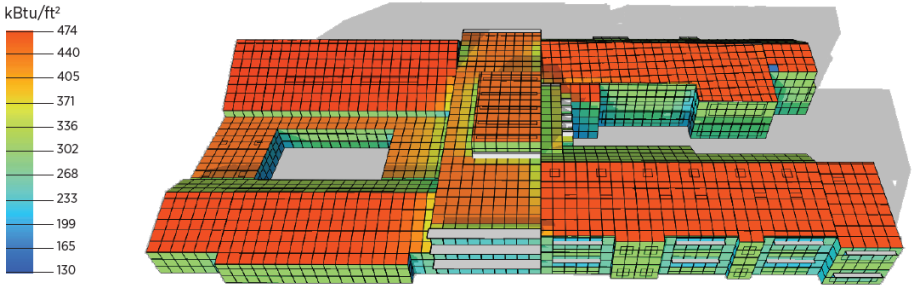
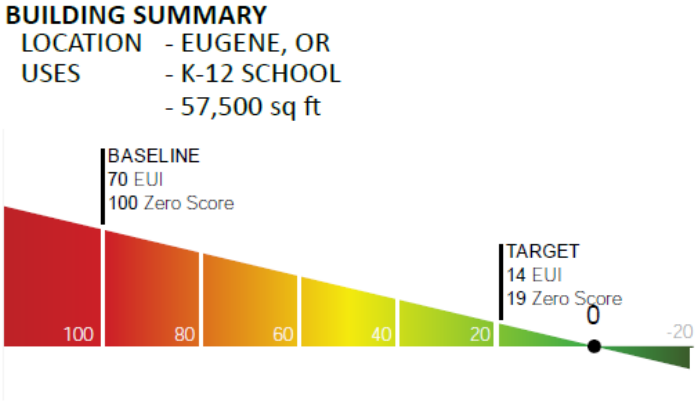


Figure 31: Full Building Energy Analysis



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.

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FOR MORE INFORMATION

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