Net-Zero Schools
from Process to Impacts

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UNIVERSITY OF OREGON

HiPE
High Performance Environments Lab

December 2019

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Final Report
December 2019

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This research has been supported by an *Energy Trust of Oregon, Inc.*, Net Zero Fellowship grant.

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Introduction

Summary

How can we remove barriers to net-zero schools design and delivery? This book reports on a comprehensive project that took a deeper look at a sample of exemplary Net-zero schools built within the last decade to specifically answer this question. The project compiled a data base of newly-constructed Net-Zero Schools (NZS) in the US and documented them on a number of building performance metrics that included their design process, design strategies employed, performance goals, as well as their designs for the site, building, envelope, and indoor environmental quality performance that impact occupants' comfort, satisfaction, and well-being. In addition to evaluating the verified schools as products, the study uncovered the processes of which design teams followed with the various stake holders, school districts, and economic analysis to design and deliver these exemplary educational buildings. The project employed a comparative case study survey design to systematically collect building and site design and performance data for the studied schools.

Out of 41 verified NZS buildings, we have focused the study on seven climatically-relevant schools to the Oregon context. This study highlights the best design strategies by gathering metrics from a combination of the design documentation and indoor environmental quality simulations. Four schools are located in the Oregon valley climate zones and the three other exemplary schools are located outside the state of Oregon but in climate zones that represent similar conditions experienced in the high desert and coastal regions of the state. While directly focusing on buildings that represent and impact the building industry in the state of Oregon, the results provide lessons and conclusions that are applicable to other neighboring states as well as the NZS design and construction worldwide. The study highlights 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 Performance. The research project resulted in a booklet of cross-cutting best practices, patterns, and detailed case studies that provide added-value to architects, engineers, and school district administrators by empowering them to build net-zero schools in their districts.

Introduction

School buildings are impactful to the environment, students, and educational districts. They approximately consume 30% of the nation's electricity, generate 35% of our waste, use 8% of water resources and are responsible for 20% of greenhouse gas (GHC) and carbon dioxide emissions. Unfortunately, these are buildings where 55 million students and teachers attend and occupy daily in the US. The EPA estimates that 40 percent of our nation's 115,000 schools suffer from poor environmental conditions that may compromise the health, safety, and learning of more than 14 million students (USGBC, 2008). In fact, according to the American Society of Civil Engineers, our educational buildings are in worse condition than any other infrastructure, including prisons. School buildings have four times the number of occupants per square foot than most work environments. Many school districts are realizing these challenges, for example Portland Public Schools (PPS) has identified a major strategy to "build, operate, and teach green." Despite these interests and objectives, the number of net-zero schools' square feet in Oregon is less than 2% of the school buildings area built in the past decade. Evidence suggests that non-energy barriers and an understanding of the real benefits and impacts of net-zero schools on people's social, environmental and financial needs are not fully understood and acknowledged.

The objective of this book is to target this problem through an analysis of best practices and building performance metrics of NZS that highlights non-energy benefits and barriers to this building type. Research tasks for this book were conducted in three phases. In phase I, we collected data from design teams, school districts, and web resources on recent net-zero schools in the US using a detailed building performance and measurement protocol. In Phase II, we followed-up with a detailed survey with the design teams, school district representatives, and non-profit organizations engaged in net-zero schools and those who completed non-net-zero schools in the Pacific Northwest recently. The objective of this phase is to uncover design process and delivery barriers to achieve net-zero schools. In phase III, we analyzed the data for a sample of exemplary schools with direct implication to the state of Oregon climate and building practices. This led to seven detailed case studies of exemplary net-zero schools to develop best practices patterns and cases of their successful design, delivery, and performance verification. One of the significant goals of this book is to link net-zero school design best practices with their impact on occupant comfort and satisfaction. Of

corollary interest is to uncover best methods of design process, communication, and engaging school officials and districts in achieving net-zero schools. The hope is to provide a comprehensive decision support tool for practitioners and school principals that will help them prioritize and evaluate net-zero school strategies in a holistic way.

This book is developed to:

- Facilitate integrated design and cooperation between NZS designers,
- Reduce environmental impacts and move us towards carbon neutrality environments in schools,
- Have a potential to be a model for future replication and dissemination,
- Expand the Energy Trust products and tools that engage stake holders and result in market transformation in resolving non-energy barriers to net-zero schools.

Knowledge Domain

Domain of Architectural Knowledge: K-12 Schools/ learning environments, practice, design, and building performance from an environmental and technological framework.

Knowledge Communities/AIA Research Priorities Served: resiliency, net-zero energy, sustainability, public health and well-being, indoor environmental quality, multi-comfort, design process and delivery.

Photo: Lorie Saull, Washington, USA

Introduction

Research Context

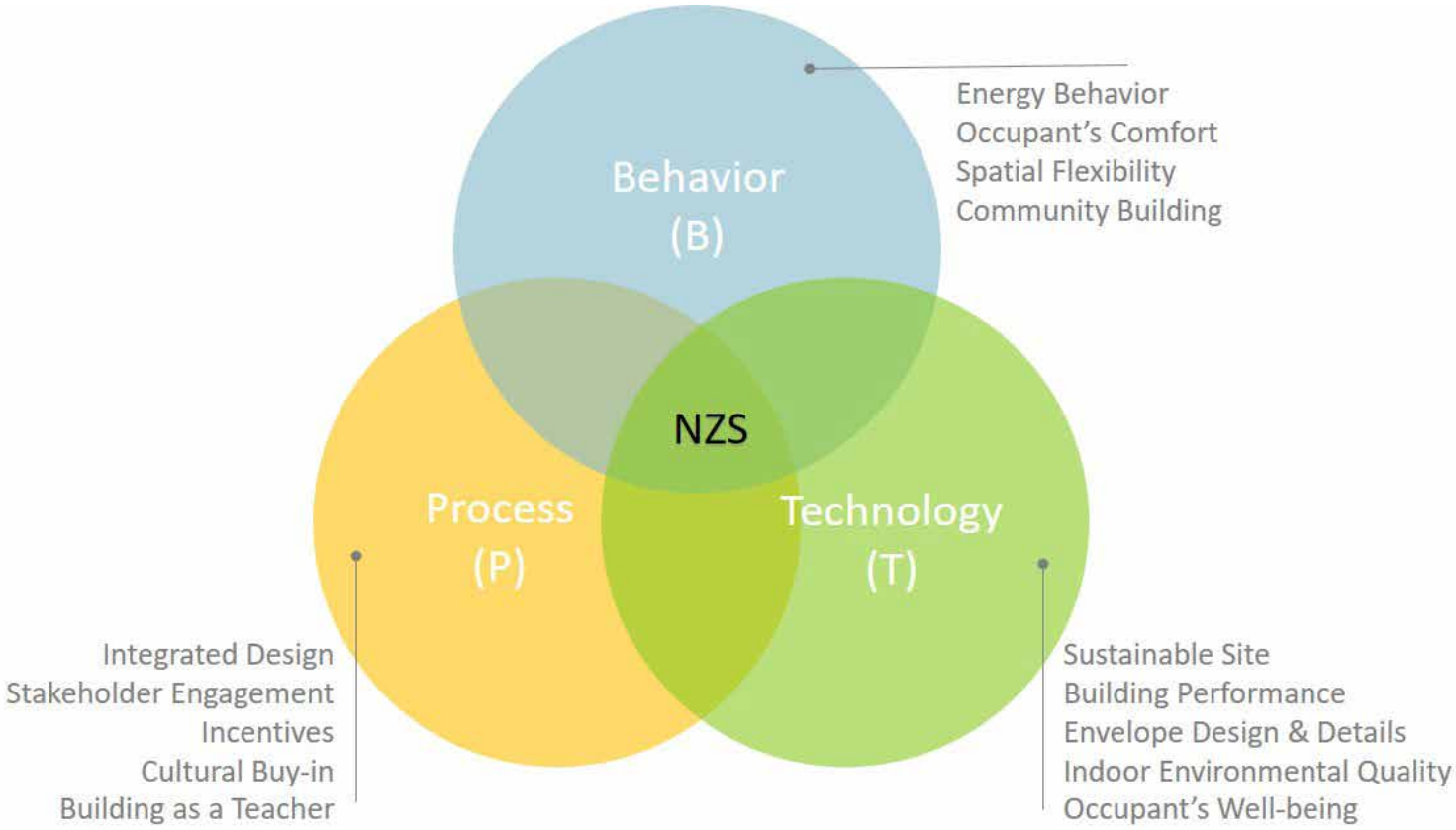
The Department of Energy's Net Zero Energy Commercial Building Initiative aims toward marketable net zero school buildings by 2025 and their mainstream adoption by 2030. At present, buildings intended to be net zero face a long struggle during which the building systems and the occupants' energy use fail to measure up to design expectations. Progress has been hampered by non-energy barriers to net-zero buildings design and delivery. These include--but are not limited to--lack of evidence on the impacts of Net-zero buildings on occupants' performance and comfort, design process, project communication, and project delivery methods between the various school stake holders and the design team. Without reliable evidence-based solutions to these barriers as well as the positive non-energy impacts of these buildings, we will continue to face limitations in design and delivery of net-zero buildings and occupants' perceptions and behavior towards them. This is a problem of huge proportions in the K-12 schools building industry due to the amount of occupied classroom space in the US, which exceeds 20 billion square feet and its market projections of 26% increases yearly (McGraw Hill Marketing Projection 2016). This research project targets this problem by developing an evidence-based practice pattern book to address non-energy barriers to net-zero schools.

There is an urgent need to develop the science and engineering knowledge that will enable designers, architects, and developers to accurately predict energy performance and emissions reductions for net-zero energy buildings. With adequate research and testing, the physical designs can be validated, but no matter how advanced the designs of the net-zero buildings, if architects and engineers do not understand how people interact with and get impacted by them for comfort and energy use, we will continue to face actual energy performance that falls short of design predictions. The national focus on net zero energy and carbon-neutral buildings, clearly part of the public policy framework, will increase the demand on building professionals to provide an array of transformational technologies for these buildings. It will also increase the drive to understand technological performance as well as occupants' behavior and their capacity to adapt their behavior. The human factor is perceived by architects, engineers, developers, and investors to pose risks to tenant satisfaction, organizational productivity and building energy performance. This book squarely addresses these perceptions with findings from empirical studies of real-world occupants and design professionals that transform the process of building design and delivery for net-zero school buildings design and construction professionals.

Conceptual Framework for NZS

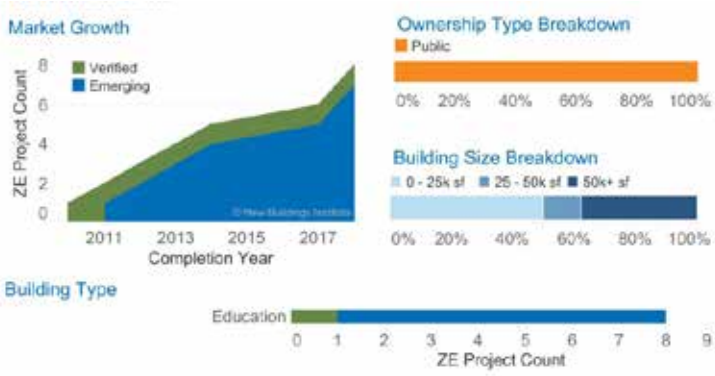
Architects, engineers, and designers lack reliable scientific evidence about the impacts of net-zero energy schools on occupant's comfort, satisfaction and other non-energy benefits such as performance and occupant's well-being. In addition, there is a lack of understanding for best practices in design process of integrated design and project delivery as it relates to net-zero schools. These factors in addition to financial barriers present a host of road blocks that complicate the adoption and implementation of net-zero schools and might limit school districts in considering this approach when embarking on new schools construction projects. Without reliable scientific evidence of the applicability of innovative net-zero design processes and best practices, designers miss the opportunity to apply them in new buildings constructions. They also miss opportunities to properly integrate and implement strategies that might lead to non-energy occupant's benefits and comfort. Architects and designers also lack the evidence-based guidelines and modeling software needed to predict building occupants' energy behavior and comfort to achieve net-zero buildings performance. Factors that are crucial for optimal energy performance might include a factor of reality or understanding of the occupant energy use and discrepancies in operations that need to be considered when modelling and simulating building performance. Such barriers leave occupants and school districts to myths of net-zero buildings as uncomfortable, costly, and hard to predict.

This book highlights optimum performance of net-zero schools (NZS) as a function of integrated design process (P) advanced technology (T) applied to the site, building, envelope, and indoor spaces of buildings, people's behavior (B), and people's interaction with it (PxBxT), or [NZS =ƒ{ (P) + (T) + (B) + (P x B x T)}].



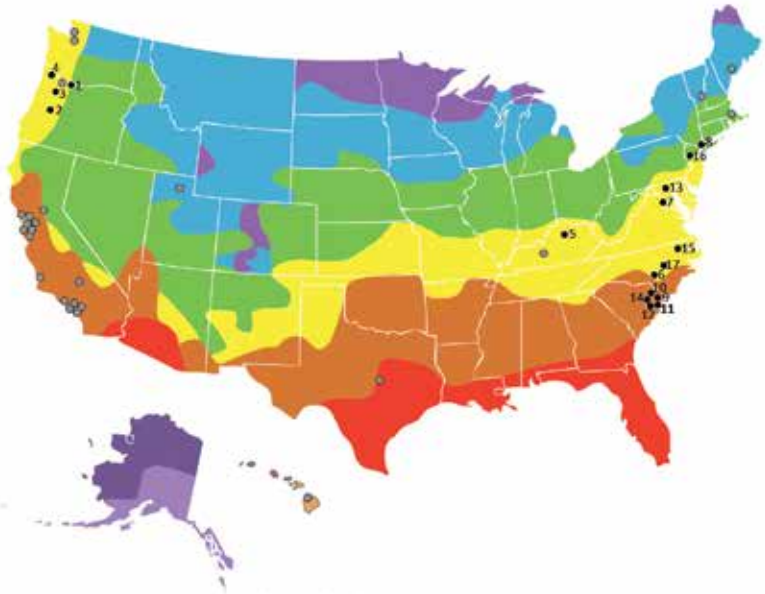
Zooming-in NZS

The project followed a comparative case study approach in three phases. In Phase 1, a net-zero schools survey was conducted on all school buildings constructed within the last decade. For Phase 2, survey of school designers and officials was performed to gather design and performance data of the NZS in our data base. Finally in Phase 3, detailed field studies of seven exemplary net-zero school buildings in both performance and design process/delivery was conducted. Data analysis and coding were performed to develop success patterns of design process and delivery for net-zero schools as well as to document successful design strategies employed and their impact on the triple bottom-line of people, planet, and profit.



NZS Database and Case Study Selections

A survey of K-12 Net-Zero Schools (NZS)--from Phase 1--identified 41 potential schools and educational facilities which are either certified or emerging net-zero buildings. The list was further filtered to eliminate those facilities that consist of a single classroom or small added spaces rather than a substantial portion of a school building. By filtering the list further to eliminate schools that are in climate zones not representative of climate zones 3-5 as well as non-verified schools, the list was further reduced to 17 buildings. We classified them into two sets of priority lists. The first represents seven schools that are located in Oregon or in climate zone mostly representative of Oregon Climates and the second list has 10 schools that are closely related (Phase 2). The seven schools included in our comparative analysis were also reported-on in detailed case studies. Four out of the seven schools represent all schools in Oregon that match the selection criteria of being fully-functional net-zero schools. These four schools are located in the Oregon mid-valley climate zone (ASHRAE CZ 4C), where most of the state's population is concentrated. The additional three schools were included as they represent climates closely related to Oregon's coastal and high desert climate zones.
All school principals and design teams of the selected schools were contacted to provide detailed data on their schools' design, construction, and operations.
In addition to school's construction documents and drawings, we collected environmental analysis reports, LEED™ certification documentation (where applicable), design process notes, incentives earned, awards, and case studies. We have analyzed the data collected from the seven schools in terms of five NZS design strategies: Design Process, Design Strategies, Site Performance, Building Performance, Envelope Performance, and Indoor Environmental Quality (IEQ).



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

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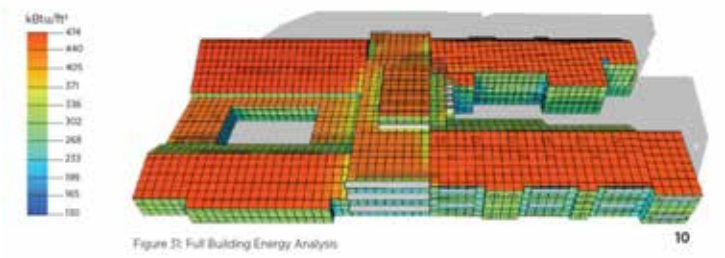
7- Discovery Elementary School

Broader Goals and Impacts

The collaborative work of architects, engineers, and building scientists has the potential to bring net-zero school buildings into a more prominent place in the building market by measuring, and drawing attention to, the triple bottom-line benefits attainable with healthier, more comfortable, and higher-performing buildings. This work is of a pressing national need.

School districts and non-profit organizations are waiting to see evidence that net-zero schools are good investments for children's education. This book is a step towards disseminating these findings and making NZS a wide accepted mainstream building type. Copies of the book are intended to be distributed free of charge electronically and in cost-to-print hard copies.



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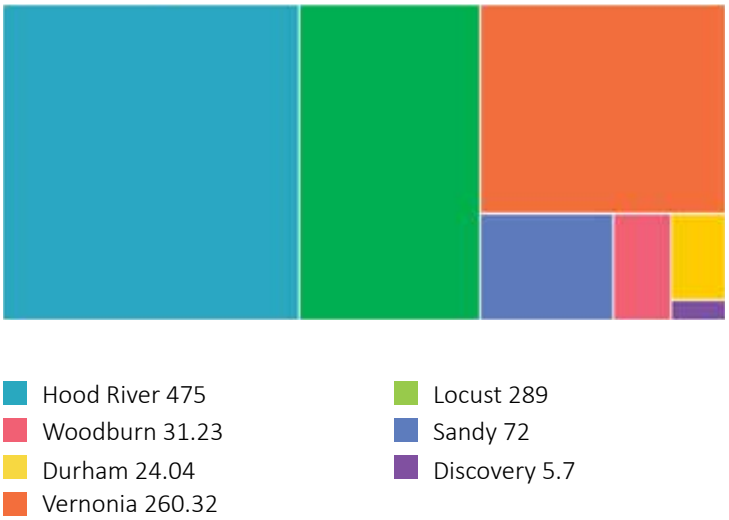
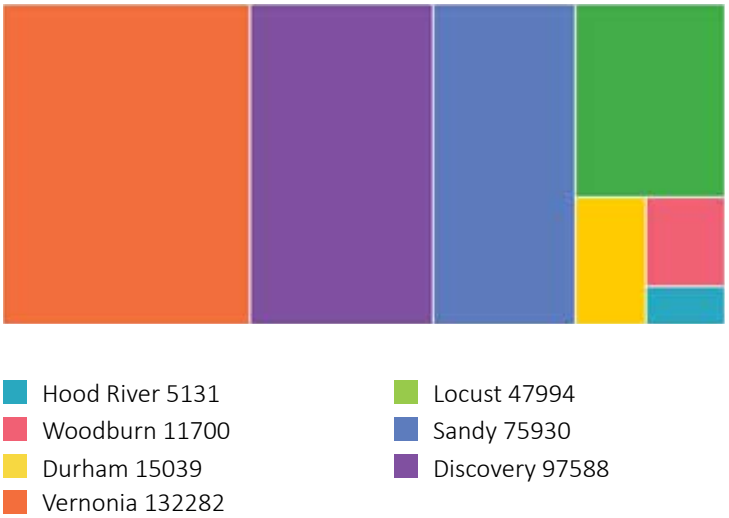
Boundary Area (Sq.Mi)

School's boundary represents the catchment area of households the school is serving. Larger catchment areas place accessibility hardships on a school's staff, teachers, and students as they have to commute longer distances. This limits alternative transportation options, such as walking and biking to school. Hood River School had the largest catchment area of 475 Sq. Mi., while Discovery elementary school had the smallest catchment area of 5.7 Sq. Mi. The smaller the catchment area the more proportional the school size is to the surrounding neighborhood and the residents. A catchment area range of 25-30 Sq. Mi. is recommended for Oregon.



Gross Floor Area (SF)

Net-zero schools were historically limited to small building size. The data collected from the schools studied show that this is no longer the case. Schools surveyed ranged from a small sectional addition of 5,131 SF to a very large school of 132,282 SF. The average building area of NZS schools is 55,000 S.F. This represents the optimum size for K-12 schools especially for elementary and middle schools.



Gross Site Area (acres)

- Hood River 0.98
- Woodburn 2.02
- Durham 3.43
- Vernonia 22.41
- Locust 82
- Sandy 25.56
- Discovery 14.7

Site area is another important metric in planning NZS. A large site area offer opportunities for installation of photovoltaic panels on the ground and the addition of sports fields yet on the other hand it impacts the overall site sustainability due to irrigation and water management impacts. The largest site area in the sample NZS studies is Locust Trace, which occupies 82 Acres site that provides experimental fields for agricultural studies related to this school's curriculum. The smallest site is Hood River School, which occupies a site close of 0.92 Acre. An average area of 10-12 Acres is optimum size for most schools.

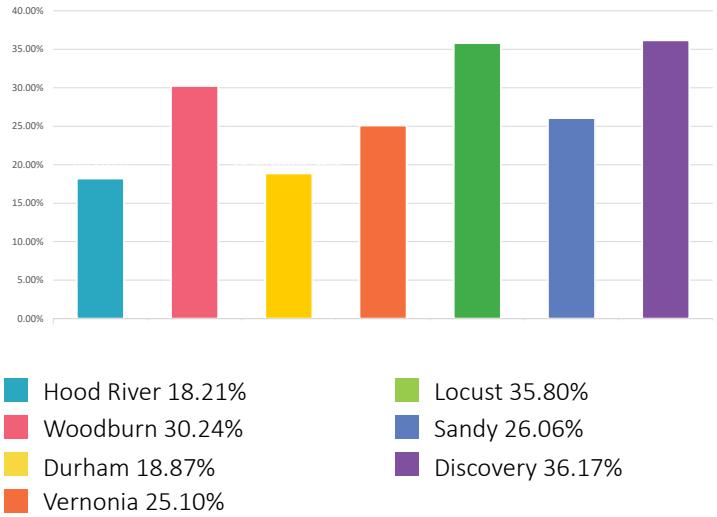
Built up Area (%)

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

This metric refers to the amount of built-up area as a percentage of the entire site. This represents the density of the NZS buildings on the site and provide an indication as to the area of the site that can be more productive for vegetation and outdoor fields. The schools surveyed varied in their built-up area percentages with Locust Trace School being the least dense at 1.32% built-up area due to occupying a very large site. The most dense built-up area NZS is Discovery at 15.3%, which occupies a semi-urban site. The average built-up area is in the range of 11-13%.

South Wall (%)

The percentage of the building walls designed as south facing in the overall massing of the building is an important metric to seek in the early design schematic stages of a NZS. The net-zero schools studied have attempted to increase this percentage to be more than 25% of the overall walls of the school, which is the optimum goal for this metric. This is achieved by stretching the schools massing along the East-West axis. The best case of NZS studied that achieved an optimum performance on this metric is Discover school with a South Wall percentage of 36.1%.



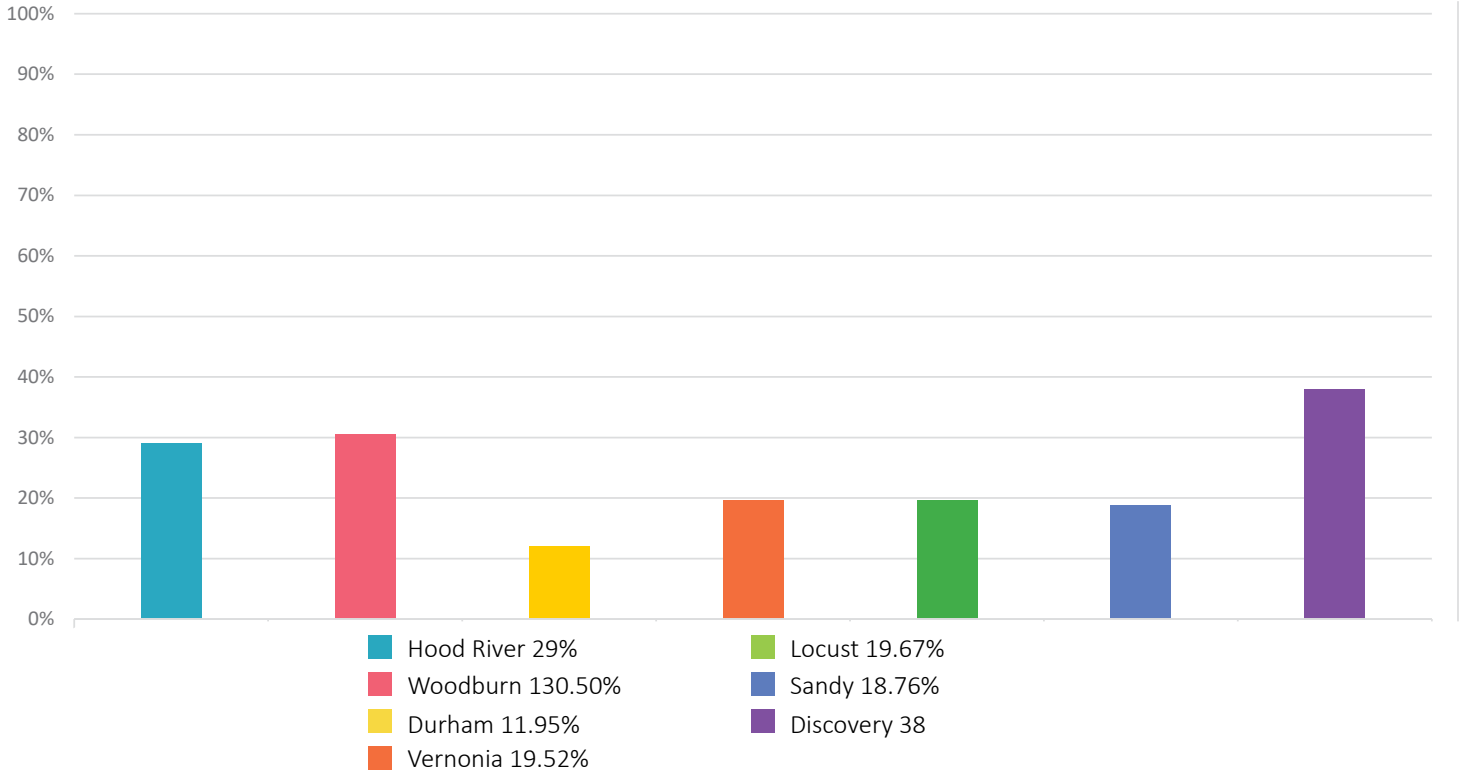
WWR (%)

The window-to-wall ratio (WWR) metric is defined as the percentage of voids areas for windows and door to the total area of the walls of a building. For NZS, lower WWR signifies the ability of the school to provide higher insulation in the walls and reduce infiltration, heat losses, and heat gains due to lower areas of performance in the envelope that is typically the resultant of windows and doors. This metric should be balanced between the reduction of envelope loads to allowing positive gains from windows in the form of daylighting, access to views, and connections to the outdoors. All of which are beneficial for occupant's well-being. For the sampled schools studied, the least WWR of 12% is observed in the Durham school and the most WWR of 38% is achieved in Discovery school. A range of 20-40 WWR is recommended and is best if optimized at lower percentages of 20% WWR.

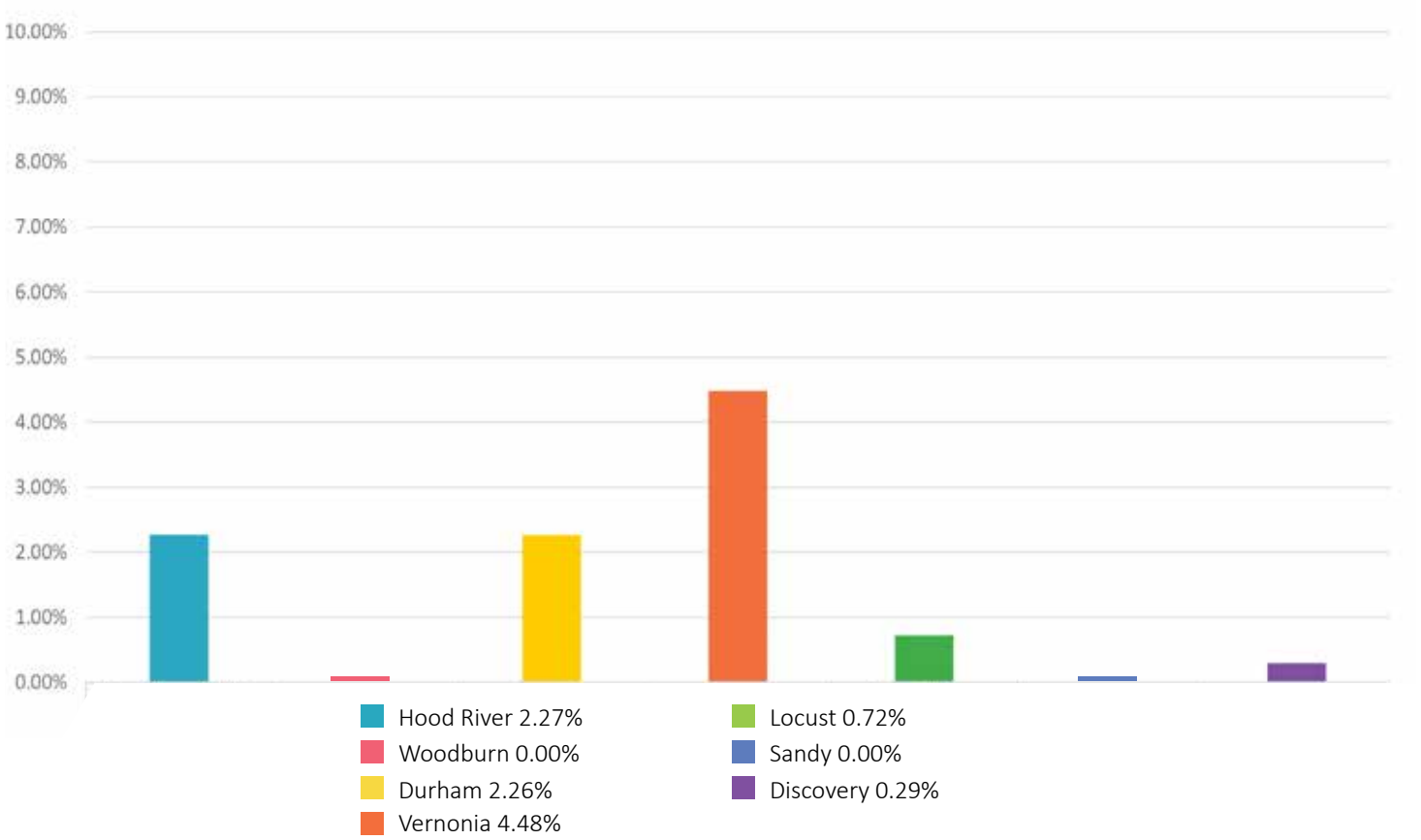
SFR (%)

The Skylights-to-Floor Ratio (SFR) metric represents the area of glazed areas in the roof of the building as a percentage of the total floor area that the glazed area (e.g. skylight) is serving. It is recommended to have an SFR of 3-5% for an optimized skylighting system that provide a good amount of daylighting for the classroom without jeopardizing the thermal performance of the roof assembly. This 3-5% SFR should be distributed evenly over the area of classrooms in modular 2x2' skylights rather than concentrated in smaller areas of the classrooms.

SFR (%)

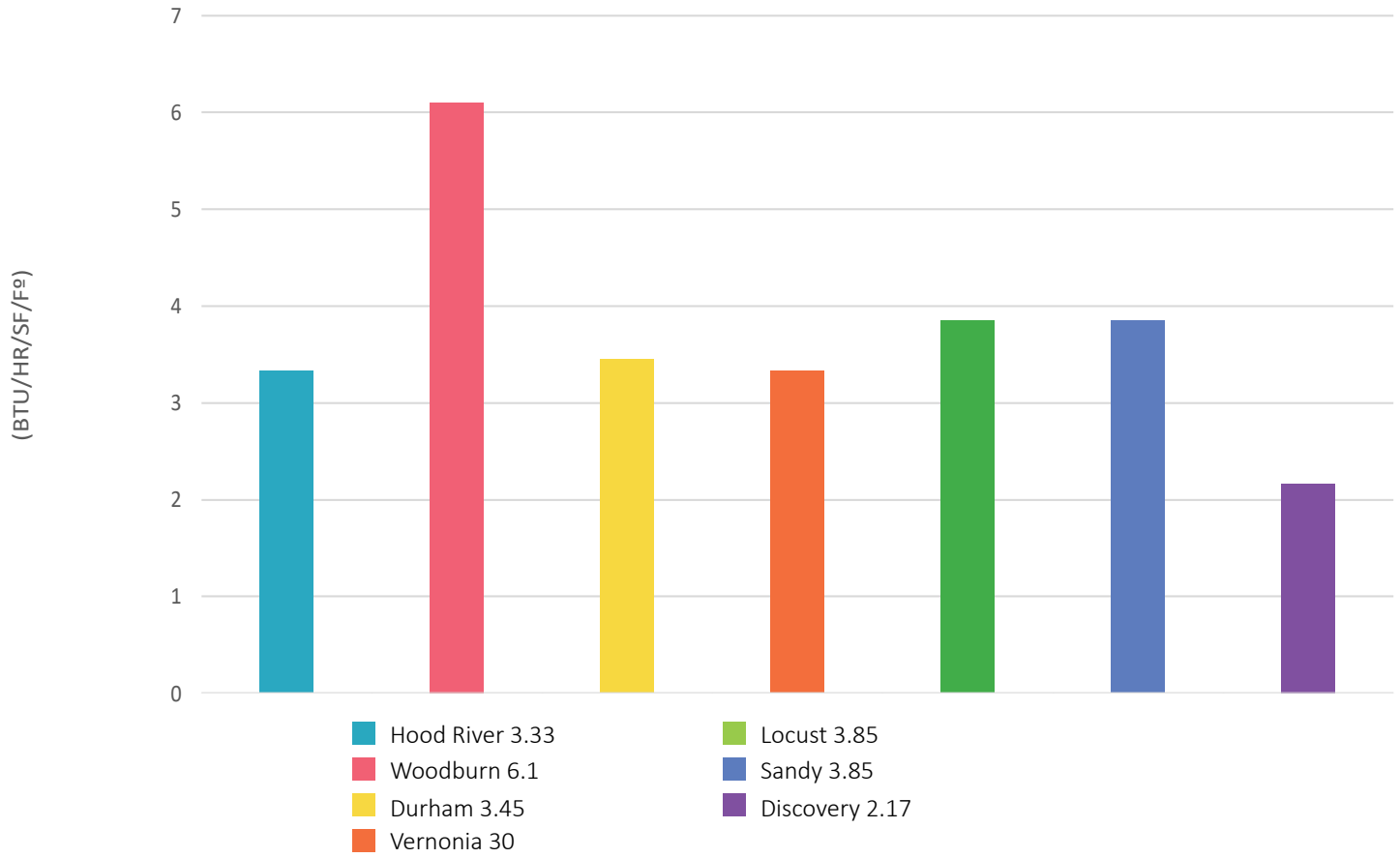

100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Hood River 29%
Woodburn 130.50%
Durham 11.95%
Vernonia 19.52%
Locust 19.67%
Sandy 18.76%
Discovery 38

WWR (%)


10.00%
9.00%
8.00%
7.00%
6.00%
5.00%
4.00%
3.00%
2.00%
1.00%
0.00%
Hood River 2.27%
Woodburn 0.00%
Durham 2.26%
Vernonia 4.48%
Locust 0.72%
Sandy 0.00%
Discovery 0.29%

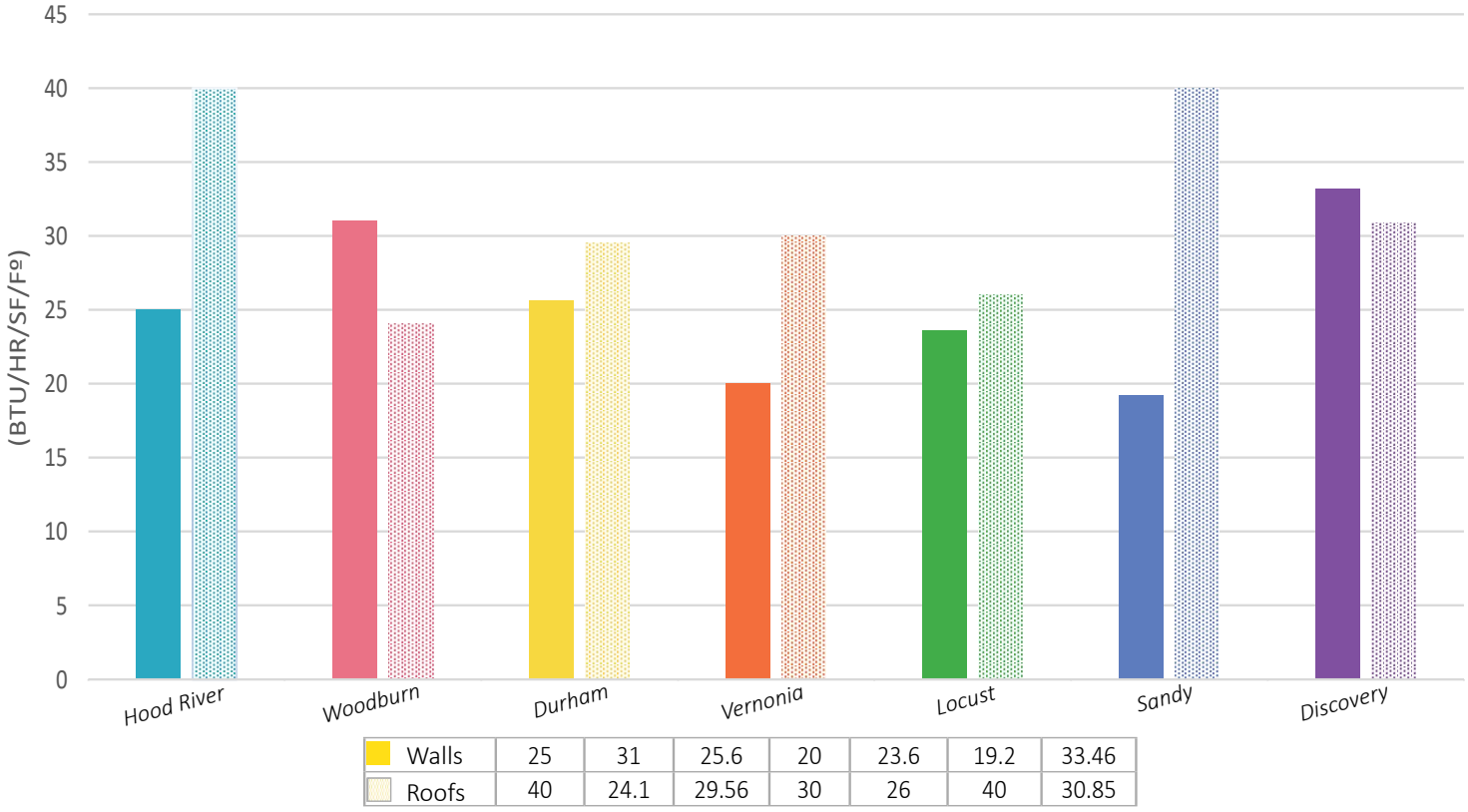
Windows R-value

Thermal conductivity of the widows represents the total insulation coefficient of an integrated glazing unit. It is typically expressed in U-value or R-value (R=1/U). Window assemblies in commercial buildings have traditionally been the weakest points of the envelope thermal resistance due to low R-values of conventional double-pane commercial glazing. This fact has changed drastically over the last decade since triple and quadruple pane are becoming viable and cost-effective options over the long-range. The average window assemblies of NZS is close to R-4. High performance quadruple pane windows of R-6 and R-10 are starting to become more available and economical, while traditional R-2 (double pane low-e windows) are becoming less desirable and obsolete.



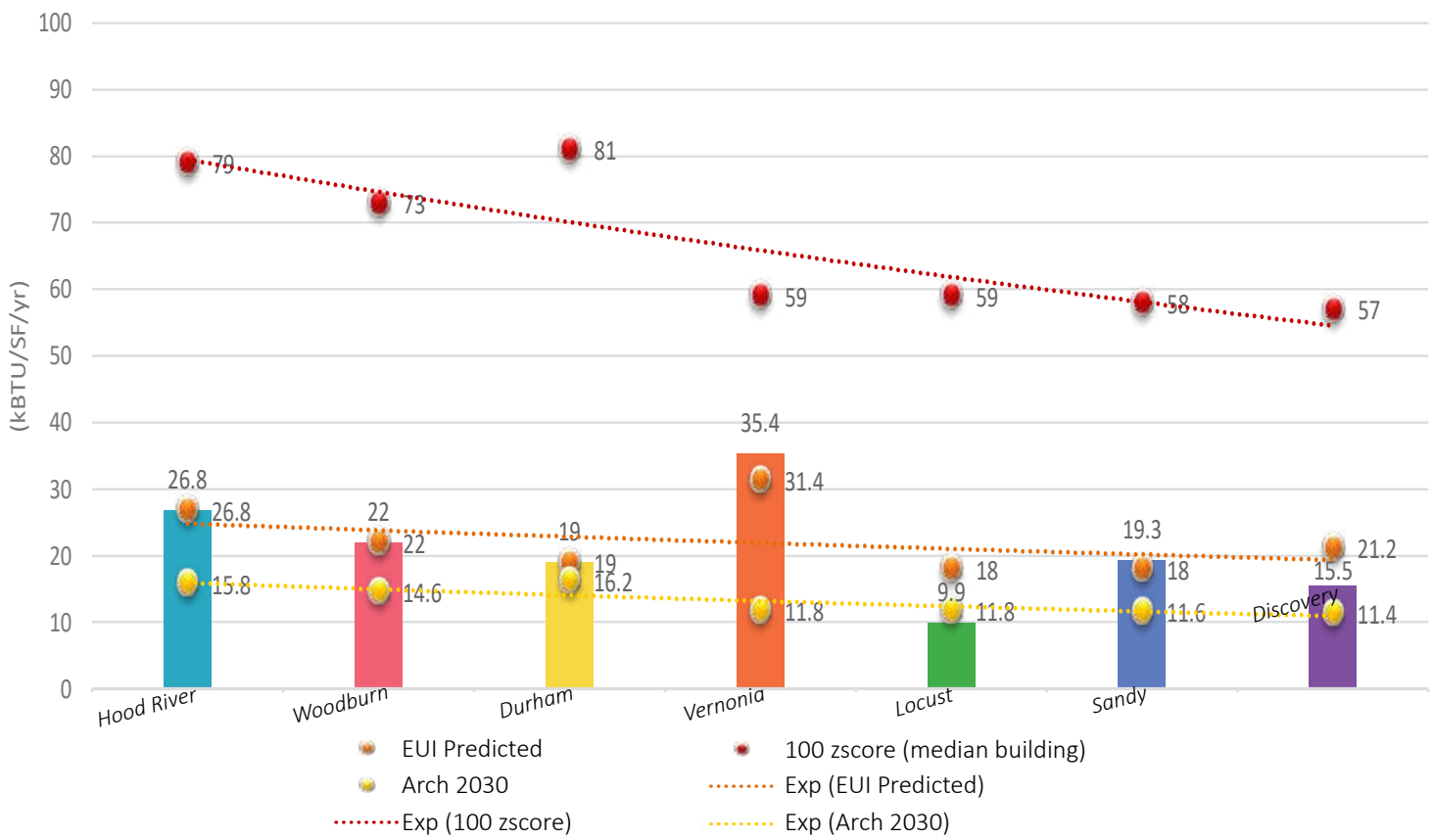
Walls and Roofs R-value

Thermal conductivity of the opaque areas of the envelope represents the total insulation coefficient of walls and roofs. It is typically expressed in U-value or R-value (R=1/U). Wall assemblies in commercial buildings have been traditionally average in their thermal resistance due to issues of thermal bridging and structural issues. This fact has changed drastically over the last decade with better details and the advance of production of high performance insulation materials that provided less thick and lighter assemblies than their traditional counterparts. This also benefited roof insulation assemblies. The average wall assembly of NZS is close to R-20. High performance insulated walls can easily reach up to R-30 to R-35. Roof assemblies of NZS surveyed are R-25-R-30, with higher performing roof assemblies reaching R-40 to R-50.

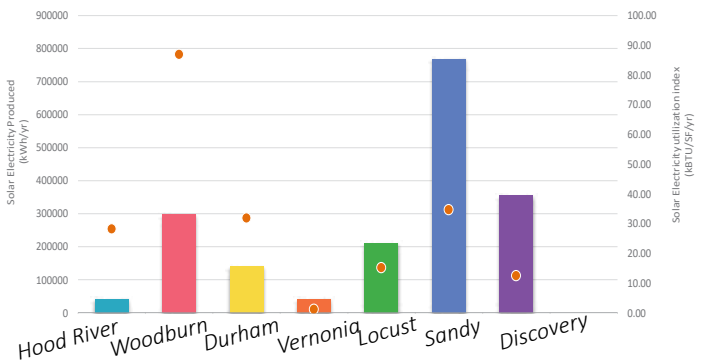


Energy Utilization Intensity (EUI: KBTU/SF/Yr.)

The building's energy consumption is typically measured by the total amount of energy consumed by its occupants and systems in thousands British Thermal Units (KBTU) normalized over the building's area in SF per year. This metric represents a much thought after indication to measure and compare building energy performance. This metric should be benchmarked against the median energy performance of a typical building built to code in the same climate zone (100 zscore) and an Architecture 2030 building, which is 80% better than the current building built to code. We collected actual energy utilization index performance data (EUI) for all NZS sampled (colored bars) as well their predicted EUI based on the design team energy models (orange-colored dots) and compared them against a benchmarked traditional building in the same climate zone, type, and area (Red-colored dots) and Architecture 2030 exemplary school buildings of the same area and in the same climate zone (Yellow-colored dots). All NZS in our study have performed well with substantial energy reductions over traditional benchmarked buildings. It is interesting to see many of them meeting or exceeding their predicted EUIs of their energy models and although not yet meeting the ARCH 2030 goals, yet they are getting closer in most cases and better in one case (Locust Trace). The trend line in energy reduction is also going down, suggesting that NZS are constantly improving in terms of their energy performance.



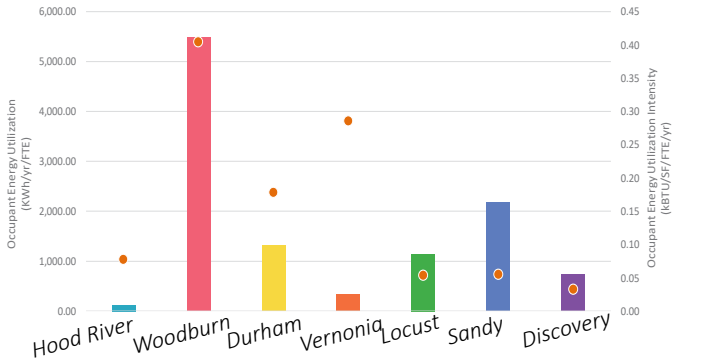
Solar Utilization Intensity (SEUI: sKBTU/SF/Yr.)



SOP	42368	298010	140000	41600	211630	768972	354300
SUI	28.16	86.86	31.74	1.07	15.04	34.53	12.38

The solar energy production is measured by the total amount of energy produced by it's the renewable technologies (e.g. PV systems of the building) in Kilo Watt Hours (KWh). Another metric to compare the energy produced to the energy consumed annually is to convert this production to thousands British Thermal Units (KBTU) and normalize it over the building's area in SF per year. This metric will provide an easier comparison to see how much of the building's energy production is matching or exceeding its consumption on a yearly basis to determine whether it is Net-zero, Net-positive or Net-negative. All NZS in our study have performed well with substantial energy reductions over traditional benchmarked buildings. Most of the schools surveyed in the study are Net-zero or Net Positive. Few examples are still struggling to meet their total energy demands due to the large size of the school and peak load demands that are not being met by optimal solar energy production. It is customary to have additional areas in the roof or the site for additional solar PV units. It is also important to allow more provisions of solar energy ready design fir future expansions.

Occupant Energy Utilization (OEUI: KBTU/SF/FTE/Yr.)

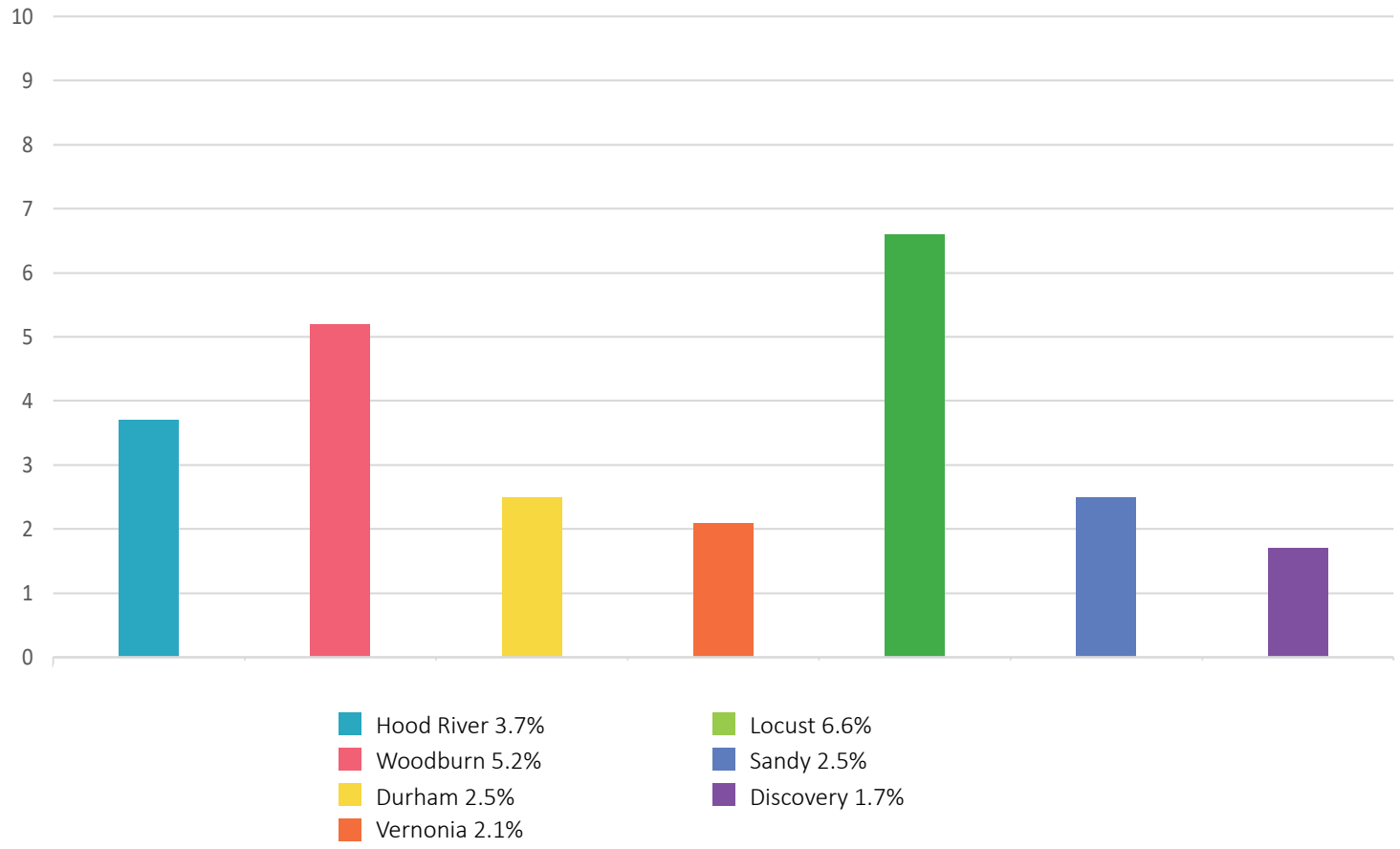


OEU	122.47	5475.6	1311.1	335.4	1144.2	2183.2	738.24
OEUI	0.08	0.40	0.18	0.29	0.05	0.05	0.03

The occupant energy conservation places emphasis on the occupant energy behavior in conserving energy. Although this metric is not widely used for building performance evaluations, it is nonetheless important to compute and track as an agent to change occupant's attitude in NZS. This metric normalizes the building's EUI by the Full-time-Equivalent (FTE) of its occupants. It is recommended that the OEUI is kept below 0.3 for most buildings. For the NZS surveyed in this study more than 50% of the schools' occupants has optimum performance of less than 0.1 OEUI with only one case that is showing excessive OEUI of 0.4.

Increase in Property Value (%)

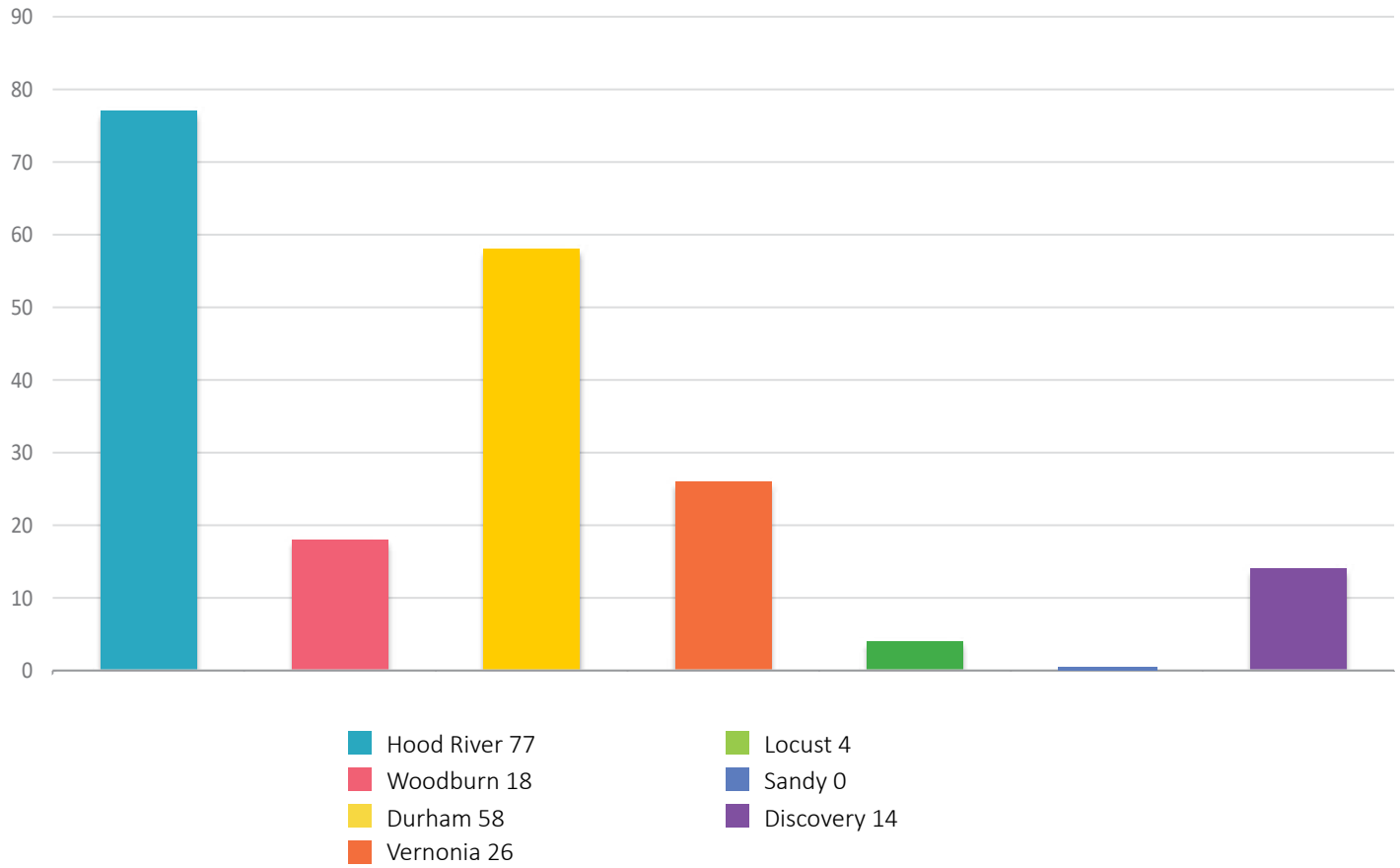
One of the non-energy impacts of NZS are the larger economic impacts on their sites and communities where they are built. By analyzing data from property values sales and Zillow real estate scores (www.zillow.com), we are able to compute the increase in property value following the construction and operation of a NZS in the neighborhood. In general all neighborhoods with a NZS has increased in value following the building a NZS. The percentage of increase in property value ranged from 1.7% to 6.6%. This is not trivial because it signifies the importance that residents place on the desire to be next to a NZS where their children would attend.



Walk score

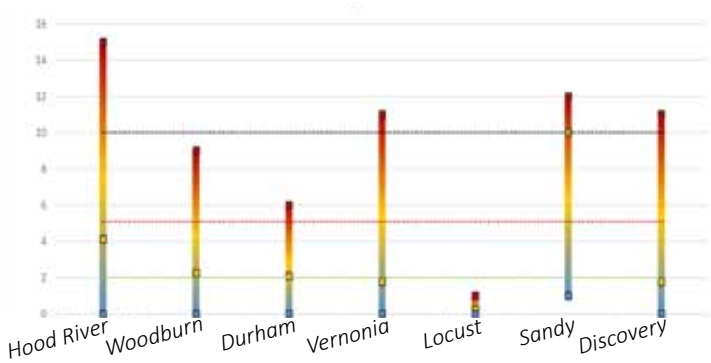
Walk score (www.walkscore.com) is a metric that measures the connectivity and accessibility of a site as well as its connection to amenities and public transportation. A score of zero signifies that the site is non-walkable and completely car-dependent. On the other hand a walk score of 100 represents a well-connected site with ultimate access to public transportation, bike routes, walkable streets, and lots of livability amenities. The choice of school sites can be influenced by the walk score of the neighborhood where they are built. It is important to consider choosing sites with high walk scores to make sure future NZS are well connected and accessible to students using alternative transportation.

Some of the non-energy benefits of NZS can be seen on their impacts on improvement in walk scores after they're built. This is observed when the sites have good walk scores to start, such as the case of Hood River School where the new NZS improved the already good walk score to a score of 77. Similarly, Durham and Vernonia schools contributed positively to improvements in their neighborhoods walk scores to 58 and 26, respectively. NZS in poorly sited walk score sites of 0-20 walk scores didn't produce much positive impacts as their sites are mostly rural and car-dependent with very low accessibility and community amenities.



Daylight Factor (%)

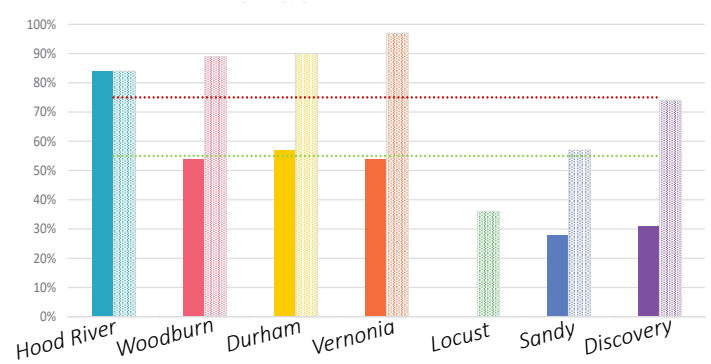
Daylight Factor (DF) is a metric to measure the percentage of daylight illumination at a certain point inside the space (typically in the center of the room) to the total illuminance levels of daylight outdoors. The metric is represented as a percentage and is climate insensitive. Although more sensitive daylighting dynamic and climate based metrics are developed now, this metric still warrant some use in the early phases of design especially with analog daylighting models. The recommended DF for classrooms is between 3-5%. Most NZS surveyed and simulated maintained good DF levels in the classrooms that met the requirement (represented in the range between the red and black dotted lines in the chart). One of the NZS surveyed underperformed in this metric and has very low DF of less than 1% and four other schools has occasions of DF exceeding 10%, which could be an indication of excessive daylighting levels with a probability for glare.



Max	15	9	6	11	1	12	11
Mean	4.12	2.24	2.08	1.78	0.26	10.02	1.78
Min	0	0	0	0	0	1	0

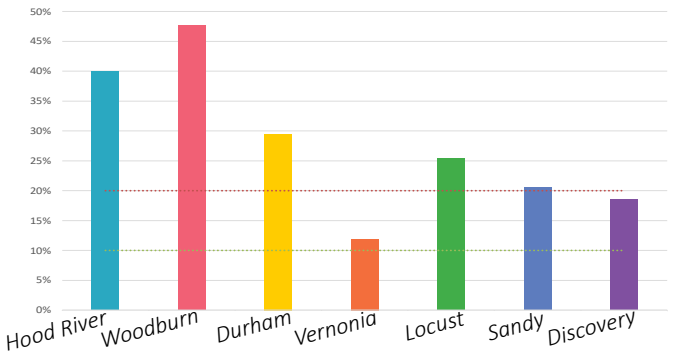
SDA & UDI (%)

Spatial Daylighting Autonomy (sDA300 50%) is one of the most common used dynamic daylighting metrics that are climate-based. The metric is computed from daylighting simulations of the classrooms for the NZS studied. It represents the percentage of the work plane area receiving 300 lux or above for 50% of the occupied hours on an annual basis. Classrooms with 55% of their work plane areas meeting this metric are satisfactory daylit and those with 75% or more of their work plane areas meeting this metric are exemplary. For the Uniform Daylight Intensity (UDI100-1000 50%), a similar metric is used but in this case the limits for indoor daylight levels on the work plane were set between 100-1000 lux, suggesting a more uniform ambient daylighting that might be supported by electric lighting for some time during the occupied hours daily. For the NZS studied and simulated, more than 50% of the schools classrooms met the sDA and almost 80% of them met the UDI metrics. Most of the classrooms for one school didn't meet neither, suggesting that daylighting strategies were not integrated properly part of the early schematic design stages of the building.



SDA	84	54	57	54	0	28	31
UDI	84	89	90	97	36	57	74
Rec	55	55	55	55	55	55	55
Excp	75	75	75	75	75	75	75

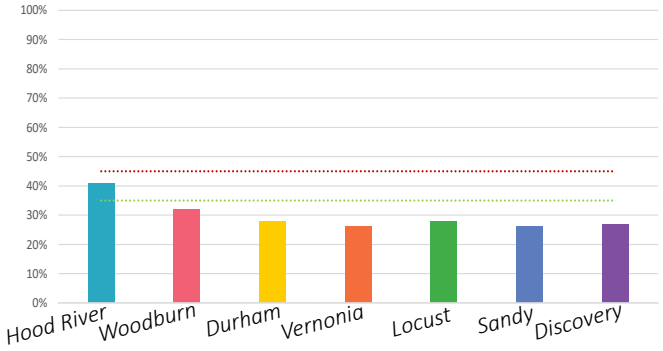
Annual Solar Exposure (%)



ASE	40	47.7	29.50	11.90	25.4	20.5	18.5
Rec	20	20	20	20	20	20	20
Excp	10	10	10	10	10	10	10

Annual Solar Exposure (ASE1000, 250H) is part of the dynamic daylighting metrics that guides the recommended practice of daylighting design in workplaces. The metric is intended to act as a proxy to prevent the design of over lit spaces that could lead to excessive or disturbing glare. The metric is computed by simulating the amount of work plane or floor area of a space receiving 1000 lux or more for 250 hours of the occupied time on a yearly basis. The acceptable threshold or 10% or less area meeting this metric might be an indication of exemplary performance and a threshold of 20% or more can be expanded to areas of limited activities and flexible occupant's seating behavior. For the NZS surveyed and simulated, a number of classrooms do not meet the recommended threshold, which suggest a higher probability of glare perception by the users in some areas of the classroom spaces.

DGP (%)

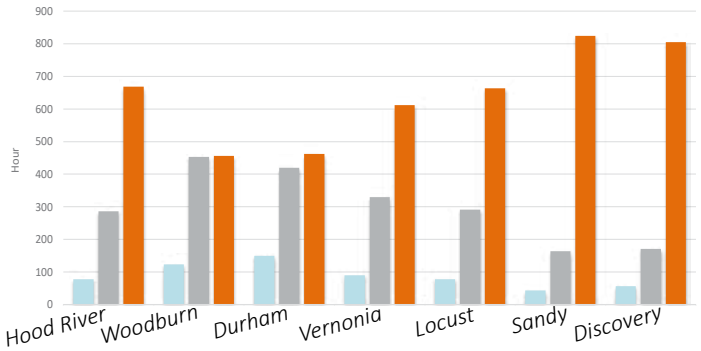


DGP	41	32	28	26	28	26	27
Rec	35	35	35	35	35	35	35
Excp	45	45	45	45	45	45	45

Daylight Glare Probability (DGP) metric represents the probability of an occupant of perceiving glare based on an angular fish-eye view shed as simulated from the occupant's perspective. As it is impossible to simulate every view shed in the classroom space, this simulation is typically carried out for the most common view shed in the space that represents the most used occupant's location. A DGP value of 0.45 (45%) represents intolerable glare in the space and a DGP value below 0.35 suggest tolerable to imperceptible glare levels. For the NZS surveyed and simulated, most classrooms do not have intolerable glare incidents for their most common occupant's view sheds. This suggests that glare probability is low for the average most used area of the classroom but their might be still probability for glare in other areas.

PMV (%)

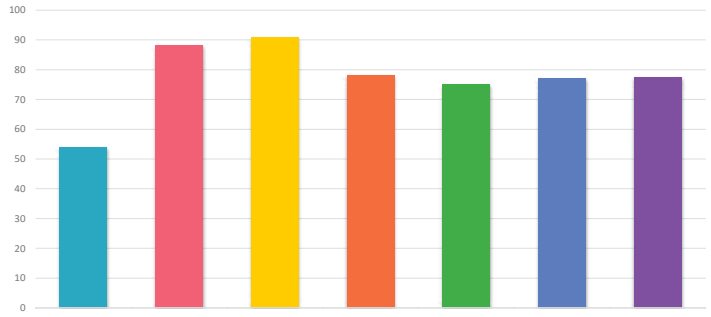
Percentage Mean Vote (PMV) is a thermal comfort metric that was simulated for the NZS classrooms under study based on ASHRAE thermal comfort Standard-55, 2017. A PMV of (-1 to +1) represents thermal neutrality perceptions of occupants and should correspond to 90% of the occupants' satisfaction with their thermal environment. Results of thermal comfort simulations across the NZS studied reveal large discrepancies between thermal comfort perceptions of the schools' occupants as many of them perceiving the indoor environment either too hot to too cold.



cold	78	123	150	90	78	44	56.6
neutral	286	453	420	330	291	164	171
Min	668	456	462	612	663	824	804.4

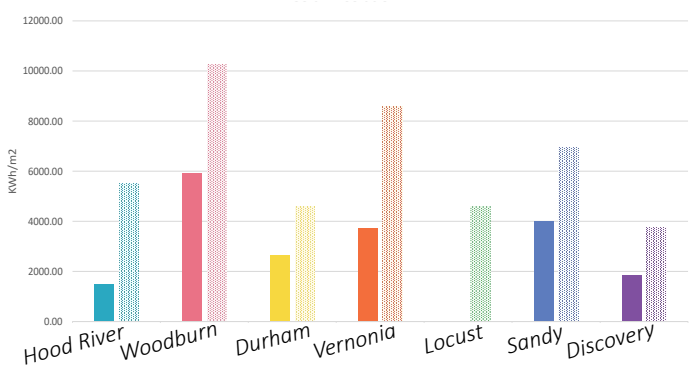
Percent in Comfort Zone (%)

This metric represents the percentage of time annually that occupants are exposed to an indoor climate that is within the prescribed ASHRAE Standard-55 thermal comfort model. Indoor climate conditions should prescribe to the thermal comfort model for 90% or more of the occupied time. Out of the NZS studied 30% of them were able to achieve this performance for thermal comfort in their classrooms.



- Hood River 54.05%
- Woodburn 88.26%
- Durham 90.98%
- Vernonia 78.04%
- Locust 75.09%
- Sandy 77.25%
- Discovery 77.53%

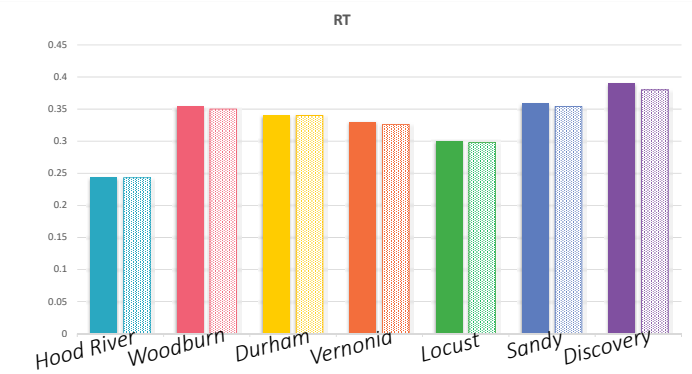
Solar Insolation (%)



The amount of solar energy harvested on the thermal mass of the floor and managed through window insolation in the heating season could have a positive impacts of the school's energy performance and conservation. It is important to work with this metric in the early phases on the building design to estimate how many hours a building can harvested direct gain from the sun during the heating season to reduce its dependence of energy consumption in order to achieve thermal comfort for its occupants. While most of the NZS attempted to achieve passive heating strategies, only 40% of the schools studied and simulated are able to achieve thermal comfort by utilizing passive heating strategies.

Floor	1510.5	5938.8	2651.39	3750.52	0	4031.33	1869.62
Window	5521.2	10258.07	4588.4	8586.83	4595.86	6942.18	3762.99

RT (sec.)



Reverberation Time (RT) is an important criteria to compute and simulate to test classroom acoustical quality. Classrooms should maintain a RT between 0.4-0.6 secs in order to have appropriate sound quality that provide good speech intelligibility without acoustical distraction and high reverberation of sound in the space. All NZS studied were able to meet this metric and resulted in classrooms of good reverberation time between 0.24 and 0.39.

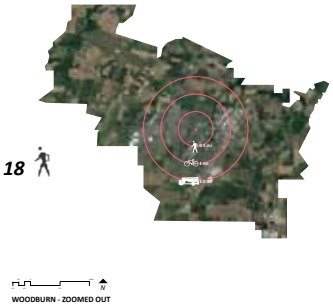
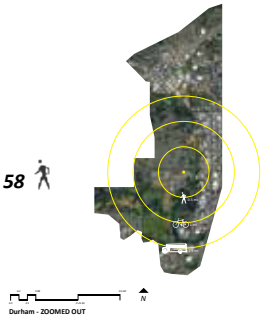
OCC	0.244	0.354	0.348	0.33	0.301	0.359	0.392
UN OCC	0.243	0.353	0.343	0.32	0.291	0.354	0.384

Site Performance

Catchment Area

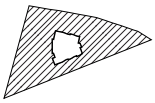
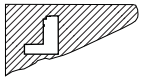
Area The School Is Serving, Extent Buses Can Drive In Order To Pick Up Students (sq. mi.)

Walk Score

Hood River	Woodburn	Durham
77	18	58
		
475	31	24

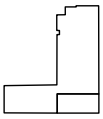
Built Up Area

Built up Area as % of Entire Site

		
12%	14%	11%

Footprint

Typical Floor Area

2,566 sf *2 Floors*	*11,700 sf* *1 Floor*	*7,520 sf* *2 Floors*
		
Bar	Cluster	L-Shape

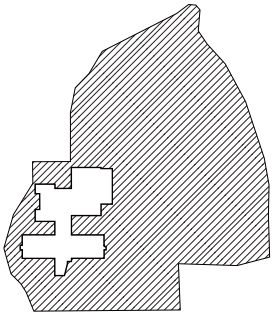
Water Retention

4,012 sf *18,000 sf of native vegetation*	*6,790 sf* *3,287 sf of native vegetation* *2 Bioswales*	*3,659 sf* *2 Bioswales*

Vernonia

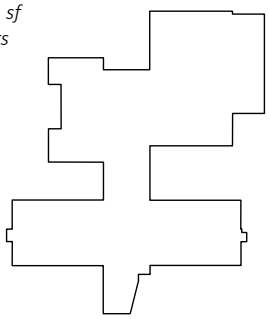
26

260



14%

66,141 sf
2 Floors



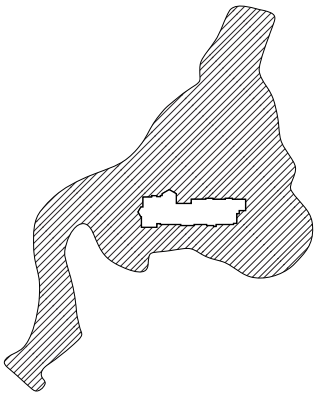
H-Shape

25,000 sf
Catchment Basin

Locust Trace

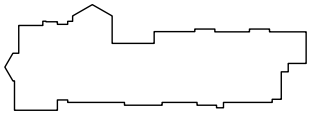
4

289



2%

47,994 sf
1 Floor



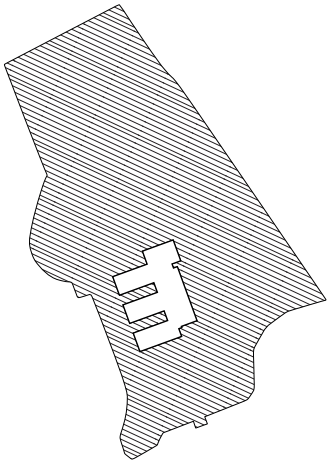
Bar

Rainwater capture from roof to
ungerground storage tanks
Permeable Pavers
Rain Gardens
Constructed Wetland

Sandy Grove

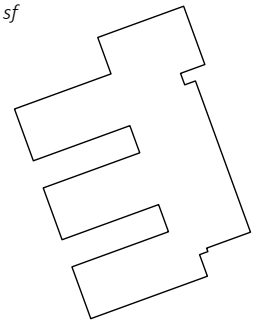
0

72



7%

75,930 sf
1 Floor



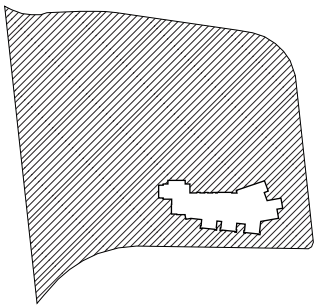
Finger

5,088 sf
4 Bioswales

Discovery

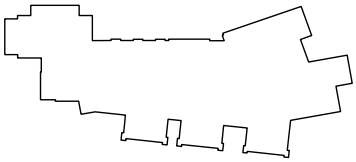
14

5.7 Acres



12%

48,794 sf
2 Floors



Bar / Cluster

9,150 sf
3 Bioswales

Building Performance

Shape Factor

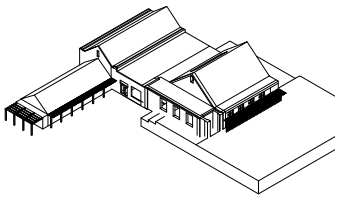
Building Massing + Roof Form

South-West Isometric

N

Hood River

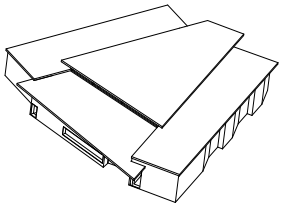
Sawtooth / Gable



2.22

Woodburn

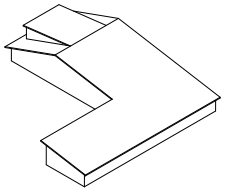
Flat



1.87

Durham

Gable w/ Roof Monitor

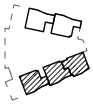


1.81

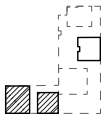
Classrooms

% of wall area facing south as classrooms

18%



30%



19%

PV Area %

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

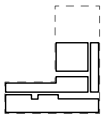
42,368 kWh
1,873 sf (37%)
Solar EUI: ***28.16***

37%

Ground Mounted

298,010 kWh
12,900 sf (0)
Solar EUI: ***86.86***

0

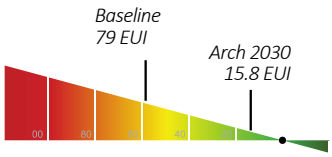


140,000 kWh
8,398 sf (50%)
Solar EUI: ***31.74***

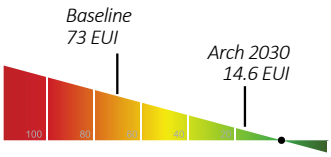
50%

Measured EUI

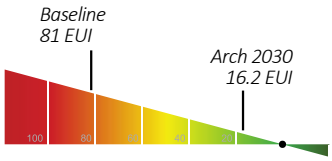
Measured vs. Arch 2030



26.8 EUI



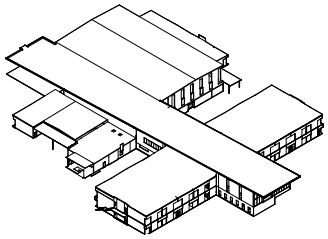
22 EUI



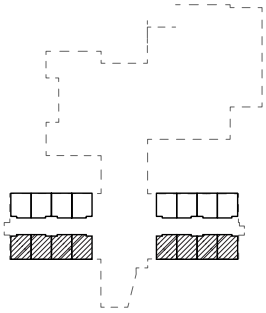
19 EUI

Vernonia

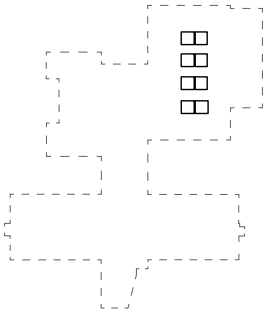
Sloped / Flat



1.31

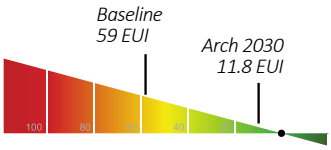


25%



41,600 kWh
2,583 sf (2%)
Solar EUI: ***1.07***

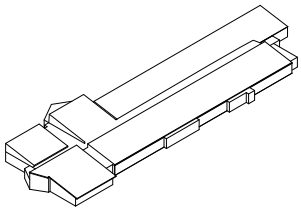
2%



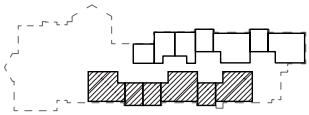
35.4 EUI

Locust Trace

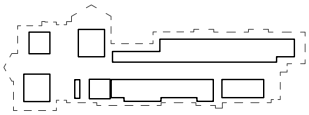
Shed



1.31

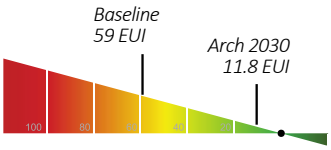


36%



211,630 kWh
16,287 sf (34%)
Solar EUI: ***15.04***

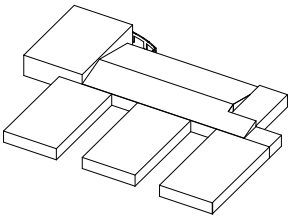
34%



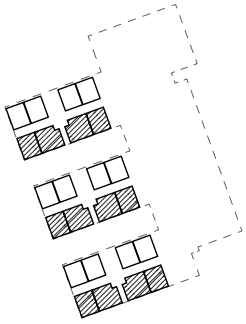
9.9 EUI

Sandy Grove

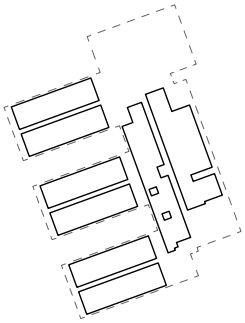
Gable / Flat



1.52

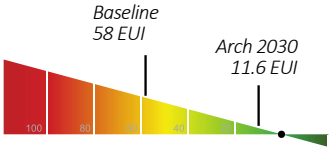


26%



768,972 kWh
38,328 sf (50%)
Solar EUI: ***34.53***

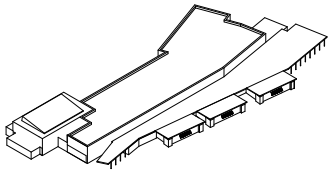
50%



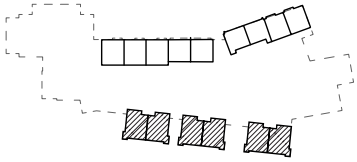
19.3 EUI

Discovery

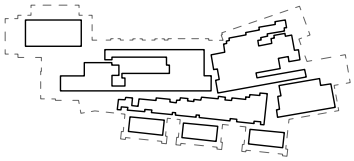
Flat w/ Roof Monitors



1.08

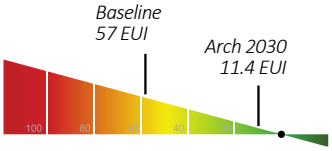


36%



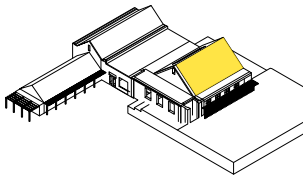
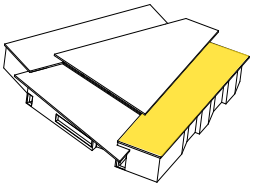
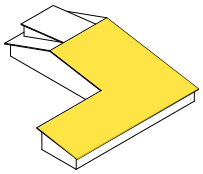
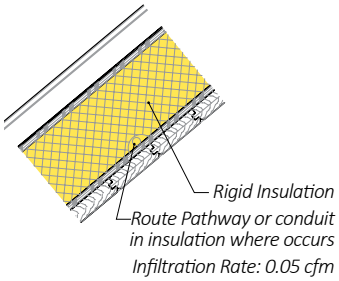
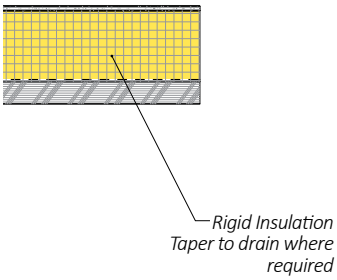
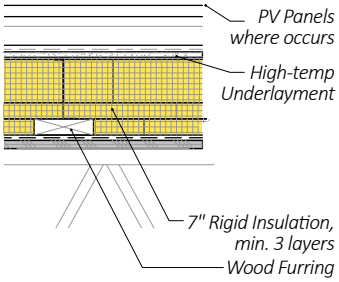
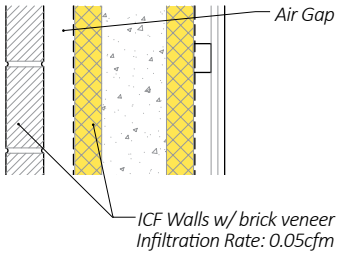
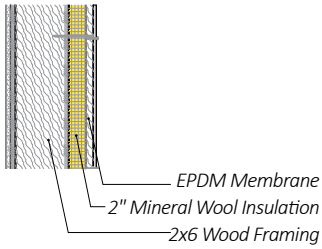
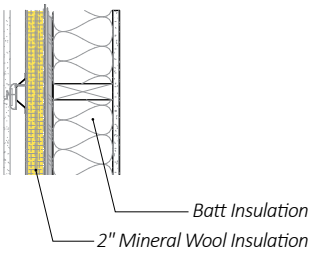
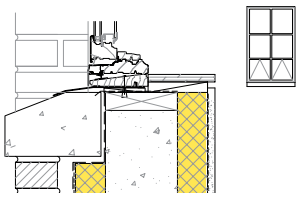
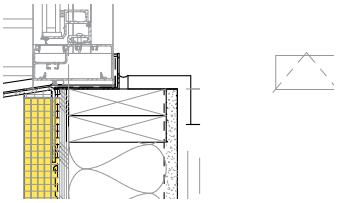
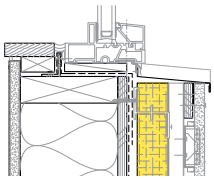
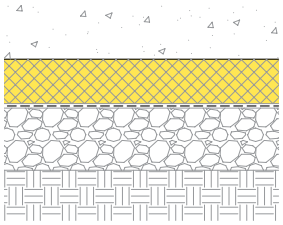
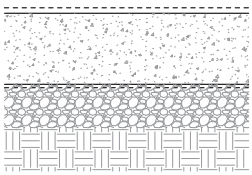
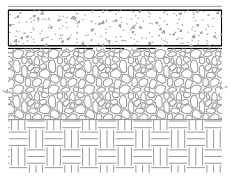
354,300 kWh
35,131 sf (36%)
Solar EUI: ***12.38***

36%

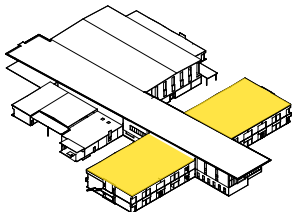


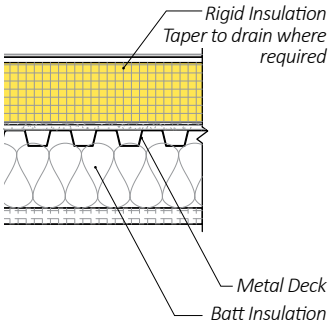
15.5 EUI

Envelope Design

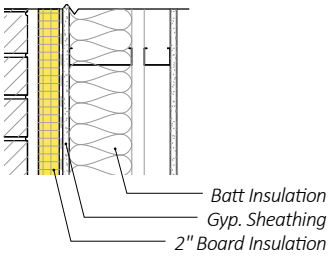
	Hood River	Woodburn	Durham
Overview Typical Roof Area			
Roof Typical Roof Detail	 **R 40**	 **R 24**	 **R 30**
Wall Typical Wall Detail	 **R 25**	 **R 31**	 **R 26**
Window Sill Typical Window Detail	 *Triple Glazed Windows* *SHGC: 0.30* *Vis. Transmittance: 0.38* **R 3.33**	 *SHGC: 0.27* *Vis. Transmittance: 0.26* **R 6.1**	 *SHGC: 0.27* *Vis. Transmittance: 0.65* **R 3.45**
Floor Typical Floor Detail	 *Continuous Insulaion Under Slab* **R 15**	 *Reinforced Concrete Slab* *No Insulation*	 *Slab on Grade, Unheated*

Vernonia

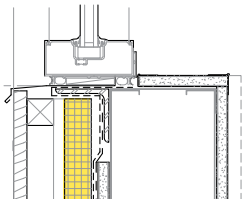




R 30

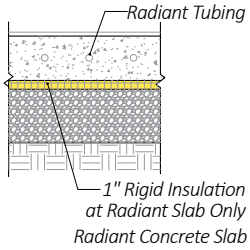


R 20



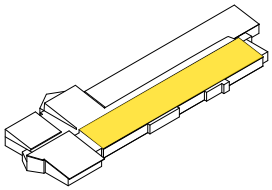
SHGC: 0.44
Vis. Transmittance: 0.7

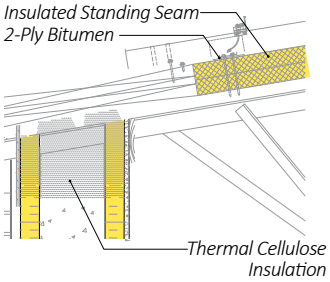
R 3.33



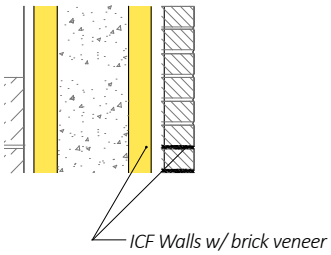
R 6

Locust Trace

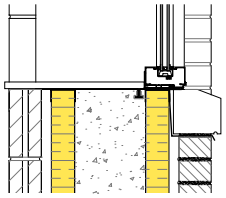




R 26

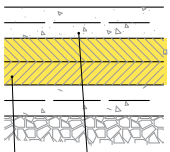


R 24



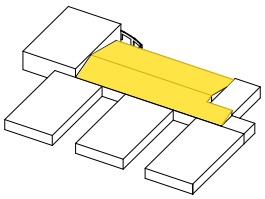
Triple Glazed Windows
SHGC: 0.36
Vis. Transmittance: 0.65

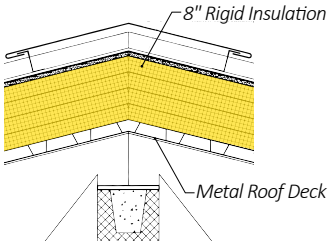
R 3.85



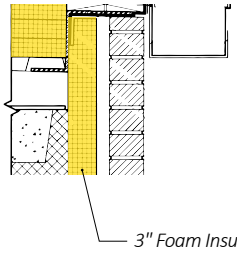
R 36

Sandy Grove

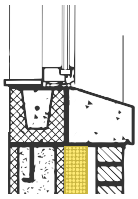




R 40

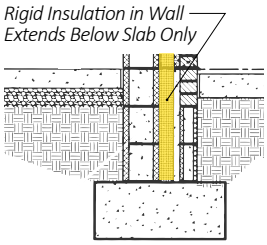


R 19

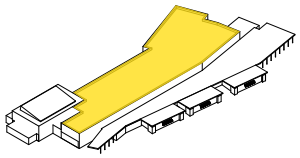


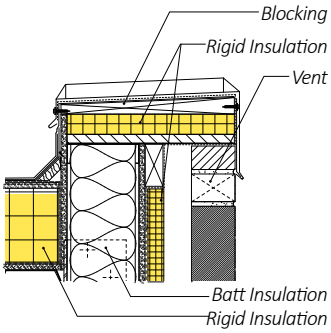
SHGC: 0.23
Vis. Transmittance: 0.28

R 3.85

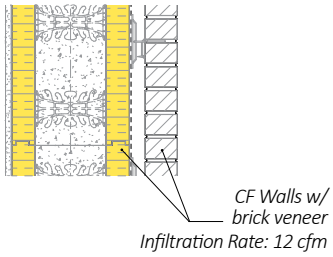


Discovery

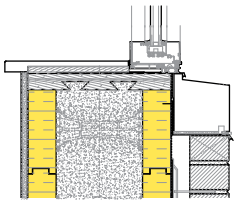




R 31

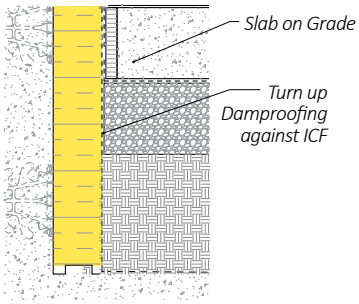


R 33

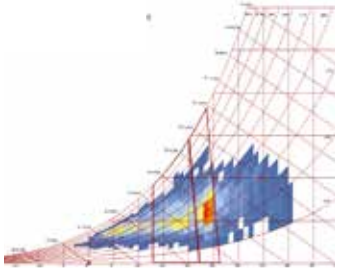
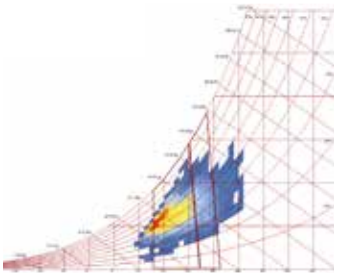
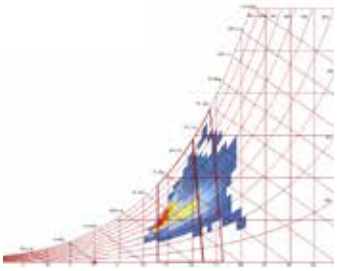
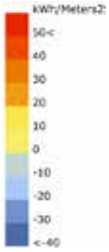
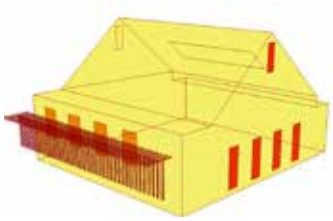
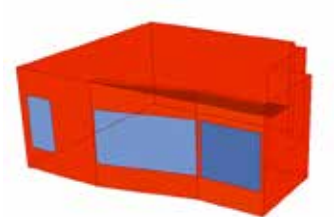
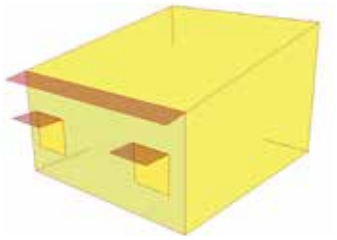
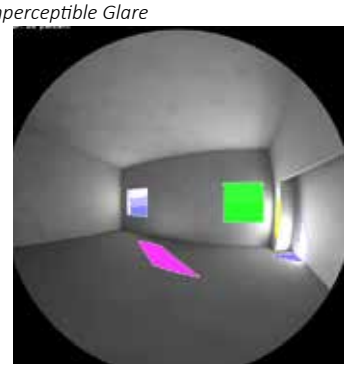
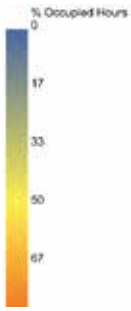
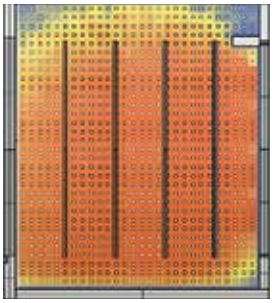
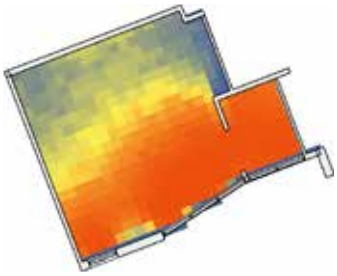
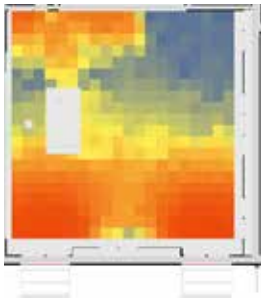


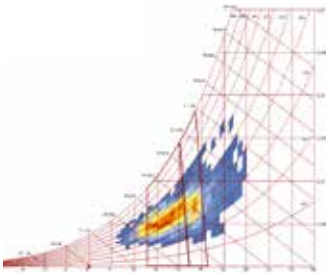
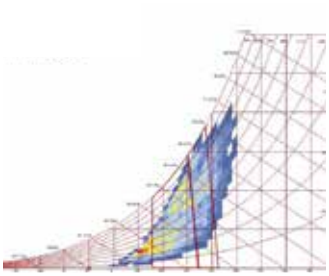
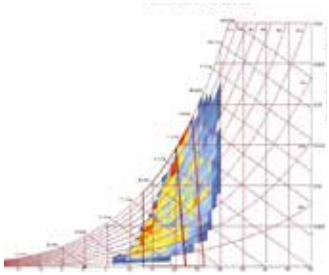
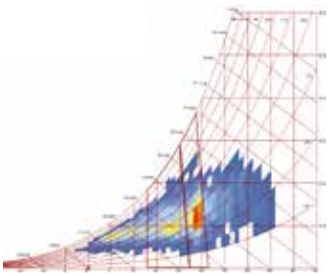
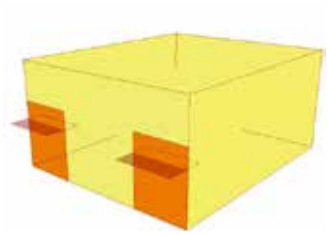
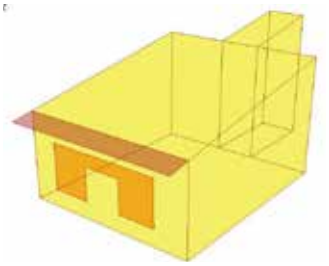
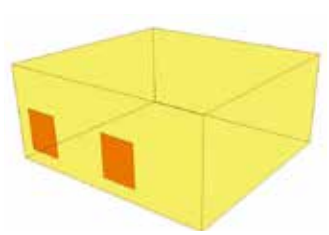
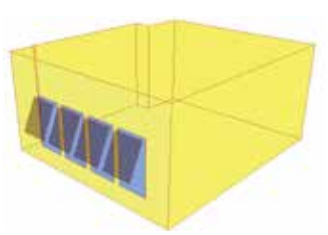
Triple Glazed Windows
SHGC: 0.36
Vis. Transmittance: 0.65

R 2.17



Indoor Environmental Qualty (IEQ)

	Hood River	Woodburn	Durham
Psychometric Chart Percentage of Time in the Comfort Zone	 **54%**	 **88%**	 **91%**
Heat Gain / Loss Spring: 			
DGP Daylight Glare Probability *Intolerable Glare* ≥ 45% *Disturbing Glare* ≥ 40% *Perceptible Glare* ≥ 30% *Impercetible Glare* < 30%	*Disturbing Glare*  **41%**	*Imperceptible Glare*  **32%**	*Imperceptible Glare*  **28%**
sDA Spatial Daylight Autonomy (DA) Analysis *Daylit Area (DA300lux [50% Annually]) Target > 55% Floor* 	 **41%**	 **32%**	 **28%**
RT Reverberation Time- Occupied (Seconds)	**0.24**	**0.35**	**0.34**

Vernonia	Locust Trace	Sandy Grove	Discovery
			
78%	75%	77.3%	77.5%
			
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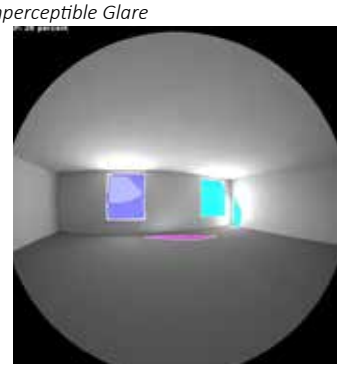
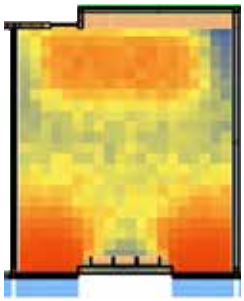
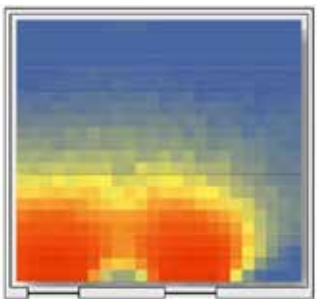
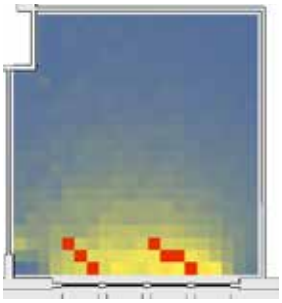
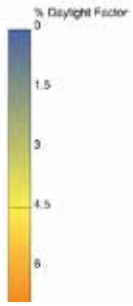
			
26%	28%	26%	27%
			
26%	28%	26%	31%
0.33	0.30	0.35	0.38

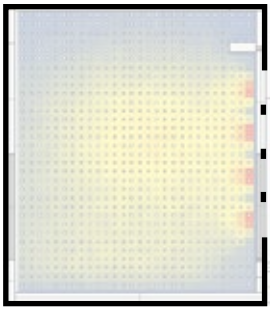
Daylighting

DF

Classroom Daylight Factor On Floor, Through South Windows

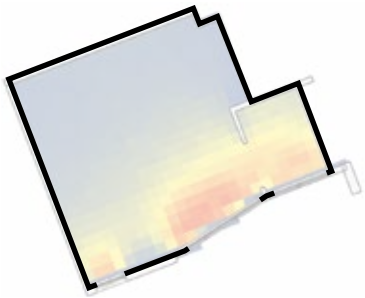


Hood River



4.1%

Woodburn



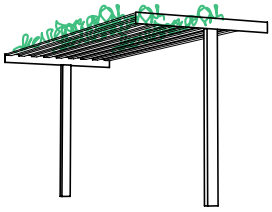
2.2%

Durham

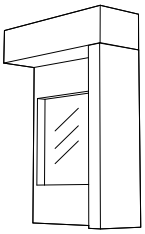
2.1%

Window Shading

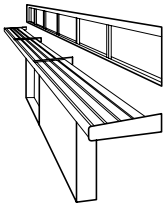
Trellis + Vines



Deep Overhangs



Horizontal Shading

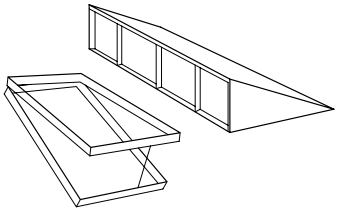


SFR

Skylight-to-Floor Ratio

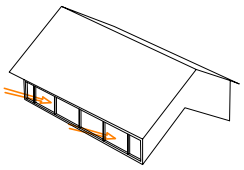
Typical Classroom

Clerestory + Skylights



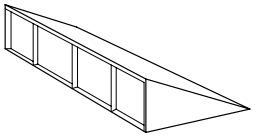
2.27%

No Classroom Toplight



0

Clerestories



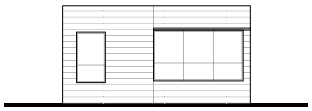
2.26%

WWR

Window-to-Wall Ratio

Typical Classroom

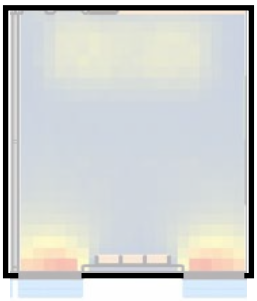
25%



33%

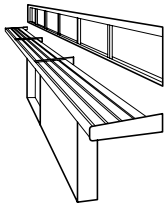
16%

Vernonia

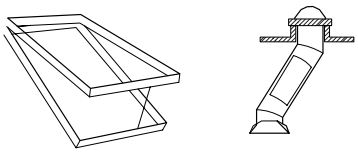


1.8%

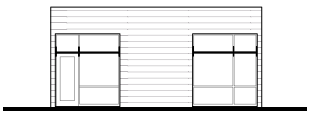
Horizontal Shading



Variety of Skylights



4.48%

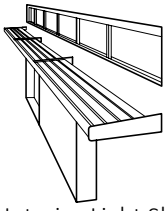


29%

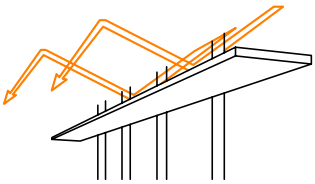
Locust Trace

0.3%

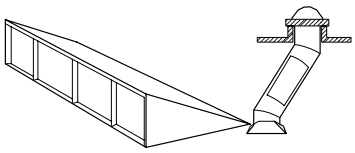
Horizontal Shading



Interior Light Shelves



Clerestory + Skylights



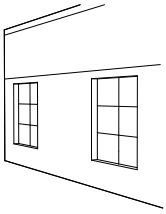
0.72%

30%

Sandy Grove

1.1%

Recessed Windows



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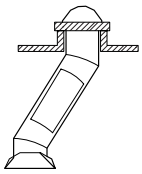
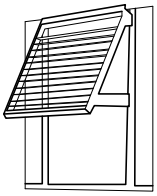


21%

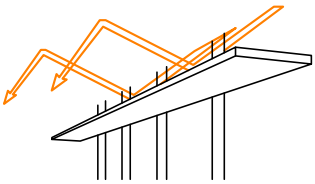
Discovery

0.7%

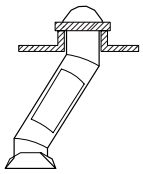
Screen



Interior Light Shelves



Skylights



0.29%

43%

LEED Platinum Certified / 1st Energy Trust Net-Zero Project Completed In Oregon / 1st Winner Of The 2030 Design Awards / AIA Committee on the Environment Top Ten Green Projects Award 2012

Hood River Middle School Addition

Hood River, Oregon, 97031

Opsis Architecture

Interface Engineering MEP, KPFF Consulting Engineers, Greenworks,

Fall 2010

Design Process

Project Statement

The Hood River Middle School Science and Music building is an addition of the existing Hood River Middle School. There was great demand for spaces dedicated to music and science, and the opportunity to make the building a teaching tool as well as funding incentives made this possible.

Site Plan

Aerial Image of Building and Site. Courtesy of Google Earth.

Recycle / Reuse

Reuse of the old bus barn storage floor joists worked well as trusses for the classrooms. The building's lumber was roughly 98% recycled.

Complimentary to reusing wood, the use of low Volatile Organic Compouds (VOCs) for paints, adhesives, flooring sysems, and composite wood products also reduced the possibility of future environmental impacts.

Deconstruction of existing bus barn. Courtesy of Opsis Architecture.

Land Use and Site Ecology

Building footprint was minimized to allow for the preservation of approximately 21,500 square feet of vegetated open space to be preserved.

At completion of the project, the landscape architects had allowed for the installation of approximately 18,000 square feet of low-water native vegetation.

Building Plan with Programs. Courtesy of Opsis Architecture.

Landscape vegetation becomes a positive learning experience for students through the science class. Students get the chance to learn about different plant species, the science behind them and how to maintain the plants through soil management and watering.

Students gathered in School Garden. Courtesy of Opsis Architecture.

Wind Studies

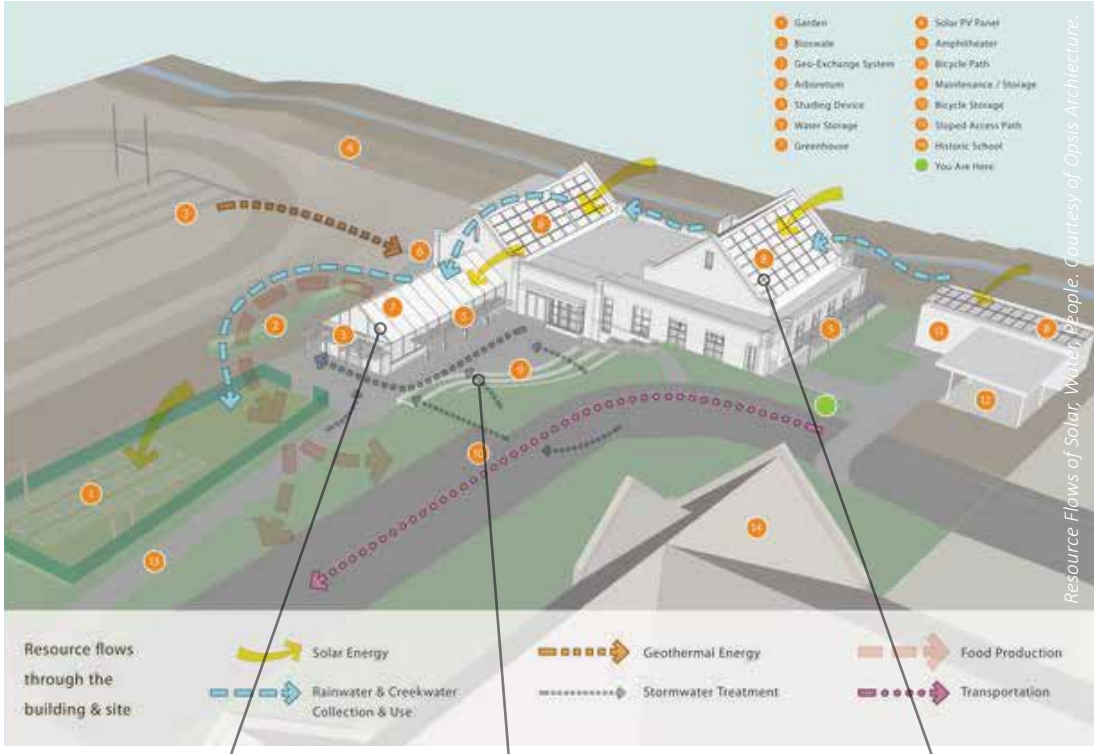
Wind analysis used to understand ways to fully maximize the potential passive ventilation within the building.

The diagramatic section below shows how wind plays into the building design.

December *March* *June* *September*

Wind Roses. Courtesy of Climate Consultant.

Designing Integrated Systems



Resource Flows of Solar, Water, People. Courtesy of Opsis Architecture.

On site Food Production

Movement of People

Solar Energy

Components of Integrated System:

- Daylighting
- Solar Energy
- Rainwater Collection
- Rainwater Use
- Geothermal Energy
- Stormwater Treatment
- Food Production on site
- Movement of People

Design Strategies

Goals

Goals for the project early on were to acheive LEED Platinum certification as well as Net Zero Energy through the use of passive strategies and solar energy production.

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.

Rainwater Harvesting

The underground cistern is a fundamental part of the building and landscape performance. Water collected on the roof of the building is directed into the 14,000 gallon tank. The water is then used in the toliets as well as site irrigation.


Glass Opening to Boiler Room.
Courtesy of Opsis Architecture.

Above seen, a glass opening allows for students to see the piping system that runs the building's water and heat flow.

A labelled pothole helps students recognize more about all the systems in place that allow the building to function the way it does.

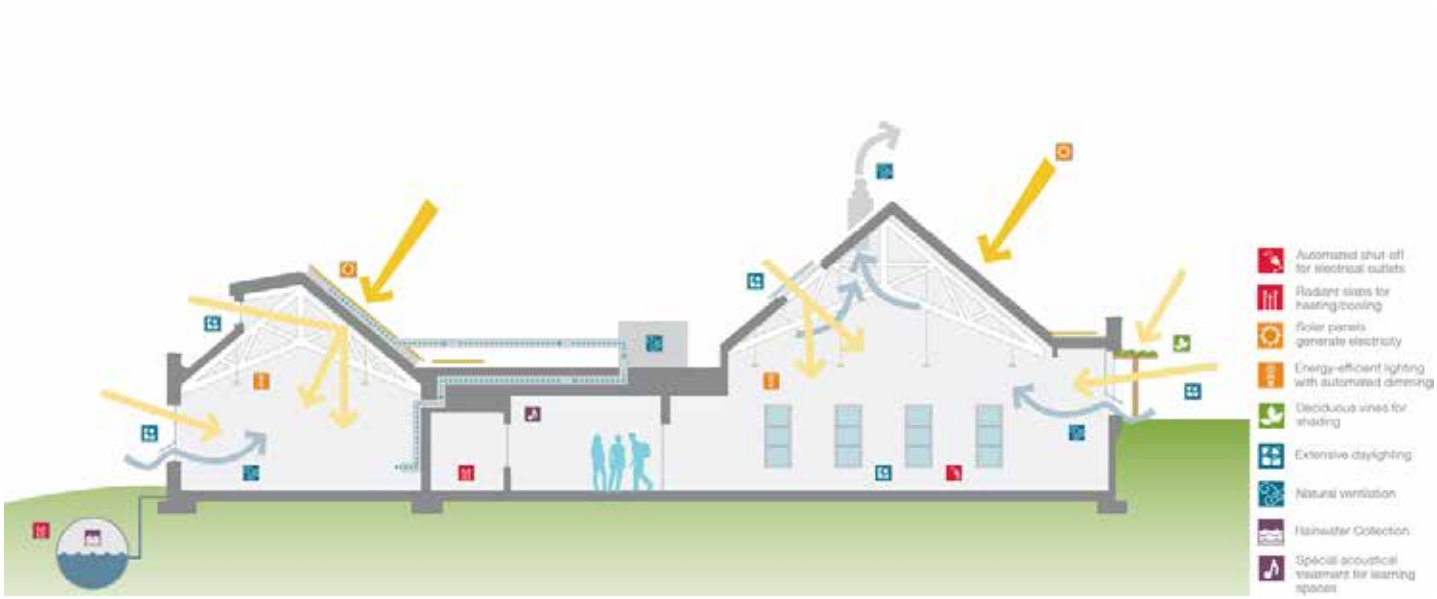

Students gathered around pothole of Rainwater Cistern.
Courtesy of Opsis Architecture.


Rainwater Cistern before being Barried.
Courtesy of Opsis Architecture.

Geothermal Radiant Floor Installation.

Passive Strategies

The diagram below visualizes the daylighting, ventilation and structural systems in place that allow for the building to be net zero as well as follow the qualifications required for its LEED Platinum certification.

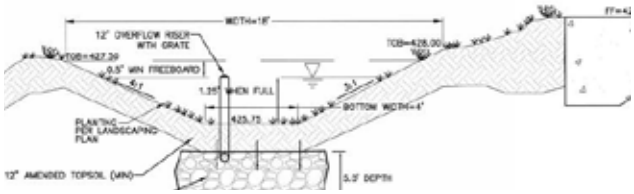


Section Drawing highlighting Passive Strategies. Courtesy of Opsis Architecture.

Water Management

Flow of Water Diagram. Courtesy of Opsis Architecture.

Rainwater that falls on the site and its surrounding drainage area is directed towards the detention ponds which allow water to percolate through the soil before disposing of the water to the cities stormwater system.



Stormwater detention swale with overflow riser.

Flow of Water Diagram. Courtesy of Opsis Architecture.

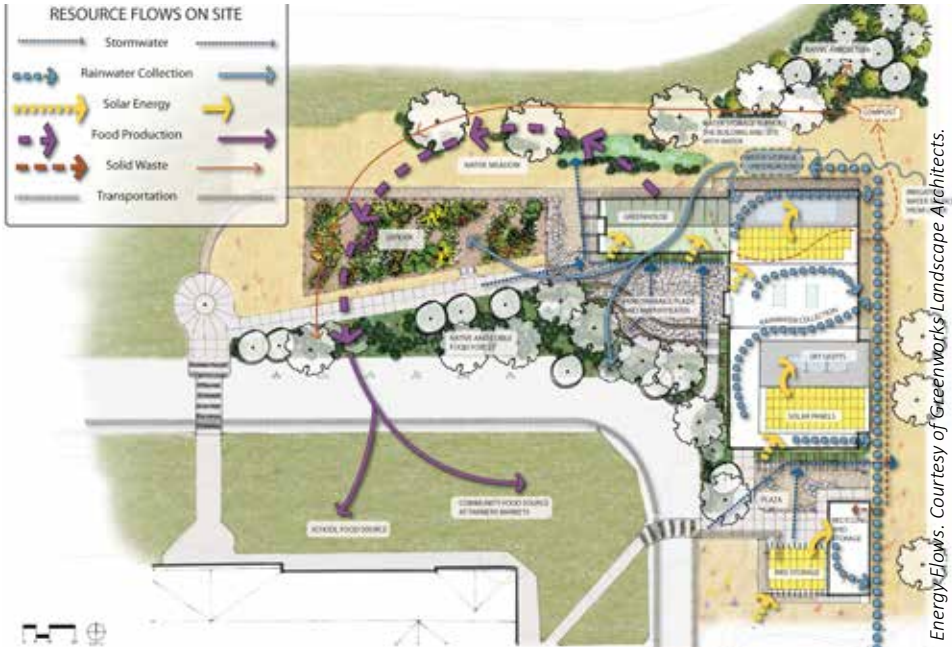
Site Performance

Site Metrics

- *Gross Floor Area (sf): 6,887*
- *Gross Site Area (sf):*
- *Athletic Fields (sf): 197,001.26*
- *Playground area (sf): 23,178.13*
- *Building footprint (sf): 7,203*
- *Built up area (%): 16.11%*
- *Paved area (sf): 4953.5*
- *Paved area (%): 11.59%*
- *Non-paved surfaces (sf): 21,559*
- *Non-Paved surfaces 50.43%*
- *PV area as % of Floor area: 30%*
- *Shape Factor (A/V): 2.22*

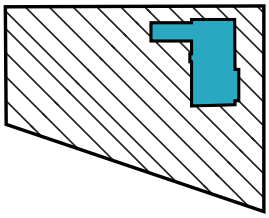
Resource Flows on Site

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



Energy Flows. Courtesy of Greenworks Landscape Architects.

Site:Building Area Ratio

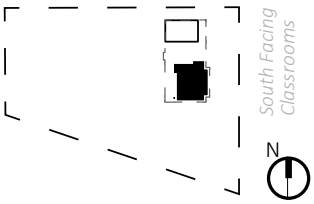


Site:Building Area

- *21,560 sf of vegetated open space is preserved.*
- *Building oriented on N-S axis, greenhouse E-W.*

Classrooms Facing South

18.21% of the building has south-facing classrooms.



South Facing Classrooms

Program

- Outdoor Classroom And Laboratory For Students To Learn Permaculture Principles
- Multisensory Food Forest / Vegetable Garden (Irrigated By Cistern)
- Onsite Rainwater Harvesting
- Small Ecological Footprint
- Native Plant Arboretum
- Learning Garden
- Harvest Plants For Food, Fiber, Dye, And Other Uses
- Prepare Produce To Sell At Local Farmers Market

Landscaping. Courtesy of Opsis Architecture.

Science teachers use the garden and landscaping to teach students more about how to grow food, what plants are native to the Pacific Northwest, and other sustainable garden practices.

Garden. Courtesy of Opsis Architecture.

Outdoor Learning

Collaboration between Opsis Architecture and Greenworks Landscaping allowed for a successful landscape around the building. Use of native plants created a more resilient garden.

Catchment Maps

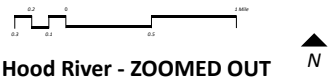
The Hood River school district spans 15 miles across and is 475 square miles in area. With a catchment area this large, transportation energy expenditures is a problem. A major concentration of residential neighborhoods around the school and a walk score of 77/100 are positive signs to reduce these environmental impacts.

Half mile radius catchment map.

- *475 sq.mi. school district*
- *farthest driving distance across district is 30 miles*
- *walk-score: **77***

School district boundary catchment map.

Hood River - ZOOMED IN

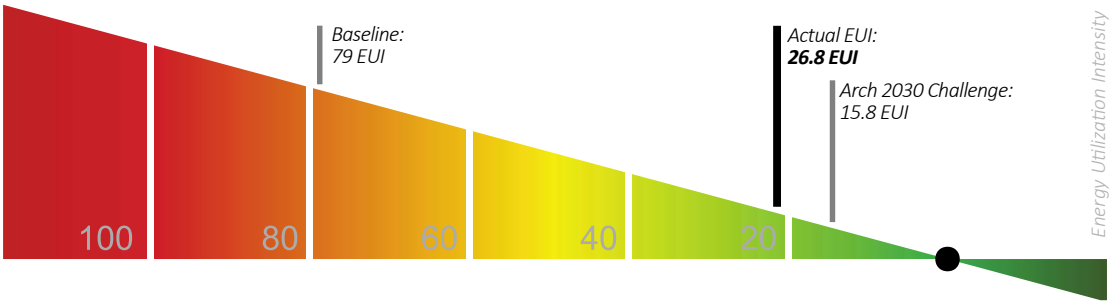


Hood River - ZOOMED OUT

Energy Utilization Intensity

Actual EUI: ***26.8***

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).

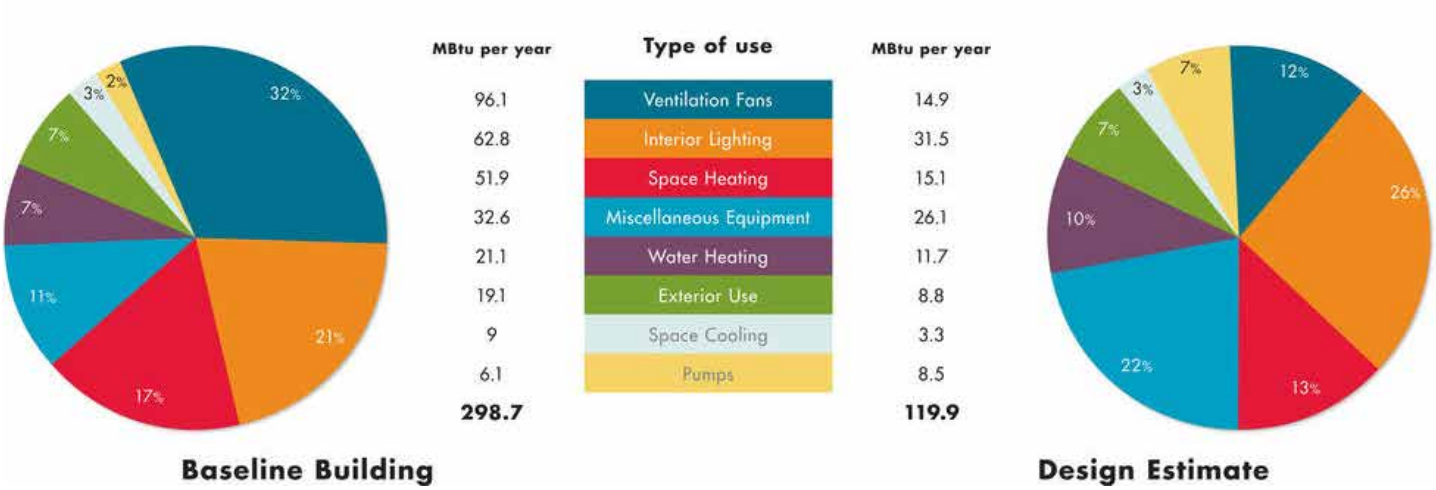


Energy Metrics

Energy Use: May 2011-April 2012

Mechanical Equipment (kWh)	Lighting/ Plug Loads (kWh)	Total Power Consumption (kWh)	PV Energy Production (kWh)	Net Power Consumption/ Production (kWh)
27,654	**14,157**	**41,811**	**42,368**	**-557**

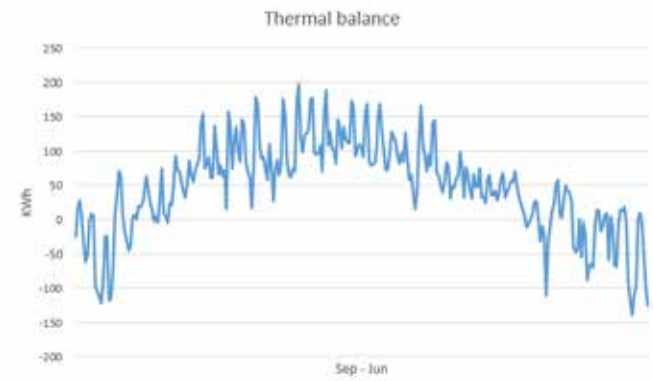
Energy Use Comparison



Baseline Energy Consumption Comparison. Courtesy of Interface Engineering.

Heat Loss & Heat Gain

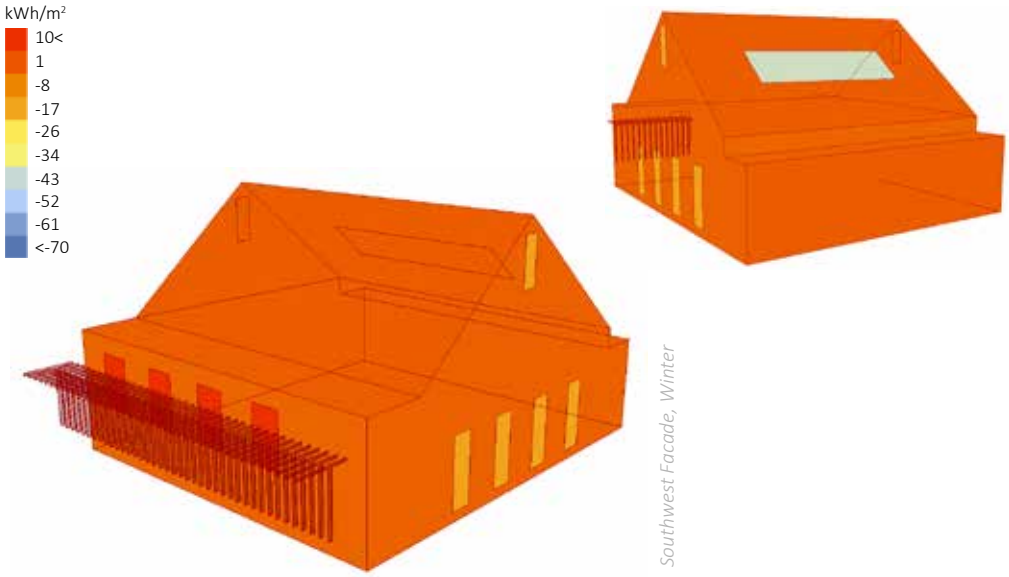
Major heat gains come during the summer that heat up the mass of the building. The architects placement of photovoltaic panels on the southern gable of the building's roof utilized that heat gain in the energy generation for the building.



Thermal Balance Chart.

Winter Heat

Minor heat gain and major heat loss in Winter. Wall, floor, and roof surfaces are gaining above 10 KWh per sq. meter. Openings are losing roughly 26 KWh per sq.meter.

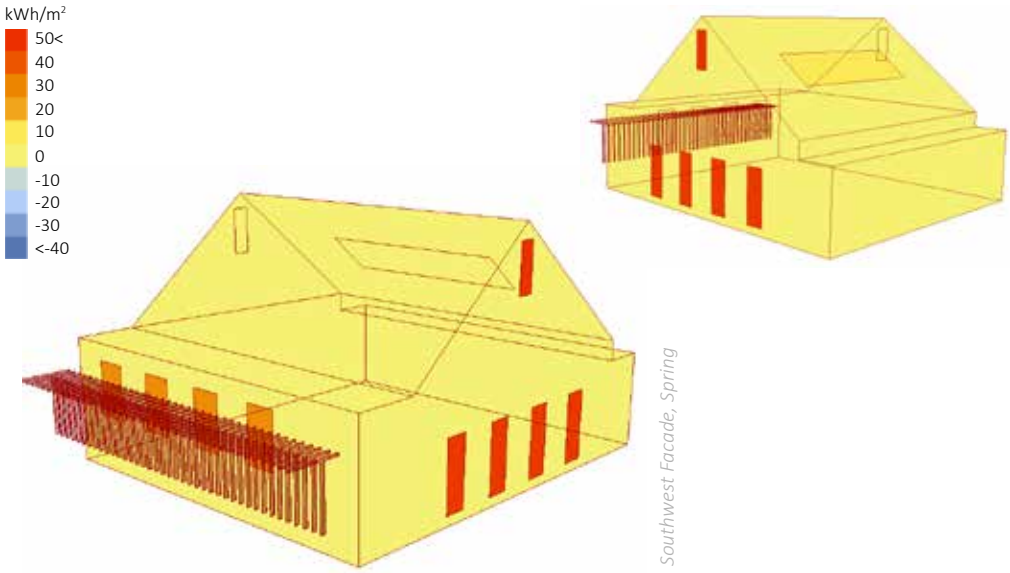


Northeast Facade, Winter

Southwest Facade, Winter

Spring Heat

Neutral and major heat gain in Spring. Walls, roof and floor aren't losing or gaining any heat. Openings are gaining over 30-40 KWh of heat per sq. meter.



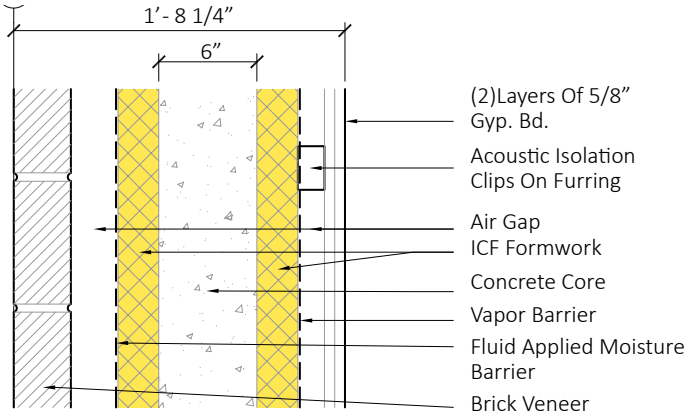
Northeast Facade, Spring

Southwest Facade, Spring

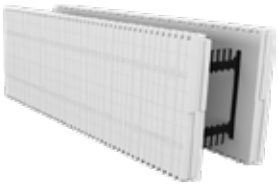
Envelope Performance

Wall Detail

- R-Value: ***25***
- Type: Insulated Concrete
- Insulation: Insulated Concrete Formwork
- Exposed Interior Material: Double-layered 5/8" gypsum board
- Exposed Exterior Material: Brick Veneer



Exterior Wall. Courtesy of Opsis Architecture.

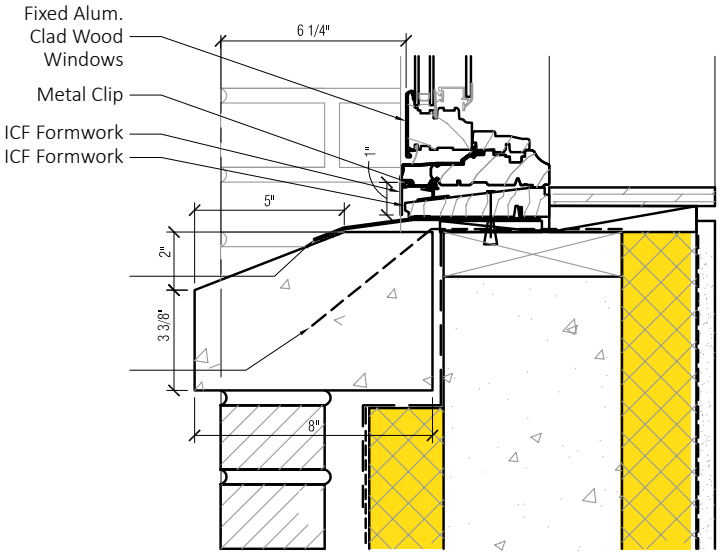


Insulated Concrete Form

"Materials that serve more than one purpose."

Fenestration Detail

- R-Value: ***3.3***
- Window type: Triple glazed
- SHGC: 0.3
- Visual Transmittance: 0.38
- Glazing Applications: Windows, Clerestories, Skylights, Greenhouse.
- Window to Wall Ratio: 29%
- South Facade Window Area: 352 sq.ft.
- Total Window Area: 1,613 sq.ft.

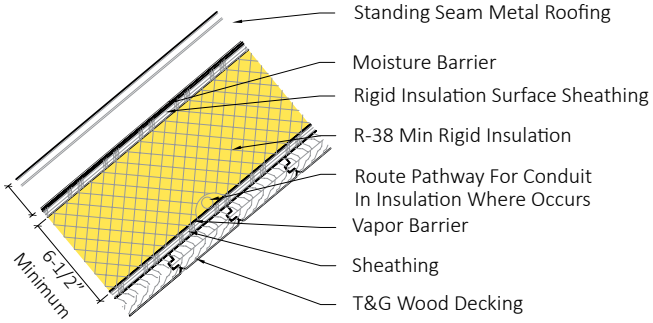


Fenestration Detail. Courtesy of Opsis Architecture.

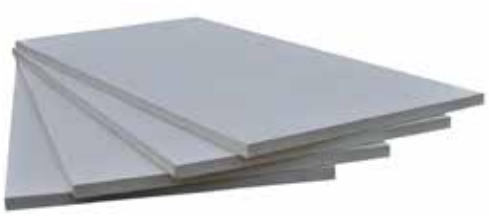
Triple Glazed Windows

Roof Detail

- R-Value: ***40***
- Energy Generation: 33,484 KWh
- Type(s): Gable, Parapet
- Insulation: Rigid (R-38)
- Exposed Interior Material: Wood Decking
- Exposed Exterior Material: Standing-seam Metal
- Water management: 14,000 gal underground cistern to collect rainwater



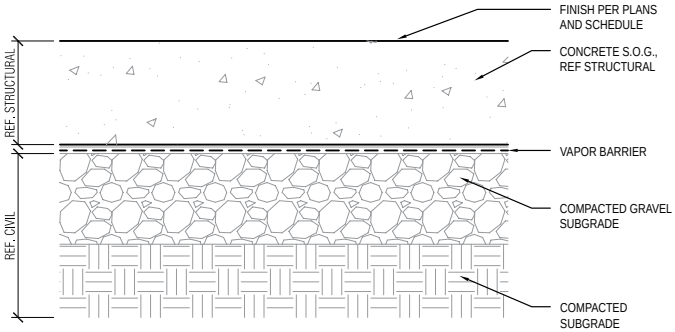
Roof Detail. Courtesy of Opsis Architecture.



R-40 Ridgid Insulation

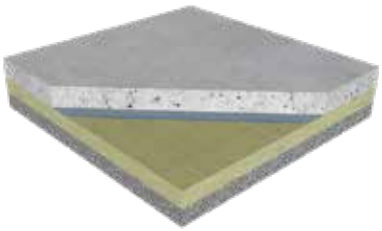
Floor Detail

- R-Value: 15
- Floor Type: Concrete slab
- Insulation: Rigid (continuous)
- Exposed Top Material: Concrete
- Subgrade Material: Compacted gravel



Floor Detail. Courtesy of Opsis Architecture.

Concrete floors provide thermal mass as well as radiant heating and cooling. This was chosen because it is durable, and easy to maintain.



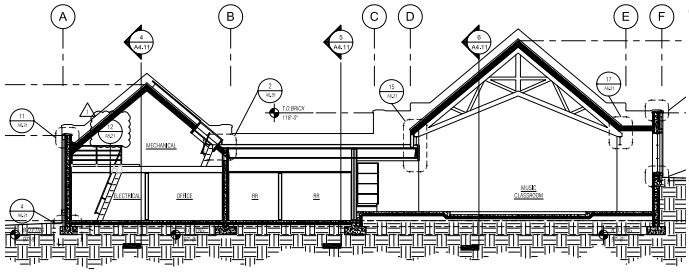
Under Slab Insulation

Acoustics

The desire to minimize materials and use of a radiant floor slab to help heat the building, created an acoustical problem due to concrete's very low Noise Reduction Coefficient (NRC). The design team solved this by using a double layer of drywall and sound absorbing panels to the interior spaces. The insulated concrete formwork (ICF) as bearing walls also help with the noise reduction and noise trespassing from the music room into the classrooms.

Air

Heat recovery ventilators intake warm air located underneath the solar panel to pre-heat the air entering the building. Air is evenly distributed into the buildings classrooms through difusers. Stacked ventilation releases warm air and carbon dioxide automatically when heat and/or CO2 reach undesired or dangerous levels.



Section Elevation. Courtesy of Opsis Architecture.

Thermal

Thermal comfort within the building was undertaken by a plurality of strategies. Starting at the envelope, the well insulated thermal mass within the exterior walls allows for slow heat release in cold winter months and protected spaces during the hot summer months. The slabs geothermal radiant floor heating also play a large part in mediating extreme temperatures. Arguably, the building's automated technology program plays the largest part in allowing this building to respond to desired indoor thermal comfort conditions.

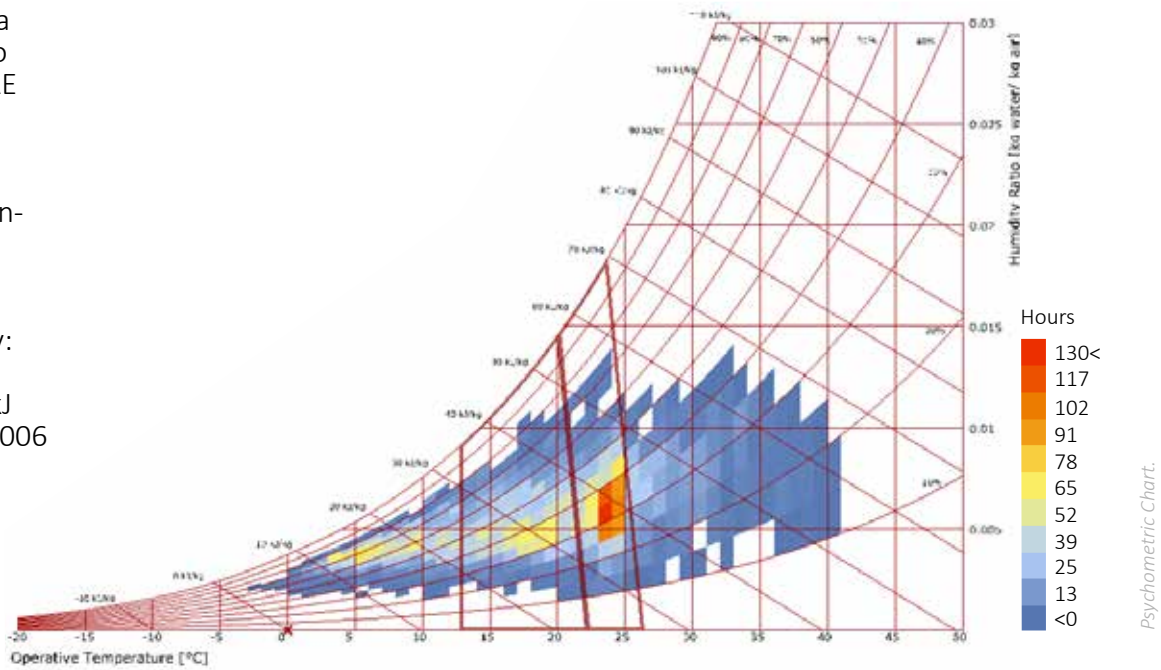
Interior View showing Material Use. Courtesy of Opsis Architecture.

Pyschometric 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:

- Temp: 25 C
- Relative Humidity: 30-40%
- Enthalpy: 65 kg/kJ
- humidity ratio: 0.006



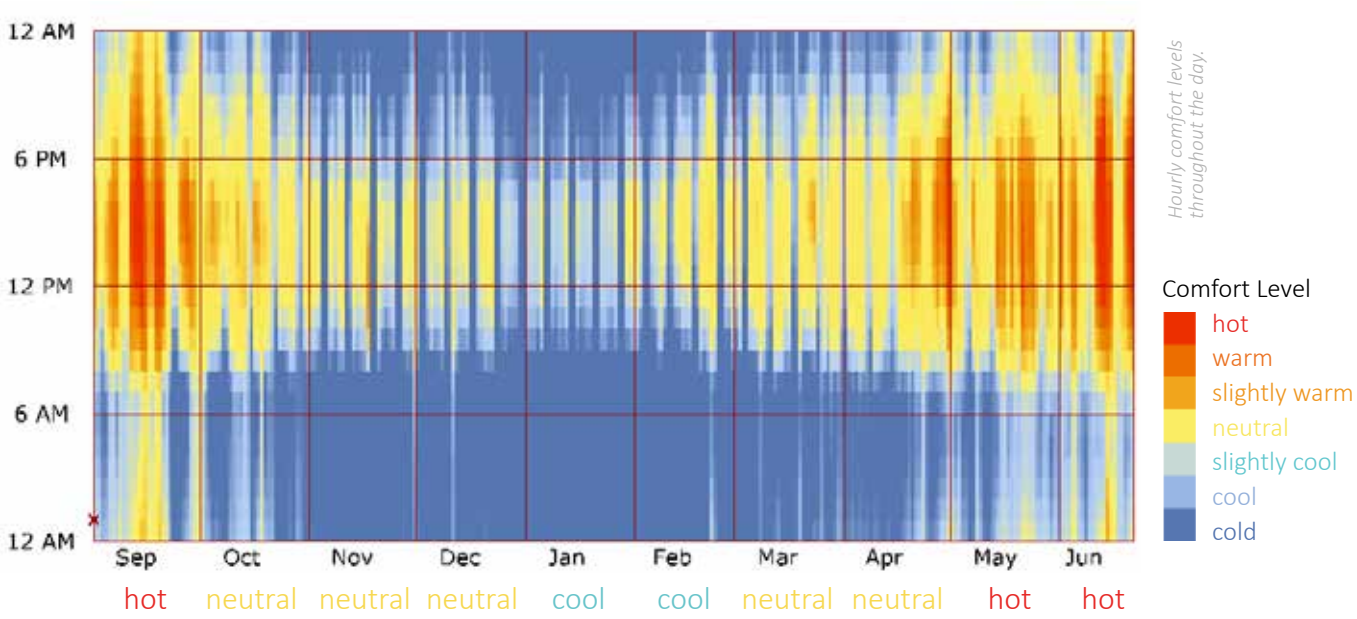
Psychometric Chart.

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 **54.0%**

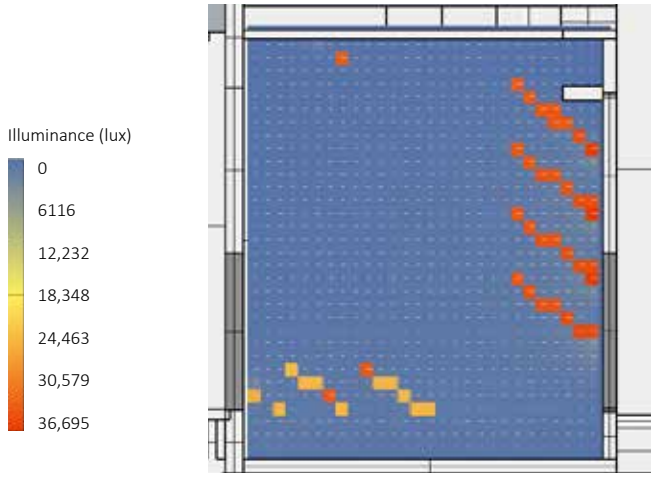


Hourly comfort levels throughout the day.

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)



Illuminance Node Analysis. Sep 21st.

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*

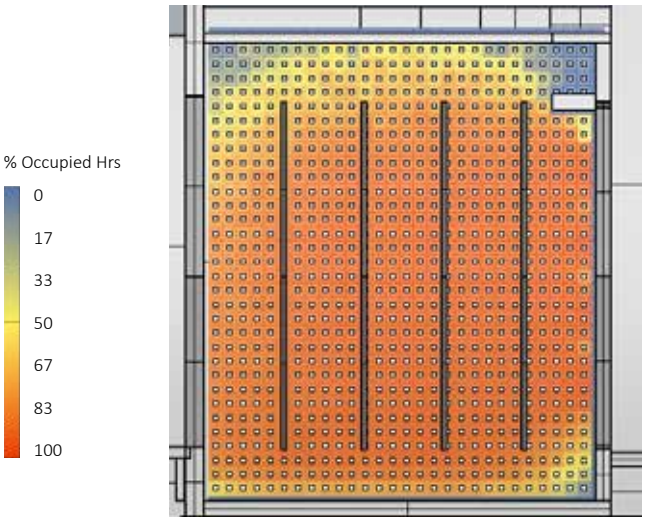
As an example, a point indicating semi-red color in the area means that 84% of the occupied time, that point meets the criteria of having daylight factor of 300 lux or above.

Illuminance Node Analysis

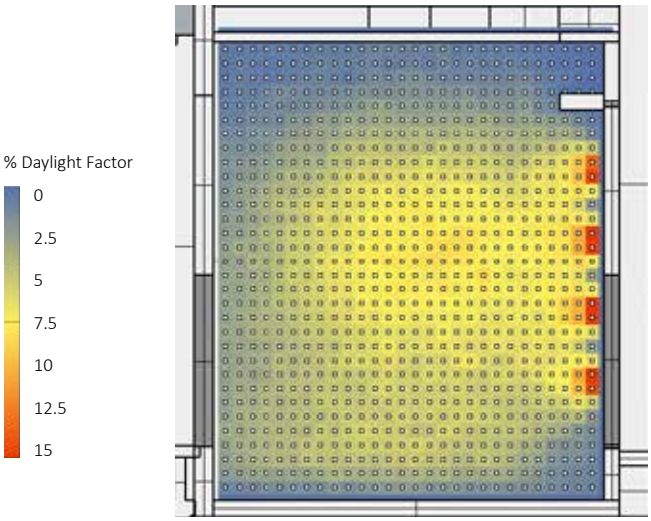
Mean illuminance: ***2017.47 lux*** (each point's value is available)

Daylight Factor

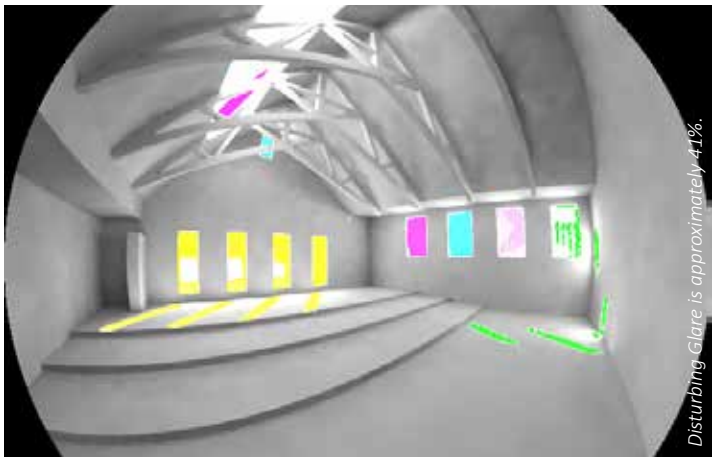
Mean daylight factor = ***4.12 %***
The daylight factor for 99.8% of the area is between 0 & 15 %
The daylight factor for 0.2% of the area is above 15%



Daylight Autonomy Analysis.

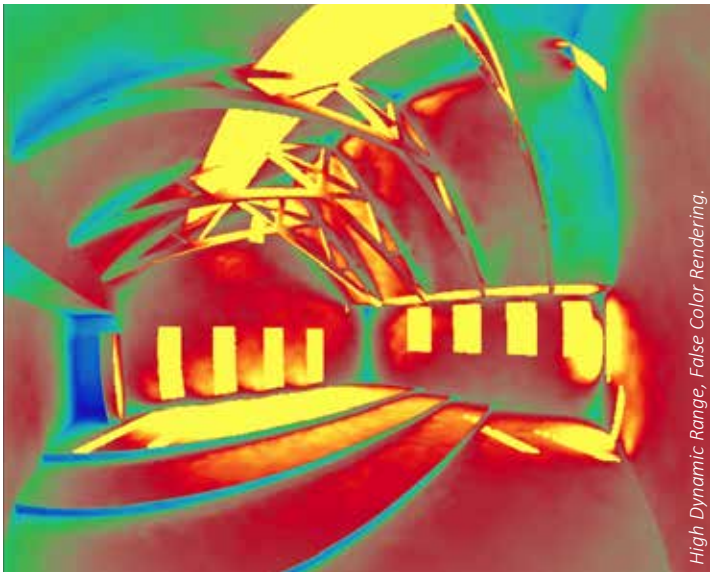


Daylight Factor Analysis.

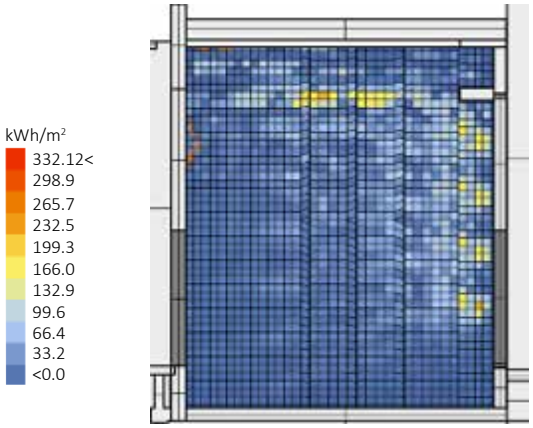


Disturbing Glare is approximately 41%.

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



High Dynamic Range, False Color Rendering.



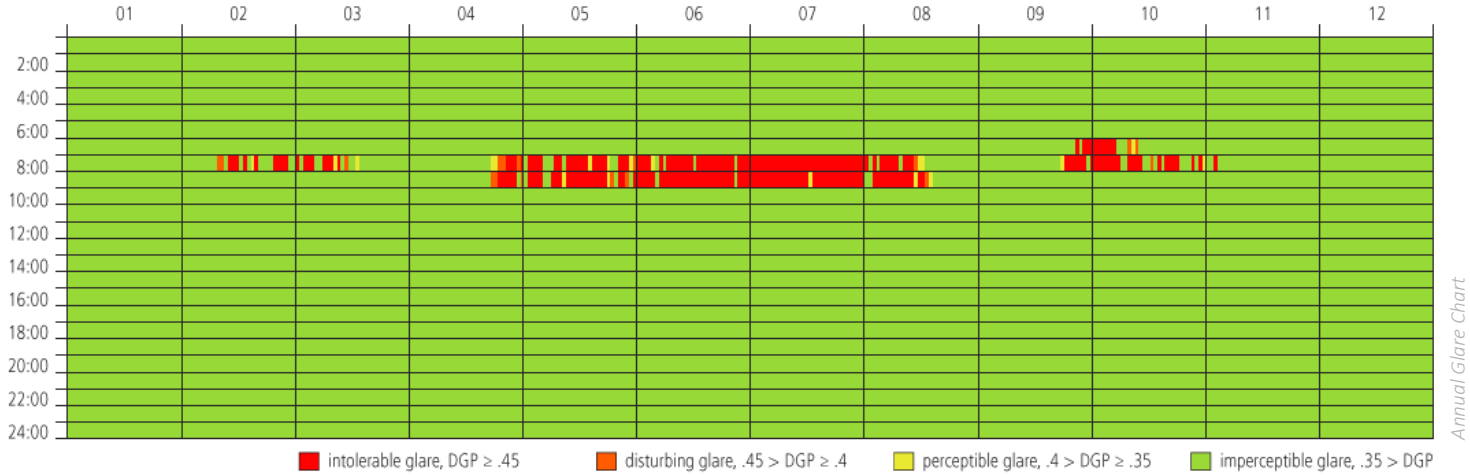
Sunlight on Floor

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).



Annual Glare Chart

Intolerable Glare from 7-8AM throughout most of the year. Intolerable Glare from 7-9AM in late Spring and early Summer.

Woodburn Success High School

Woodburn, Oregon, 97071.

Opsis Architecture

Interface Engineering MEP

2018

Design Process

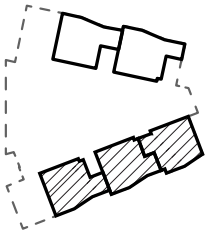
Project Statement

Woodburn Success High School is determined to use net zero design practices to evvnsure that students can learn in a place that they know isn't adding to the carbon emissions of most other buildings.

Aerial Photo with School Layout and Site Boundaries.

Maintaining Even Daylighting Levels

30.24% of the building's walls are facing south. Allowing for 3 out of the 5 classrooms to have south-facing daylight.



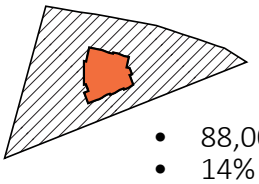
South Facing Classrooms.

- 30.24% South-facing
- 3 out of the 5 classrooms access South daylight

Building Plan. Courtesy of Opsis Architecture.

Land Use and Site Ecology

The Woodburn Success High School building takes up roughly 14% of the 88,000 square foot site. The athletic field North of the school is a shared outdoor area and is not included in the site lot. A portion of the site is dedicated to a stand-alone ground-mounted solar array that provides energy for the building.



- 88,000 sq.ft.
- 14% site occupancy

Land Use Diagram

Common area. Courtesy of Opsis Architecture.

Spatial Programming

With a total of five classrooms, three are located along the Southeast facade and the other two are located along the Northeast façade. Each of the classrooms has a complimentary breakout space for individual study, counseling and other intensive learning areas.

The administration area takes up the western façade, consisting of admin break rooms, meeting rooms, kitchens and offices. The admin area looks into the large-volume central commons area; where there's a raised roof and clearstory glazing skirting below the outer edges of the roof to bring in daylight and connect to surrounding views of nature.

Common area. Courtesy of Opsis Architecture.

Strategizing Light

Opsis Architecture went through variations on daylighting details, ranging from interior materials, texture and color, as well as fenestration design to harvest light into the large common area located at the center of the building.

Light From Above

Clerestory window openings bring in direct and indirect daylight into the central space. Aesthetically, this lighting strategy highlights the roof shape, granting more visual attention to the space's volume.

This design element remained consistent throughout the entirety of the project.

Morning Light

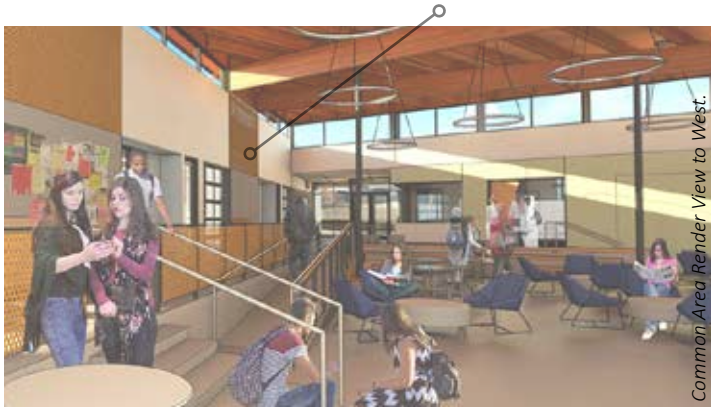
Floor to ceiling glass panels bring in daylight from the East facade, deeply illuminating the Eastern end of the central space as well as providing views out to the surrounding landscape.

Bright Surfaces

The use of white paint on interior walls, bright blue and grey on acoustic panels, and non-dark wood stains allow for greater light reflectance value in the interior of the space.

In the conceptual phase, wall surfaces were warmer, yet darker, trading off more light for more visual warmth.

Common Area Render View to East.



Common Area Render View to West.

Design Strategies

Energy Reduction Strategy

To reduce the total energy of the building, a Variable Refrigerant Volume system served by several Energy Recovery Ventilators providing dedicated outside air; were used to dramatically reduce the heating and cooling energy the school requires as compared to the baseline rooftop heat pumps.

Building Zoning

The common area is a very large open area and is difficult to hide any sort of ductwork in the ceiling therefore it was decided to have side-wall diffusers direct air from the north and south walls into the center common area.

Classrooms and conference rooms are given their own fan coil unit for direct thermal comfort control as well as their own rooftop heat pump unit.

The smaller study spaces were considered part of the classroom units. They utilized the classroom's rooftop heat pump units and each study space has recessed ceiling fan coils.

Building operations and electrical rooms each have their own dedicated fan coil as well.

The admin spaces are also grouped to be served by a single rooftop heat pump unit.

Architecture as a Teaching Tool

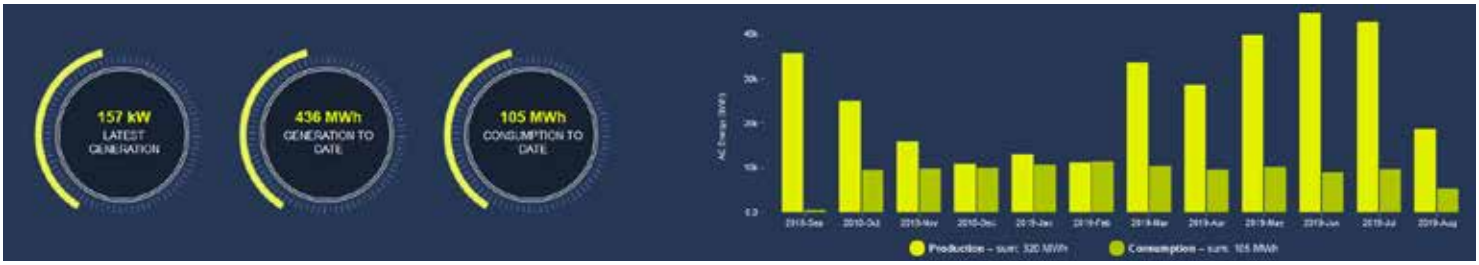
Photovoltaic Panels were installed on site to supply power for the building and allow students to learn from it as they spend time around outdoor areas. In addition, exposed structures ensued that all architectural elements are visible and educational.

Classroom Opening. Courtesy of Opsis Architecture.

Interior Circulation. Courtesy of Opsis Architecture.

Space utilization using Garage Door

Interior accessibility and Transparency between spaces.



Ground Level Solar Array. Courtesy of Google Earth

Solar Data. Courtesy of Opsis Architecture.

Ground Level Solar Array

The solar array installed next to the athletic feild is a strategy to reduce building roof load by having panels on ground as well as a teaching tool for students who spend time around the outdoor areas of the school.

According to ASHRAE standards for 4A zones, roughly 27% of building floor area should match to the solar panel area for the given building.

728 solar panel units were mounted on the ground which produce 251 kilowatts (DC) of energy for the school building.

Bird's Eye View.

Ventilation Pairing

A portion of the units surrounding the commons area complimentarily serve the adjacent interior spaces for the purpose of air ventilation and conditioning.

The architects and engineers installed side wall diffusers to distribute a portion of the classroom's air to the central space. A collective of air from the five total classrooms allows for enough air to ventilate and control the indoor environment of the central space.

Common Area Ceiling.

High-Efficiency Lighting

Baseline lighting fixtures are fluorescents with dimming ballasts in areas required by code with lighting power densities assigned to each space type. The proposed lighting design replaces fluorescents with LED lighting fixtures which use less energy and last longer.

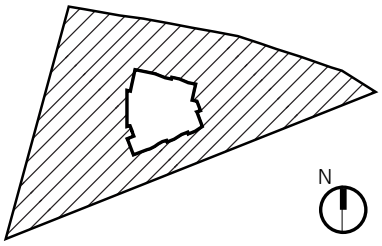
Site Performance

Site Program

- Parking Lot
- Street Access
- Outdoor Basketball Court and Recreation Area
- Bioswales
- Trees and vegetation
- Walking paths connecting school to street
- Solar Array
- Athletic Field (shared with neighboring school)

Site:Building Area Ratio

Building is set within the middle of the site. Parking is located to the West and the sports fields to the North.



Site to Building Area.

Classrooms Facing South

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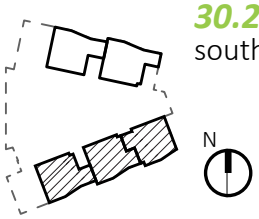


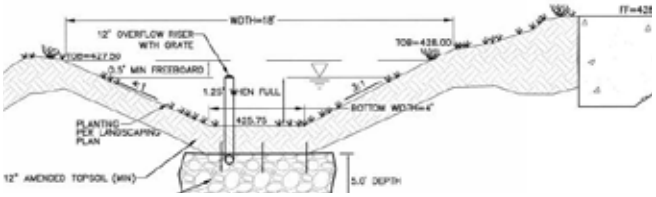
30.24% of the building has south-facing classrooms.

Building partially oriented SW to NE and partially oreinted E to W.

South Facing Classrooms.

Stormwater

Rainwater that falls on the site and its surrounding drainage area is directed towards vegetated detention swales which allow water to percolate through the soil before disposing of the water to the cities stormwater system.



Stormwater detention swale with overflow riser.

East Facade View of School.

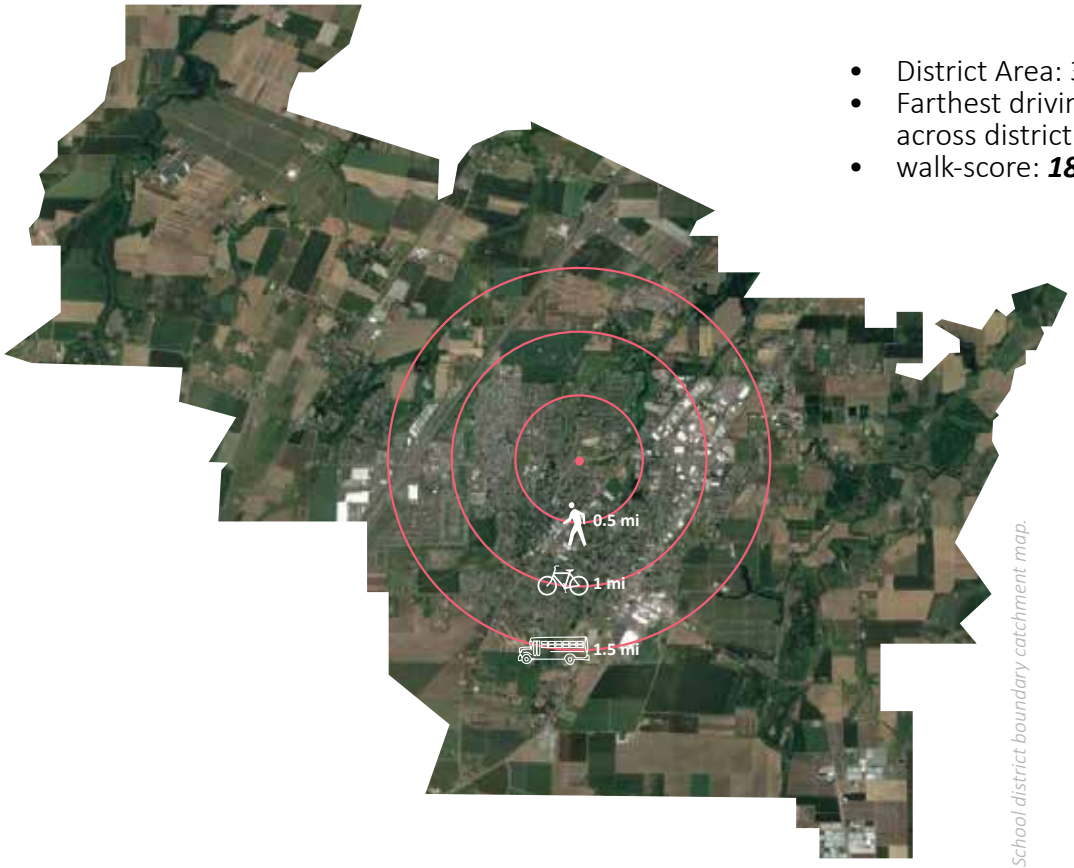
School Catchment Analysis

The purpose of analyzing the school's catchment areas is to understand the level of transportation accessibility to the school.

With a large catchment area, this school is highly car dependent and has a low walk score of 18.

Half mile radius catchment map.

- Located within a residential neighborhood.
- 80 students total
- 54 full-time occupants



School district boundary catchment map.

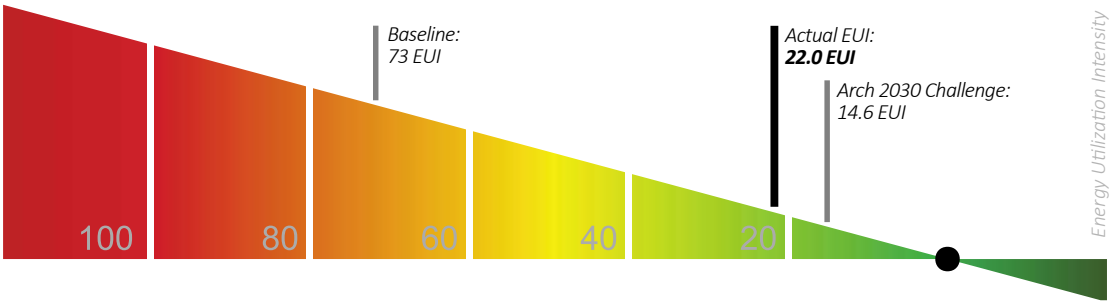
- District Area: 31.2 sq.mi.
- Farthest driving distance across district is 4.4 miles
- walk-score: ***18***

Building Performance

Energy Utilization Intensity

Actual EUI: ***22.0***

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/ft^2/yr).



Energy Metrics

Energy Use: May 2018-April 2019

Mechanical Equipment (kWh)	Lighting/ Plug Loads (kWh)	Total Power Consumption (kWh)	PV Energy Production (kWh)	Net Power Consumption/ Production (kWh)
NA	**NA**	**NA**	**298,010**	**NA**

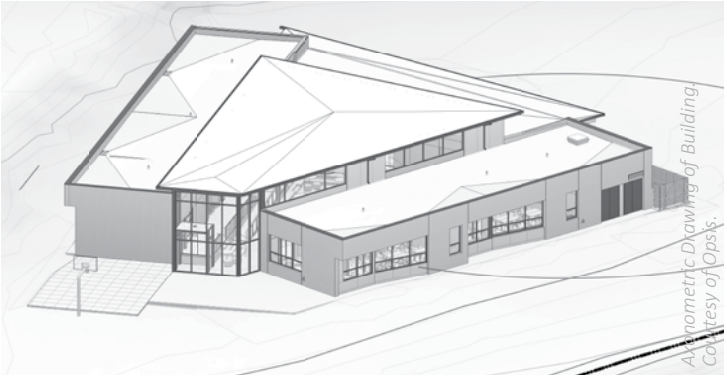
Financial Returns

Energy recovery ventilators:

Savings	13,348 kWh/year ($1068/year)
Cost	$15,000 over baseline, 18.4-year payback
Incentives	Up to $2,236

LED Interior Lighting:

Savings	14,875 kWh/year ($1190/year)
Cost	$5,000 over baseline with a 5.5-year payback
Incentives	Up to $2,492

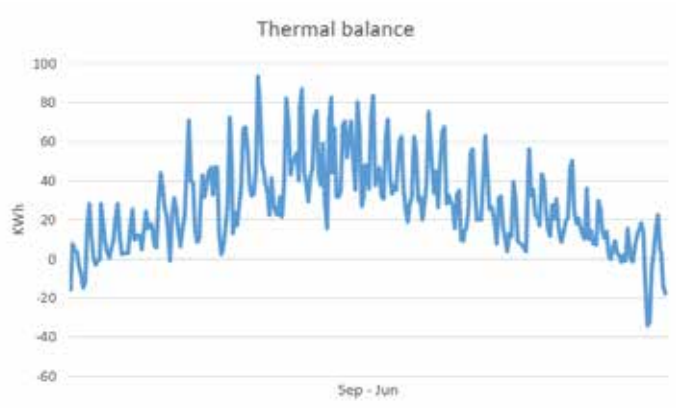


Axonometric Drawing of Building
Courtesy of Opsis

Heat Gain/Loss Classroom Analysis

Cavity indentations within South-facing walls of classrooms serve as a shading device and glare protection from the high-elevation sun.

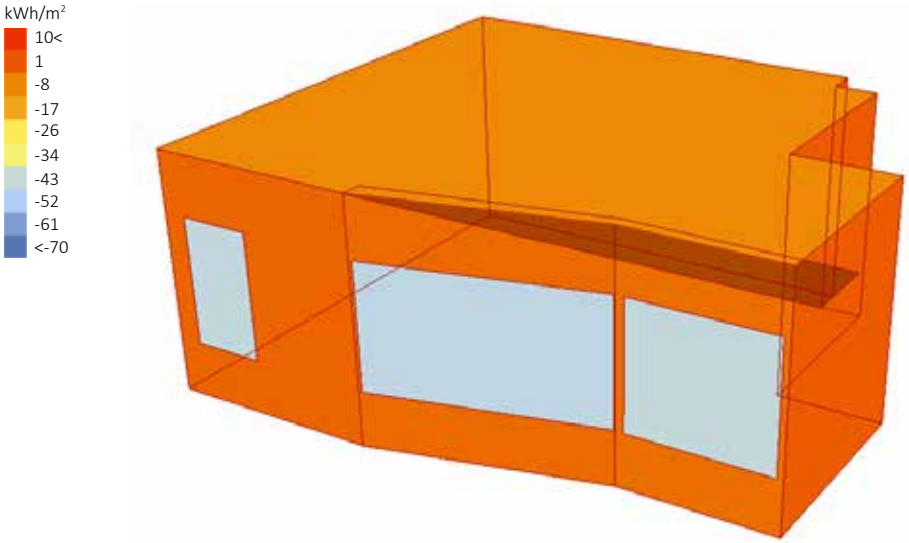
Shown in the model simulation below, the South Facade in winter recieves 10 KWh per sq. meter of solar insolation and 30 KWh per sq. meter in the spring and fall seasons. Thanks to superior glazing specifications and exterior shading, the glazing remains cooler with 0 KWh per sq.meter throughout the seasons.



Thermal Balance Chart.

Winter Heat

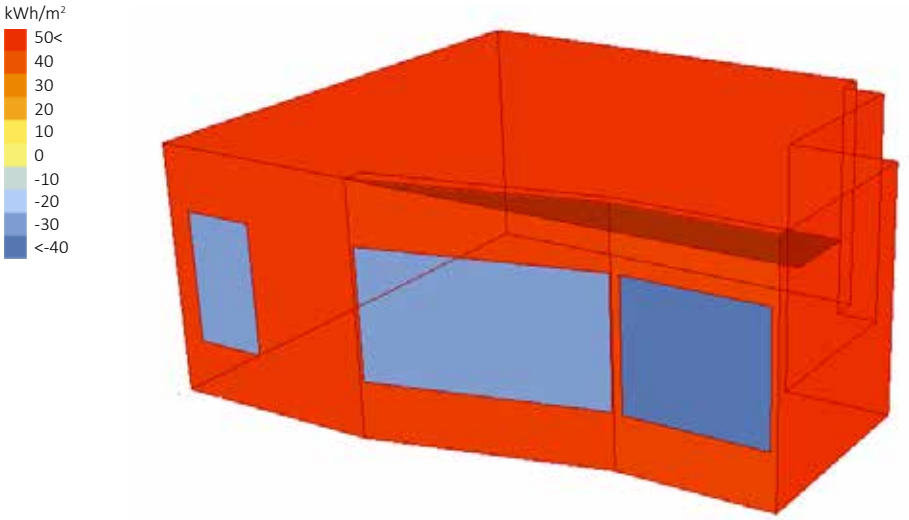
Minor heat gain and major heat loss in Winter. Walls, floor and roof are gaining only about 1 KWh per sq. meter. Openings are losing over 52 KWh per sq.meter.



Solar Heat Gain in Winter.

Spring Heat

Major heat gain and loss in Spring. Walls, floor, and roof are gaining over 50 KWh per sq. meter. Openings are losing between 20-30 KWh of heat per sq. meter.

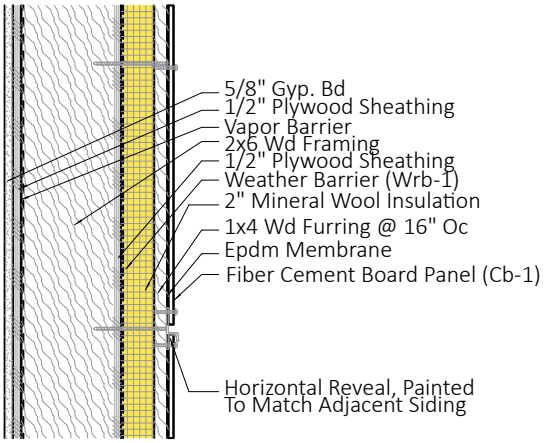


Solar Heat Gain in Spring.

Wall Detail

Cement Board on Wood Stud

- R-Value: ***30.9***
- Type: 2x6 Wood Stud Framing
- Insulation: 2" Mineral Wool
- Exposed Interior Material: 5/8" gypsum board
- Exposed Exterior Material: Fiber Cement Board



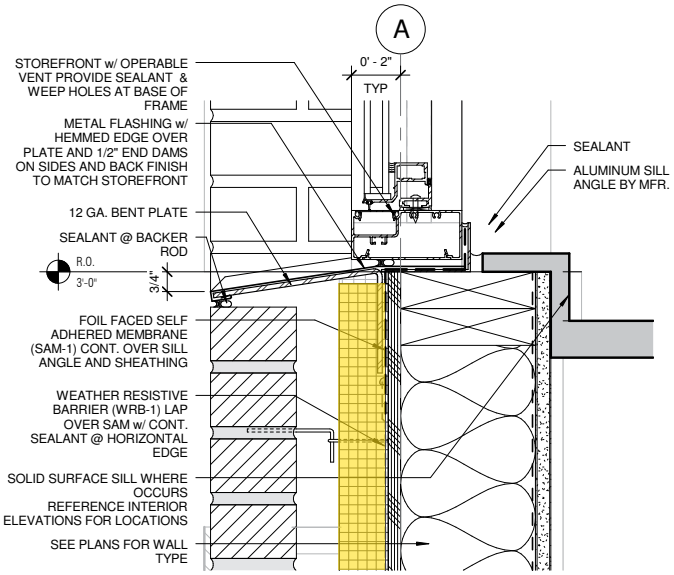
Wall Section. Courtesy of Opsis Architecture.

Brick Veneer on Wood Stud

- R-Value: ***31.5***
- Type: 2x6 Wood Stud Framing
- Insulation: 2" Mineral Wool
- Exposed Interior Material: 5/8" gypsum board
- Exposed Exterior Material: Brick Veneer

Fenestration Detail

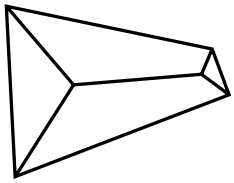
- R-Value: ***6.1***
- Window type: Double glazed
- SHGC: 0.25
- Visual Transmittance: NA
- Glazing Applications: Windows, Clerestories
- Window to Wall Ratio: 30.5%
- South Facade Window Area: 745 sq.ft.
- Total Window Area: 2,632 sq.ft.

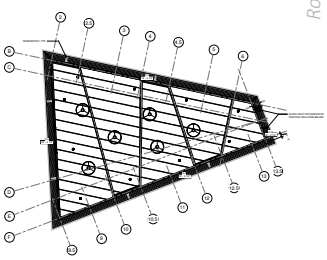


Fenestration Section. Courtesy of Opsis Architecture.

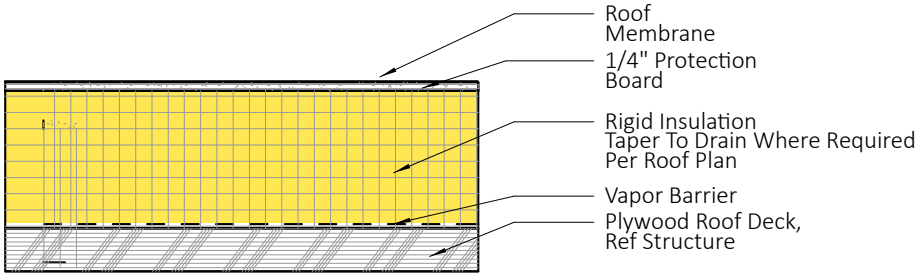
Roof Detail

- R-Value: ***24.1***
- Energy Generation: NA (Ground-mounted solar)
- Type(s): Parapet
- Insulation: Rigid
- Exposed Interior Material: Plywood Decking
- Exposed Exterior Material: Roof Membrane
- Water management: Rain gutter drains to Bioswale

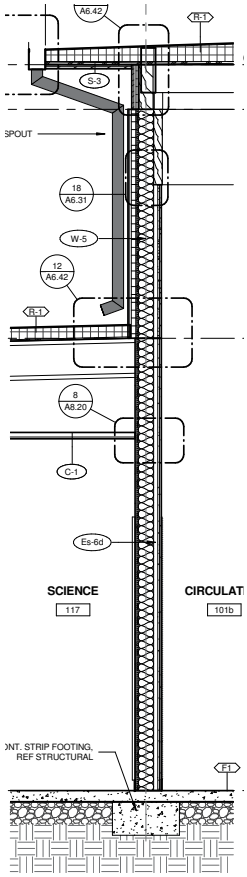




Roof and Ceiling Plan.



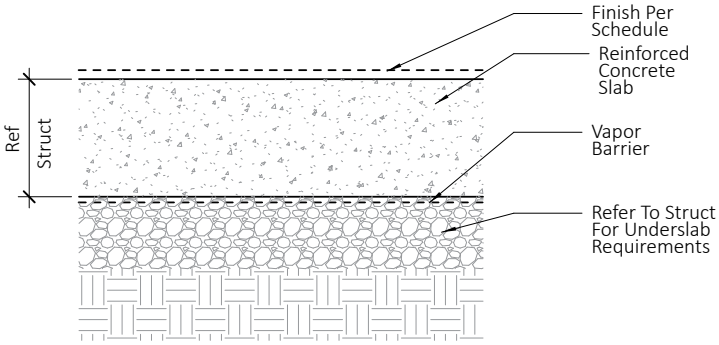
Roof Section. Courtesy of Opsis Architecture.



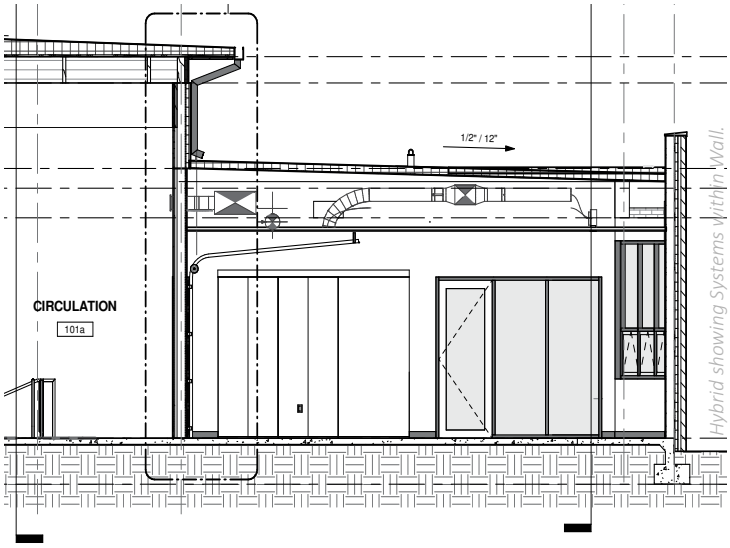
Water flow Section. Courtesy of Opsis Architecture.

Floor Detail

- R-Value: ***0.4***
- Floor Type: Concrete slab
- Insulation: No underslab insulation
- Exposed Top Material: Concrete
- Subgrade Material: Compacted gravel



Floor Section. Courtesy of Opsis Architecture.



Hybrid showing Systems within Wall.

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.

acoustic panels

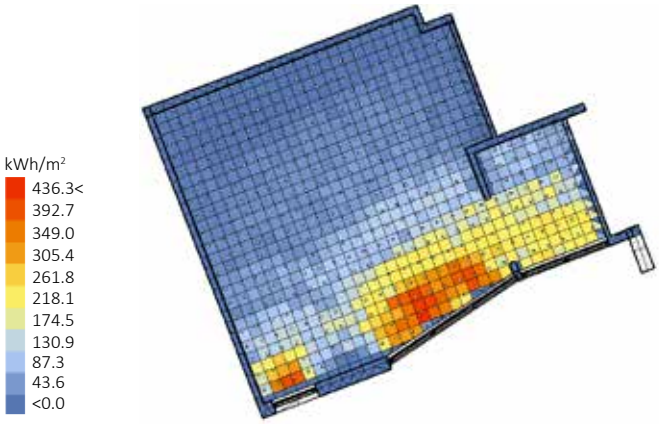
Acoustic Panel. Courtesy of Opsis Architecture.

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.



Radiation on Floor

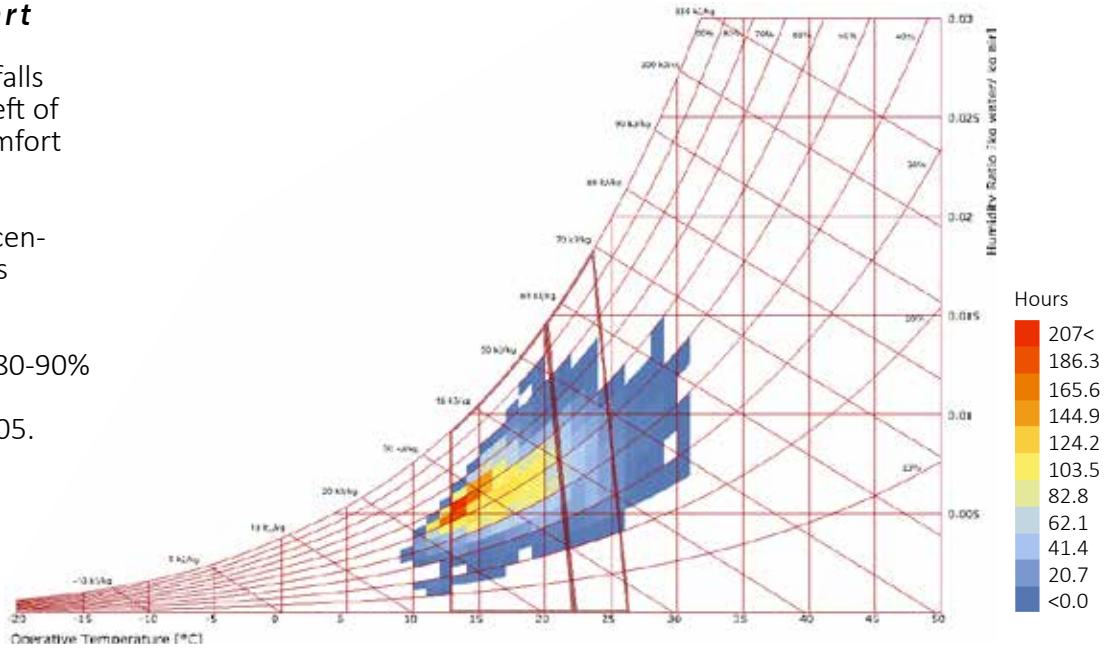
Radiation on Windows

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.



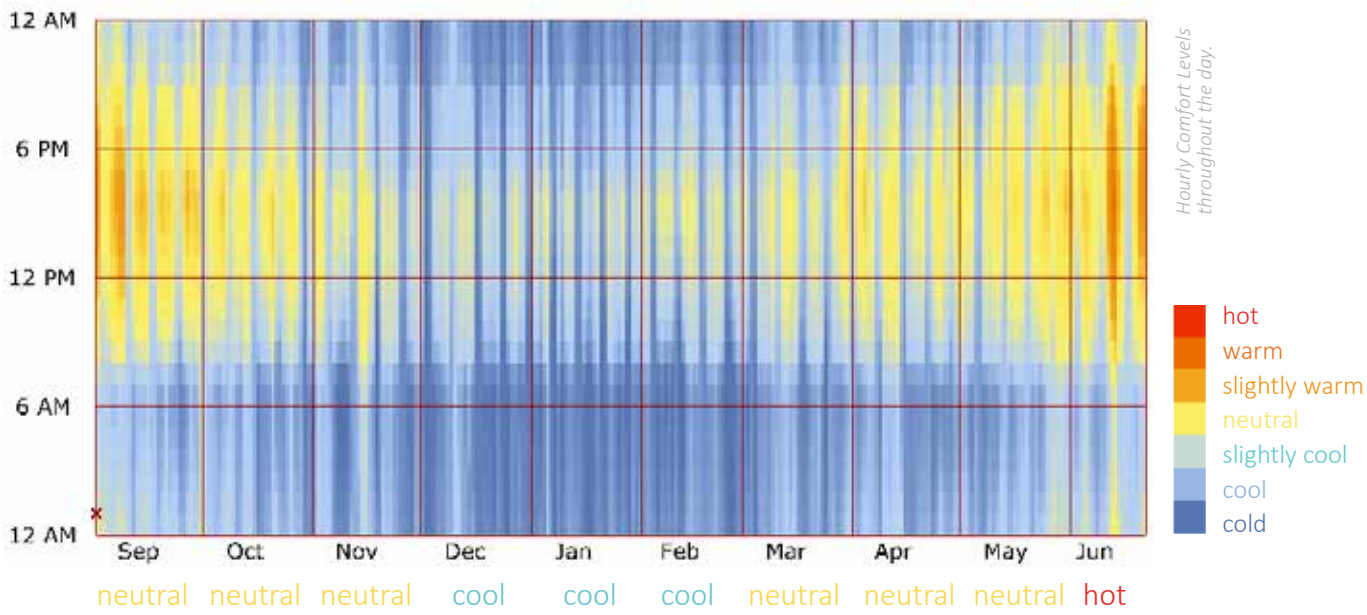
Psychometric Chart.

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

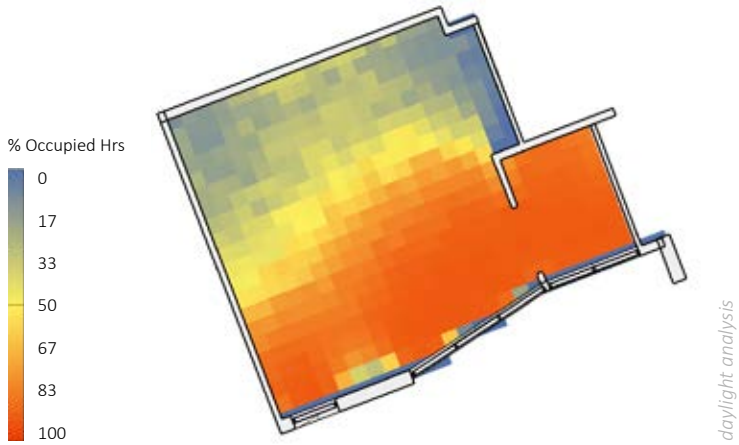
The percentage of the time occupants within the school are inside the comfort zone is **88.3%**



Hourly Comfort Levels throughout the day.

Daylighting Performance

Average Illuminance: ***4709.01 lux*** (annual levels)

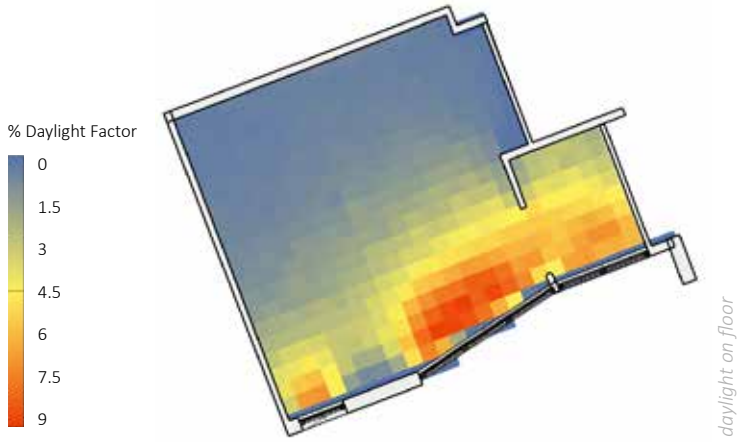


Daylight Autonomy Analysis

The mean luminous autonomy is 300 lux for active occupant behavior. The percentage of the space meeting the daylight autonomy levels for 50% of the year is ***54%***.

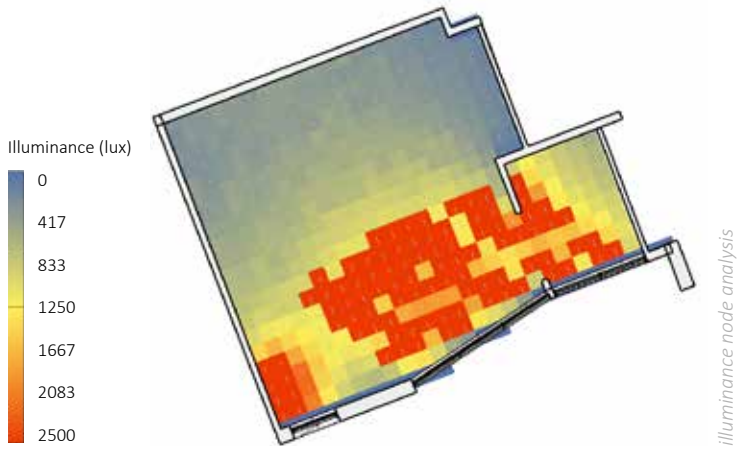
Daylit Area (DA_{300lux}[50%])	*54% of floor Area*
Mean Daylight Factor	*2.2%*
Occupancy	*3650 hours/yr*

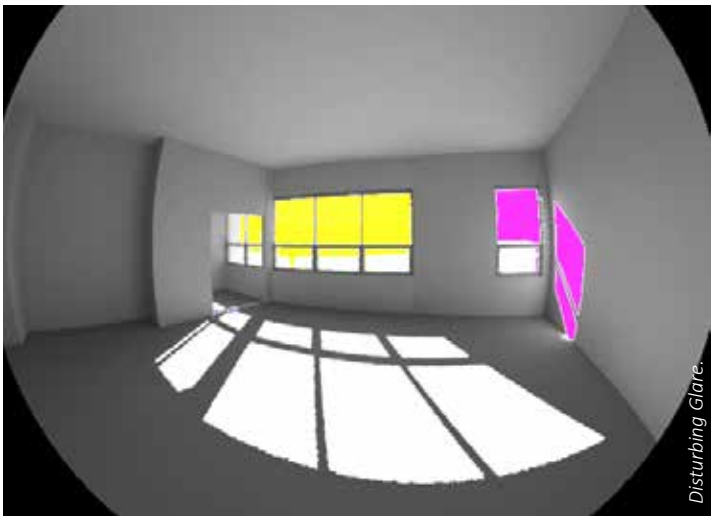
As an example, a point indicating semi-red color in the area means that at 83% of the whole occupied time, that point meet the criteria of having daylight factor of 300 lux or above.



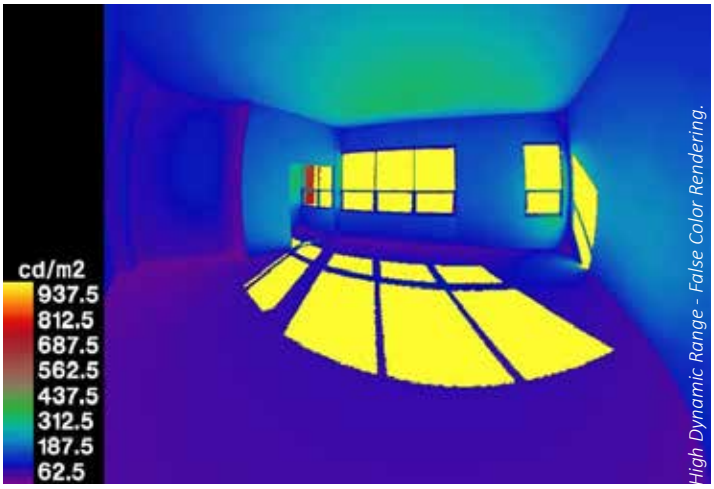
Illuminance Levels Analysis

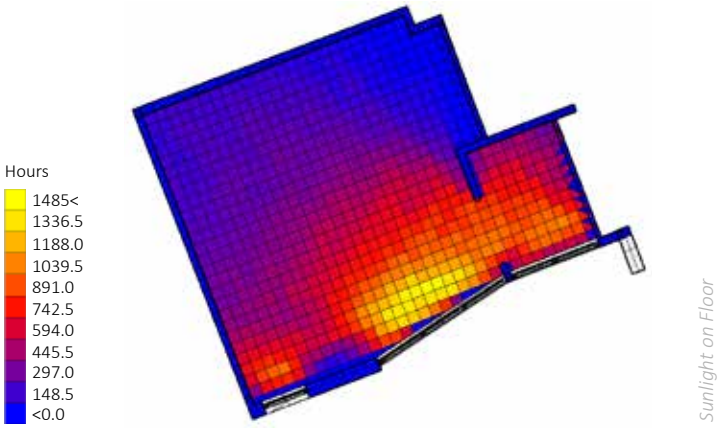
Mean daylight factor = ***2.24 %***
The daylight factor for 100% of Area between 0 & 9 %
The daylight factor for 0.2% of the area is above 15%
0% of Area > 9 %





*Disturbing Glare is approximately **41%**.*





Sunlight and Disturbing Glare

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).

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. Colors match across the false color rendering to the left and the chart below.

Incidents of disturbing glare at 8-9AM in winter season and 9-10AM in fall season.

Durham Center Alternative School

Tigard, Oregon, 97224

BORA Architects

Glumac Engineering

2019

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

Aerial View. Courtesy of Google Earth.

Response to Neighborhood Context

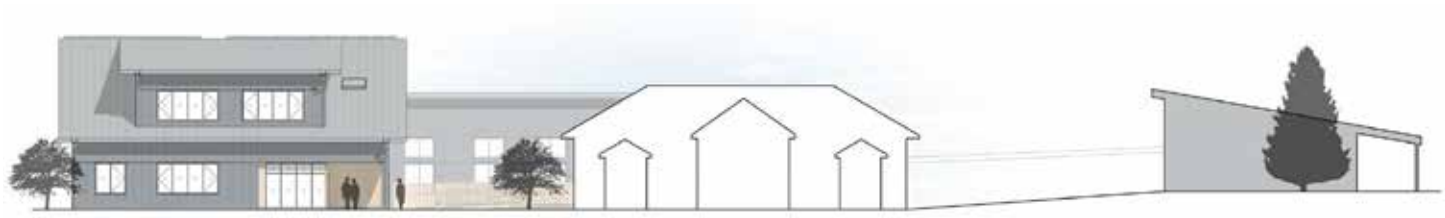
The New Classroom Building is an addition to the Creekside Community High School. Its shape surrounds the existing 'Old Schoolhouse' on the site to define a communal courtyard meant to foster social interaction between students.

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.

Building Orientation

The southward-sloping metal roof maximizes the capacity for solar panels.

They're planned to produce all the electricity needed during the year, making the New Classroom Building the fi rst Net-Zero Energy building in the Tigard-Tualatin School District.

Render, View from Above. Courtesy of BORA Architects.

North Elevation. Courtesy of BORA Architects.

Building Features

- Lobby
- Commons area
- Administration suite
- Variety of classrooms
- Computer lab
- Science classroom
- Makerspace
- Large kitchen
- Outdoor vegetable garden

Site Features

- 24-car parking lot
- Car drop-off area
- Outdoor courtyard between buildings
- Trees and vegetation
- Science classroom
- Makerspace
- Large kitchen
- Outdoor vegetable garden

Achieving Net Zero Energy

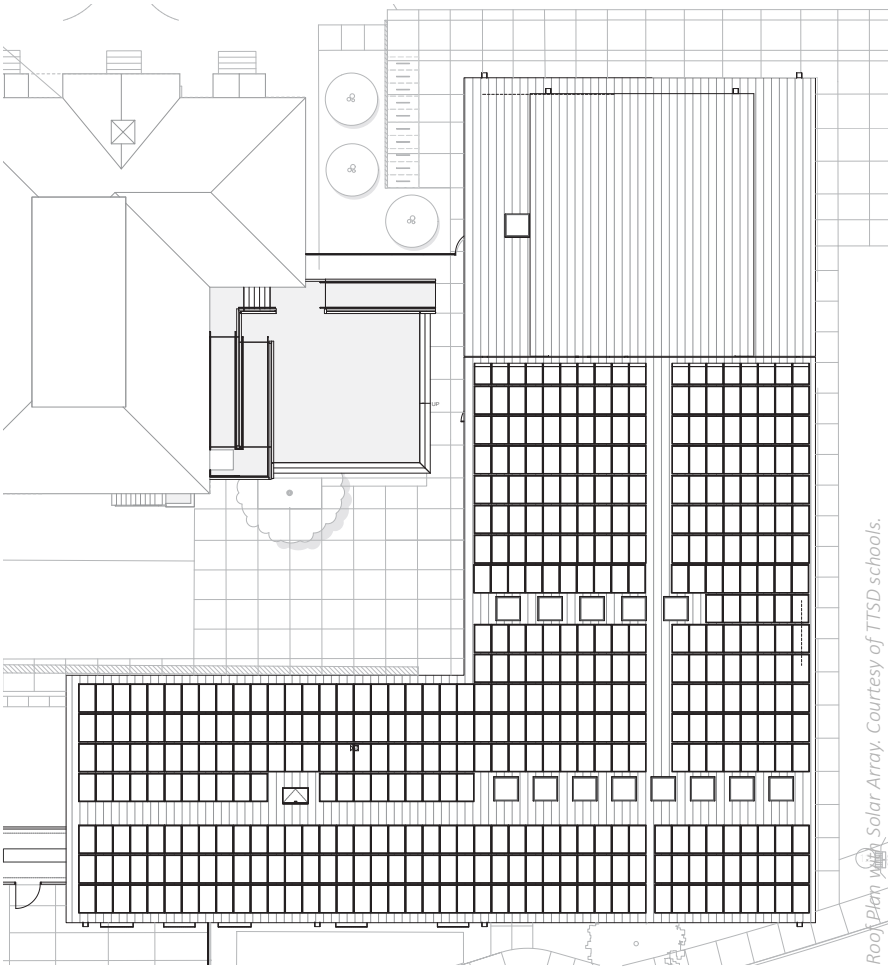
An array of 455 photovoltaic solar panels were placed on the south facing gable roof. As a system, the array is estimated to produce 28.7 kBTU/sq.ft/year. The building's Energy Utilization Index (EUI) was estimated to be 19 kBTU/sq.ft/year.

This production would make the building net positive.

Annually, the building would consume roughly 286,000 kBTU. With the solar array installed, the energy return would cover roughly 432,000 kBTU; about 146,000 kBTU of solar energy in surplus.

The effectiveness of this system was the result of early design planning.

Decisions on the form and building orientation were able to cover the costs of energy for the building at the expense of purchasing and installing the solar panels; as well as designing the building's structure to support the roof load with the additional weight of the panels.



Roof Plan with Solar Array. Courtesy of TTSD schools.

South Elevation. Courtesy of BORA Architects

Aerial Rendering of Proposed Building. Courtesy of TMD Schools.

Architecture as a Teaching Tool

The large kitchen and outdoor vegetable garden promote students to experience how buildings can support functions such as culinary education. Interior layout takes inspiration from the school curriculum to provide a variety of spaces and flexibility to meet the diverse needs of students and staff.

Interior Science Room Render View. Courtesy of BORA Architects.

Interior Classroom Render View. Courtesy of BORA Architects.

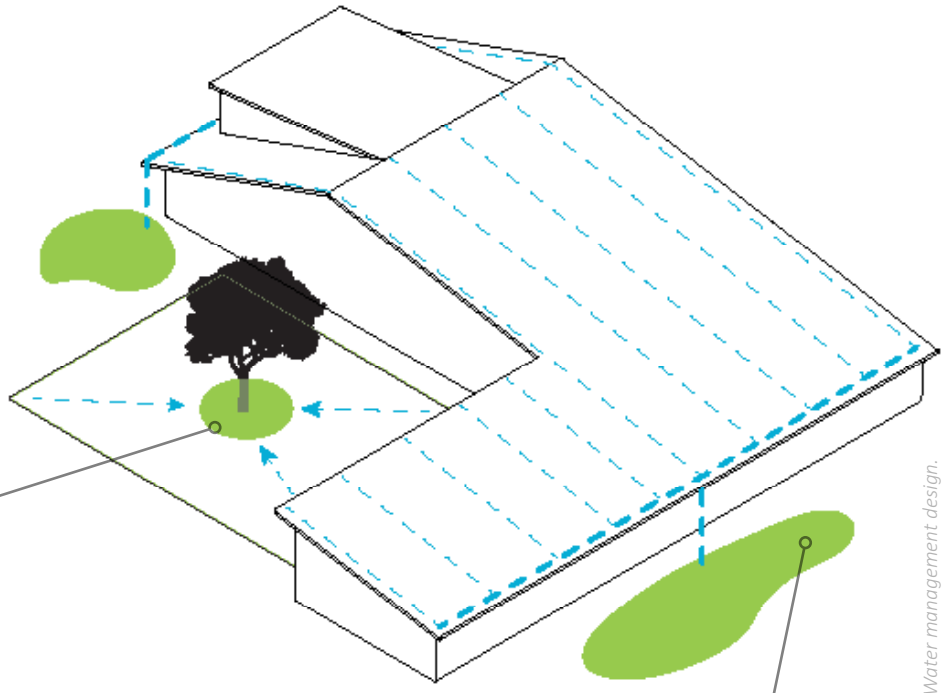
Simple and cost-effective use of plywood paneling and steel truss-beams illuminates to students how building structure works as well as how buildings can be made very simply.

Site Performance

Stormwater Runoff Management

Rainwater that falls on the site and its surrounding drainage area is directed towards detention ponds which allow water to percolate through the soil before disposing the water to the cities stormwater system.

Concrete slabs of central area designed to slope towards the central tree to capture fallen rainwater. This is considered a rainwater sink, where the tree is the drain.

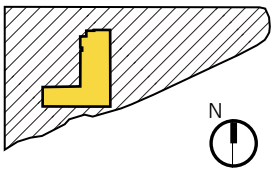


Water management design.

Landscaping at corners of the building where water drains down through gutter piping. Strategically, this is a rainwater capture strategy that benefits the vegetation.

Building Elevation Showing corner Vegatation. Courtesy of BORA Architects.

Site:Building Area Ratio



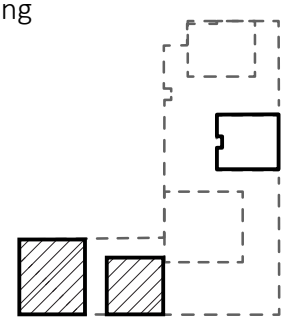
Built up area.

21,560 sf of vegetated open space is preserved.

By being an extension of an existing school site, the design focused on using the remaining space for creating an enclosure with the existing school building and using the rest of the land for vegetated open space.

South-Facing Classrooms

18.87% of the building has south-facing classrooms.



South facing classrooms.

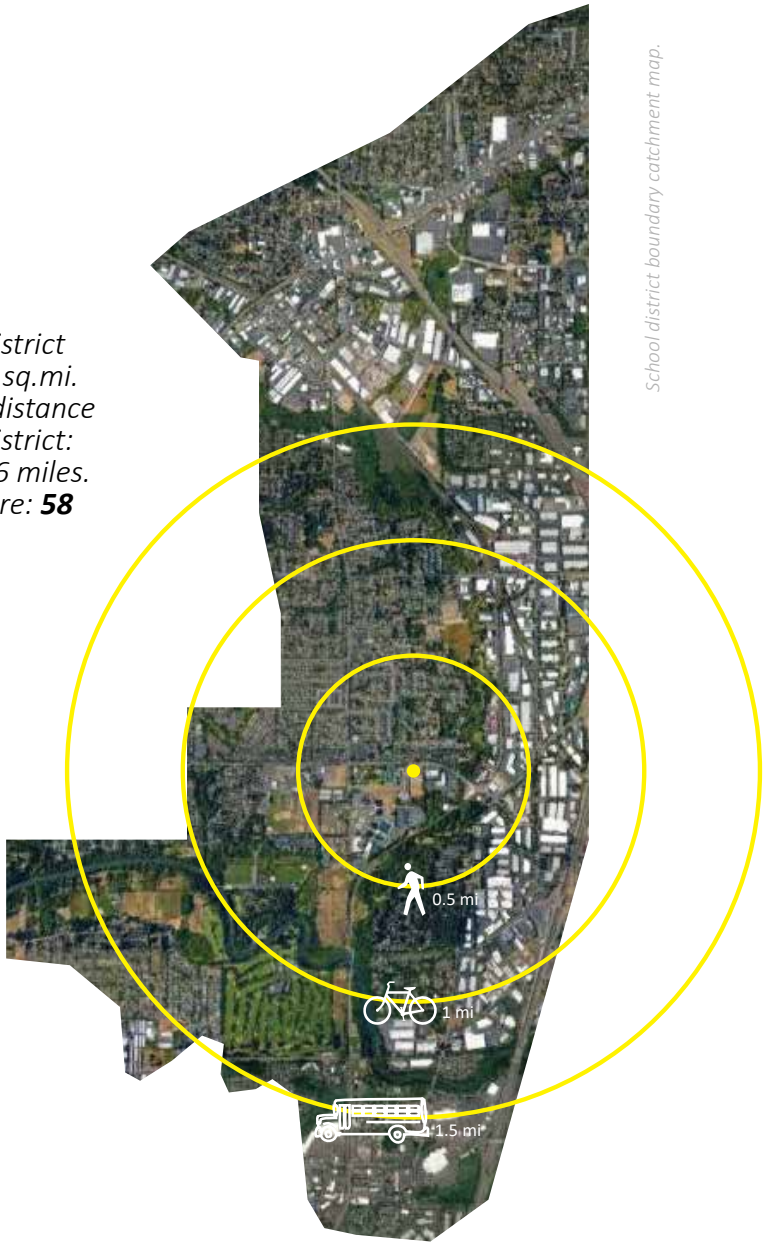
Site Program

- Outdoor Classroom And Laboratory For Students To Learn Permaculture Principles
- Multisensory Food Forest / Vegetable Garden (Irrigated By Cistern)
- Onsite Rainwater Harvesting
- Small Ecological Footprint
- Native Plant Arboretum
- Learning Garden
- Harvest Plants For Food, Fiber, Dye, And Other Uses
- Prepare Produce To Sell At Local Farmers Market

Catchment Maps

The Durham school district spans 6 miles across and is 24 square miles in area. With a catchment area this small, bus rides to and from school are short and will not require excessive fuel for each trip. A major concentration of residential neighborhoods are located 500 feet North of the school. This will encourage alternative transportation (walking and biking) to the school.

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



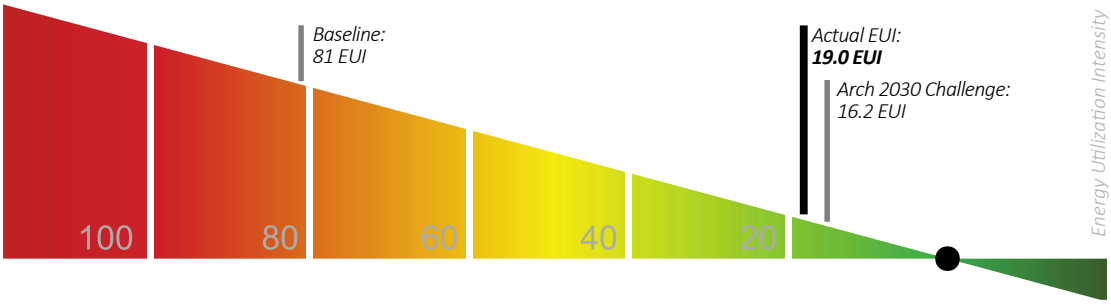
School district boundary catchment map.

Half mile radius catchment map.

Energy Utilization Intensity

Actual EUI: ***19.0***

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).



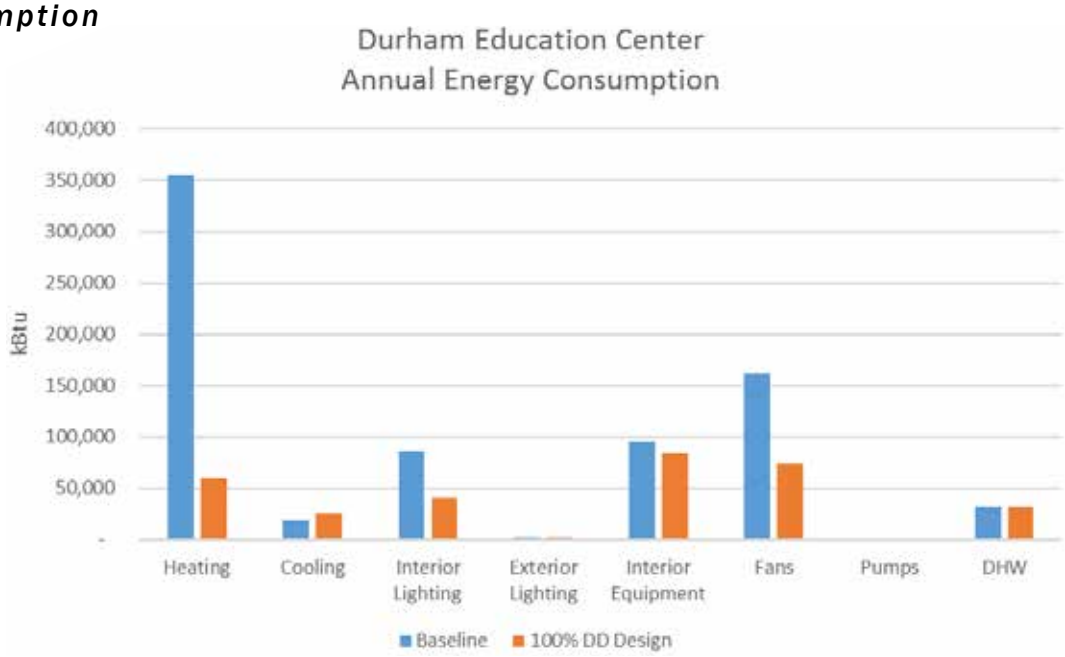
Energy Metrics

Energy Use: Predicted

Mechanical Equipment (kWh)	Lighting/ Plug Loads (kWh)	Total Power Consumption (kWh)	PV Energy Production (kWh)	Net Power Consumption/ Production (kWh)
158,679	**43,408**	**319,507**	**140,000**	**- 179,507**

Building Energy Consumption

The graph to the right compares more finite energy consumption details of this building (red) to a standard baseline building (blue). Each component goes to show how much energy is required per given building component. In most cases, the energy to heat, ventilate and illuminate the building take up the majority of the energy.

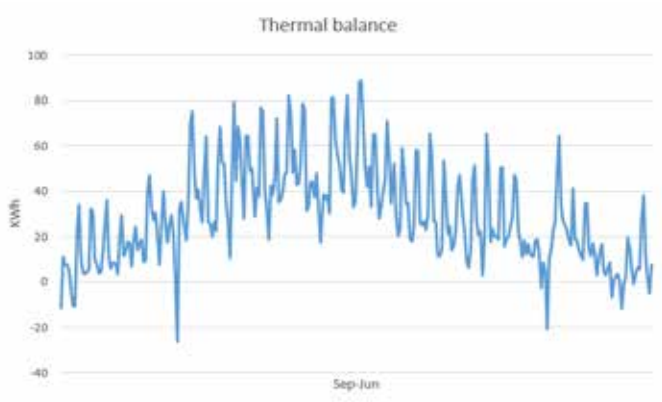


Annual Energy Consumption Bar Graph. Courtesy of Glumac.

Heat Gain/Loss Classroom Analysis

Window shades and overhangs within South-facing walls of classrooms provide shading and glare protection from the high-elevation sun angles.

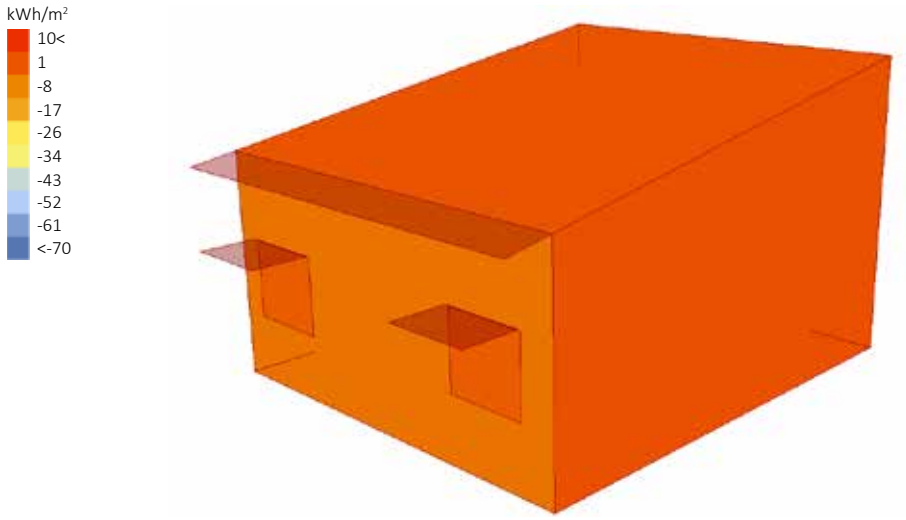
Shown in the simulations below, the south facade in Winter recieves over 10 KWh per sq. meter of solar insolation and 30 KWh per sq. meter of solar insolation in the Spring.



Thermal Balance Chart.

Winter Heat

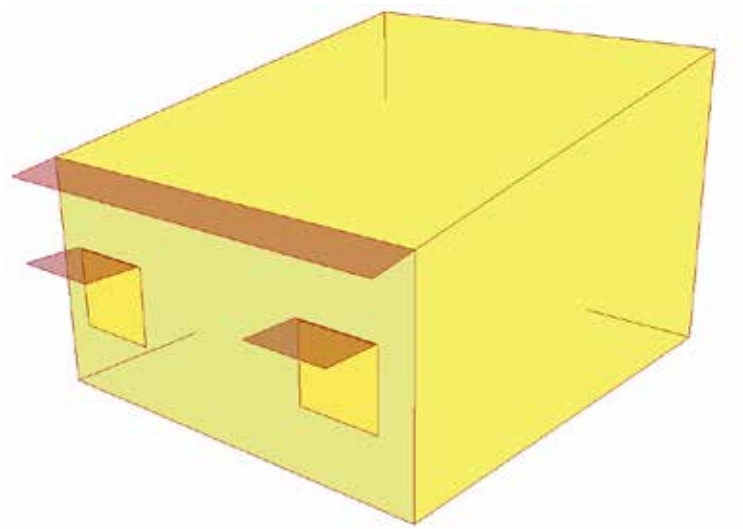
Minor heat gain in Winter. Walls, floor and roof are gaining over 10 KWh per sq. meter. Openings are gaining over 10 KWh per sq.meter as well.



Solar Heat Gain in Winter.

Spring Heat

Neutral and major heat gain in Spring. Walls, roof and floor aren't losing or gaining any heat. Openings aren't losing or gaining any heat either.

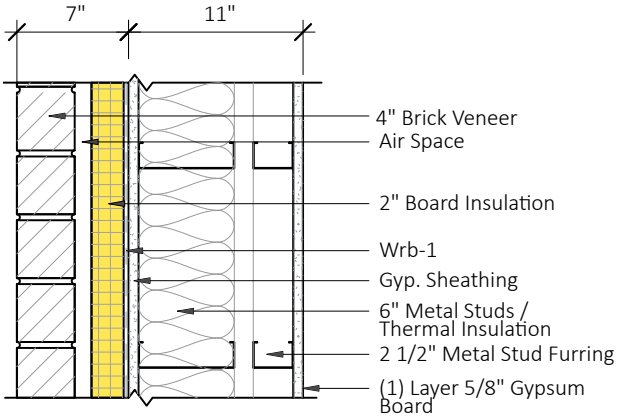


Solar Heat Gain in Spring.

Envelope Performance

Wall Detail

- R-Value: ***20***
- Type: 6" Metal Stud Framing
- Insulation: 2" Board, Thermal Batt
- Exposed Interior Material: 5/8" gypsum board
- Exposed Exterior Material: Brick Veneer



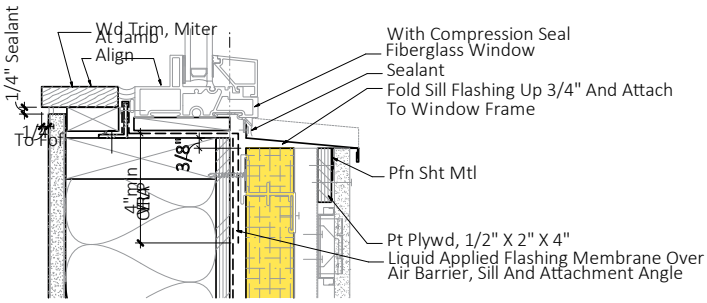
Exterior Wall Section. Courtesy of BORA Architects.

Durham Education Center in Construction. Courtesy of Google Earth.

Durham Education Center in Construction. Courtesy of Google Earth.

Fenestration Detail

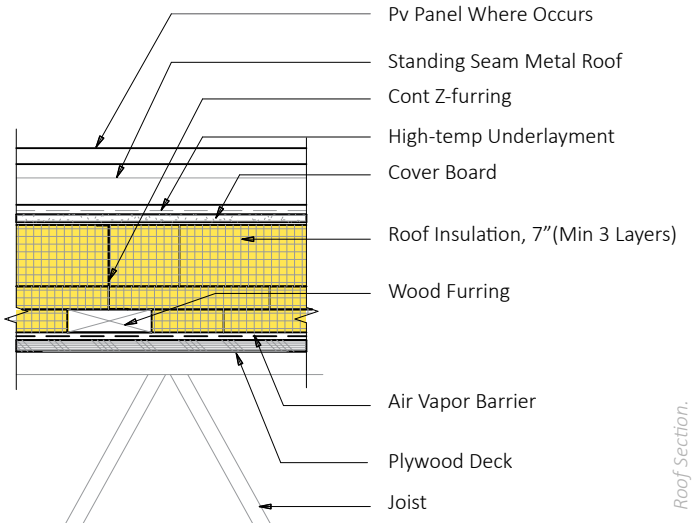
- R-Value: ***3.45***
- Window type: Double Glazed
- SHGC: 0.27
- Visual Transmittance: 0.65
- Glazing Applications: Windows, Clerestories, Skylights
- Window to Wall Ratio: 12%
- South Facade Window Area: 267 sq.ft.
- Total Window Area: 1,484 sq.ft.



Window Sill Section. Courtesy of BORA Architects.

Roof Detail

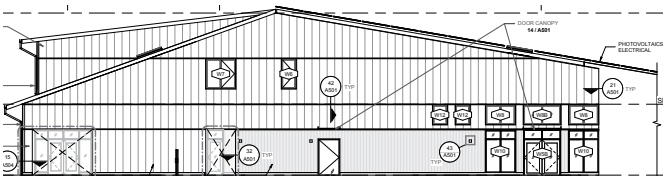
- R-Value: ***30***
- Roof Area: 14,749 sq.ft.
- PV Area: 8,398 sq.ft.
- Energy Generation: 140,000 KWh
- Type(s): Gable
- Insulation: 7" Rigid (3 layers)
- Exposed Interior Material: Plywood Decking
- Exposed Exterior Material: Standing-seam Metal
- Water management: Rainwater drains from gutter into bioswales



Roof Section. Courtesy of BORA Architects.

Upper Floor Common Area Render View. Courtesy of BORA Architects

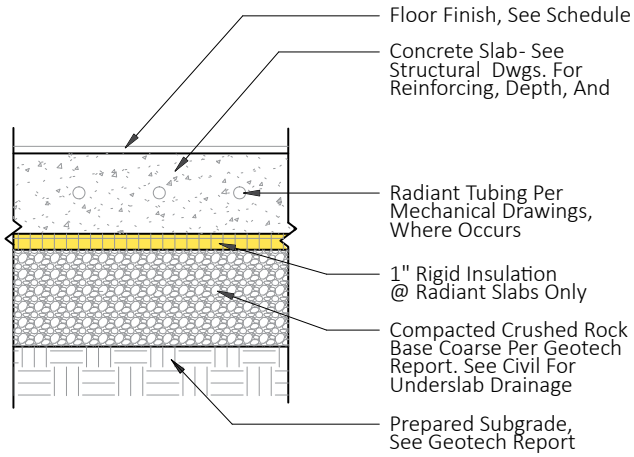
Water management: Terraced drainage off ends of low-sloping roofs. Water drains to gutter and ends in bioswales.



Sloped Roof Construction. Courtesy of BORA Architects.

Floor Detail

- R-Value: ***1.61***
- Floor Type: Radiant concrete slab
- Insulation: 1" Rigid
- Exposed Top Material: Concrete
- Subgrade Material: Compacted Crushed Rock



Floor Slab Section. Courtesy of BORA Architects.

Common Area Render View. Courtesy of BORA Architects.

Acoustics

Reverb Time: ***0.35 seconds***

The desire to minimize materials and use a concrete floor slab created an acoustical problem due to concrete's very low Noise Reduction Coefficient (NRC).

To counteract this issue, designers implemented carpeted flooring over the concrete floor in addition to acoustic panels on the walls (common area only).

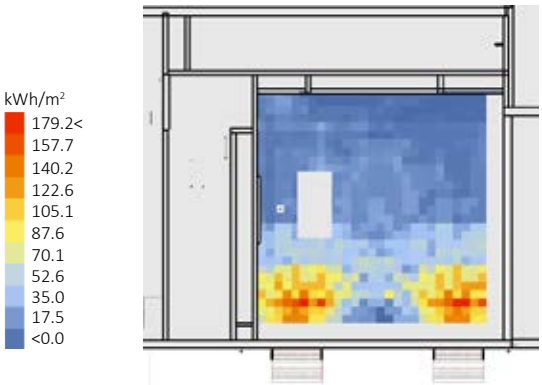
This is planned to create a significant reduction in reverberation time throughout the building.

Air

Exposed ducts within the ceiling provide regulated-temperature air year round. Indoor air temperature is controllable through thermostats throughout the school building. Classrooms and common spaces vary in their indoor thermal environments.

Thermal

Thermal radiation levels between 87-175 KWh per sq. meter are found only near the window openings. The depth of the classrooms causes solar radiation to fall to levels of 52 KWh per sq. meter and below.



Radiation on Floor

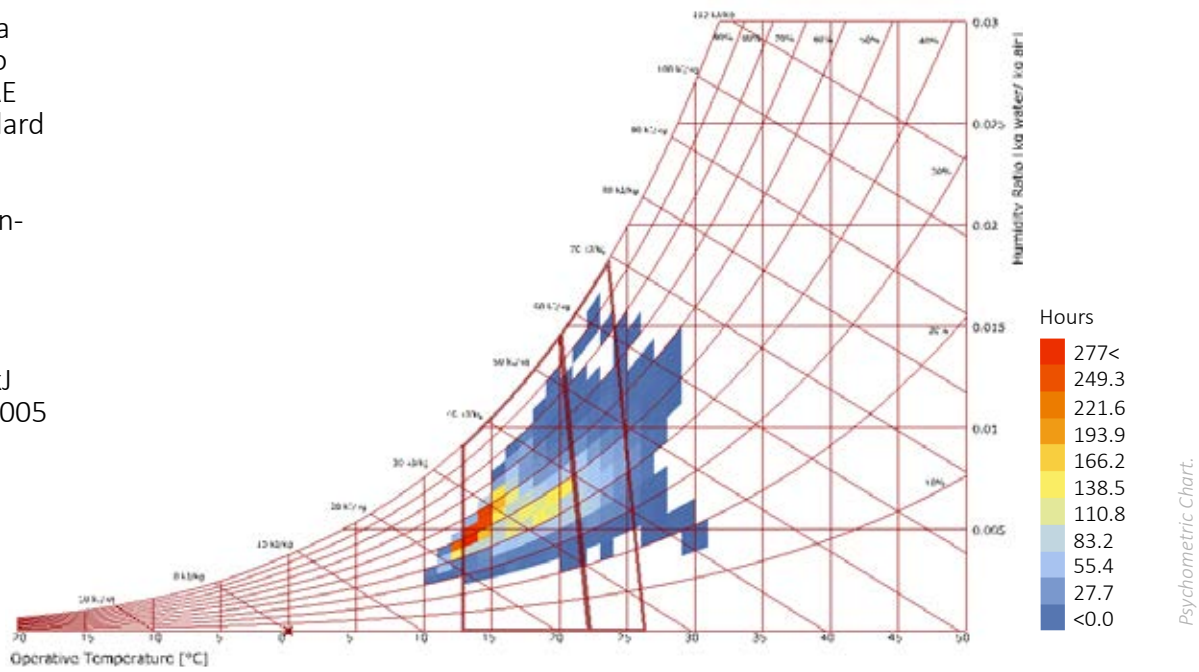
Radiation on Openings

Psychometric Chart

Mean average of data falls just inside and to the left of the ASHRAE indoor comfort standard 55 zone.

The school's most concentrated number of hours lies at:

- Temp: 16 C
- R. Humidity: 50%
- Enthalpy: 25 kg/kJ
- humidity ratio: 0.005



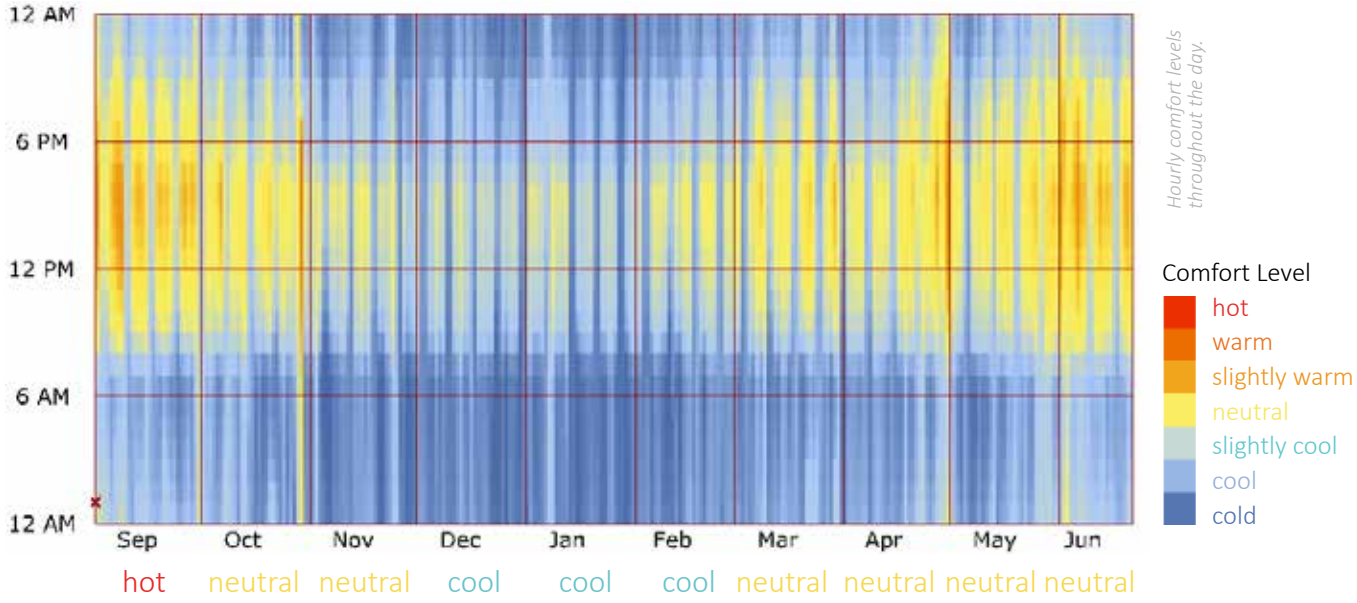
Psychometric Chart.

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

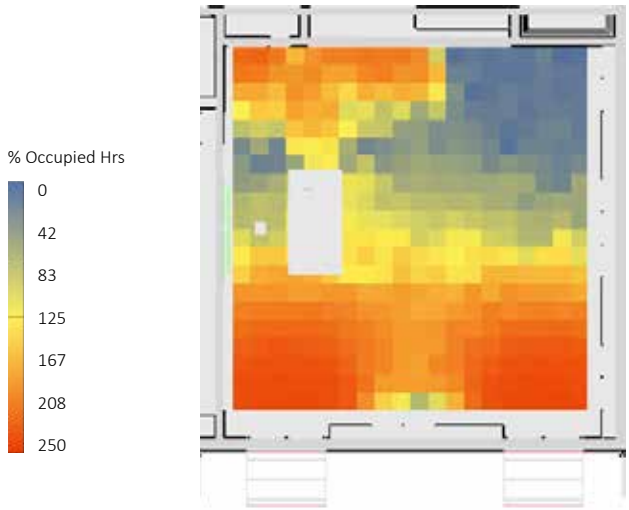
The percentage of the time occupants within the school are inside the comfort zone is **91.0%**



Hourly comfort levels throughout the day.

Daylighting

Average illuminance: ***1789.98 lux*** (annually)

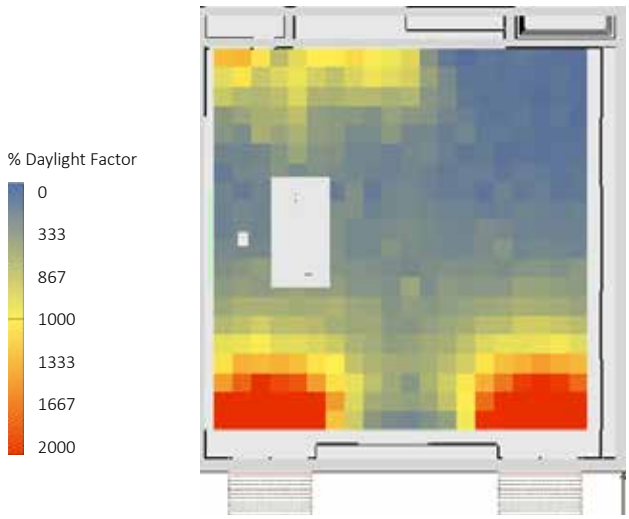


daylight on floor

Daylight Autonomy Analysis

The spatial daylight autonomy is 55% for active occupant behavior. The percentage of the space for this metric is ***54%***, which is slightly below the standard.

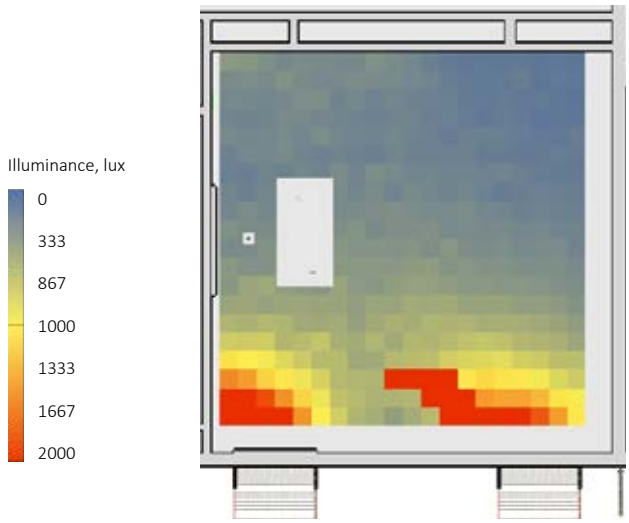
Daylit Area (DA_{300lux}[50%])	*54% of floor Area*
Mean Daylight Factor	*2.2%*
Occupancy	*3650 hours/yr*



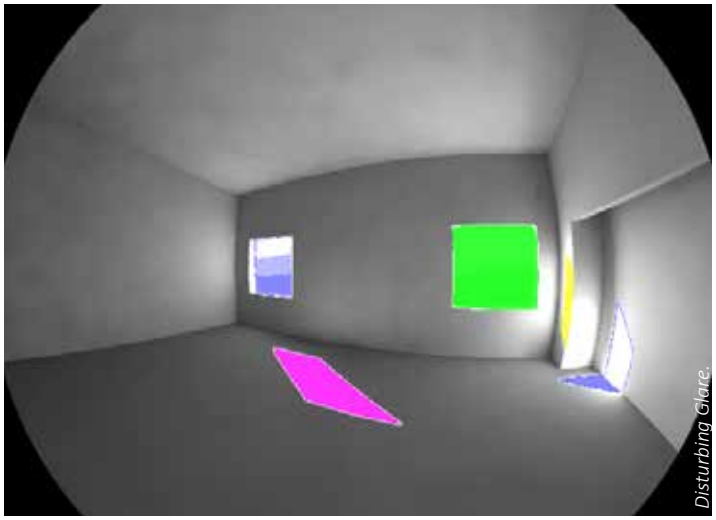
Daylight Analysis.

Illuminance Node Analysis

Mean daylight factor = ***2.24 %***
The daylight factor for 100% of Area between 0 & 9 %
The daylight factor for 0.2% of the area is above 15%
0% of Area > 9 %

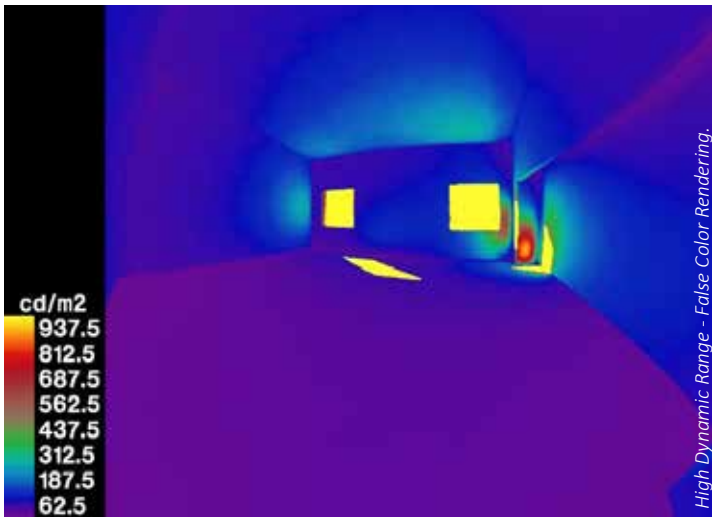


illuminance node analysis

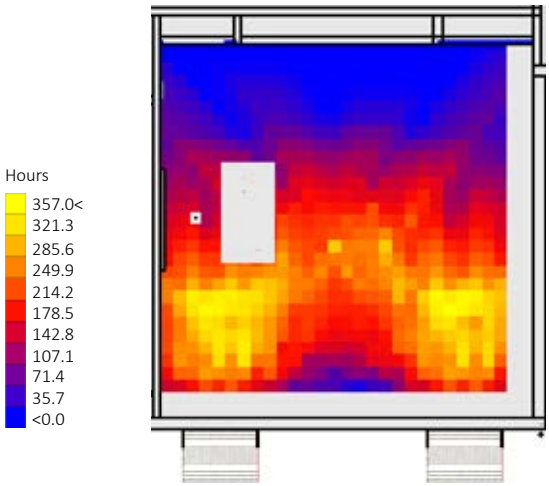


Disturbing Glare.

*Daylight Glare Probability is approximately **28%**.*



High Dynamic Range - False Color Rendering.



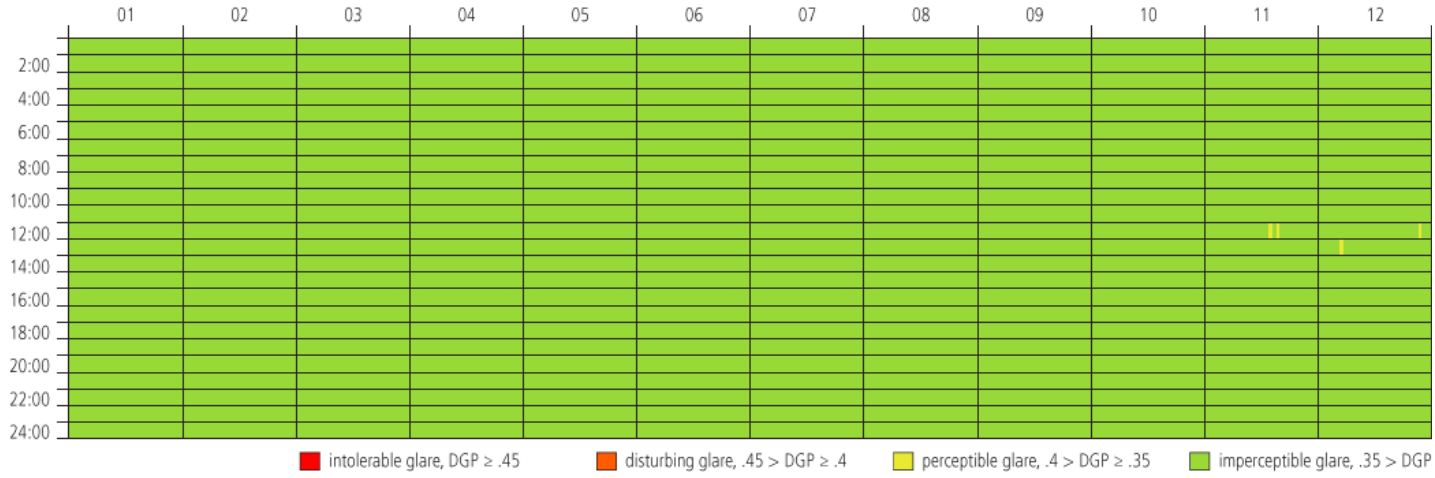
Sunlight on Floor

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 radiance software from indoor space (The false color rendering to the left represents this view).



Annual glare chart.

Minor incidents of perceptible glare between 12-2PM in early winter.

AIA Portland People's Choice Award
2013 Newsmaker, Daily Journal of Commerce
Excellence in Concrete, American Concrete Association, Portland Chapter
LEED Platinum Certified

Vernonia K-12 School

Vernonia, Oregon, 97064

BORA Architects

SOLARC Architecture and Engineering Inc, KPFF Cons. Engineers,Green Building Services

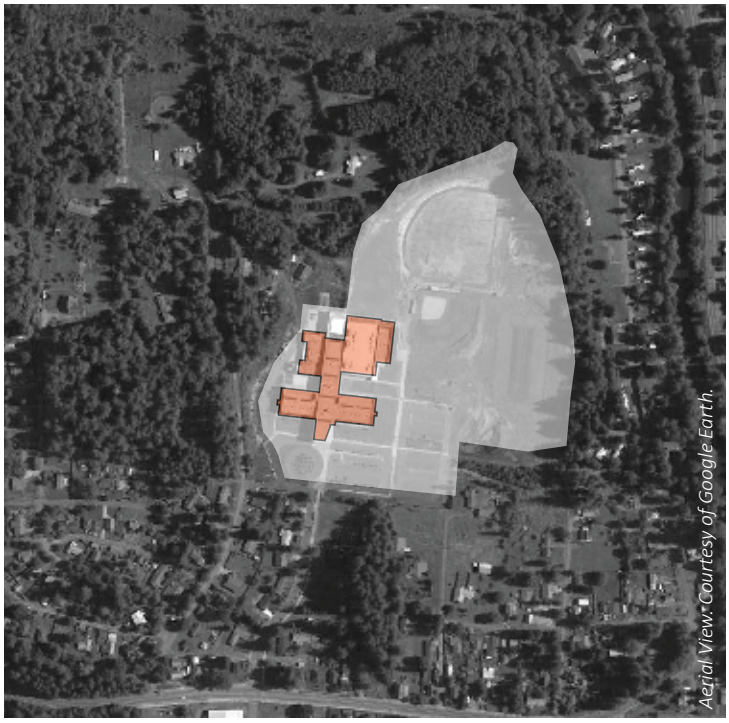
2019

Design Process

Project Statement

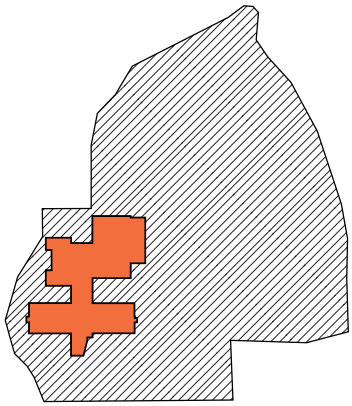
Close collaboration between the architects, engineers and clients began at an early stage to ensure an integrated design approach where all parties remained involved with the goal of designing a net zero building.

Site Plan



Aerial View: Courtesy of Google Earth.

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.

Metrics

- Site Area: 976,389 sq.ft.
- Building Area: 66,141 sq.ft.
- Athletics Area: 41,645 sq.ft.

Site Assessment

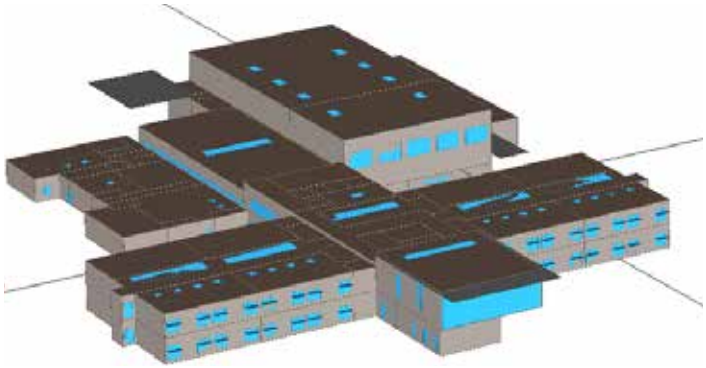
Site assessments were made to understand the best integration of landscape features. An analysis on wind quality, directional prevalence and speed helped conjure the insight for tree placement between the building and the most dominant wind paths. This reduced the wind load and envelope infiltration on the building. The architectural form induces the funneling of desirable breezes to support natural air ventilation.

Main Entrance. Courtesy of BORA Architects

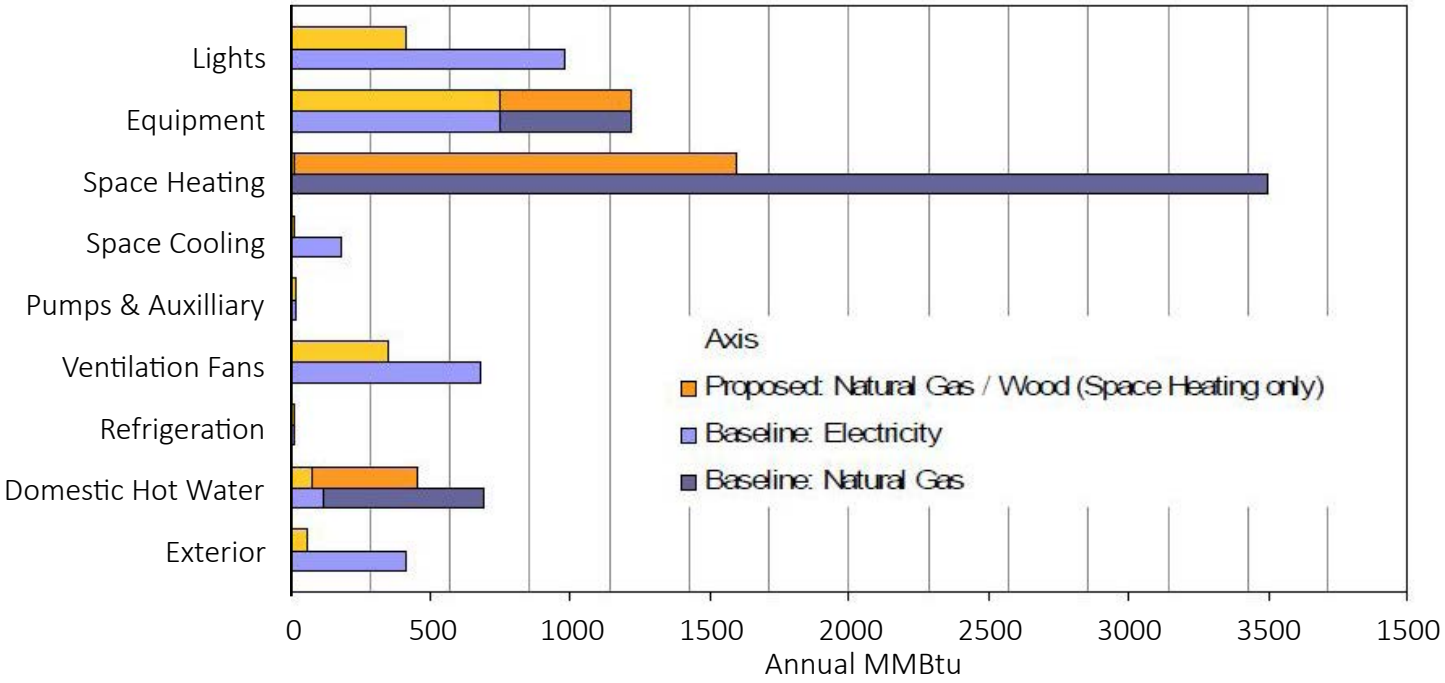
Energy and Cost Savings Evaluation

In collaboration with SOLARC Architecture and Enginerring, Inc., Bora Architects conducted a High Performance Schools Energy and Cost Savings Evaluation.

The goal here was to help the building acheive LEED Platinum Certification, and Net-Zero recognition as this was the intent for the project early on.



Annual End Use & Fuel Use Summary



Courtesy of SOLARC & BORA Architects

Main Entrance. Courtesy of BORA Architects

Cost Effectiveness

A major aspect the architects and engineers had in mind was being not only sustainable in terms of building design but also sustainable in building cost.

By implementing unconventional and highly efficient building systems, the annual energy expenditures are greatly reduced. Within 9.2 years, the expenses from the proposed design are paid off through a $60,569 annual reduction in energy expenditures due to the implementation of energy efficient systems.

Interior Wing. Courtesy of BORA Architects.

Incremental Investment Cost	***Annual Savings ($)***	*Annual Savings (MMBtu)*	***Gross Simple Payback (years)***	*Net Present Value Savings ($)*	*Benefit to Cost Ratio*	*% Energy Use below Building Code (%)*
$557,395	***$60,569***	*3562.9*	***9.2***	*$630,617*	*2.1*	*46.2%*

	Building Energy Use (MMBtu)	*Building Electricity Use (KWh)*	*Building Biomass Energy Use (MMBtu)*	*Building Natural Gas Energy Use (therms)*	*Building Energy Cost ($)*
Baseline Design	*7714.5*	*929,727*	*0*	*45,414*	*$141,593*
Proposed Design	*4151.6*	*504,500*	*1588.9*	*8,409*	*$81,024*
Savings	*3562.9*	*425,277*	*(1588.9)*	*37,005*	***$60,569***

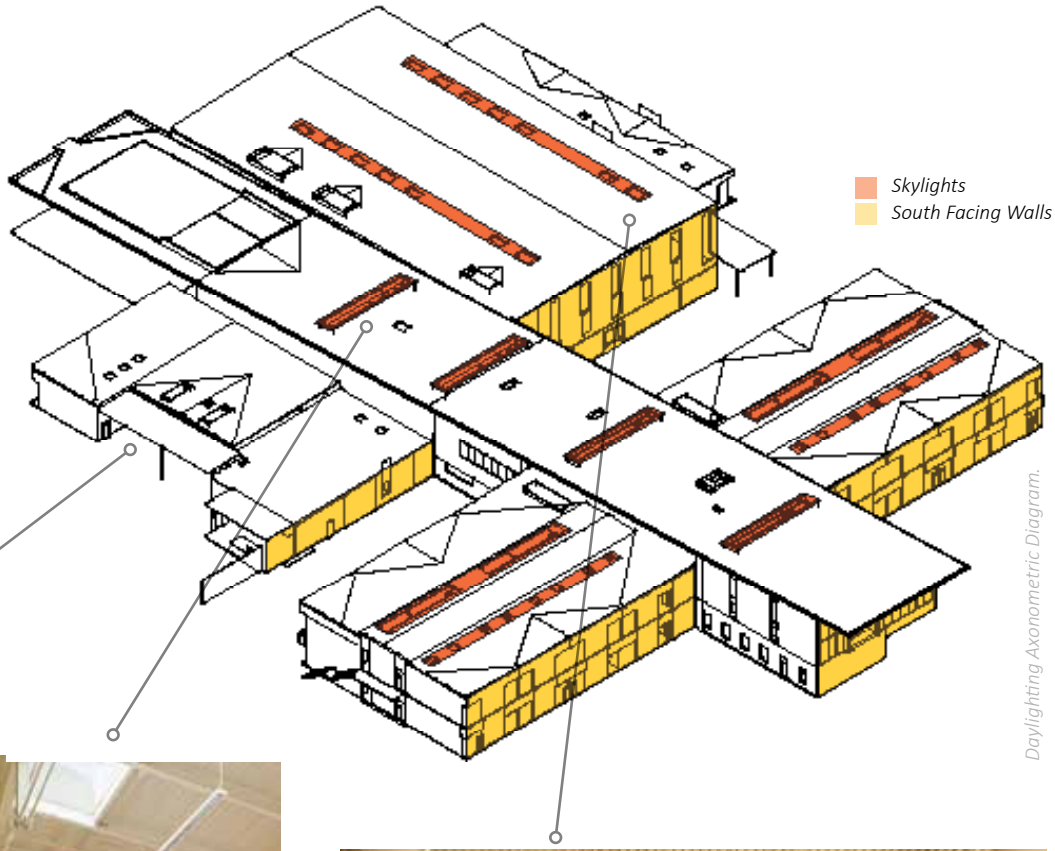
Cost-Effectiveness Summary. Courtesy of SOLARC

Daylight Optimization

Tall building volumes allowed for the ability to maximize the amount of daylight harvested from both clerestories and wall openings.

Floor to Ceiling Glazing. Courtesy of BORA Architects

Floor to Ceiling Glazing was placed mainly on the East, West and South facing facades. This was strategically done to bring in indirect daylight when the school is operating during the time when the sun is around the Southern angle.



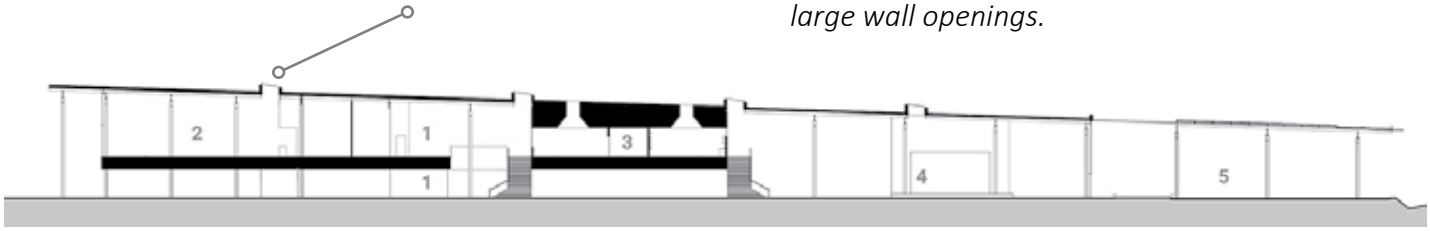
Daylighting Axonometric Diagram.

Skylights. Courtesy of Opsis Architecture.

Skylights take advantage of the large interior volumes to harvest daylight into more distant spaces.

Gymnasium Skylights. Courtesy of Opsis Architecture.

Skylight system installed on roof of gynasium to harvest daylight into space, with the addition of daylight from large wall openings.



Building Volumes. Courtesy of BORA Architects

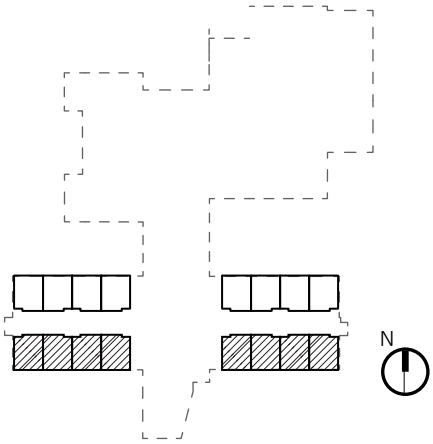
Site Performance

Site Metrics

- *Built Up Area: 133,000 Sq.ft. (13.6% Of Total Site)*
- *Paved Area: 116,360.26 Sq.ft. (11.9% Of Total Site)*
- *Unpaved Area: 727,028 Sq.ft. (74.5% Of Total Site)*
- *25,000 Sf Catchment Basin*

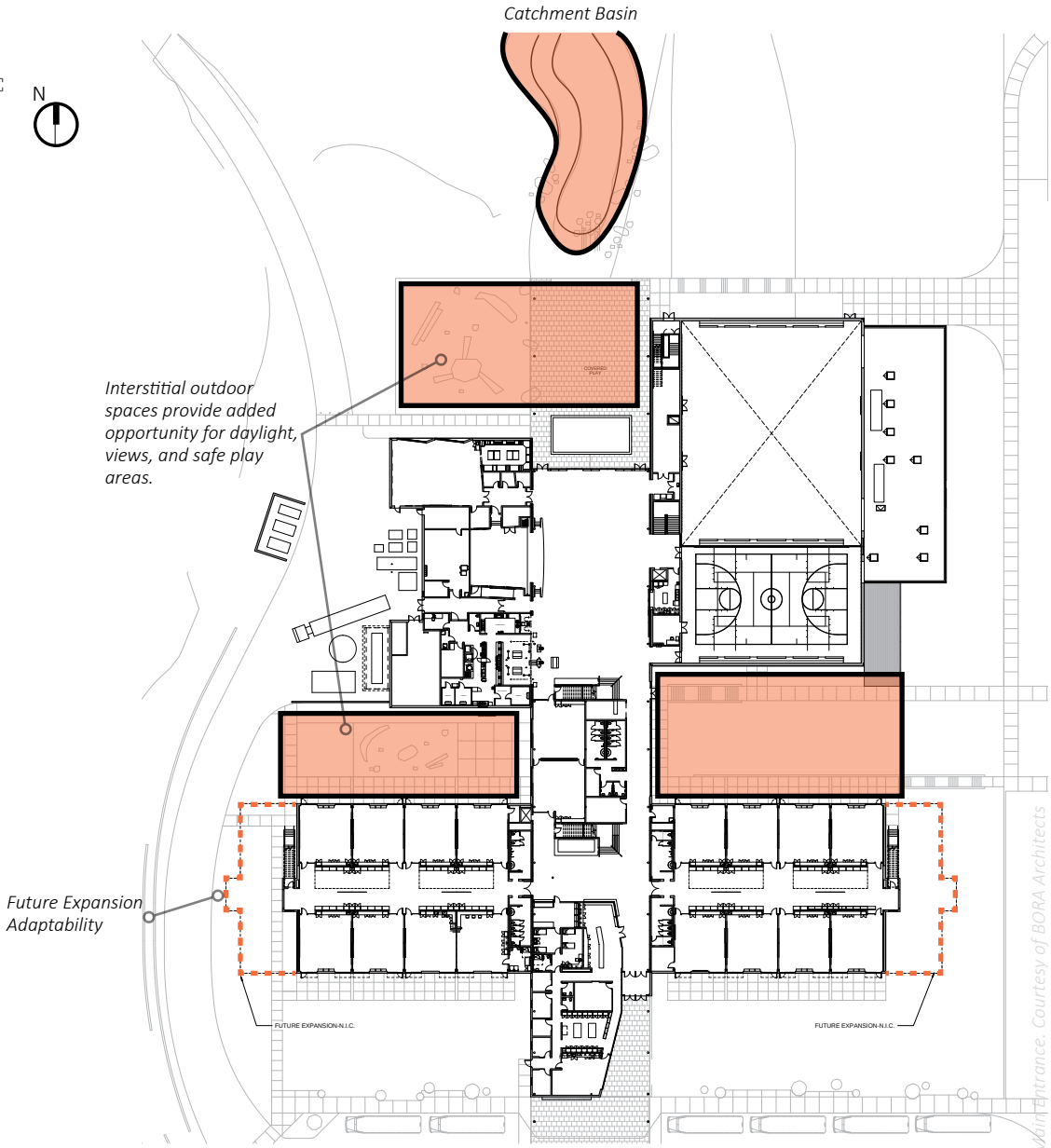
Site Plan. Courtesy of Google Earth.

South-Facing Classrooms



25.1% of classrooms are south facing. About a quarter of all the classrooms in the school building.

Architectural Site Plan

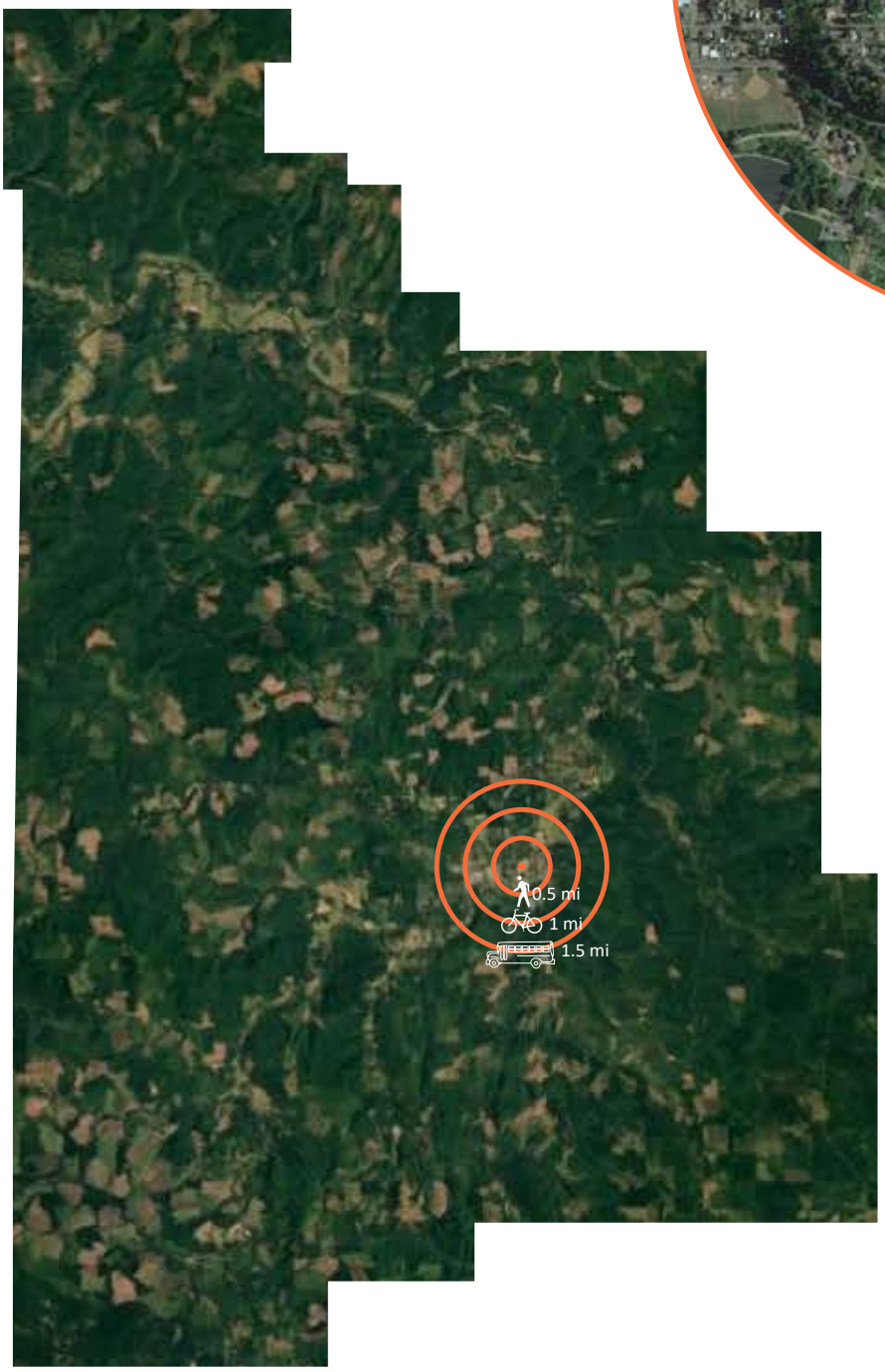


Main Entrance. Courtesy of BORA Architects

Catchment Maps

The Durham school district spans 6 miles across and is 24 square miles in area. With a catchment area this small, bus rides to and from school are short and will not require excessive energy for each trip. A major concentration of residential neighborhoods is to the North of the school.

Half mile radius catchment map.



School district boundary catchment map.

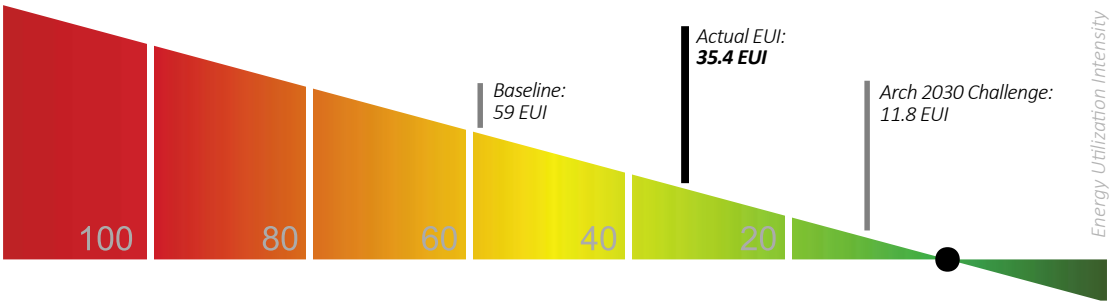
- *school district area: 260.3 sq.mi.*
- *longest distance across district: roughly 24 miles.*
- *walk score:* ***26***

Building Performance

Energy Utilization Intensity

Actual EUI: ***35.4***

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/ft^2/yr).



Energy Metrics

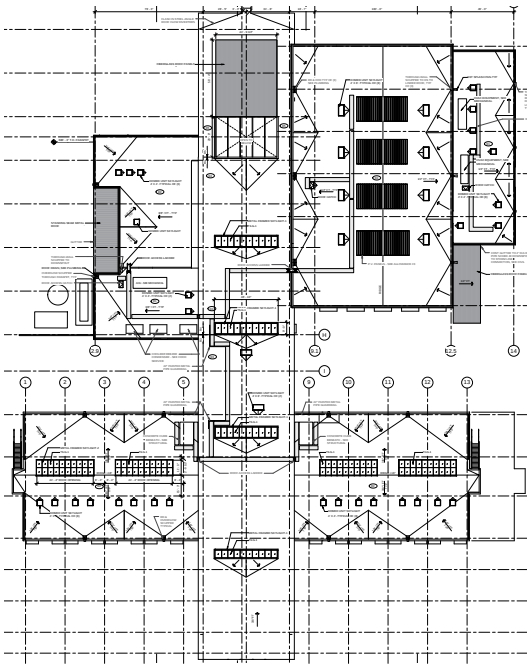
Energy Use: Predicted

Mechanical Equipment (kWh)	Lighting/ Plug Loads (kWh)	Total Power Consumption (kWh)	PV Energy Production (kWh)	Net Power Consumption/ Production (kWh)
NA	**NA**	**504,500**	**41,600**	**-462,900**

Solar Ready

Large roofs give way to more space for a solar array. Since this school building installed a very minimal amount of solar panels relative to its projected energy consumption, they have left room to add more solar panels in the future when it's more affordable.

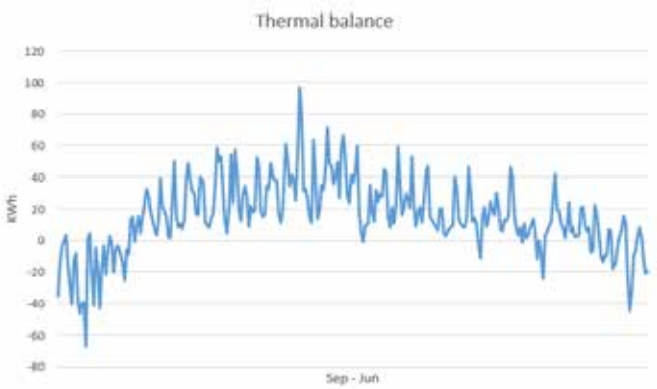
To plan for this the client requested architects and engineers to design the building to have a large enough roof and strong enough structure to support installation of solar panels in the future.



Roof Plan. Courtesy of Opsis Architecture.

Heat Loss and Heat Gain

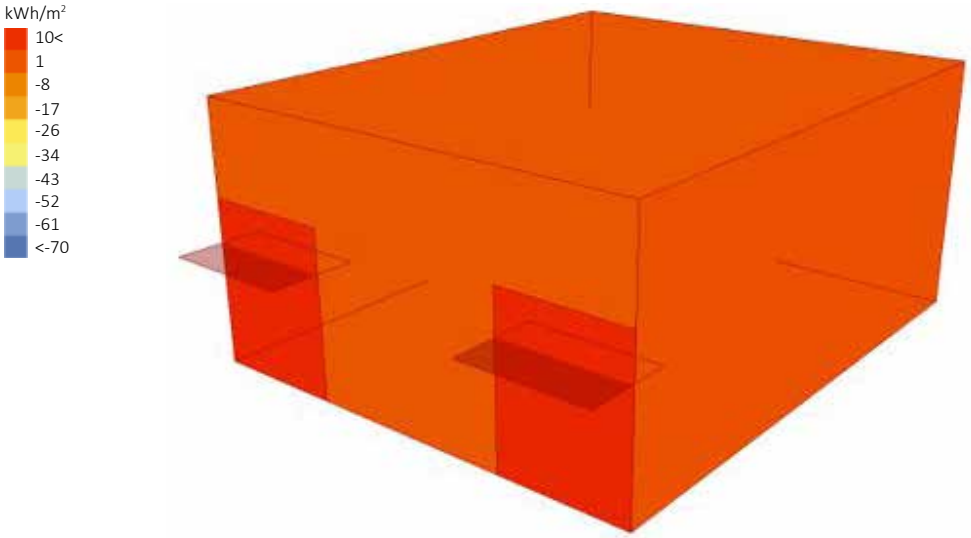
Heat loss measures the amount of heat being lost by the building due to heat transfer. Heat gain measures the amount of heat being gained by the building due to heat transfer. Both heat loss and heat gain are measured in KWh per square meter.



Thermal Balance Chart

Winter Heat

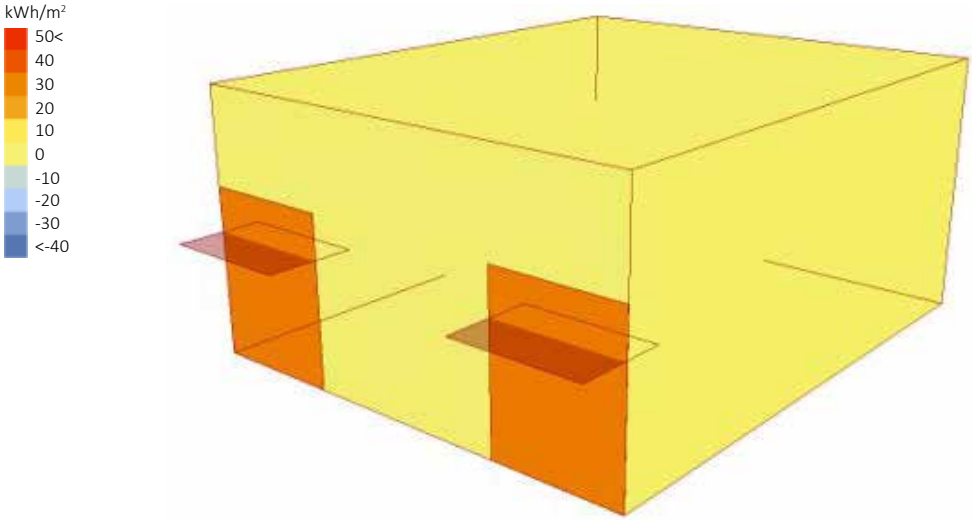
Minor heat gain in Winter. Walls, floor and roof are gaining over 10 KWh per sq. meter. Openings are gaining over 10 KWh per sq.meter as well.



Solar Heat Gain in Winter.

Spring Heat

Neutral heat transfer for walls, floor and roof that ranges between 0-10 KWh per square meter. Openings are gaining over 30 KWh of heat per square meter.

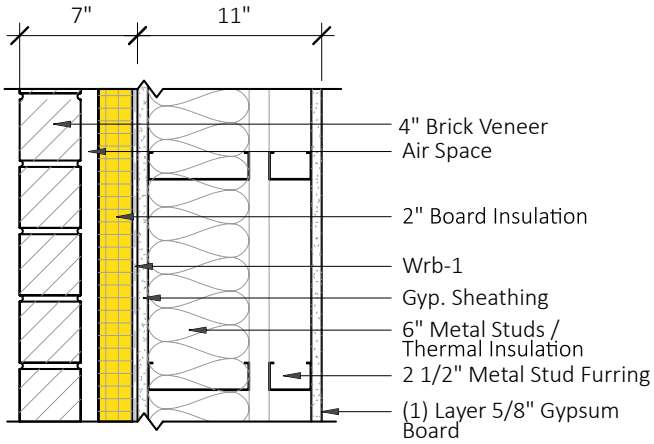


Solar Heat Gain in Spring.

Envelope Performance

Wall Detail

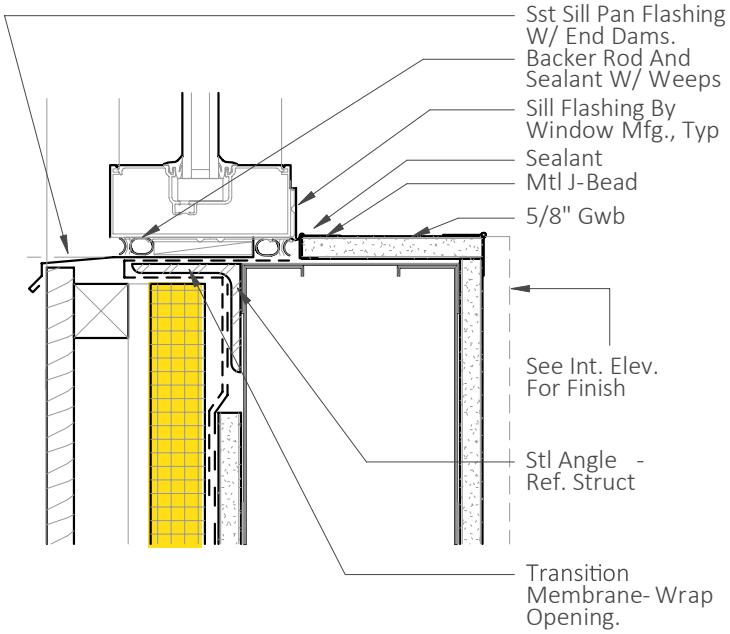
- R-Value: ***20***
- Type: 6" Metal Stud Framing
- Insulation: 2" Board, Batt
- Exposed Interior Material: 5/8" Gypsum Board
- Exposed Exterior Material: Brick Veneer



Exterior Wall. Courtesy of Opsis Architecture.

Fenestration Detail

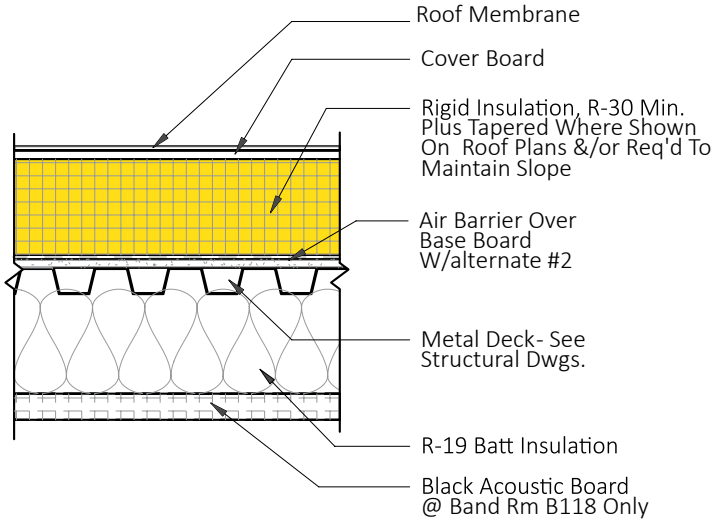
- R-Value: ***30***
- Window Type: Double Glazed
- SHGC: 0.44
- Visual Transmittance: 0.70
- Glazing Applications: Windows, Clerestories, Skylights.
- Window to Wall Ratio: 19%
- South Facade Window Area: 5650.02 sq.ft.
- Total Window Area: 14,434.9 sq.ft.



Fenestration Detail. Courtesy of Opsis Architecture.

Roof Detail

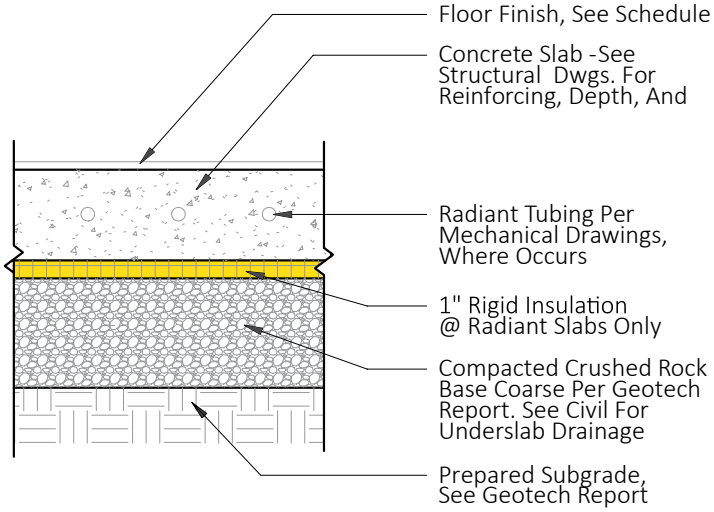
- R-Value: ***30***
- Roof Area: 98,939 sq.ft.
- PV Area: 2,583 sq.ft.
- Energy Generation: 41,600 KWh/year
- Type(s): Parapet
- Insulation: Rigid (R-30)
- Exposed Interior Material: Gypsum Board
- Exposed Exterior Material: Roof Membrane
- Water Management: NA



Roof Detail. Courtesy of Opsis Architecture.

Floor Detail

- R-Value: ***2.17***
- Floor Type: Radiant concrete slab
- Insulation: 1" Rigid
- Exposed Top Material: Concrete finish
- Subgrade Material: Compacted crushed rock
- Benefit: Durable and easy to maintain



Floor Detail. Courtesy of Opsis Architecture.

Air

Large central ventilation air ducts provided air from the ceiling of the building. Variations in space heights differentiate the effectiveness of ceiling air outtake. Exposed HVAC systems were used to minimize the need for cover up material and easier maintainence.

Carpeted flooring in Library. Courtesy of Opsis Architecture.

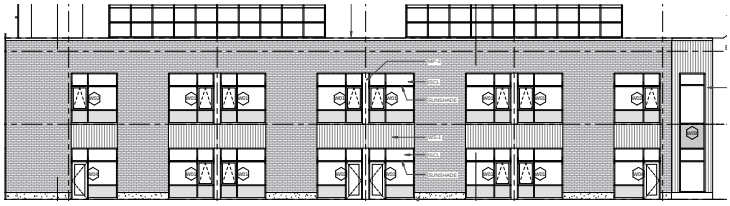
Acoustics

Reverb Time- **0.326 seconds**

In the library of this school, it is evident that carpet flooring can contribute to the reduction in reverberation time, providing greater acoustic comfort for the space.

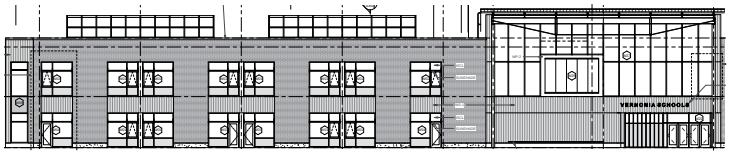
Thermal

Temperature within each space is controlled by a central control system, where the indoor air temperature can be controlled and changed depending on external thermal conditions.

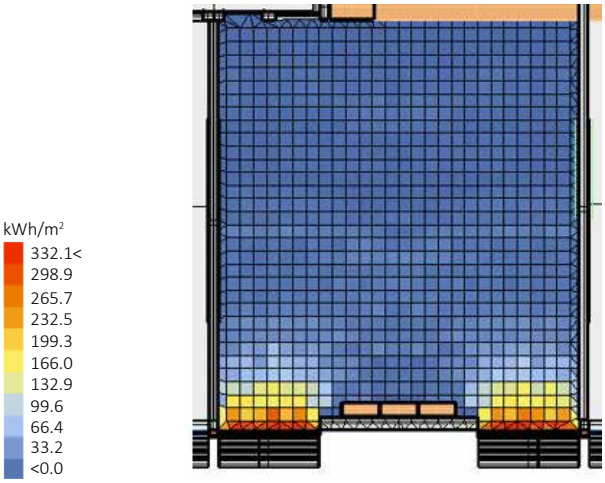


Openings on South Facades. Courtesy of Opsis Architecture.

Classrooms are arranged on wings. For classrooms facing South, they have two large windows which allow in radiation, shown in the simulations to the right.



Annual radiation falling on South openings is **8586.8 KWh**.



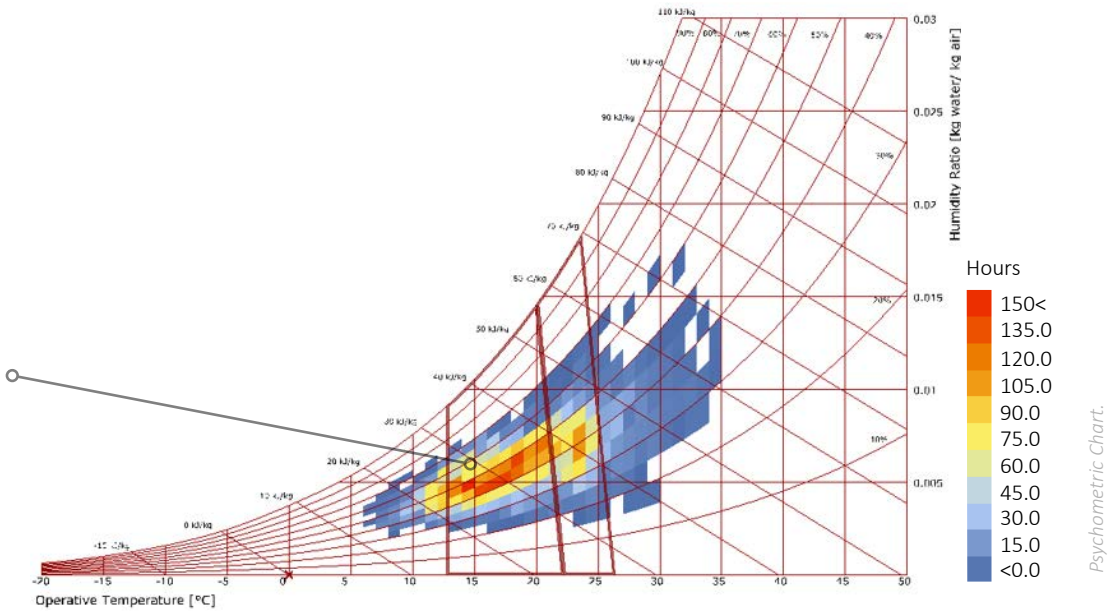
Radiation on Floor.

Radiation on Openings.

Psychometric Chart

Mean average of data falls at within the center of the ASHRAE indoor comfort standard-55 zone. The school's most concentrated number of occupied hours lies at:

- 17 degrees Celsius
- Relative humidity: 80-90%
- Enthalpy: 30 kg/kJ
- Humidity ratio: 0.03.

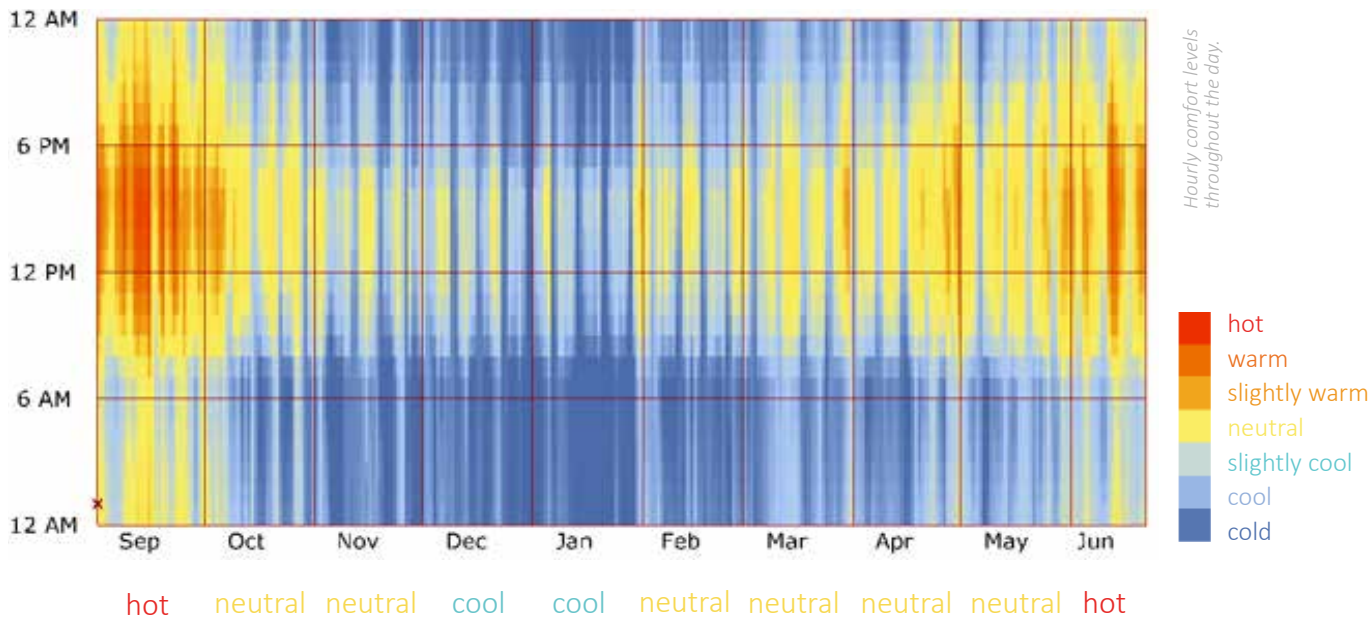


ASHRAE Thermal Sensation

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

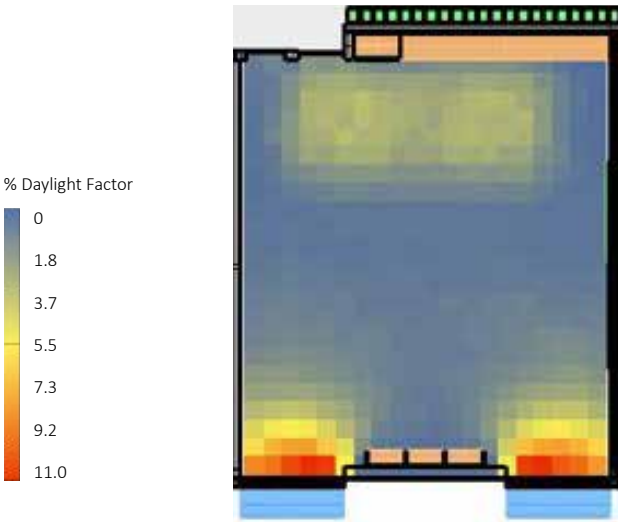
Indoor Comfort Results

The percentage of the time occupants within the school are inside the comfort zone is **78.0%**



Daylighting

Average illuminance: ***972.83 lux*** (annually)



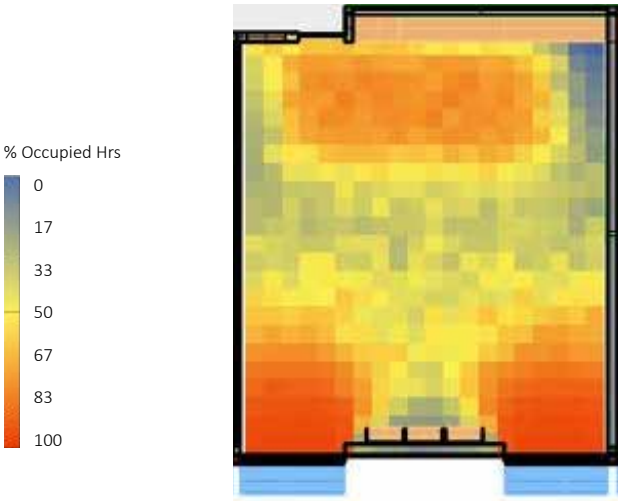
Daylight Analysis.

Daylight Autonomy Analysis

The spatial daylight autonomy for 300 lux for active occupant behavior. The percentage of the space meeting the daylight autonomy levels for 50% of the time is ***54%***.

Daylit Area (DA_{300lux}[50%])	*54% of floor Area*
Mean Daylight Factor	*1.7%*
Occupancy	*3650 hours/yr*

As an example, a point indicating semi-red color in the area means that at 83% of the whole occupied time, that point meet the criteria of having daylight factor of 300 lux or above.



Daylight Autonomy.

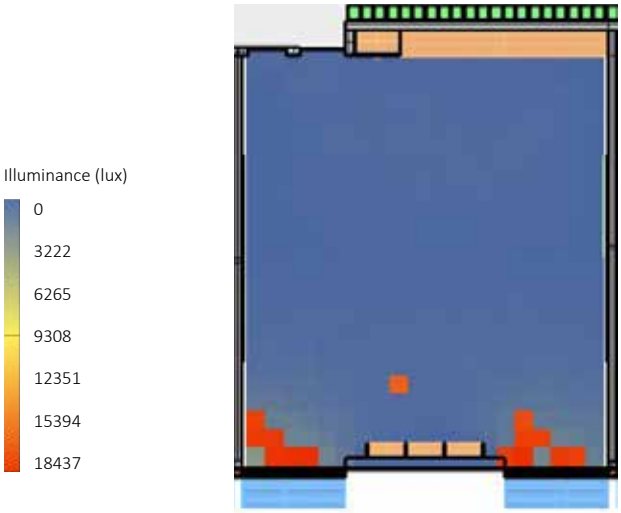
Illuminance Levels Analysis

Mean daylight factor = ***1.7 %***

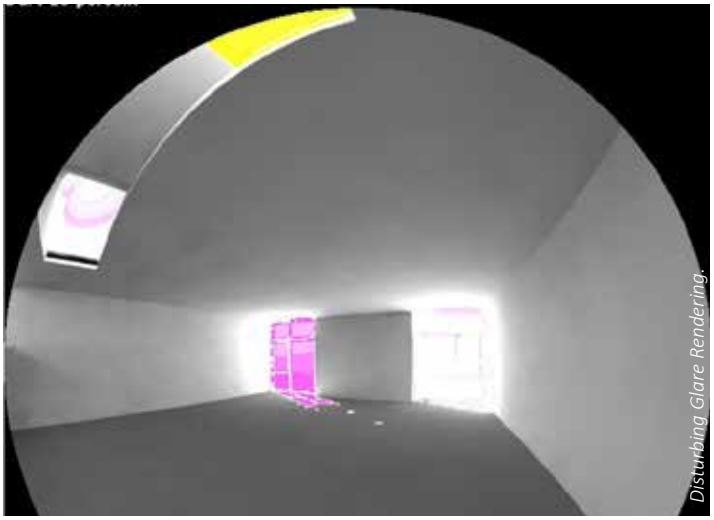
The daylight factor for 100% of Area between 0 & 9 %

The daylight factor for 0.2% of the area is above 15%

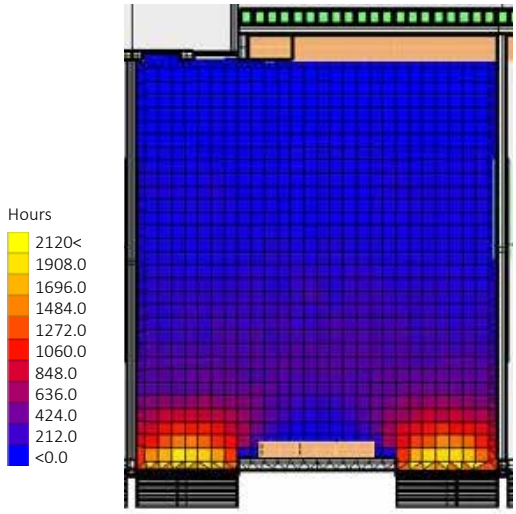
0% of Area > 9 %



Illuminance node analysis.

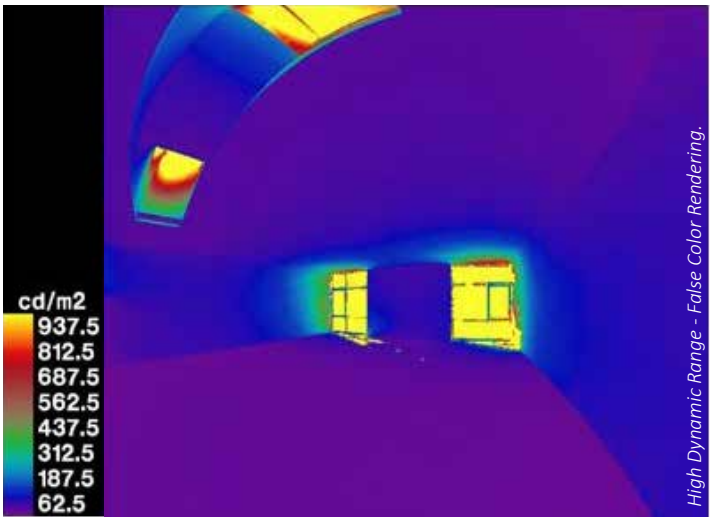


Disturbing Glare Rendering.



Sunlight on Floor

*Daylight Glare Probability is approximately **28%**.*



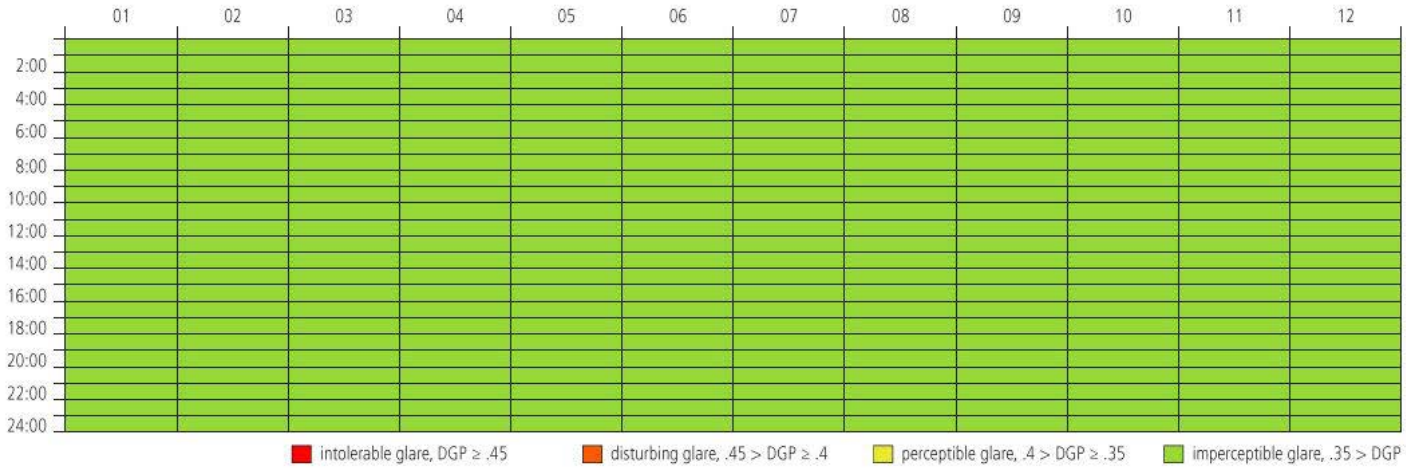
High Dynamic Range - False Color Rendering.

Sunlight and Disturbing Glare

Occurences of sunlight and disturbing glare nearest to windows. Most concentration lies within interior perimeter of window and tapers off further into the classroom. Glare is also seen at the skylights in the false color rendering to the left.

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. Colors match across the false color rendering to the left and the chart below.



Annual Glare Chart.

No incidents of glare.

LEED Platinum Certified

Locust Trace Agriscience Center

Lexington, Kentucky, 40511

Tate-Hill-Jacobs Architects
CMTA Inc.
2012

Design Process

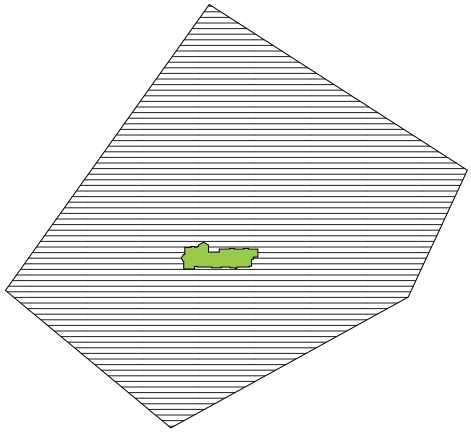
Project Statement

Active involvement from the clients, end-users, architects, design consultants and government officials brought to life the vision of the clients to create an agricultural and science center for learning and application.

Site Plan

Built-Up Area

This cutout of the overall site plan was used to compare the size of the classroom building footprint to the overall size of the site in order to understand the amount of space needed for a school of this size and allow for agricultural space.



- Building Area: 47,994 sq.ft
- Site Area: 3,571,920 sq.ft.
- Built-up Area Ratio: 1.32%

Sustainable Goal Setting

The design team set goals early on to ensure that they were in direction of net zero. This was tackled through smaller, more reachable goals:

Integrated Design Process (IDP)

The architect's defined their integrated design process (IDP) as a design approach that takes into account the building's envelope, mechanical system and operations from the beginning of the design process.

'Sitting Lightly on a Greenfield'

A greenfield is an entirely untouched site where all additions or site modifications are new.

Sitting lightly refers to being the least physically obstrusive on the part of the site to which the building has been placed.

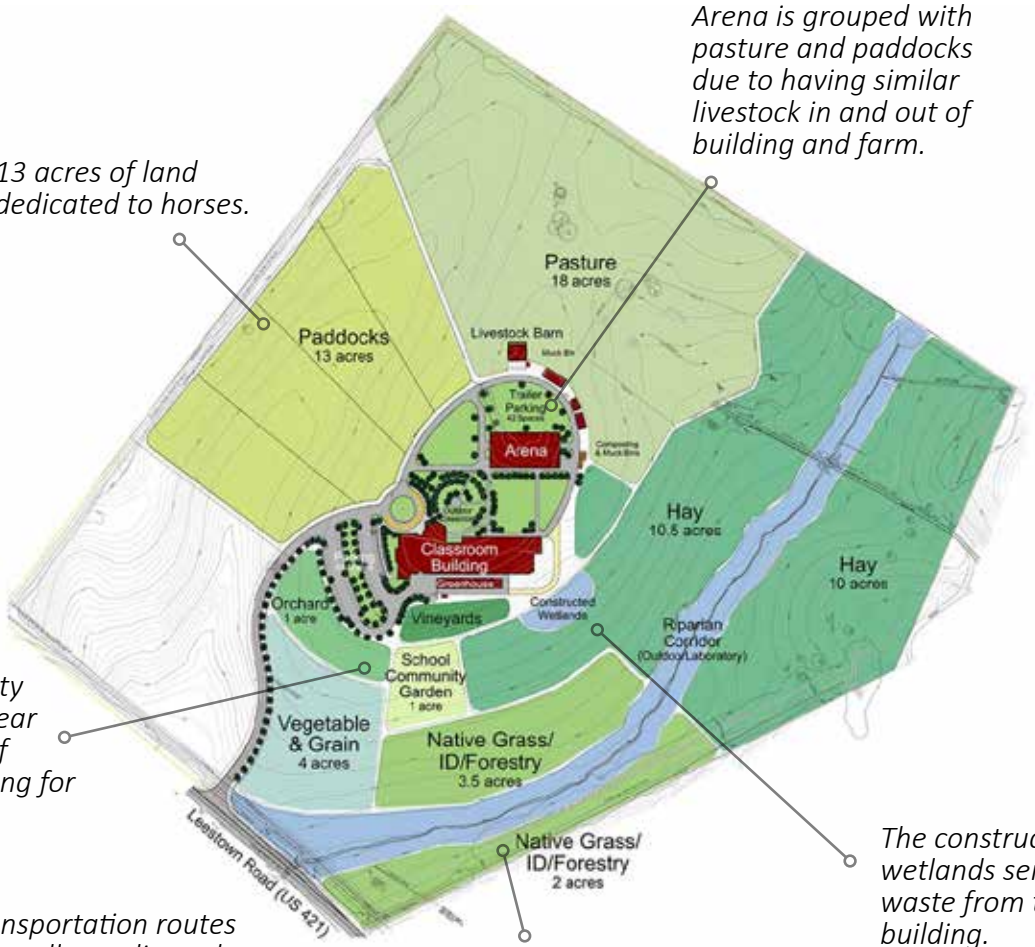
On Site Energy Generation

Due to both the goals of the design team and the remoteness of this site, the building is entirely sustenent on its own self-produced solar energy. This energy is provided by the photovoltaic panels.

On Site Water Capture

The arrangement of water shed landscape features allow for the site to retain and contain fallen rainwater from the building and landscape in order to reuse it for future purposes.

Site Planning



13 acres of land dedicated to horses.

Arena is grouped with pasture and paddocks due to having similar livestock in and out of building and farm.

School community garden placed near Southern edge of Classroom building for convenience.

The constructed wetlands serve to filtrate waste from the site and building.

Transportation routes are well coordinated with the land division and placement

Implanting native vegetation allows for more resilient, long term growth.

Site Planning. Courtesy of Tate-Hill Jacobs Architects.

Community-Oriented Design

According to the architects, a major contributor to the success of the project can be awarded to the involvement of the school owner, end users, community partners and design consultants from the early phases of the project design.

Students gathering for a photo on the site during construction phase.

HVAC Systems

- Geothermal is the base system used.

  Consists of high efficiency, dual stage water source heat pumps with energy recovery dedicated outside air unit to provide code required ventilation.

- Demand-control ventilation system used to measure C02 in spaces and adjust the outside air to each space based on its occupancy load.

- Building has much larger heating load than cooling

  Large thermal radiant heating system consisting 169 evacuated tube panels=40,000 Btu/days.

  This array is the first stage of building heat and then the geothermal water-to-water heat pumps are used when solar is insufficient.

  Solar system can regenerate the well field in the summer if ground temperature begins to lose heat capacity over time.

Heating and Cooling Zones

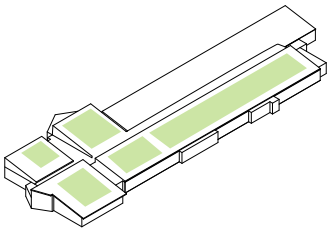
The mismatch between having a indoor-conditioned building to function as a farm contradicts the tradition of farming and agriculture taking place outdoors or in unconditioned indoor environments.

The design team acted upon this challenge by creating thermal environments that ranged in temperature in order to more appropriately simulate the variance one would find in an outdoor environment.

Heating and Cooling Zones Plan. Courtesy of

Energy Production and Consumption

This large solar roof array generates 211,630 KWh of energy; creating the opportunity for the building to generate more than enough energy than the 188,600 KWh it consumes.



With a roof area of 46,122 sq.ft., different mounting styles were used, such as scattered, compact or long rows.

Building Solar Roof, Courtesy of Tate-Hill Jacobs Architects.

Architecture as a Teaching Tool

One of the initial goals of this project was for the building to serve as a teaching tool for the students occupying it and is expressed in the following teaching strategies:

Visible Green Roofs

Green roof Porch.

Tilting down the porch roof makes the vegetation on top much more visible, showing users one of the many efforts towards achieving a sustainable building.

Solar Energy

On site solar energy production intends to hold the symbol for students of a building producing its own energy.

HVAC Exposure

Blue highlighted Piping.

Interior hallways serve as learning tool, exposing piping and mechanical systems for ventilation, nonpotable, hydronic solar, and geothermal water.

Glazing Highlights

Blue highlighted Clerestory.

Highlighting clerestories similarly to the exposed piping gives attention to how daylighting plays a major role in teaching occupants about the daylighting systems in place.

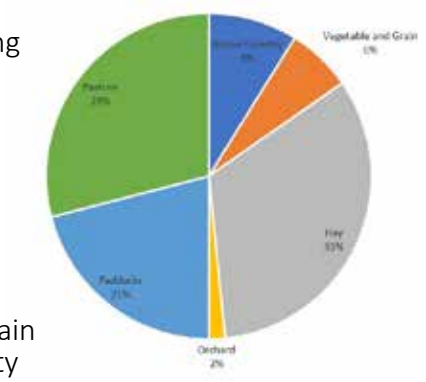
Site Performance

Site Metrics

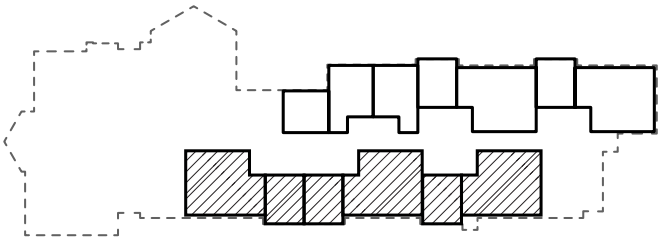
- *Gross Floor Area (sf): 47,994*
- *Gross Site Area (sf): 3,571,920*
- *Building footprint (sf): 47,000*
- *Built up area (%): 1.32%*
- *Paved area (sf): 80,509*
- *Paved area (%): 2.25%*
- *Non-paved surfaces (sf): 3,444,411*
- *Non-Paved surfaces 96.43%*
- *PV area as % of Floor area:*
- *Shape Factor (A/V): 1.31*
- *Sky Exposure Angle:*
- *Walk Score: 77, Very walkable (most errands accomplished by foot)*

Site Program

- Classroom Building
- Arena
- Paddocks
- Pasture
- Livestock Barn
- Trailer Parking
- Composting Area
- Orchard
- Vineyards
- Vegetable and Grain
- School Community Garden



South Facing Classrooms



- ***35.8%*** of classrooms are facing South.
- Classrooms positioned along South facade are purposely positioned in close proximity to the greenhouse, vineyards and community garden.

Water Catchment

Permeable Pavers were used to allow stormwater to drain through the majority of the 80,000 sq.ft. of paving on site.

Building positioned close enough to a low-volume water corridor/stream to use as part of on site farm irrigation strategies.

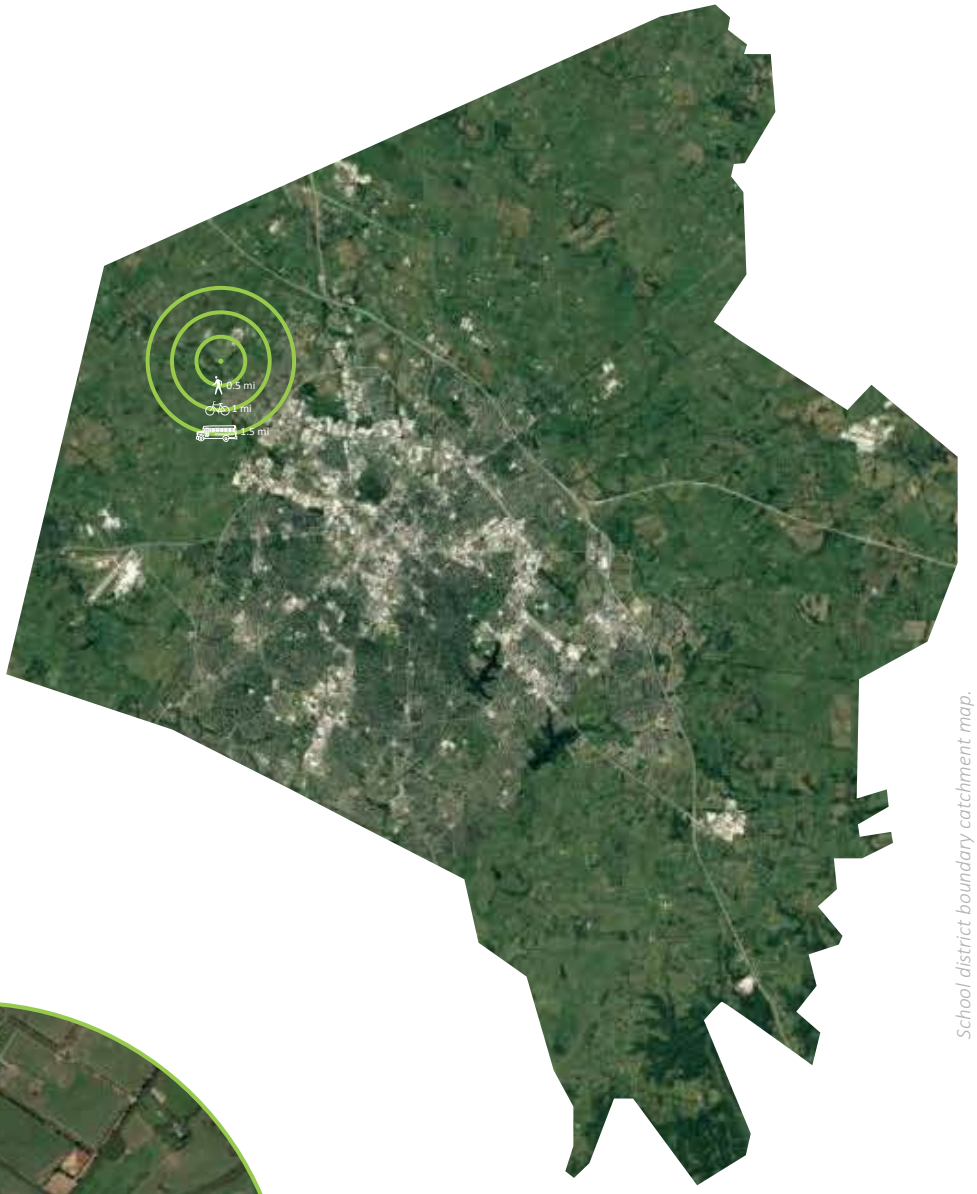
The stream is also used as an outdoor laboratory for educational purposes.

Catchment Area

Catchment area is the overall school district area, providing an understanding of the extent transportation plays a role in site sustainable strategies.

The catchment of Locust Trace is relatively large, spanning over 20 miles across the longest point. This shows how transportation systems are an integral part of how people get to and from a building.

Since schools run every weekday and in many cases have weekend activities for students and faculty, it becomes very important to know how driving distances may impact the experience of a school and its overall transportation energy expenditures.



School district boundary catchment map.

Half mile radius catchment map.

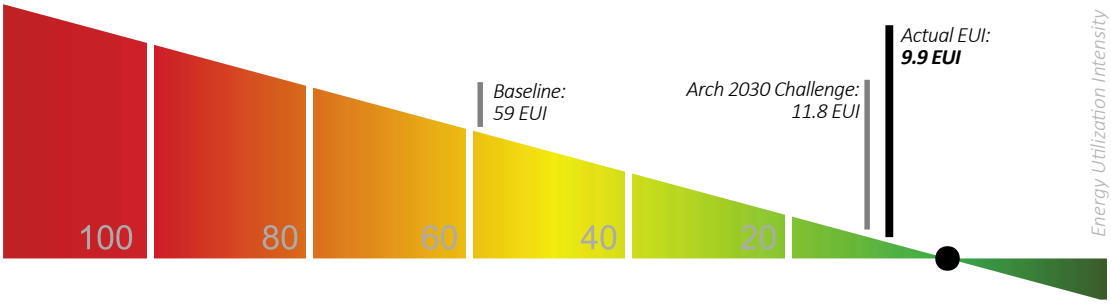
- *school district area: 289 sq.mi.*
- *longest distance across district: roughly 22 miles.*
- *walk-score: **4***

Building Performance

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/ft^2/yr).



Energy Metrics

Energy Use: May 2011-April 2012

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 Water Heaters on Roof.

There are 7,400 sq.ft. of Solar Thermal Panels located on the roof of the building.

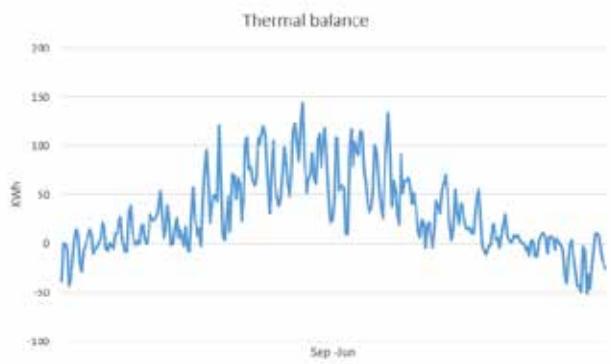
Building energy consumption can be significantly reduced through using solar thermal panels to heat the building's hot water supply. In turn, less of the energy produced by the building goes into heating water.


Daylight use instead of electric lighting use.

Investments of design analysis towards good daylighting design significantly reduces the dependence on electric lighting. As a result, it can reduce the energy consumption for the building's lighting energy loads.

Heat Loss and Heat Gain

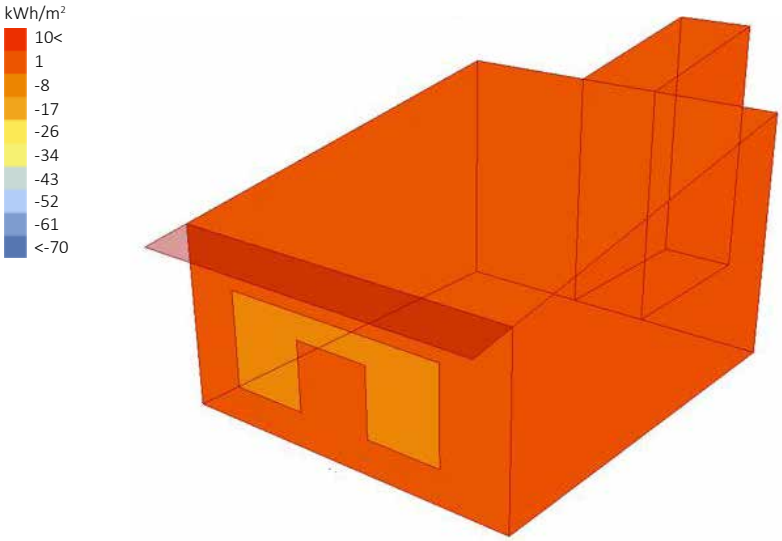
Heat loss measures the amount of heat being lost by the building due to infiltration and lack of insulation. Heat gain measures the amount of heat being gained by the building due to heat gains and losses. Both heat loss and heat gain are measured in KWh per square meter.



Thermal Balance Chart

Winter Heat

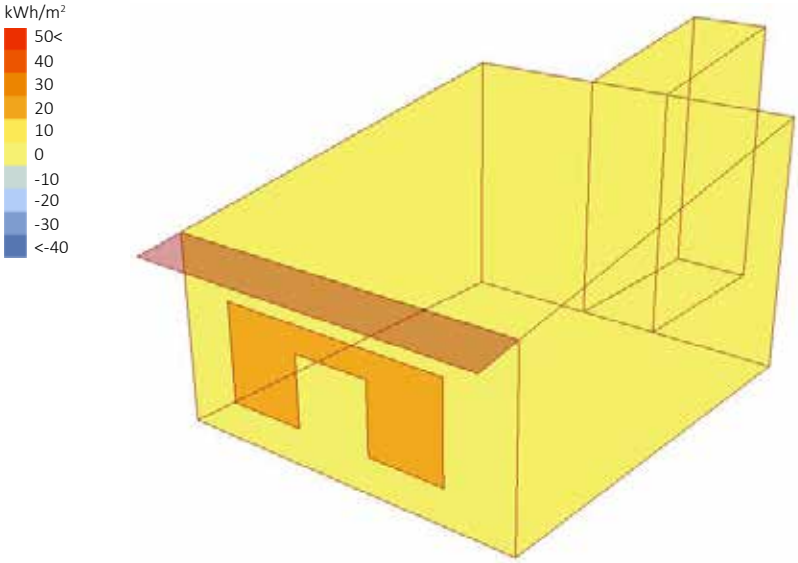
Major heat gain and loss in Winter. Surfaces are gaining above 10 KWh per sq. meter. Openings are losing roughly 17 KWh per sq.meter.



Solar Heat Gain in Winter.

Spring Heat

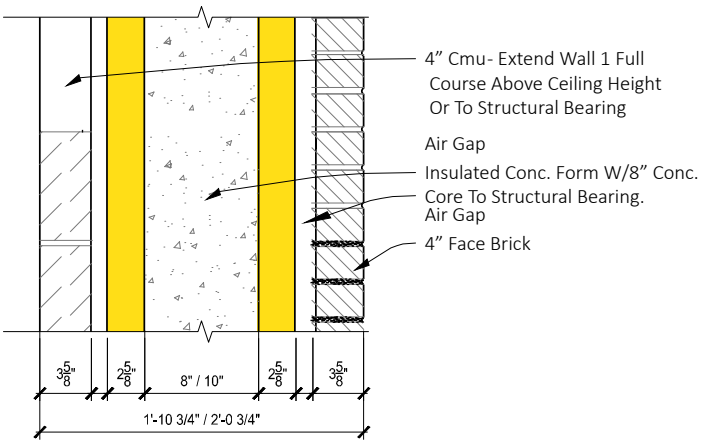
Neutral heat transfer in Spring. Walls, roof and floor aren't losing or gaining any heat. Openings are gaining over 30 KWh of heat per sq. meter.



Solar Heat Gain in Winter.

Wall Detail

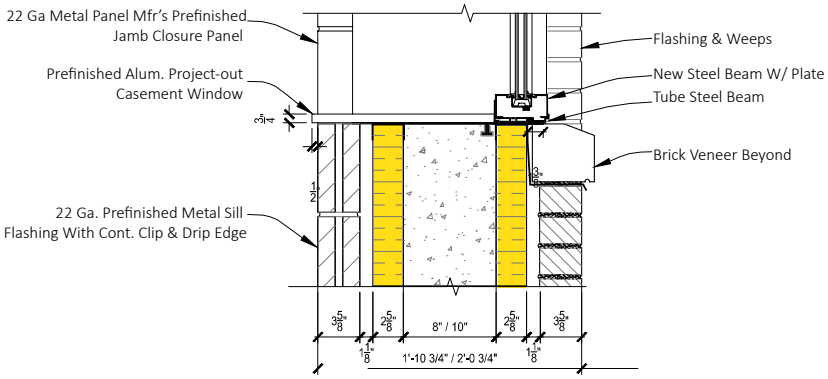
- R-Value: ***23.6***
- Type: Insulated Concrete
- Insulation: Insulated Concrete Formwork
- Exposed Interior Material: 4" CMU
- Exposed Exterior Material: Brick Veneer



Wall Detail. Courtesy of Tate-Hill Jacobs Architects.

Fenestration Detail

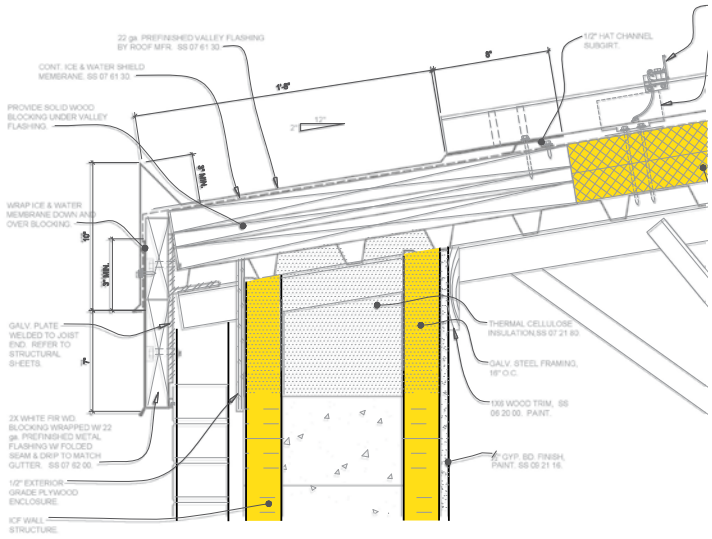
- R-Value: ***2.17***
- Window Type: Triple Glazed
- SHGC: 0.36
- Visual Transmittance: 0.65
- Glazing Applications: Windows, Clerestories, Skylights, Greenhouse.
- Window to Wall Ratio: 20.4%
- South Facade Window Area: 1179.5 sq.ft.
- Total Window Area: 3330.5 sq.ft.



Fenestration Detail. Courtesy of Tate-Hill Jacobs Architects.

Roof Detail

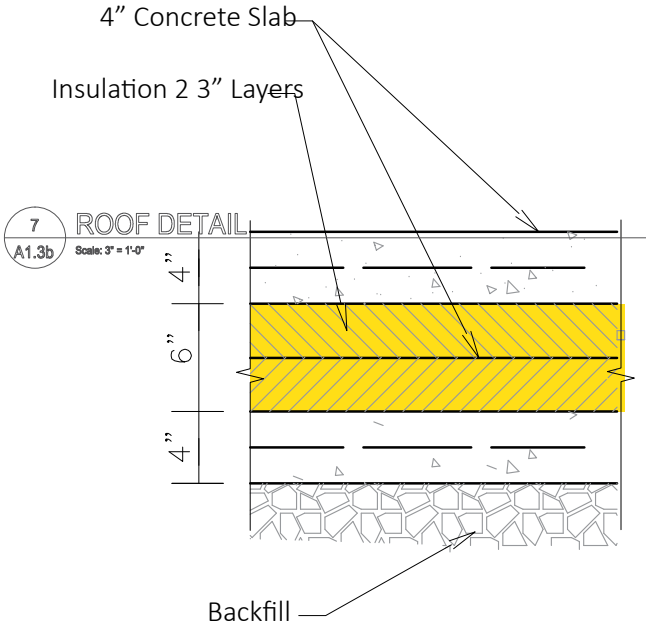
- R-Value: ***26***
- Roof Area: 46,122.3 sq.ft.
- PV Area: 16,287.6 sq.ft.
- Energy Generation: 211,630 KWh/year
- Type(s): Gable, Parapet, Shed
- Insulation: Rigid
- Exposed Interior Material: Gypsum Board
- Exposed Exterior Material: Standing-seam Metal
- Water management: NA



Roof Detail. Courtesy of Tate-Hill Jacobs Architects.

Floor Detail

- R-Value: ***1.61***
- Type: Radiant concrete slab
- Insulation type: 3" Rigid (2 layers)
- Exposed Top Material: Concrete
- Subgrade Material: Backfill
- Benefit: Durable and easy to maintain



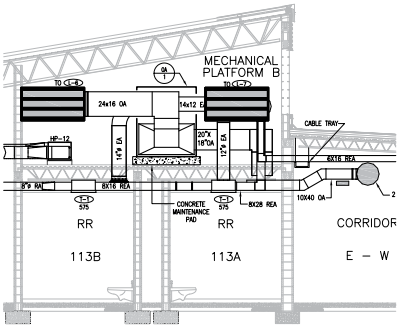
Floor Detail. Courtesy of Tate-Hill Jacobs Architects.

Acoustics

Reverb Time: ***0.298 seconds***

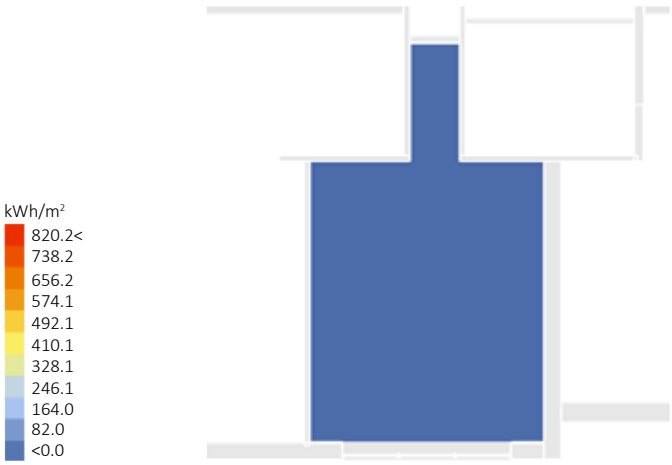
Interior Acoustics - CMU Wall. Courtesy of Tate-Hill Jacobs Architects.

Air Ventilation



HVAC Systems in Classroom. Courtesy of Tate-Hill Jacobs Architects.

High volume, low velocity fans are hidden within the classroom volume. Air is naturally ventilated and heated through geothermal heating systems from underground pipes. Fans have automatic energy recovery programmed when users are not using the space.



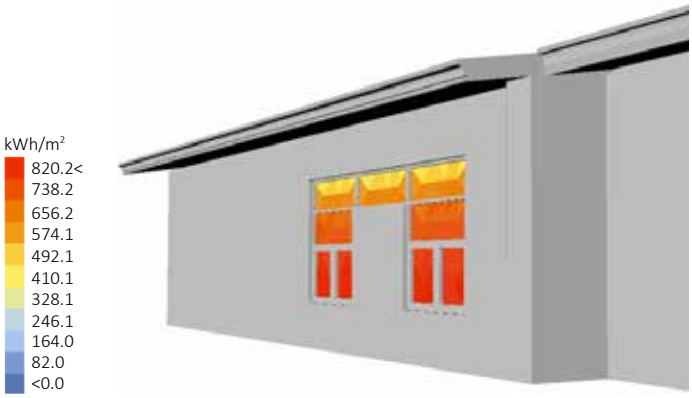
Radiation on Floor.

The overall amount of radiation resulting on the floor of the south classrooms is ***0 KWh/m².*** This indicates proper sizing and orientation of windows.

Thermal

The purpose of simulating the amount of radiation on windows is to determine how much heat, measured in KWh per square meter, is resulting on the window openings. This helps to understand the impact of thermal radiation on the classroom.

In this classroom simulation, between 410-820 KWh/m² resulted on the window openings. Higher levels of radiation can be seen on the lower part of the window, this is mainly due to the overhang that blocks much of the radiation hitting the upper level of the window opening.



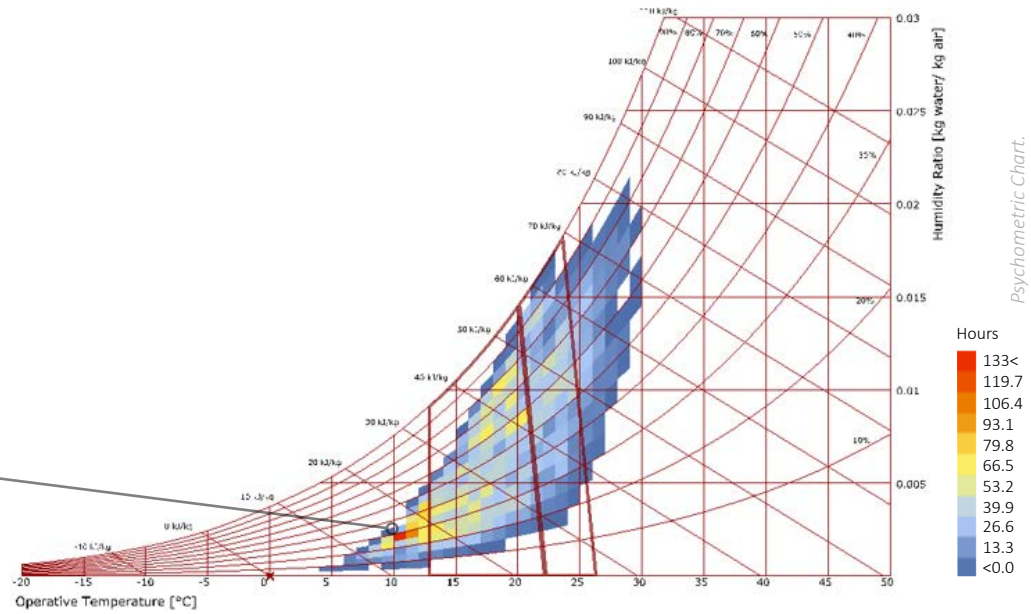
Radiation on Openings.

The overall amount of radiation resulting on South openings is ***4595.9 KWh/m².***

Pyschometric Chart

Mean average of time spent falls at outside to the left of the ASHRAE indoor thermal comfort standard-55 zone. The building will be cooler than the desired temperature. The school's most concentrated number of hours lies at:

- Temp: 11 C
- R. Humidity: 35%
- Enthalpy: 30 kg/kJ
- humidity ratio: 0.003



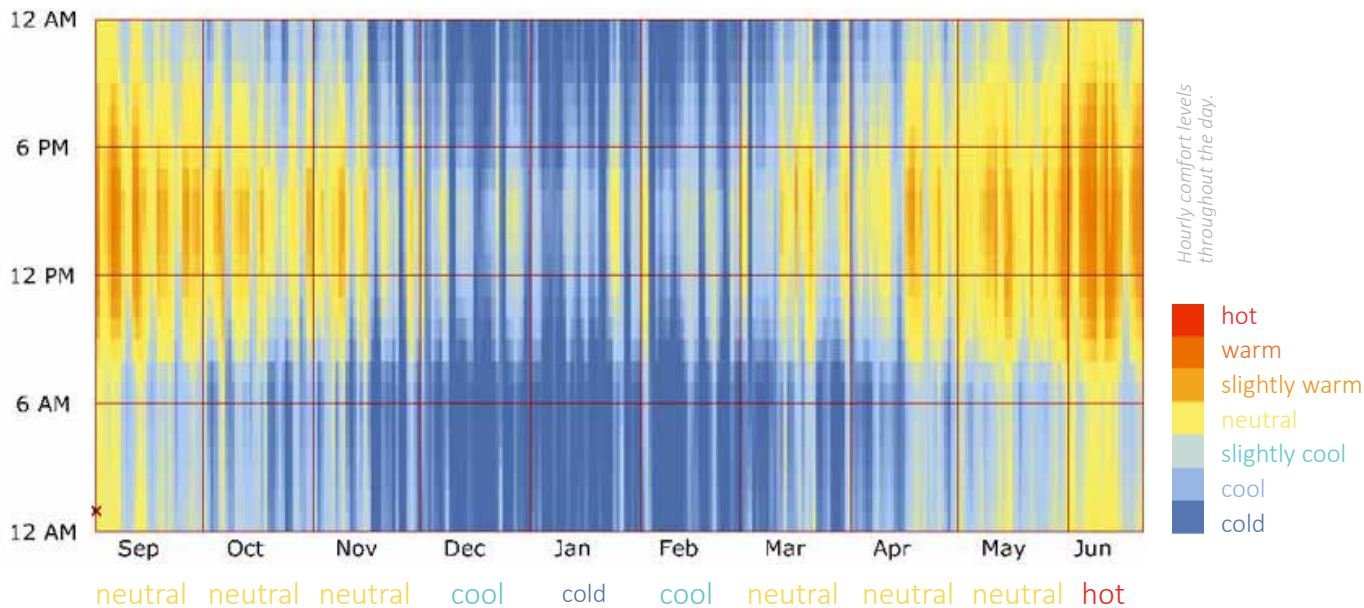
Psychometric Chart.

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

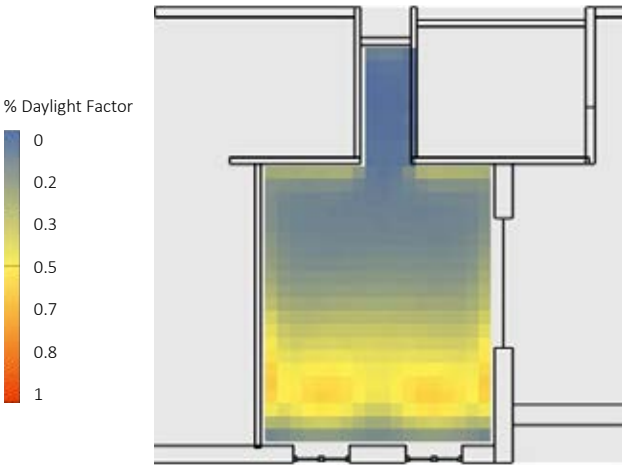
The percentage of the time occupants within the school are inside the comfort zone is **75.1%**



Hourly comfort levels throughout the day.

Daylighting Performance

Mean illuminance: ***55.84 lux*** (each point's value is available)



daylight on floor.

Daylight Autonomy Analysis

The spatial daylight autonomy is 55% for active occupant behavior. The percentage of the space with a daylight autonomy larger than 50% of the time is ***36%***.

Daylit Area (DA_{300lux}[50%])	*36% of floor Area*
Mean Daylight Factor	*0.3%*
Occupancy	*3650 hours/yr*

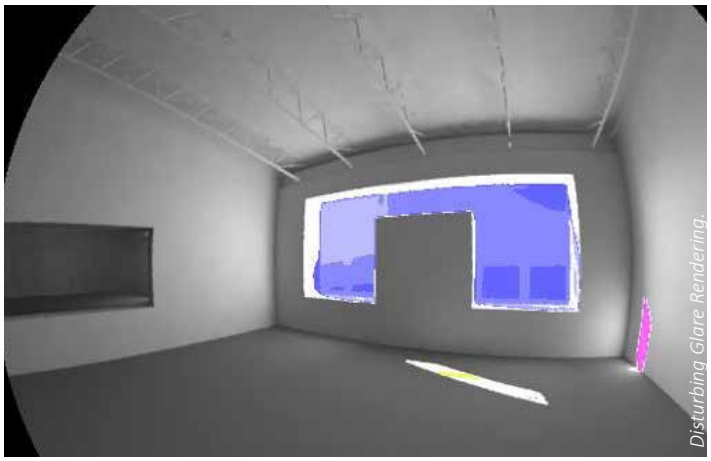
As an example, a point indicating semi-red color in the area means that at 83% of the whole occupied time, that point meet the criteria of having daylight factor of 300 lux or above.

daylight analysis.

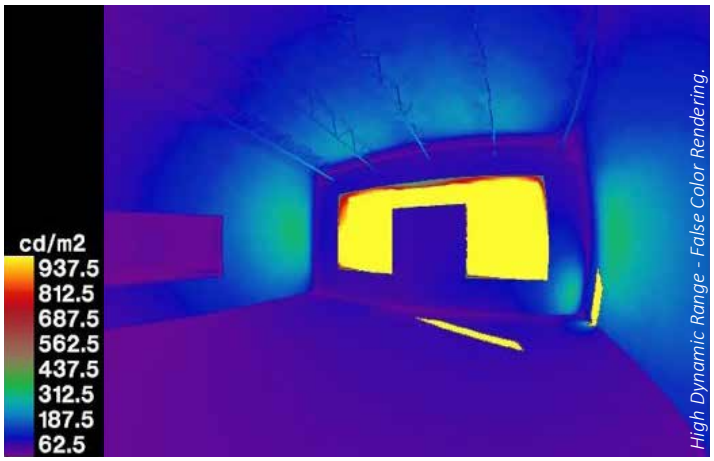
Illuminance Node Analysis

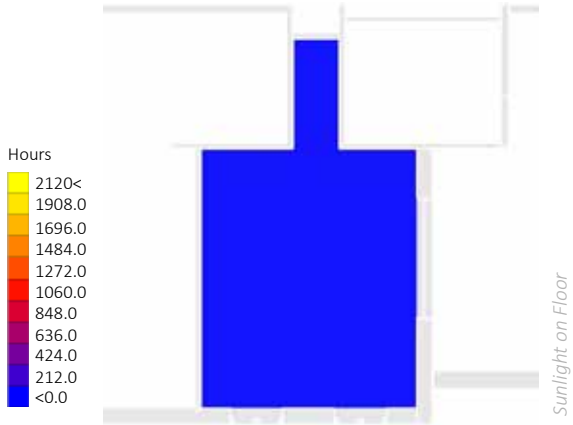
Mean daylight factor = ***0.26%***
The daylight factor for 100% of Area is 0%.

illuminance node analysis.



Daylight Glare Propability in this classroom is ***28%.***



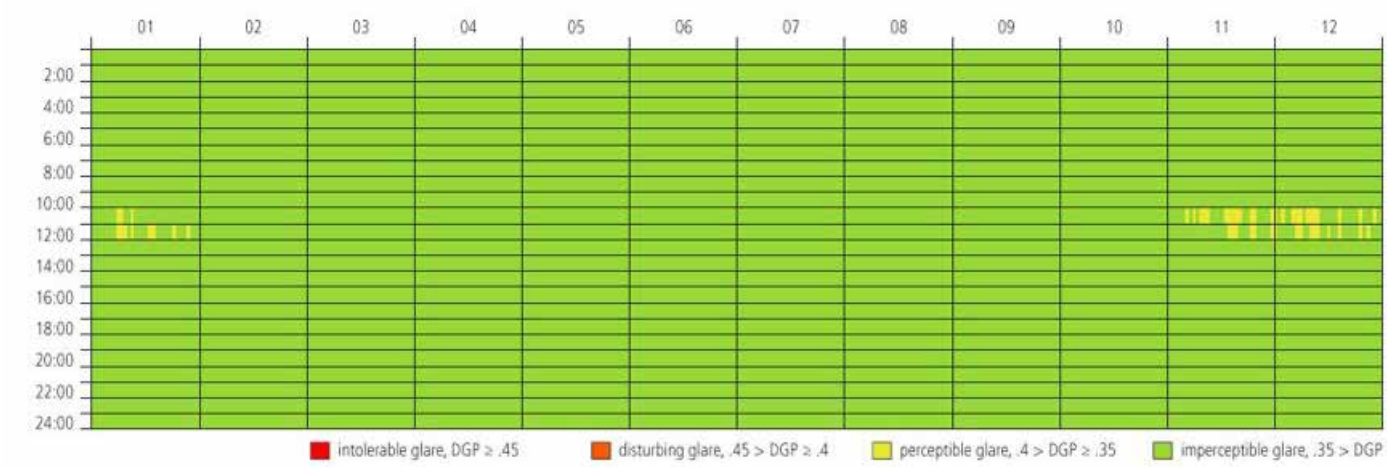


Glare Analysis

Glare found most concentrated at the windows. Very little glare found beyond the window surface.

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).



Incidents of perceptible glare between 10AM - 12PM during the months of November to January.

Engineering News Record: Best K-12 School Project 2013
2017 LEED Gold Certification
2015 ASHRAE Region IV Technology Award First Place for New Educational Facilities
AIA Eastern North Carolina – 2014 Honor Award (Service Category)

Sandy Grove Middle School

Lumber Bridge, North Carolina, 28357

SFL+A Architects

Optima Engineering, LHC Structural Engineers

2013

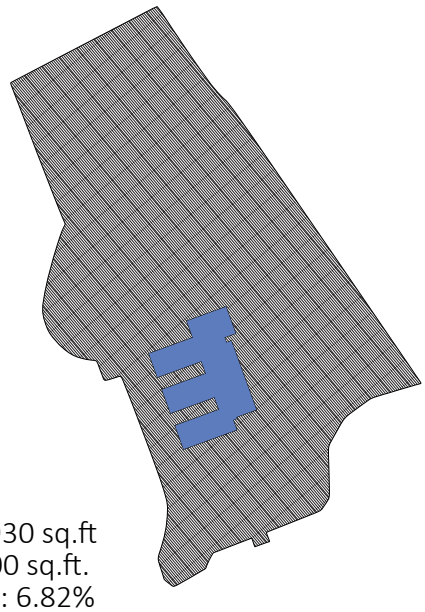
Design Process

Project Statement

Sandy Grove Middle School was an integrated collaboration between the school district, local government and the client representatives. This created large financial incentives by reducing operation costs by way of sustainable features. As photovoltaic panels are the main source making this a net energy school, there are many other sustaibale features that make this school a great example.

Site Plan

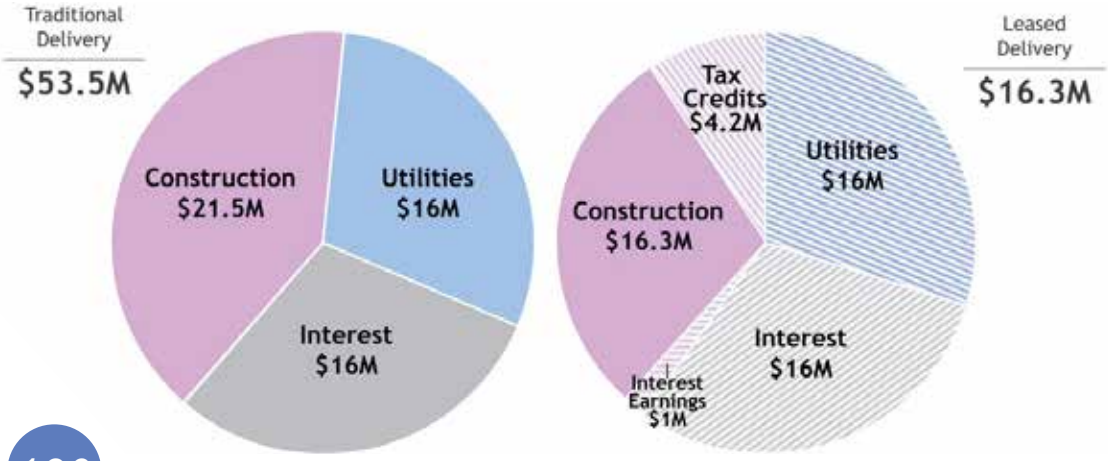
Site to Building Ratio



- Building Area: 75,930 sq.ft
- Site Area: 1,113,300 sq.ft.
- Built-up Area Ratio: 6.82%

An Aim To Reduce Costs And Expenses

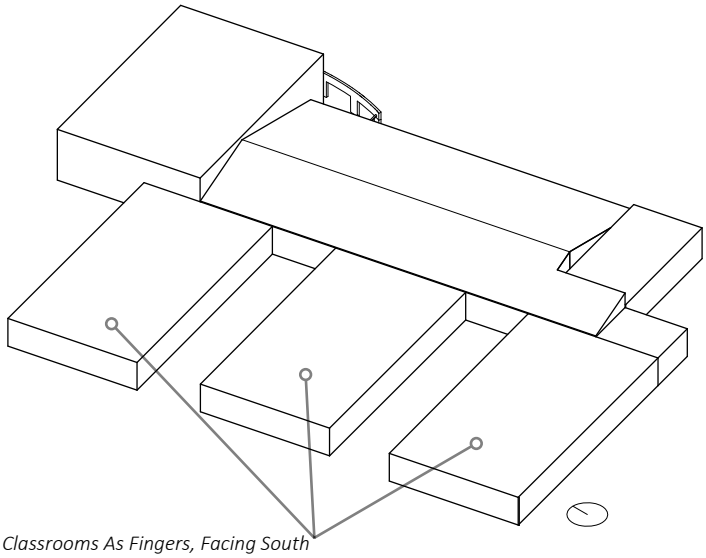
The school managed to reduce the cost from $53.5 million in project delivery costs to a total of $16.3 million due to the leased delivery model allowed for a public-private partnership with the design team.



Engaging consultants in the early design process was beneficial to reduce cost and work on sustainable and appropriate technologies.

The design consultants were represented in an integrated design approach design and delivery model.

- *Crawford Design Company (Civil Engineer + Landscape)*
- *Lasater hopkins Chang (Structural Engineer)*
- *Foodesign Associates (Kitchen Consultant)*
- *Optima Engineering (PME / FP Engineer)*



Classrooms As Fingers, Facing South

Additional Sustainability Features

Courtesy of sf+A Architects

- *Highly efficient plumbing fixtures cause a 40% reduction in water consumption*
- *Enhanced envelope (see Envelope Performance)*
- *LED Lighting*
- *Geothermal Heat Pump System*
- *75% of construction waste was diverted from the dump*
- *20% of construction*
- *materials was recycled*
- *30% was regionally sourced*
- *Furniture used in the scholl is certified 'green'*

Rendering of Sandy Grove Middle School (courtesy of sf+A Architects)

Courtesy of sf+A Architects

Design Strategies

Architecture as a Teaching Tool

The placement of the "solar trees" at the entryway of the building is a statement towards the building's overall attitude on sustainability. Solar is a representative tool that holds together the icon of sustainable design as it replaces our dependence on the most detrimental element which is carbon dioxide. For students growing up in this middle school, it's hoped to be something they remember for a lifetime, a symbol that their childhood revolving around the value of sustainability.

Building as an Energy Plant

The overall production of solar energy outweighs the amount of overall energy consumption of the building. This is partly due to the engineering and design of the systems underlying the buildings many functions. Efficient energy use, 'Solar Trees', and a rooftop solar array allowed for the building to be a solar energy plant.

Solar Tree Installation. Courtesy of SHIA Architects

Public Private Partnership (P3)

Private Public Partnership (P3) is a strategy aimed towards easing the process of financing, designing, constructing, and maintaining a building through the establishment of a contract between government, developer, and user. It is an integrated building model incorporating Design, Build, Finances, and Operation solutions.

Government's Role is to provides incentives for the developer such as:

1. transfer of assets
2. one time grant
3. tax break and credits

Developer's Role is to recieve government incentives and carry out tasks such as:

1. Finance management
2. Building design
3. Building construction
4. Building maintanence

User's Role is to operate and utilize the building facilities.

In addition, user may be responsible for utility cost and some maintanence.

P3 Advantages:

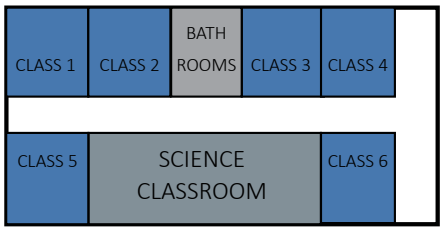
- Harnessing of private sector's expertise and efficiency
- 'Off-balance sheet' method of financing the delivery of public sector assets
- Speed of delivery
- Possible tax credits and breaks
- Energy tax credits
- Potential new market tax credits
- Elimination of bid day risk
- Elimination of construction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

STEM Building Program as an Organizational Building Strategy

STEM stands for science, technology, engineering and mathematics. STEM Schools use interdisciplinary and applied teaching practices towards student learning.

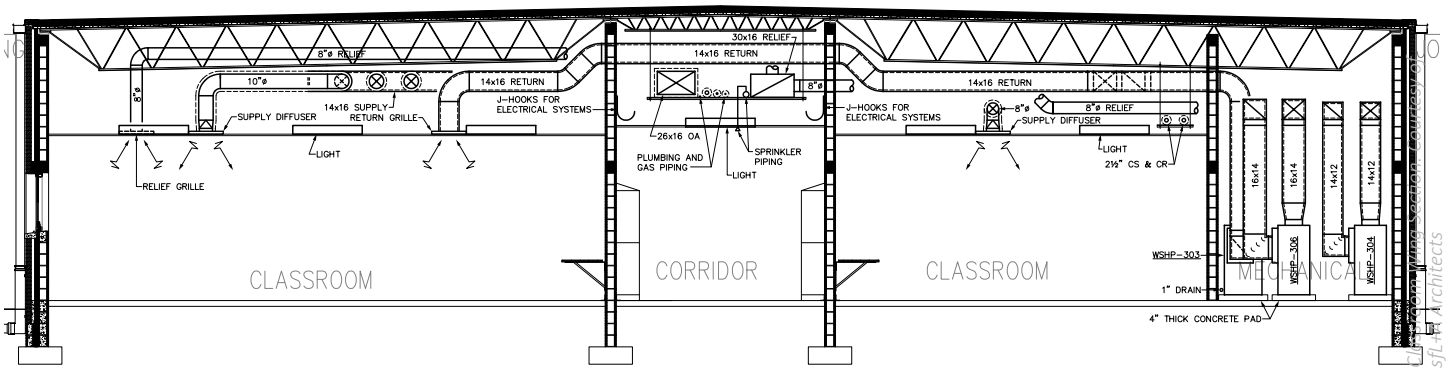
The order of the overall building separates the STEM classrooms from the rest of the building through the use of finger or wing school building. The building is made up of three major massing components:

1. Gymnasium building
2. Finger/wing classroom buildings
3. Administrative building



The science classrooms have been placed in near proximity to the nearby classrooms in each building wing. The close proximity between classrooms and science rooms allows for interdisciplinary work to occur. The proximity of bathrooms and meeting spaces as well allows for faster and easier accessibility.

Program Diagram. Courtesy of sfL+A Architects



sfL+A Architects

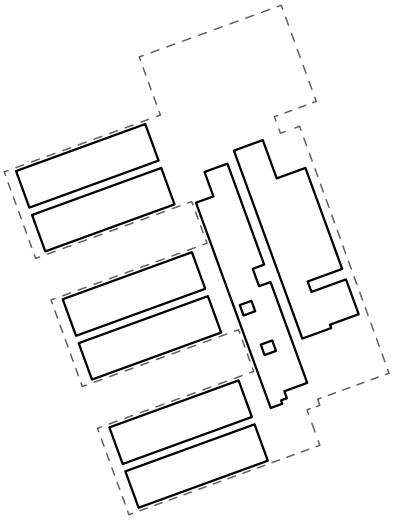
Main section through the classroom wings showing sound isolation and proxemics between classrooms.

Site Performance

Site Metrics

- *Gross Floor Area (Sf): 75,930*
- *Gross Site Area (Acres): 25.56*
- *Building Footprint (Sf): 75,930*
- *Built Up Area (%): 6.82%*
- *Paved Area (Sf): 110,863*
- *Paved Area (%): 9.96%*
- *Non-Paved Surfaces (Sf): 926,507*
- *Non-Paved Surfaces 83.22%*
- *Pv Area As % Of Floor Area: 50%*
- *Shape Factor (A/V): 1.52*
- *Geothermal Well Field ± 256 Wells (8'X32') Spaced At 20' Underneath Track & Field*
- *3 EV Charging Stations*

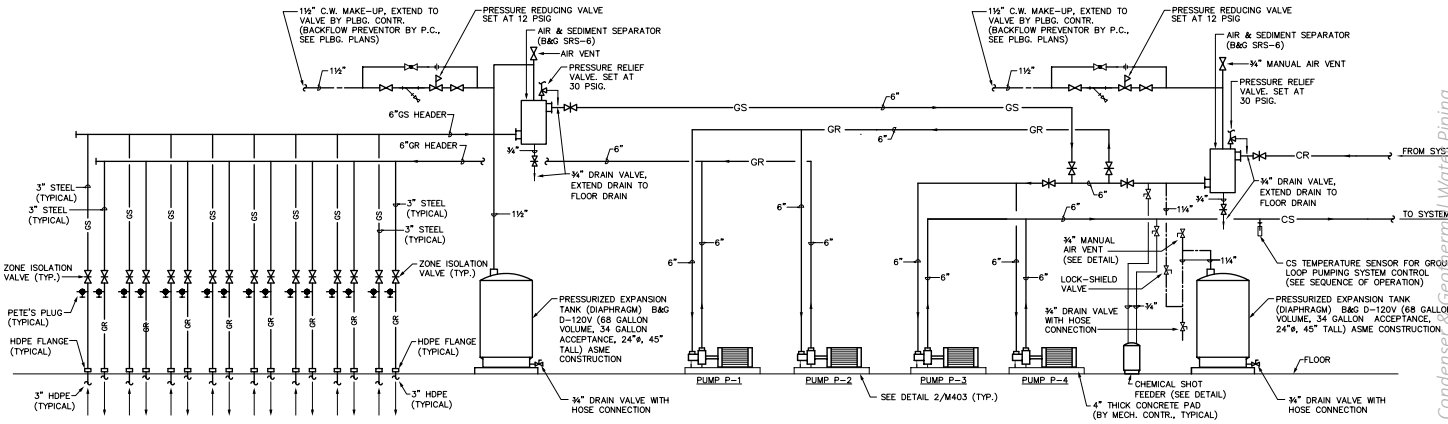
***50%** Of Building Footprint Has Pv Panels*



768,972 kWh
38,328 sf (50%)
*Solar EUI: **34.53***

Photo of Solar Trees. Courtesy of sfL+A Architects

Diagram of Geothermal Heat Pump System. Courtesy of sfL+A Architects.



Condenser & Geothermal Water Piping Schematic. Courtesy of sfL+A Architects

Geothermal system diagram.

Catchment Area

Located within the farming town of Sandy Grove, this school requires a car or bus in order for transportation.

The catchment of Sandy Grove is about mid-size, spanning over 13 miles across the longest point. This goes to consider how transportation systems are an integral part of how people get to and from the school.

Site Program

- *5,088 sf*
- *4 Bioswales*
- *Track & Field for Soccer / Football*
- *300 ft Baseball Diamond*
- *225 ft Baseball Diamond*
- *Pathways to classrooms*
- *Parking & Student Pick-up / Drop-off*
- *Loading Dock*

School district boundary catchment map.

- *school district area: 72 sq.mi.*
- *longest distance across district: roughly 13.2 miles.*
- *walk-score:* ***0***

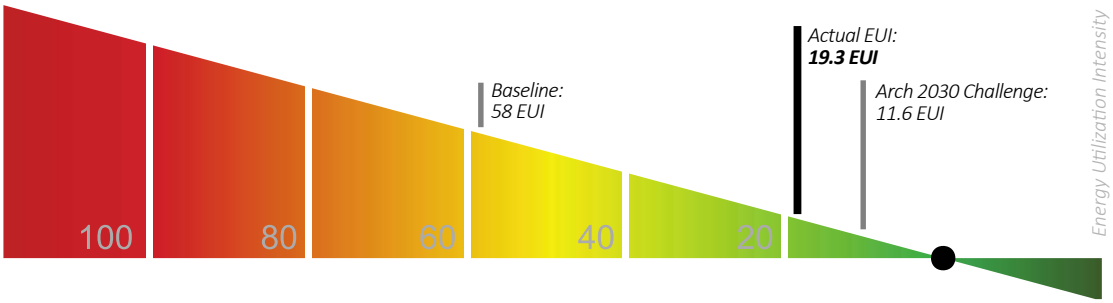
Location of Geothermal Field

Half mile radius catchment map.

Energy Utilization Intensity

Actual EUI: ***19.3***

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/ft^2/yr).



Energy Metrics

Energy Use: May 2011-April 2012

Mechanical Equipment (kWh)	Lighting/ Plug Loads (kWh)	Total Power Consumption (kWh)	PV Energy Production (kWh)	Net Power Consumption/ Production (kWh)
NA	**NA**	**541,136**	**768,972**	**+ 227,836**

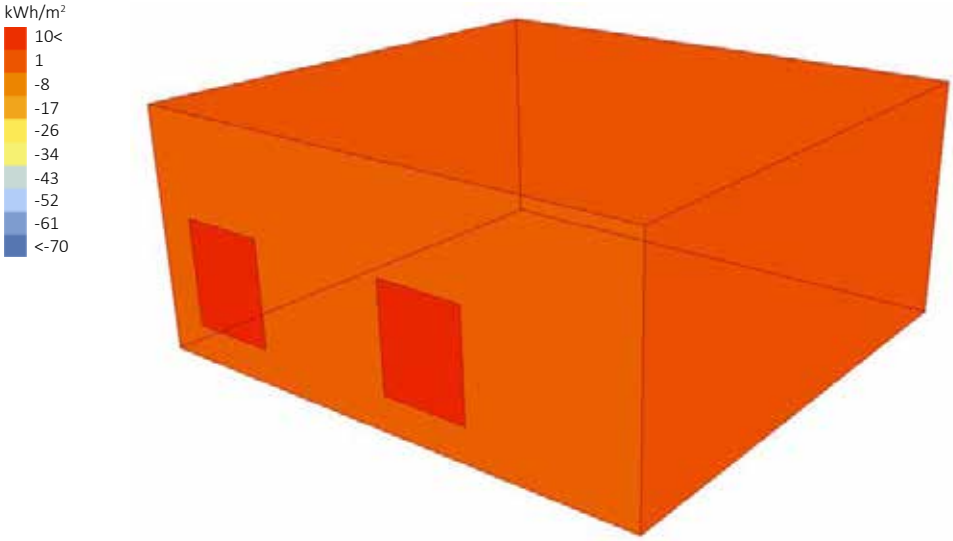
Heat Loss and Heat Gain

Heat loss measures the amount of heat being lost by the building due to infliltration and insulation deficiencies. Heat gain measures the amount of heat being gained by the building due to heat transfer. Both heat loss and heat gain are measured in KWh per square meter.

Thermal Balance Chart

Winter Heat

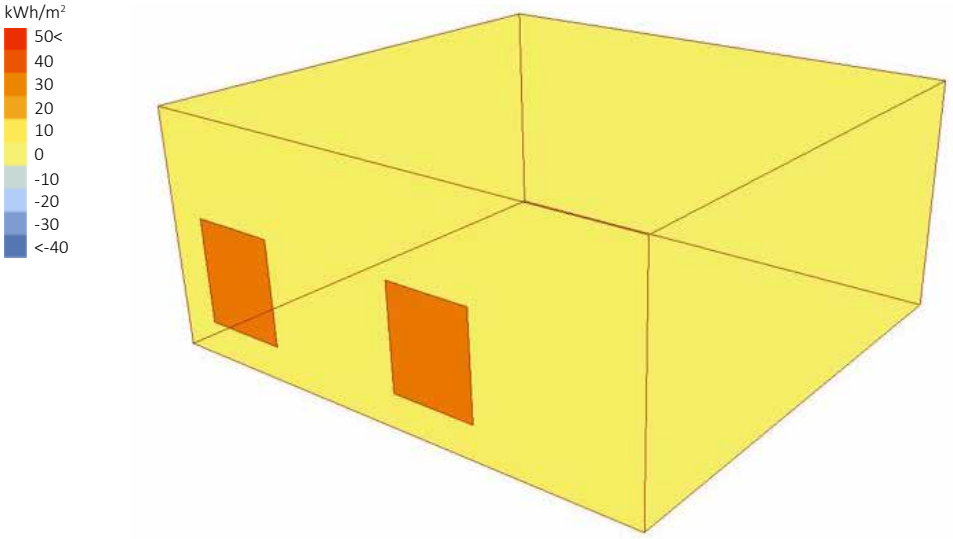
Some heat gain in Winter. Surfaces are gaining only about 1 KWh per sq. meter. Openings are gaining over 10 KWh per sq.meter.



Solar Heat Gain in Winter.

Spring Heat

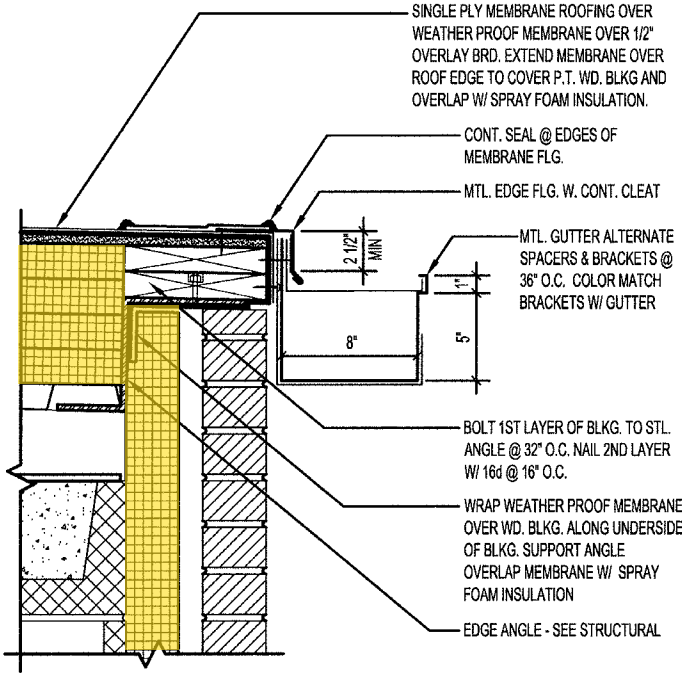
Neutral and major heat gain in Spring. Walls, roof and floor aren't losing or gaining any heat. Openings are gaining over 30 KWh of heat per sq. meter.



Solar Heat Gain in Spring.

Wall Detail

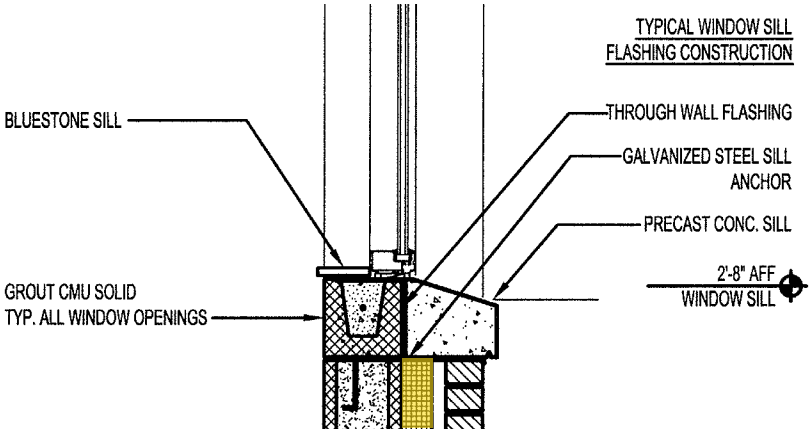
- R-Value: ***NA***
- Type: 6" CMU
- Insulation: Spray foam
- Exposed Interior Material: 6" CMU
- Exposed Experior Material: Brick Veneer



Exterior Wall. Courtesy of SFL+A Architects.

Fenestration Detail

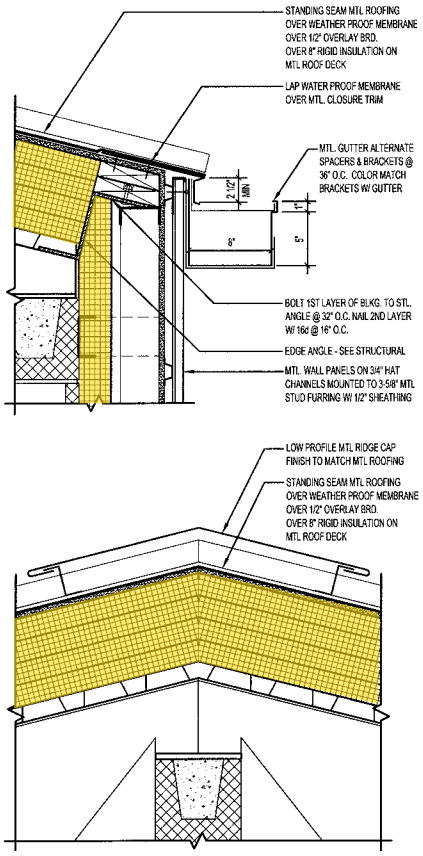
- R-Value: ***2.17***
- Window Type: Triple Glazed
- SHGC: 0.36
- Visual Transmittance: 0.65
- Glazing Applications: Windows, Clerestories, Skylights (in gymnasium only)
- Window to Wall Ratio: 19.7%
- South Facade Window Area: NA
- Total Window Area: NA



Fenestration Detail. Courtesy of SFL+A Architects.

Roof Detail

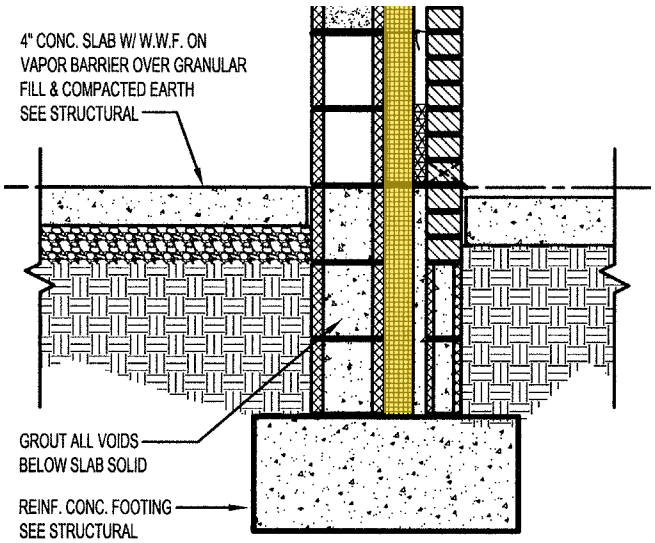
- R-Value: ***NA***
- Roof Area: 76,717 sq.ft.
- PV Area: 38,328 sq.ft.
- Energy Generation: 768,972 KWh/year
- Type(s): Shed, Gable
- Insulation: 8" Rigid
- Exposed Interior Material: Corrugated Metal Decking
- Exposed Exterior Material: Standing Seam Metal
- Water Management: NA



Roof Detail. Courtesy of SFL+A Architects.

Floor Detail

- R-Value: ***NA***
- Floor Type: Concrete slab
- Insulation: NA
- Exposed Top Material: Concrete
- Subgrade Material: Compacted Gravel



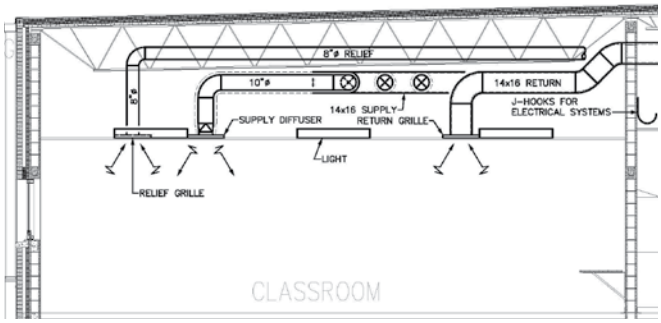
Floor Detail. Courtesy of SFL+A Architects.

Acoustics

Reverb Time: ***0.354 seconds***
Noise reduction measures were taken for classroom walls and surfaces. Concrete masonry units and concrete floors are not effective materials for interior noise reduction, thus most of the noise reduction was maintained through ceilings and wall choices.

Classroom Interior View
Courtesy of SFL+A Architects.

Air Ventilation



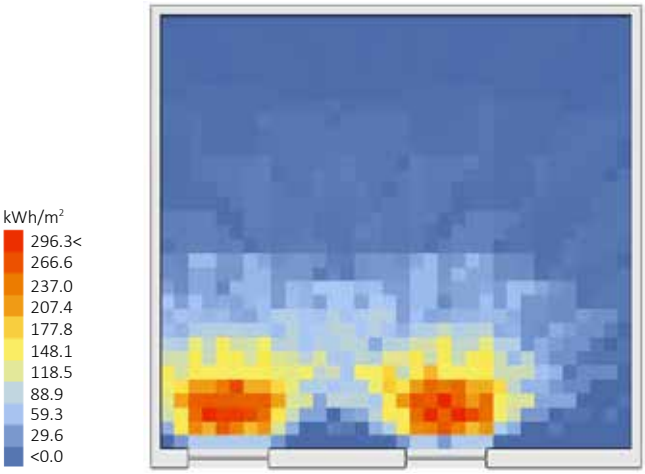
HVAC Systems in Classroom.
Courtesy of Optima Engineering.

Each classroom has its own dedicated heat pump and thermostat for users to have control over their class environment. Overall building has 162 vertical geothermal wells dug 300 feet deep to draw heat from underground into the building's air heating system.

Thermal

We have conducted IEQ simulations to calculate the amount of radiation on windows and floors is to determine how much heat, measured in KWh per sq. meter, is resulting on the window openings. This helps to understand the impact of thermal radiation towards the overall heat in the classroom.

In this classroom simulation, between 776 and 971 KWh/m^2 resulted on the window openings. Higher levels of radiation can be seen on the lower part of the window, this is mainly due to the overhang that blocks much of the radiation hitting the upper level of the window opening.



Radiation on Floor.

The overall amount of radiation resulting on the floor of the south classrooms is ***4031 KWh/m^2.***

Radiation on Openings.

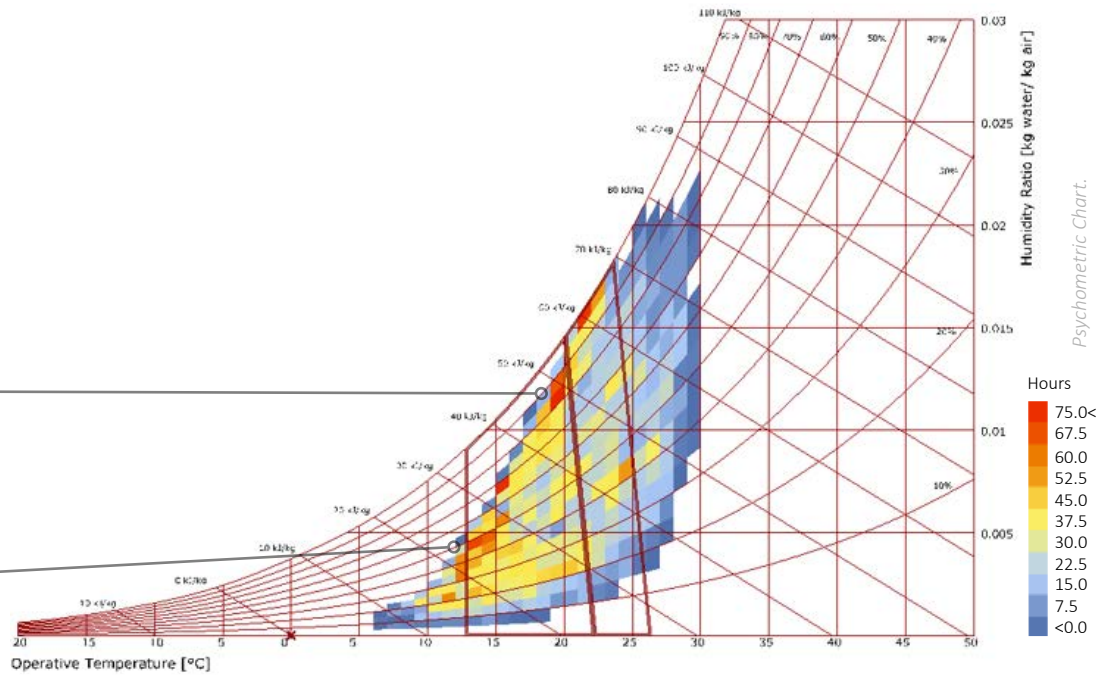
The overall amount of radiation resulting on South openings is ***6942 KWh/m^2.***

Pyschometric Chart

Mean average of data falls at both the middle left and upper right corner of the ASHRAE indoor thermal comfort standard-55 zone. The school's most concentrated number of hours lies at two points:

Point A Metrics
- Temp: 19 C
- R. Humidity: 80%
- Enthalpy: 65 kg/kJ
- humidity ratio: 0.006
-

Point B Metrics
- Temp: 13 C
- R. Humidity: 50%
- Enthalpy: 25 kg/kJ
- humidity ratio: 0.005



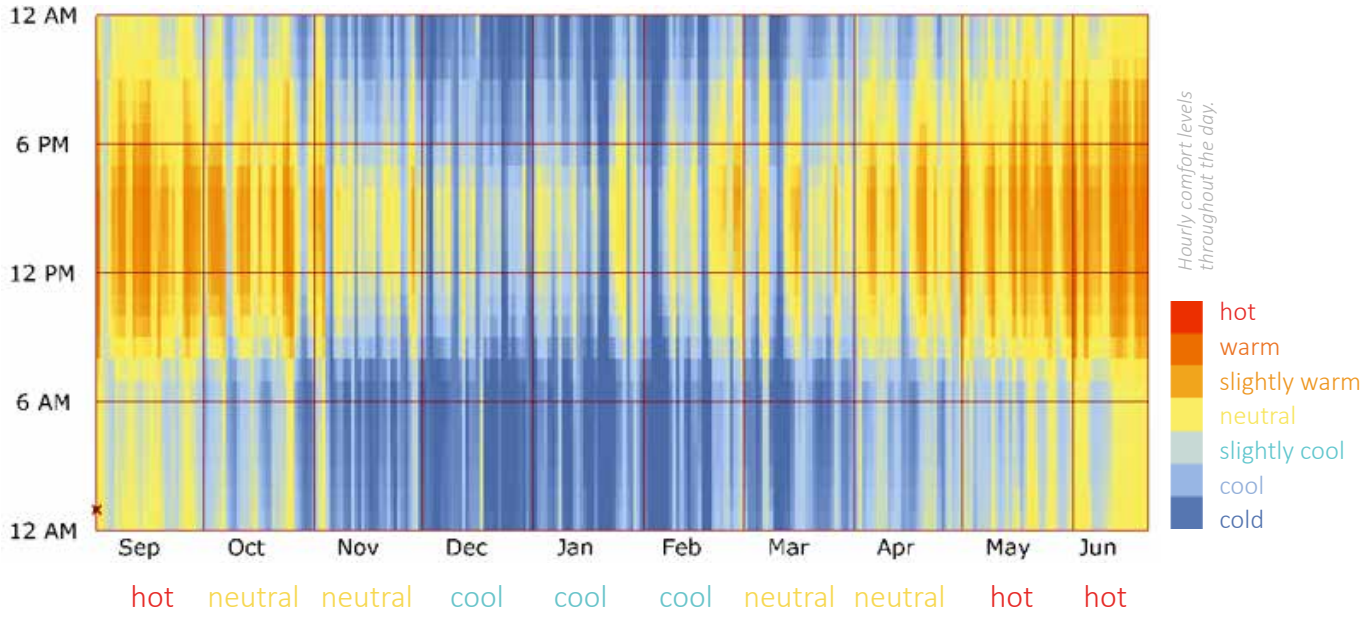
Psychometric Chart.

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 ***77.3%***

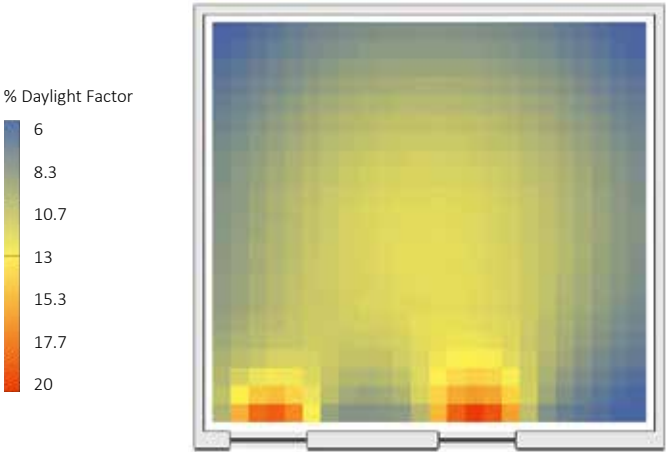


Hourly comfort levels throughout the day.

Daylighting Performance

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 deeper into the space. Electric lighting is automatically dimmed when daylight is adequate.

Average Illuminance: ***4709.01 lux*** (annual levels)

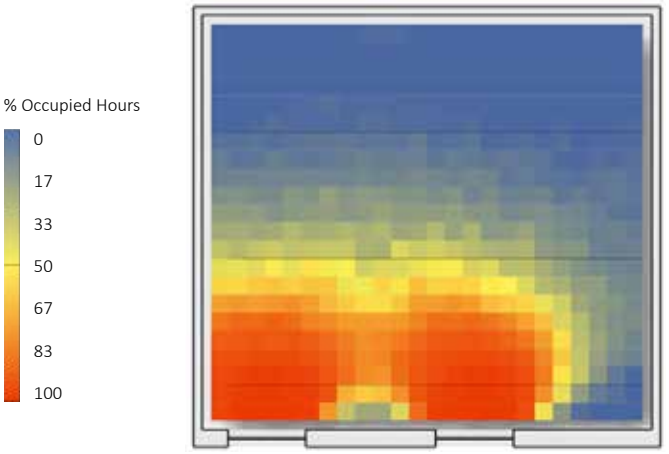


daylight on floor.

Daylight Autonomy Analysis

The mean spatial daylighting autonomy represents the percentage of floor area recieving 300 lux or above throughout the occupied hours annually. The percentage of the space meeting the daylight autonomy levels for 50% of the year is ***28%***.

Daylit Area (DA_{300lux}[50%])	*28% of floor Area*
Mean Daylight Factor	*1.1%*
Occupancy	*3650 hours/yr*



daylight analysis.

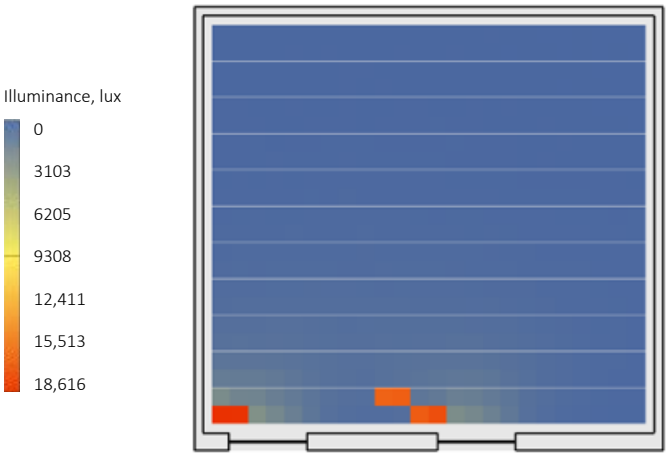
Illuminance Levels Analysis

Mean daylight factor = ***10.02 %***

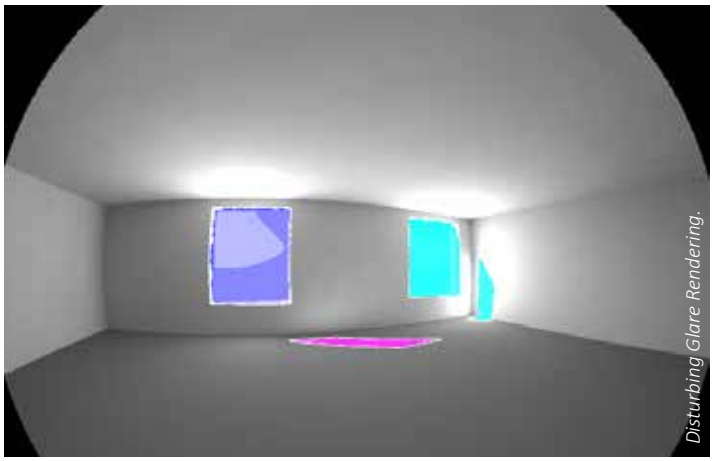
The daylight factor for 100% of Area between 0 & 9 %

The daylight factor for 0.2% of the area is above 15%

0% of Area > 9 %

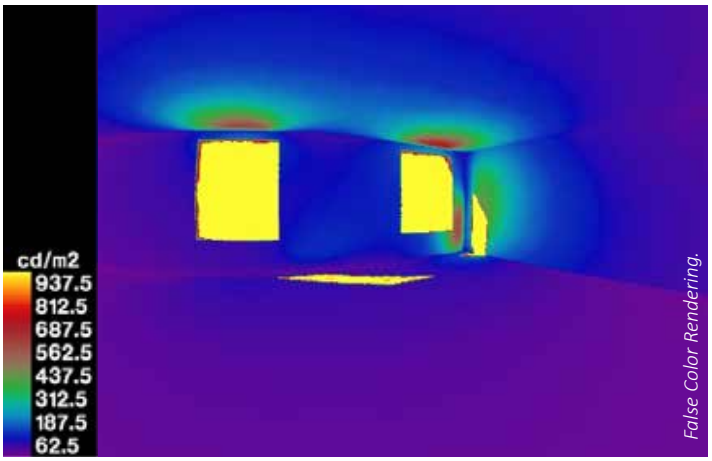


illuminance node analysis.



Disturbing Glare Rendering.

Daylight Glare Propability in this classroom is ***26%.***



False Color Rendering.

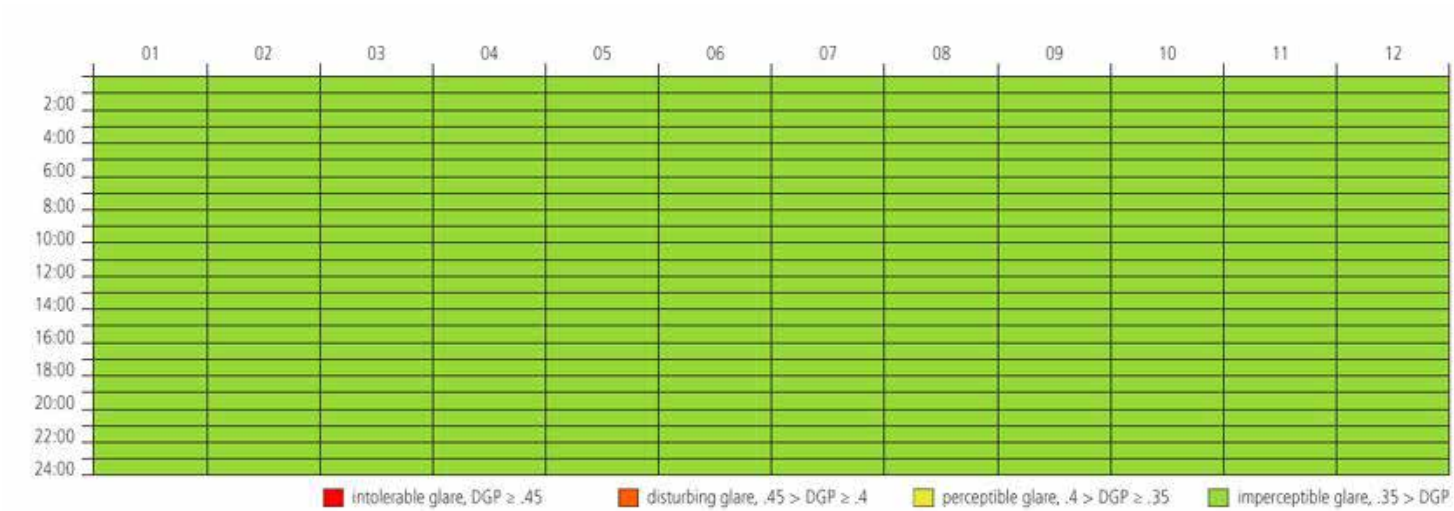
Sunlight and Disturbing Glare

A daylight glare probability of 26% indicates perceptible yet tolerable glare. Sunlight glare can significantly impact focus levels of students and teachers using the classroom space if the sunlight glare is to disturb them.

High concentrations of glare occur at the surface of the windows as well as the surfaces near to the window. A high level of glare occurs on the floor between the two windows, most likely caused by light entering during the morning and afternoon (East and West).

Annual Glare Analysis

The chart below represents the result of an annual glare simulation in which the intolerable glare, disturbing glare, perceptible glare and imperceptible glare are shown with their relative color. Colors match with the false color rendering to the left.



Annual Glare Chart.

No incidents of disturbing glare throughout the year.

Discovery Elementary School

Arlington, Virginia, 22207

VMDO Architects

CMTA Consulting Engineers, 2RW Plumbing Engineers, Fox and Associates

2015

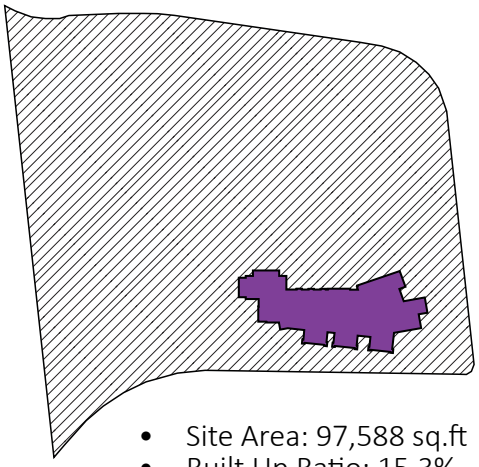
Design Process

Project Statement

Discovery Elementary School is designed to meet 21st century rapidly growing student enrollment levels. The project was designed to meet a net zero energy goals for a large public school facility.

Site Plan

Site to Building Ratio



- Site Area: 97,588 sq.ft
- Built Up Ratio: 15.3%
- Paved Area: 9.12%

Setting Goals of Sustainability

To preserve space, the school shares the site with an existing middle school and has been master planned for future middle school expansion. Open, programmable space is preserved as much as possible by situating a full third of the building's footprint on existing slopes. The school tiers into an existing hill to minimize the perception of its size while featuring exterior proportions that are residential in nature and scale. Pre-K and Kindergarten students are grouped into three "kinderhouses" that mimic the size and spacing of adjacent homes.

The "Discovery Explorers" name reflects the forward-looking, inquiry based learning that takes place in the building. The school name also serves as a tribute to John Glenn, who lived adjacent to the site when he became the first American to orbit the earth in 1962. In 1998, while still a sitting senator, Glenn returned to space as a crew member of the space shuttle Discovery, becoming the oldest person to fly in space. The project found the right balance between preserving and enhancing natural resources, while adding a large facility that is respectful of the site's residential context.

Site to Building Ratio

The school's design takes advantage of the topography of the site to create distinct, tiered academic zones and separate exterior play spaces for early childhood, primary, and elementary grade levels.

In addition to shading large expanses of glass that provide a strong visual connection to the outdoors, the roof overhang provides covered outdoor dining and play spaces.

Overall Building Render View. Courtesy of VMDO

As students progress through the school, their "world expands" – with the first floor themed around animals found in earth eco-systems and the second floor themed around the elements of the sky and the solar system.

Students start out as Backyard Adventurers in Kindergarten and finish Fifth Grade as Galaxy Voyagers. This storyline is graphically communicated along an entry wall highlighting each Explorer grade level.

Plan Diagrams. Courtesy of VMDO Architects.

- *Core Spaces*
- *Administration*
- *Learning Commons*
- *Mechanics / Support*
- *PK/K Backyard Kinderhouses*
- ***1st Grade - Forest***
- ***2nd Grade - Ocean***
- ***5th Grade - Galaxy***
- ***3rd Grade - Atmosphere***
- ***4th Grade - Solar System***
- *Specialty Classrooms*

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*

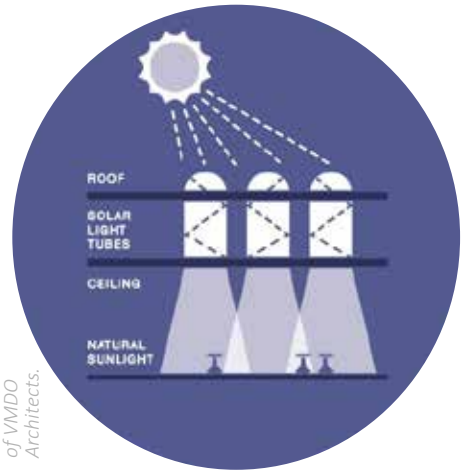
Balancing Net Zero Strategies

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.

Photovoltaic Systems

Discovery Middle School takes full advantage of its large roof area by populating it with solar panels. Southern building orientation makes the solar panel installation easier by aligning it with the geometry of each roof boundary.

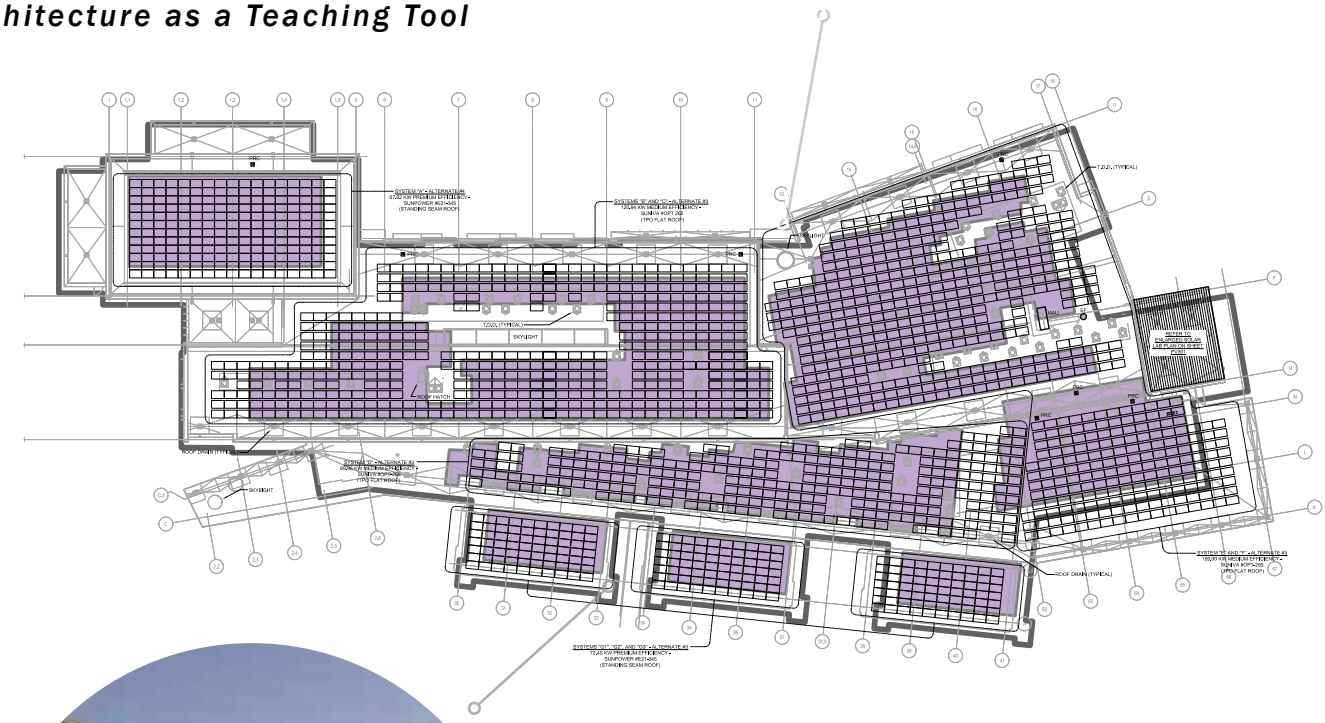


Solatubes. Courtesy of VMDO Architects.

New Technology Use

This school has 62 solar tubes located in classrooms and corridores, which bring daylight deep inside the building. The natural daylight from the windows and these solar tubes allow users to use less electric light on sunny days, and help to save energy.

Architecture as a Teaching Tool



Roof Plan. Courtesy of VMDO Architects.

Solar Roof near Classroom. Courtesy of VMDO Architects.

Visible Solar

The true power of Discovery Middle School's focus on solar energy production is the connection it makes with the students, teachers, and staff. The image above shows how classrooms were arranged to look out onto the solar array on the roof, located on the southern most part of the school.

Site Performance

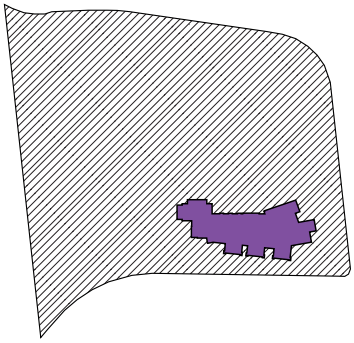
Site Metrics

- *Gross Floor Area (Sf): 97,588*
- *Gross Site Area (Acres): 640,332*
- *Building Footprint (Sf): 98,000*
- *Built Up Area (%): 15.3*
- *Paved Area (Sf): 58,400*
- *Paved Area (%): 9.12%*
- *Non-Paved Surfaces (Sf): 483,932*
- *Non-Paved Surfaces (%): 75.58*
- *Shape Factor (A/V): 1.08*

Site Program

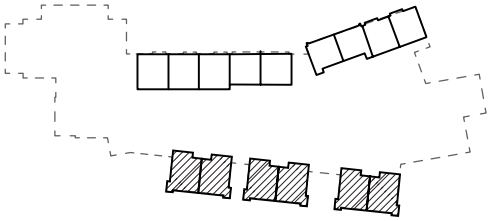
- *School Neighborhoods*
- *Playground Areas*
- *Athletic Fields (shared with other middle school)*
- *Two parking lots (one is shared with other middle school)*
- *Walking paths between school and adjacent street.*

Built Up Area



- School takes up ***12%*** of the overall site.

South Facing Classrooms



- ***36%*** of school classrooms are facing South.
- These classrooms face the sloped hill.

Site Optimization

Open and programmable space is preserved as much as possible through situating an entire third of the building's footprint on an existing hill. This was planned to minimize the perception of its size.

In addition, the exterior materials used on the building mimic residential home materials to further match to its context.

Catchment Area

Catchment area is the overall school district area, providing an understanding of the extent buses can drive in order to pick up students.

The catchment area ofDiscovery Elementary School is average, spanning over 7 miles across the longest point. This goes to show how transportation systems are an integral part of how people get to and from a building.

School district boundary catchment map.

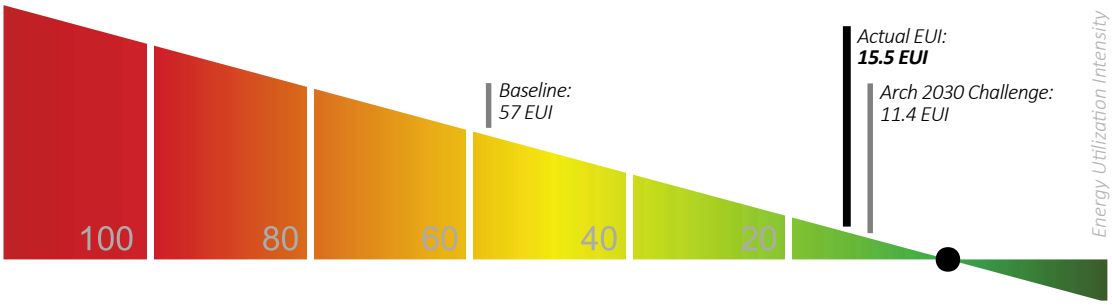
- *school district area: 5.7 sq.mi.*
- *longest distance across district: roughly 7 miles.*
- *walk-score: **14***

Half mile radius catchment map.

Energy Utilization Intensity

Actual EUI: ***15.5***

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/ft^2/yr).



Energy Metrics

Energy Use: May 2011-April 2012

Mechanical Equipment (kWh)	Lighting/ Plug Loads (kWh)	Total Power Consumption (kWh)	PV Energy Production (kWh)	Net Power Consumption/ Production (kWh)
NA	**NA**	**246,000**	**354,300**	**+ 108,300**

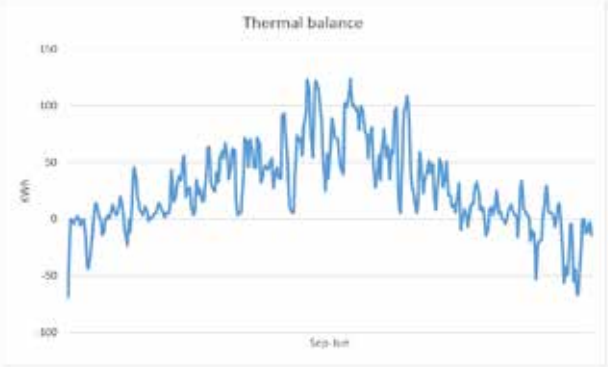
Energy Awareness

Daylight use instead of electric lighting use.

Daily metric on live power consumption, production and net power. Accessible through the web for anyone to see the building's energy metrics.

Heat Loss and Heat Gain

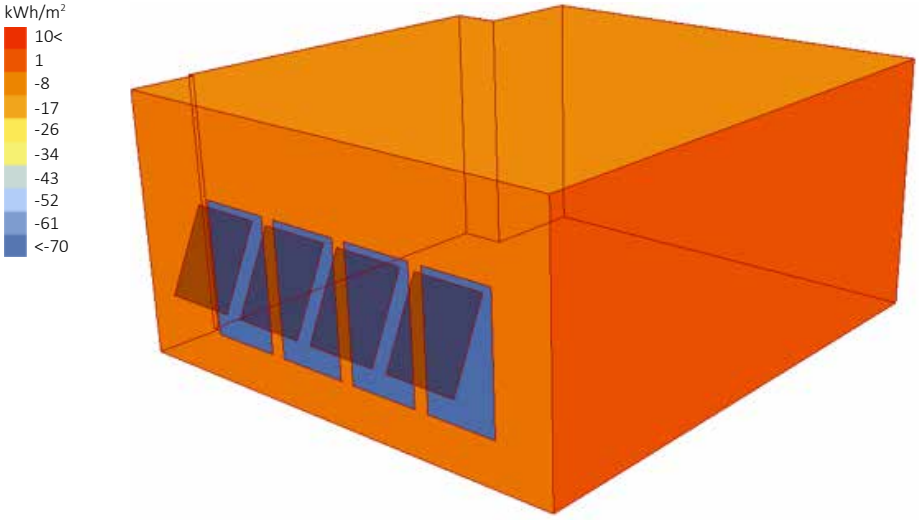
Heat loss measures the amount of heat being lost by the building due to infliltration and insulation deficiencies. Heat gain measures the amount of heat being gained by the building due to heat transfer. Both heat loss and heat gain are measured in KWh per square meter.



Thermal Balance Chart

Winter Heat

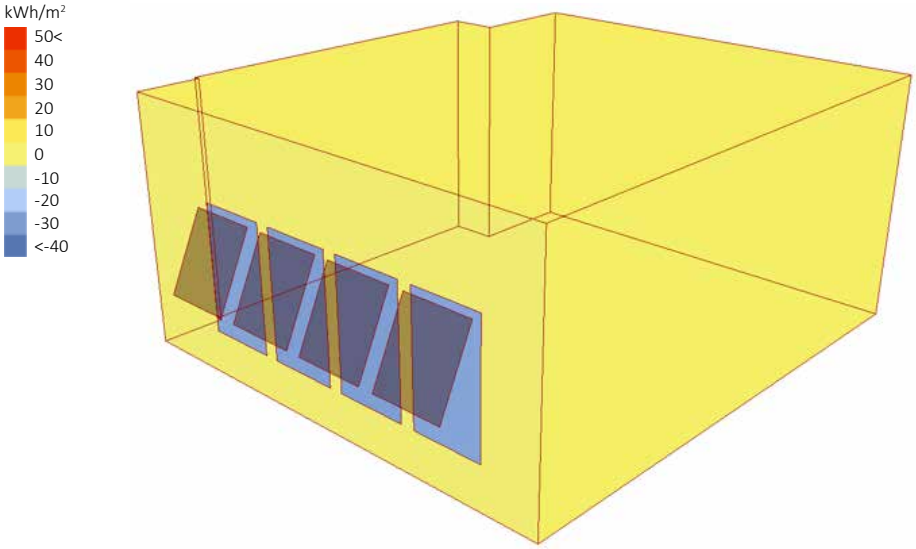
Major heat loss in Winter. Walls, roof and floor are losing roughly 17 KWh per sq. meter. Openings are losing over 70 KWh per sq.meter.



Solar Heat Gain in Winter.

Spring Heat

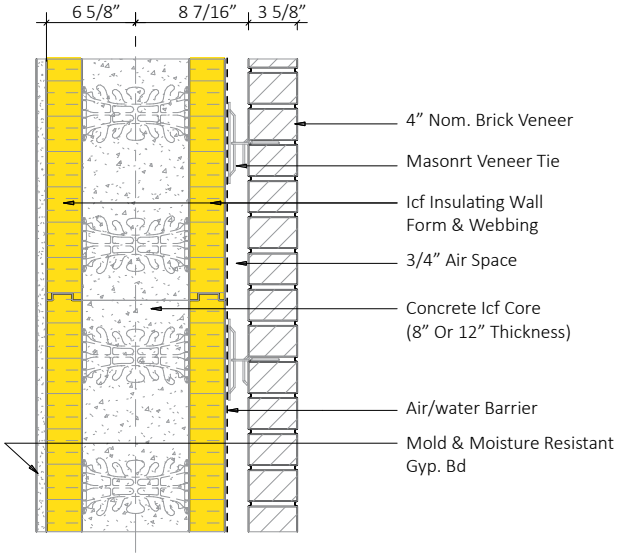
Neutral and major heat loss in Spring. Walls, roof and floor aren't losing or gaining any heat. Openings are losing roughly 30 KWh of heat per sq. meter.



Solar Heat Gain in Spring.

Wall Detail

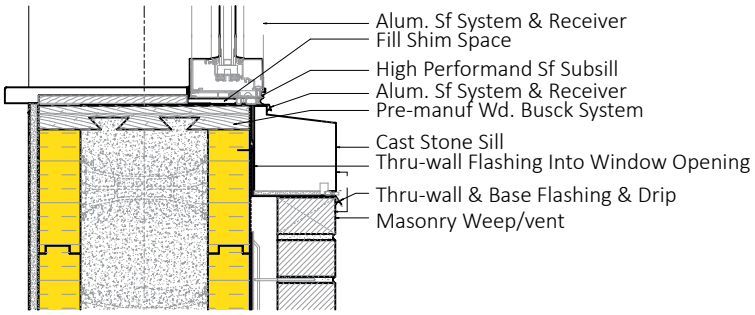
- R-Value: ***33***
- Type: Insulated Concrete
- Insulation: Insulated Concrete Formwork
- Exposed Interior Material: Gypsum board (moisture resistant)
- Exposed Exterior Material: Brick Veneer



Exterior Wall. Courtesy of Opsis Architecture.

Fenestration Detail

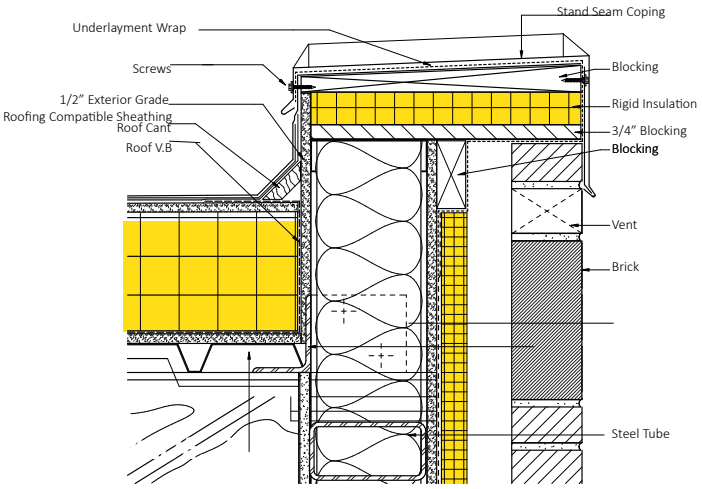
- R-Value: ***2.17***
- Window type: Double Glazing
- SHGC: 0.23
- Visual Transmittance: 0.42
- Glazing Applications: Windows, Clerestories, Skylights.
- Window to Wall Ratio: 29%
- South Facade Window Area: 352 sq.ft.
- Total Window Area: 1,613 sq.ft.



Fenestration Detail. Courtesy of Opsis Architecture.

Roof Detail

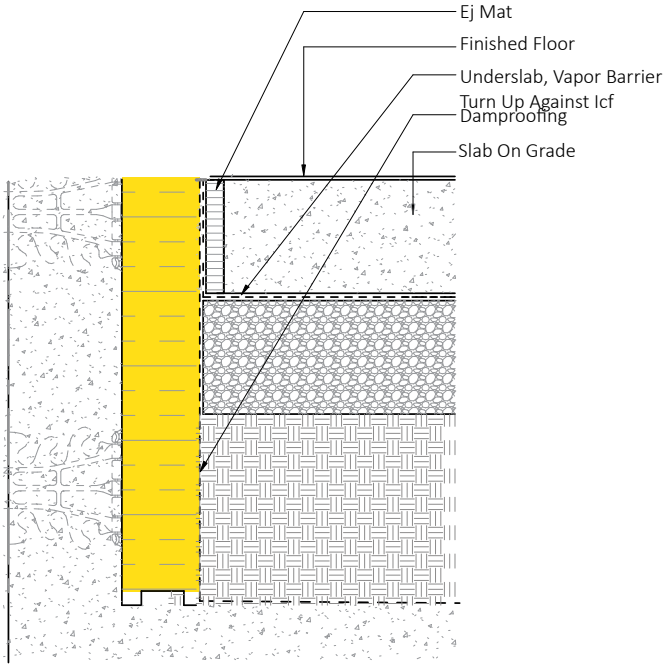
- R-Value: ***31***
- Roof Area: 63,066.7 sq.ft.
- PV Area: NA
- Energy Generation: 354,300 KWh/year
- Type(s): Parapet, Shed
- Insulation: Rigid
- Exposed Interior Material: Corrugated Metal Decking
- Exposed Exterior Material: Roofing Membrane
- Water management: NA



Roof Detail. Courtesy of Opsis Architecture.

Floor Detail

- R-Value: ***NA***
- Floor Type: Concrete slab
- Insulation: Rigid (continuous)
- Exposed Top Material: Concrete finish
- Subgrade Material: Compacted gravel



Floor Detail. Courtesy of Opsis Architecture.

Acoustics

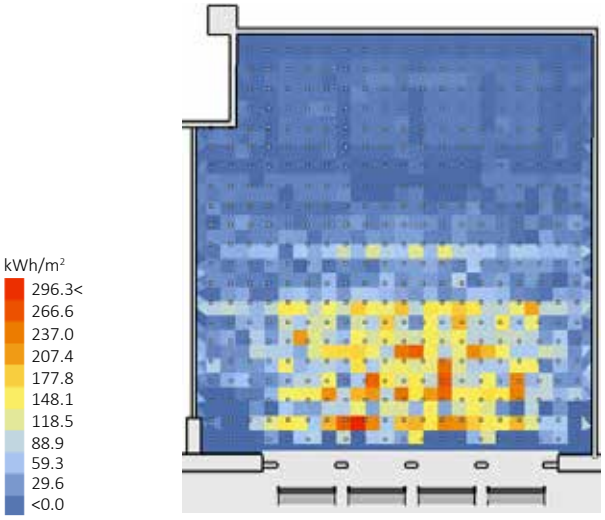
Reverb Time: ***0.380 seconds***

Applications of insulative concrete formwork and gypsum board as wall components of classroom provided noise-reducing materials. The reverb time still shows to be relatively average at 0.38 seconds.

Classroom Interior View. Courtesy of SFL+A Architects.

Air Ventilation

Air vents provide fresh air for classrooms. Natural ventilation is provided through shaded operable windows.



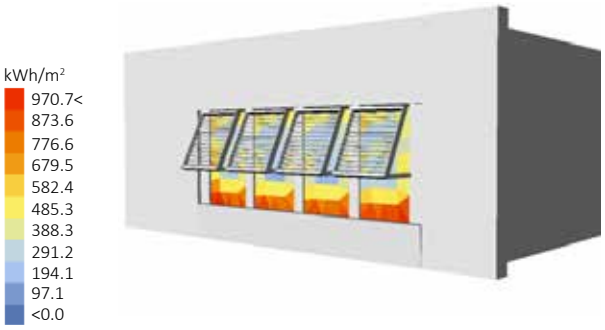
Radiation on Floor.

The overall amount of radiation resulting on the floor of the south classrooms is ***4031 KWh/m².***

Thermal

The purpose of simulating the amount of radiation on windows and floors is to determine how much heat, measured in KWh per sq. meter, is resulting on the window openings. This helps to understand the impact of thermal radiation towards the overall heat in the classroom.

In this classroom simulation, between 97 and 971 KWh per sq. meter resulted on the window openings. Higher levels of radiation can be seen on the lower part of the window, this is mainly due to the overhang that blocks much of the radiation hitting the upper level of the window opening.



Radiation on Openings.

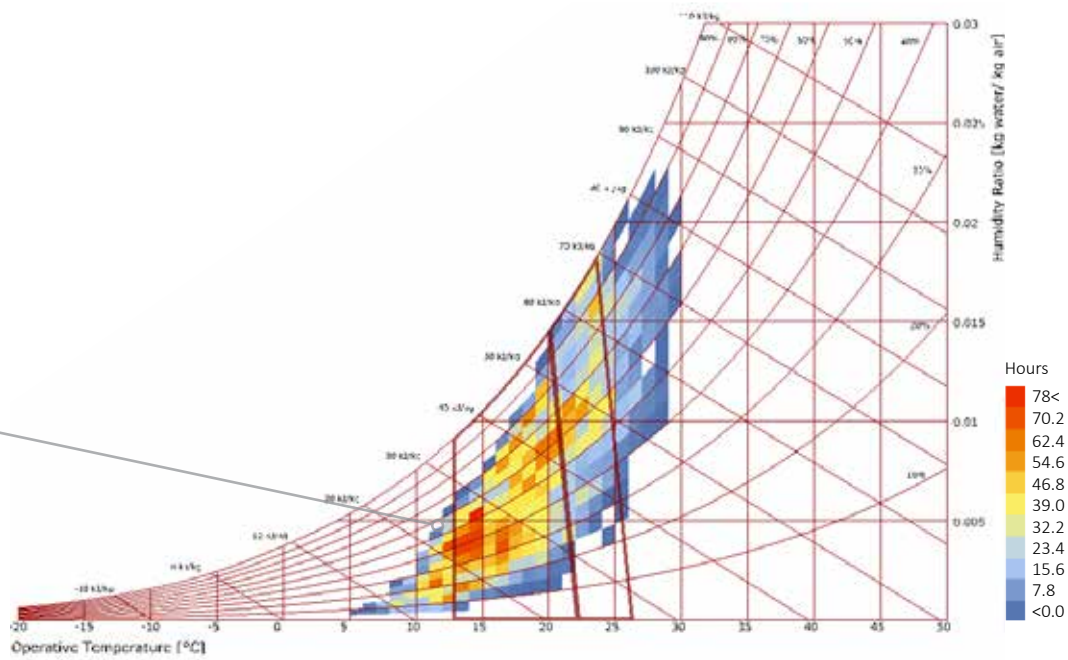
The overall amount of radiation resulting on South openings is ***6942 KWh/m².***

Psychometric Chart

Mean average of data falls at both the middle left and upper right corner of the ASHRAE indoor thermal comfort standard-55 zone. The school's most concentrated number of hours lies at:

Point A Metrics

- Temp: 13 C
- R. Humidity: 40%
- Enthalpy: 25 kg/kJ
- humidity ratio: 0.03

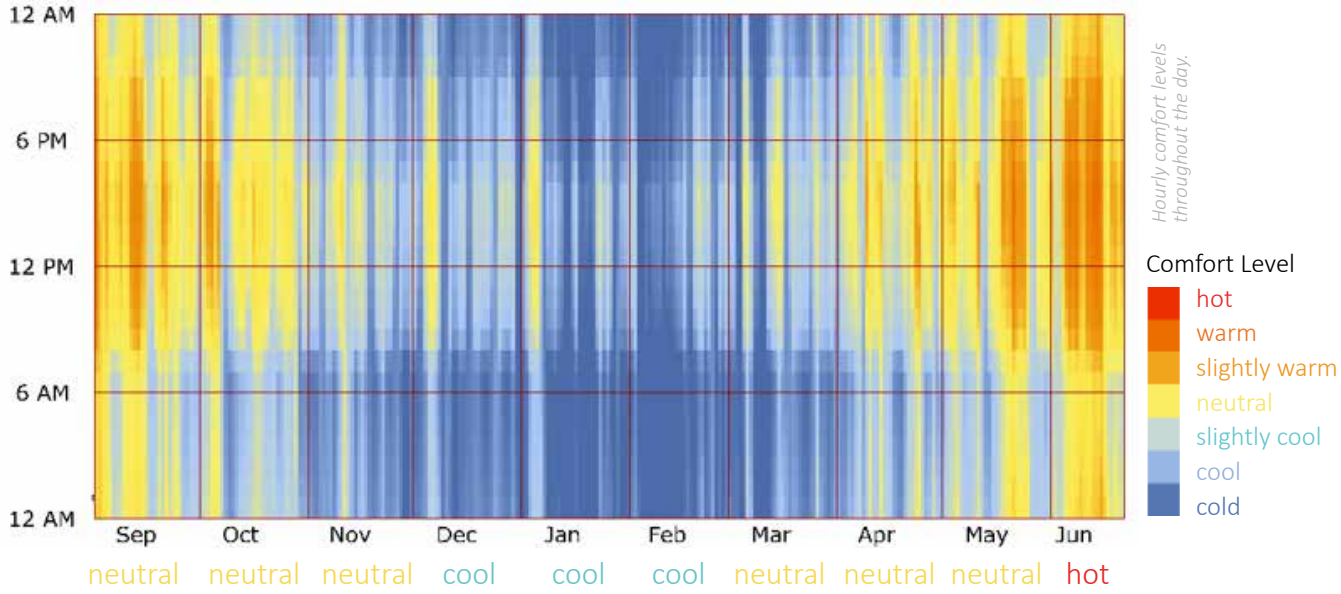


ASHRAE Thermal Sensation

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

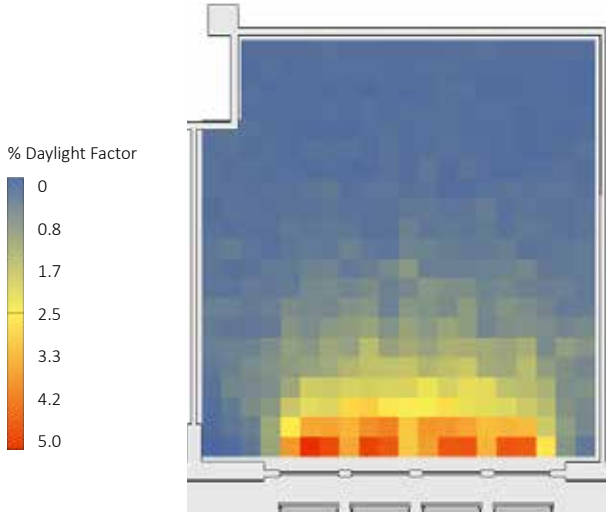
The percentage of the time occupants within the school are inside the comfort zone is **77.5%.**



Daylighting Performance

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 deeper into the space. Electric lighting is automatically dimmed when daylight is adequate.

Mean daylight factor = ***10.02 %***
The daylight factor for 100% of Area between 0 & 9 %
The daylight factor for 0.2% of the area is above 15%
0% of Area > 9 %



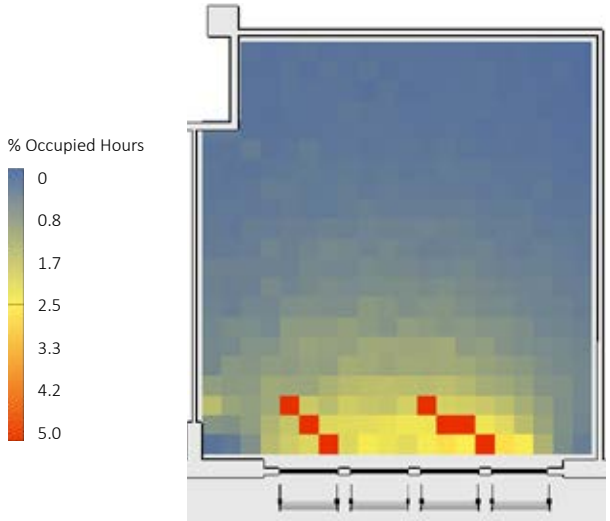
daylight on floor.

Daylight Autonomy Analysis

The mean spatial daylighting autonomy represents the percentage of floor area recieving 300 lux or above throughout the occupied hours annually. The percentage of the space meeting the daylight autonomy levels for 50% of the year is ***31%***.

Daylit Area (DA_{300lux}[50%])	*31% of floor Area*
Mean Daylight Factor	*0.7%*
Occupancy	*3650 hours/yr*

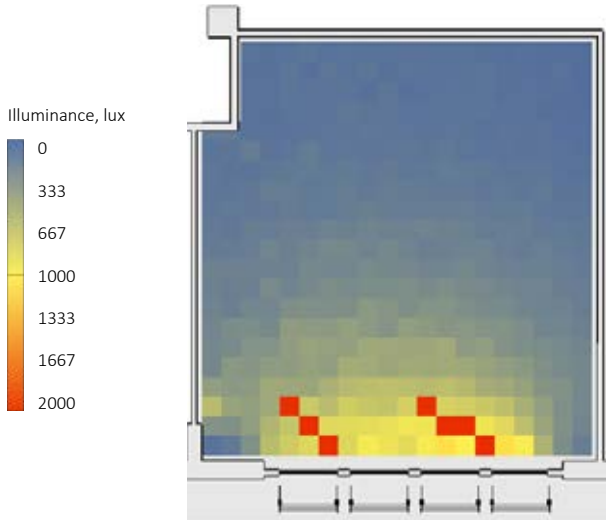
As an example, a point indicating semi-red color in the area means that at 83% of the whole occupied time, that point meet the criteria of having daylight factor of 300 lux or above.



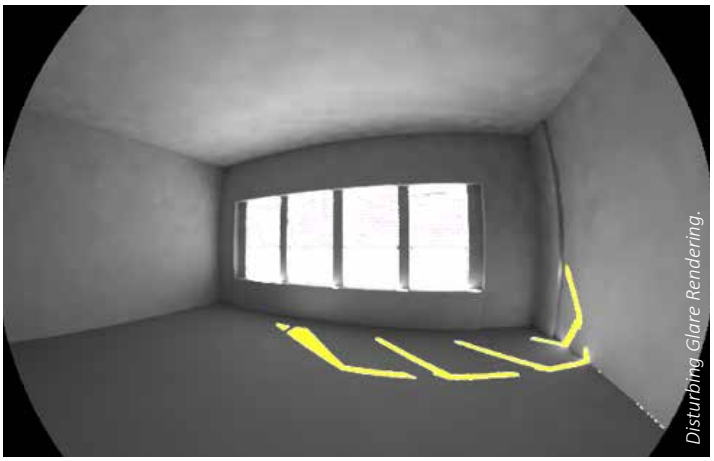
daylight analysis.

Illuminance Levels Analysis

Average Illuminance: ***559.25 lux*** (annual levels)



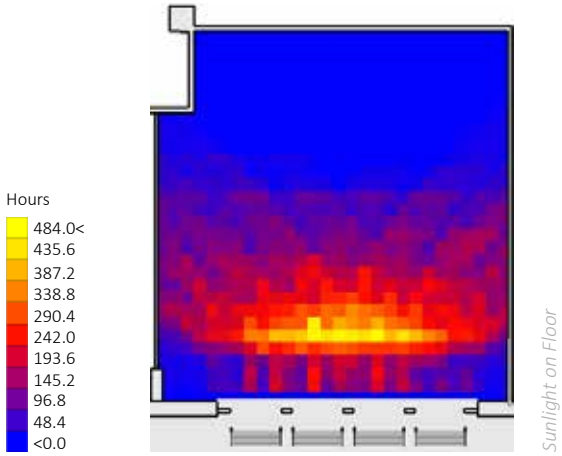
illuminance node analysis.



Disturbing Glare Rendering.

The daylight glare probability in this classroom is ***27%.***

False Color Rendering.



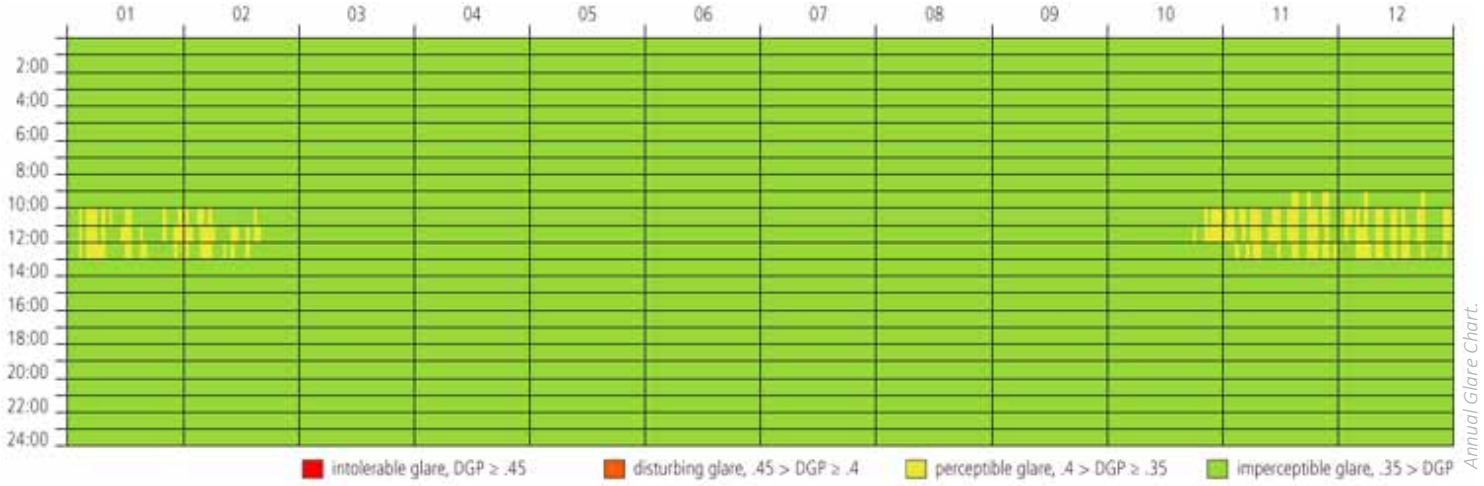
Sunlight on Floor

Annual Sunlight Exposure

A daylight glare probability of 27% indicates perceptible yet tolerable glare. 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

The chart below represents the result of an annual glare simulation in which the intolerable glare, disturbing glare, perceptible glare and imperceptible glare are shown with their relative color. Colors match with the false color rendering to the left.



Annual Glare Chart.

Incidents of perceptible glare found between 10AM to 1PM during January, Febrauary, November and December. The majority of the Winter months will recieve several hours of perceptible glare.

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December 2019

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