Middlebury Elementary Report For The Middlebury Selectboard

Middlebury Zero Energy School Team

May 3rd, 2018

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i. Project Summary

Figure 1. View of the main entrance and southern facade.

Mary Hogan is the sole public elementary school for the towns of Middlebury and East Middlebury, located in the Champlain Valley of Vermont. Nestled between public athletic fields and the highly-trafficked Route 7 commercial corridor, Mary Hogan currently educates 450 students in Kindergarten through 6th grade. The current building has been developed through a mix of additions and renovations, leaving it programmatically disjointed. While still functional, the building systems are sub-par, requiring high operating and maintenance costs. The noise of mechanical systems often disrupts educational activities, and many features will need to be repaired or replaced in the coming years. Instead of constantly pouring money into Mary Hogan, we propose the construction of a low-maintenance, adaptable Zero Energy elementary school that caters to the needs of students and community members. In order to foster a connection with the natural environment and reduce issues of traffic noise and congestion, the new project is located on the fields near the county's middle school, adjacent to a nature preserve, and only a mile away from the current site.

Our project aims to design a Zero Energy elementary school that complements the evolving educational and programming needs of the 21st century. The vision of the school is embedded in its name: Middlebury Elementary School. The school design serves to create a centralized learning hub (the "middle") modeled after the community of small-town Vermont (the "bury"). Designed to mirror the elements of a thriving town, the building is centered around a "Main Street" that connects central spaces and smaller learning environments. The school prioritizes flexible spaces to foster collaborative learning communities and interdisciplinary connections. Through visible Zero Energy design features and connections to the natural environment, the school strives to instill sustainability as an everyday learning ethos. By highlighting, not hiding, Zero Energy design strategies, Middlebury Elementary is intended to serve as a learning tool and an inspiration for school districts and communities around Vermont. The state's long, frigid winters lead to high energy expenditures, and contribute to skepticism about the potential of Zero Energy design in the state. Through experiential learning that engages students and community members in conversations about energy efficiency and renewable energy, Middlebury Elementary hopes to serve as a beacon for the town and surrounding New England communities.

Design Strategy

We are an interdisciplinary team with a diversity of backgrounds representative of Middlebury College's liberal arts approach to higher education. For this project, we used an integrated design process that drew upon the skills and unique experiences of each of our team members and focused on communicating with community members to design a school meant to fit the needs of Addison County.

Project Data

- Middlebury, VT, USA
- Climate Zone: 6A
- 71, 595 ft^2
- Two-story, 500 student capacity
- 21 classrooms + 4 labs
- 58.1 kBtu/ ft^2•yr Source Energy

Technical Specifications

- Wall Insulation = R-48 (effective value, adjusted for thermal bridging)
- Roof Insulation = R-75
- Slab Insulation = R-20
- Window Performance: mix of fixed and operable triple pane windows, SHGC = 0.21 - 0.35, U-Factor = 0.1099 - 0.1299 Btu/h•ft^2•°F
- HVAC specifications = GSHPs. Demand-controlled DOAS with HRVs to provide ventilation air
- Lighting Power Density = 0.38 W/ft^2 overall

ii. Team Information

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Team Lead and Project Manager

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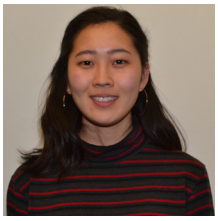

Karen Kobayashi
HARC '18.5
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Architecture

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Architecture & Interior Design

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ES/Psych '18
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Deliverables

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Deliverables

School Profile

Middlebury College is a small liberal arts college located in Middlebury, VT that draws its 2,600 students from all over the world. Middlebury has long been a pioneer in the pursuit of a more sustainable future. With the country's oldest undergraduate environmental studies program, Middlebury has been training students to solve pressing environmental issues for over fifty years. On-campus efforts act as a learning ground for students to better understand environmental challenges as they transition into the professional world. This commitment permeates through coursework across all disciplines at the College such as "Architecture and the Environment"and "Micro Housing: An Introduction to Architectural Design." Outside of the classroom, the Middlebury student body has been the driving force behind many of the College's environmental initiatives. Student proposals have, among other accomplishments, led to the completion of a combined heat and power biomass plant in 2009, an on-site photovoltaic array in 2012, Solar Decathlon entries in 2011 and 2013, and attainment of carbon neutrality in 2016. The spirit of these efforts remains alive today and has led to the formation of this team.

Industry Partners

This project would not have been possible without the expertise provided by experienced professionals who helped guide our work and ensure that our design is feasible. We want to thank them for donating their time to teach us about all these exciting topics related to designing a Zero Energy school.

Alpen High Performance Windows provided guidance in choosing windows and tuning glazing.

Tom Buzzell, principal of Mary Hogan, provided guidance on programmatic design and current operating costs.

Greg Sellers provided insight on the structural systems required to support our building.

Wayne Nelson and Derek Siegler provided guidance on choosing our HVAC system and how to create a system layout.

Jack Kerby-Miler '14.5 provided envelope design reviews.

Myron Selleck and Spencer Clark of Middlebury's Facilities provided electrical and HVAC design reviews.

Dennis Senesac provided guidance on selecting the GSHP equipment.

Solatube provided design guidance for using their product to daylight interior spaces.

Ashley Cadwell '80 is our consultant for sustainable school design that supports inquiry project-based intra-disciplinary curricula.

Andrea Kerz-Murray, Sam Ostrow, and Ashar Nelson provided architecture critiques and design reviews.

Larson Lovdal '15.5 provided design suggestions on the lighting, BMS, and air curtains.

Peter Schneider '97 provided design review and contacts with other industry experts.

Susan Davis provided landscape design consultation

Aubrey Gewehr assisted with the DOAS ventilation system design.

Liam Murphy reviewed the radon management plan.

iii. Project Highlights

The Vision

The design of Middlebury Elementary School is centered around the principle of **building sustainable learning communities.** Design decisions were shaped by a desire to strengthen communities of all sizes, incorporating spaces ranging from a large presentation space in the multipurpose room to group learning nooks. The design seeks to utilize sustainability not as a buzzword but as an ethos; fostering community sustainability and vibrancy, sustainability in materials and energy use, building durability, and spatial flexibility to ensure long-term adaptation to changing educational needs. Furthermore, the design is intended to excite students to come into school each day and undertake a new journey of discovery and learning.

Sustainable Building, Sustainable Learning Communities

"Middle Bury": By creating a microcosm of Middlebury's small-town environment, the layout of the school is intended to teach students how to live in a sustainable, rural community. Applying the language of Vermont's vernacular forms to the core of the school's design allows us to offer an innovative learning environment that remains comfortable and familiar. Small New England towns are typically organized around a town square surrounded by neighborhoods, both commercial and residential. We have mirrored this in our design with our own town square at the focal point of the building. As in many traditional town squares, the center of ours is built around a circle that offers a natural site for the convergence of students as they enter. The town square is open to the second floor and hosts color-coded tubes that cascade from above and report the relative energy consumption of each grade through color-changing LEDs. Interactive displays and activities about energy consumption and production are all located in this central space that also doubles as an amphitheater for small presentations. Located adjacent to the town center is the mechanical "Systems Heart," which holds most of the central heating and ventilation equipment and is clearly labeled and visible to occupants through large glass

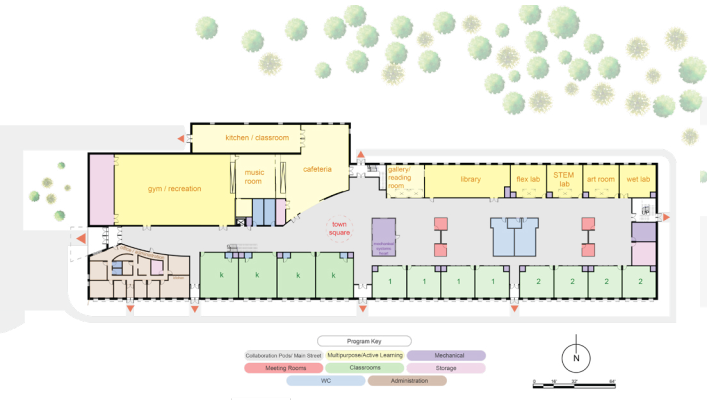


Figure 2. First Floor Plan. See Figure B in Section VI.

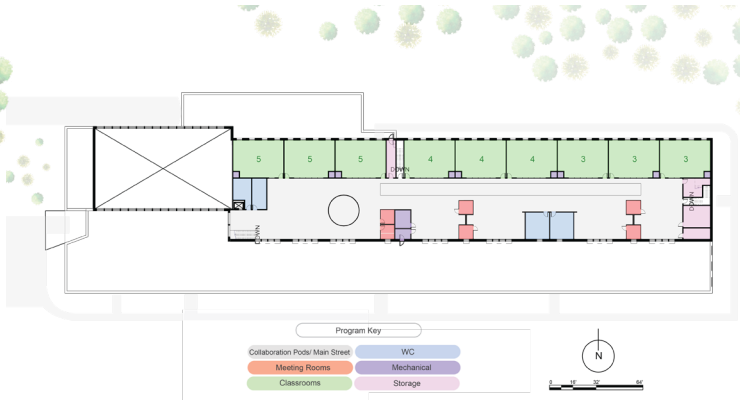


Figure 3. Second Floor Plan. See Figure C in Section VI .

windows to encourage inquiry and transparency.

Stemming from the town center along the building's East-West axis is "Main Street." This central hallway connects the community center (gym, dining room, kitchen), learning spaces, and administrative spaces. The first floor is visually connected to the second floor through glass floor panels that run down the center of Main Street through the education neighborhoods. Indoor plants, benches, and 28-inch Solatubes on the second story fill this space with natural light and give this hallway the feeling of an outdoor breezeway. The multipurpose cafeteria space opens up to both the teaching kitchen and the town center, making food a central aspect of students' learning and reducing stigma associated with school meals (nearly half of all students in the town receive free or reduced lunch).

Flexible Common Spaces: Branching out from the town center, the community center spaces are consolidated and separated (yet centrally accessible) from other major programmatic elements of the building, designed to maximize adaptability and multi-functionality of the space. By dividing programming spaces with soundproof but movable partitions, the design can accommodate a number of large community events while meeting the day-to-day demands of small class-size activities. This flexibility will enable the town to take advantage of the space for everything from Town Meeting to fundraising events.

Educational Neighborhoods: Our educational spaces feature enclosed, traditional classrooms that open up to larger collaboration spaces where students from multiple classes or grades can work together. We refer to each cluster of classrooms and their common spaces as a neighborhood, each with its own sink, restrooms, and small meeting rooms. Every educational

space has been fitted with multifunctional and movable furniture, allowing students and teachers to take ownership of their classrooms and shape their environment to meet their needs. Changing educational needs demand a flexible learning space, and our neighborhoods provide ample opportunity both for traditional and more innovative styles of collaborative learning. Shared spaces are designed to encourage information flow across classrooms and keep students engaged throughout the day.

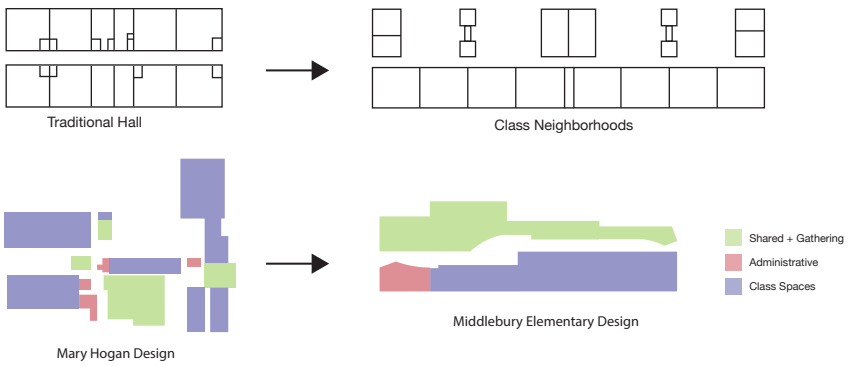


Figure 5. Design Vision for the First Floor. The proposed Zero Energy Middlebury Elementary takes the programmatic chaos and traditional double-loaded corridor of the existing Mary Hogan Elementary School and cohesively organizes it around class neighborhoods for each grade.

Our school is carefully organized to ensure that the practical needs of both students and teachers are met. Kindergarten classrooms are located closest to the main entrance to facilitate pick up and are equipped with their own bathrooms. Third, fourth, and fifth grade classrooms are on the second floor.

Specialty classrooms such as the art room, STEM, and Wet Lab open out onto Main Street with simple yet effective garage doors. These openings allow students to easily pass between a more traditional classroom setting to the collaborative learning spaces across the corridor, encouraging group work and more innovative learning techniques. Our team envisions that these large openings will facilitate exhibitions and science fairs, as well as encourage students to bring together multiple disciplines into their projects.

Students primarily access the second floor via a wide main staircase that utilizes hanging supports and transparent risers to minimize flow and lighting impacts on the first floor. As students climb to the second floor, they can turn around and see two large windows that showcase the school's photovoltaic array arranged on the roof of the building. Additional staircases are located on the North and East walls, allowing the upper grades to exit or access communal spaces without passing by other classrooms.

Daylight and Interior Design: In designing Middlebury Elementary, our team strove to take advantage of natural daylight and thoughtfully arrange windows to maximize occupant comfort. All classrooms on the first floor are south-facing and shallow so that the sun naturally illuminates much of the space without additional lighting. Each classroom features one row of windows at the eye level of the students, meeting building code standards as well as providing the children with a greater connection to the beautiful landscape outside. A second row of windows eight feet off the ground incorporates built-in light shelves that redirect daylight up to the sloped ceiling and toward the back of the room. For the older grades on the second floor, traditional classrooms are moved to the north side of the building as students are expected to spend increasingly more time in the collaborative learning environments along the south wall. Our team has

Figure 4. All classroom furniture is movable and the trapezoidal desks allow for many classroom arrangements. Commonality allows for easier replacement.

also taken steps to bring natural daylight into the central corridors of the school with tubular daylighting devices. These devices flood the collaboration spaces and Main Street with natural daylight.

Exterior: Our team designed the exterior of Middlebury Elementary to meet the expectations of a modern building while still blending into the unique Vermont landscape. To achieve this delicate balance, our team elected to use a corrugated CORTEN steel cladding reminiscent of the barns and grain silos that dot the surrounding countryside. Not only does our choice of corrugated steel age beautifully and contribute to our building's rustic aesthetic, it is also a durable

and cost-effective cladding solution.

In keeping with Middlebury's agricultural roots, we have included plans for an extensive educational farm to the south of the building that will allow students to reconnect with their agricultural heritage and learn about the systems that bring food to their table. Interaction with the outdoors is emphasized with carefully placed windows that showcase the spectacular fields and dense forest that surround our building. Easy access to the Jeffrey Murdock Nature Preserve and nearby trails serve to inspire students to protect Vermont's beautiful public lands and rugged wilderness.

Visible Engineering

Decentralized and Educational MEP: Every mechanical, electrical, and plumbing design decision was made to prioritize energy efficiency, visibility for the students, and occupant comfort. To best achieve these goals, our team took a decentralized approach to the water, heating, and ventilation systems. Not only do decentralized MEP systems lead to greater efficiency, they reduce construction costs by minimizing long duct and pipe runs. An added benefit of a decentralized system is that it allows for a new level of interaction and competition between students. Students in each neighborhood of our school will be able to monitor their energy usage on interactive screens in the town square. This will encourage friendly competition and help students develop sustainable energy habits. Energy usage can be monitored visually through the LED displays located around the town square, or through more detailed tracking on the energy monitoring system built into our school's electrical design.

Ground Source Heat Pumps (GSHPs): Our team determined that ground source heat pumps are the best long-term solution to provide heating and cooling for the school. GSHPs can operate very efficiently due to the stability of ground temperatures compared to outside air. While GSHP's require a larger up-front investment, they provide financial savings in the long term due to the demanding heating requirements of the Northeast. The building's planned occupancy during the summer (Mary Hogan currently operates at 50% capacity and we expect this to increase because of the air conditioning) will provide a cooling load to help limit thermal drift of the ground temperature over time.

Ventilation and Heat Recovery: We have designed a decentralized ventilation plan that minimizes ductwork and complexity while maximizing control and resiliency. Each classroom has its own dedicated outdoor air system with a heat recovery ventilator. These units use a CO_2 sensor to only provide as much outside air as the occupancy demands. The heat recovery component of these systems ensures that very little energy is required to bring outside air to ambient temperature before being recirculated. Central spaces are served by larger units, with air flow to each space controlled by adjustable dampers and CO_2 sensors.

Point Source Water Heating: Point source water heating systems will be used across the school to minimize energy waste. Water heating can represent as much as nine percent of energy use for the average building, particularly in Vermont where tap water temperatures are often as low as 42 degrees. Point source water heating has the unique advantage of creating hot water only when it is needed, avoiding the heat loss associated with transportation and long-term storage.

Photovoltaic Array: Used to offset the school's yearly electricity consumption, photovoltaic panels on the roof and above the parking lot will also serve as a visible reminder of our school's Zero Energy goal. The electricity production of the array will be closely monitored and accessible to all students and faculty via large windows on the second floor and informative screens located around the town square. Our school will also incorporate a ground-mounted rotate-able PV panel for curricular demonstrations on energy production.

Resilient Design

Structure: All materials used in our structural and envelope design were chosen to maximize the building's overall lifespan and energy efficiency. Whenever possible, our team used materials from responsible origins, eliminating the use of energy-intensive foam whenever possible and maximizing the use of products made from natural materials such as rock wool. Many of our design decisions were informed by our team's dedication to innovative and collaborative learning strategies. Not only should our school serve multiple learning strategies, it should be adaptable to whatever the future may bring. Middlebury's current elementary school faces significant challenges with fluctuating class and grade sizes. Our team has planned a flexible and dynamic building that can easily adapt to changing pedagogies and enrollment needs. While designed for the 400 students currently enrolled in kindergarten through fifth grade at the existing school, our proposed school could easily accommodate 500 students without any changes. The simple and intuitive nature of the design also allows for more classrooms to be added in the design stage with minimal changes.

Design Process: Our final school design is a product of our team's drive to incorporate diverse perspectives in our design process. Our team has sought out the opinions of students, educators, community members, and professionals. Many facets of our design are a direct result of needs and desires expressed by the faculty and staff of the current Middlebury elementary school.

II. Design Constraints Description

i. Location

Middlebury is the shire town of Addison County, located in Vermont's Champlain Valley. The town is located in ASHRAE Climate Zone 6A, with long, cold winters and short, warm summers. The average January temperature is 21° F, while the average July temperature is 71° F. The town experiences 7,340 heating degree days and 555 cooling degree days.

The proposed elementary school is located directly south of Middlebury Union Middle School (MUMS), a 250-person public school serving all of Addison County. We propose building on land owned by the school district that comprises a baseball diamond south of the middle school as well as empty fields to the southeast. This 11.4-acre lot is oriented on an east-west axis with a southern extension on its eastern section. It is bordered to the west by a narrow empty lot, adjacent to South Ridge Drive. The entire eastern half is horseshoed by forested land, while the empty field located to the south could easily accommodate a replacement baseball diamond.

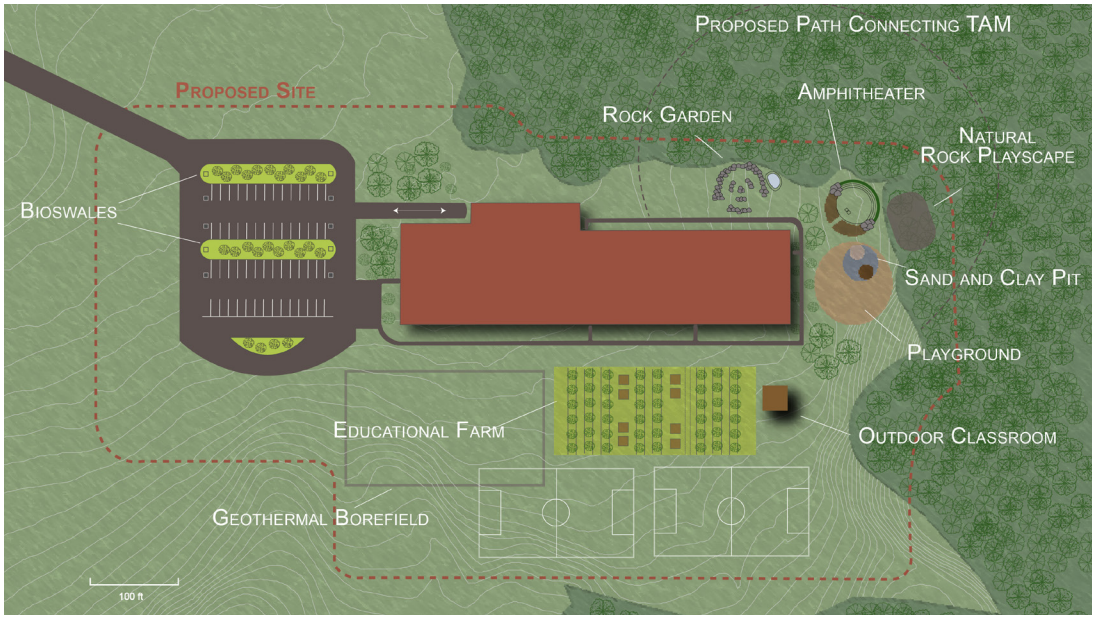


Figure 6. Plans for the 11.4-acre site. Minimal site work will be needed, although playing fields will need to be relocated and the access road installed. See Figure A for more details.

The proposed building would be located on the easternmost section of the lot. A small unpaved road and parking lot currently allow for access from the northwestern corner, offering a possibility to extend an access road eastward from the main road. Directly north of the proposed school building lies the Jeffery Murdock Nature Preserve, a patch of forested land preserved by the Middlebury Area Land Trust (MALT). The Trail Around Middlebury (TAM), an 18-mile trail encircling the town, runs through the nature preserve, approximately 150 feet from the proposed site. Middle school students currently utilize the nature preserve for recreation and curricular activities, and we plan to take further advantage of the preserve and its experiential learning possibilities

ii. Occupants

Mary Hogan Elementary School currently enrolls approximately 450 students in pre-Kindergarten through sixth grade. 65 students per grade are currently split into four classrooms in grades kindergarten through second and three classrooms in grades three through six. In addition to teachers, Mary Hogan employs a wide variety of physical therapists, occupational therapists, and special education teachers. This allows the school to provide a quality education to students of all abilities and backgrounds, including to many students who require one-on-one instruction.

Mary Hogan Elementary School draws students from a diverse set of economic backgrounds. In recent years, Mary Hogan has experienced a sharp increase in students eligible for free or reduced lunch, and consequently nearly half of all students participate in the program today. The school serves as a vital source of nutrition for many students, serving breakfast and 250 to 300 lunches each day.

The school district has recently debated moving all sixth graders in Addison County to Middlebury Union Middle School (MUMS) in order to more effectively implement the International Baccalaureate program. MUMS was originally designed to have more than twice as many students as its current enrollment and could easily accommodate the influx of sixth graders. The construction of a new school provides the perfect opportunity for grade reorganization, and the shared lot makes the transition even simpler. Our proposed building is designed to accommodate 400 students at current

class sizes, with room for 500 students should enrollment increase. This is increasingly likely as dwindling school-age populations in neighboring towns are forcing local elementary schools to close. In the near future, we expect many of these town elementary schools to consolidate into one Addison County Elementary School. This would be easily accomplished with the proposed design. Additionally, there is space for the approximately 50 faculty and staff members to accommodate all teachers and support staff. If expected enrollment is greater than 500 due to consolidation, one additional classroom per grade can easily be included.

iii. Programs and Standards

One of the key design goals is to ensure that the school fits with the needs and aspirations of the Middlebury community. To help accomplish this continuity, the design attempted to fulfill the general and educational goals laid out in the Middlebury 2017 Draft Town Plan. The Strategic Foundational Goals of the Addison Central Supervisory Union's 2015-2020 Strategic Plan were considered in the educational design of the school. The building was designed to strictly adhere to all local and state requirements, including the minimum size requirements laid out in the Vermont School Construction Planning Guide. The Vermont State Fire Code, based off of the NFPA 101 and IBC standards, was meticulously considered from the beginning of the design process to ensure safety without compromising the school's design vision.

iv. Neighborhood and Community Setting

The site is located near the central commercial corridor of Middlebury in a medium density residential zone. Situated between the highly-trafficked Route 7 and Otter Creek, which separates the town of Middlebury from the college that bears its name, the surrounding neighborhood includes many key community facilities while maintaining a high proportion of natural space compared to other parts of the town. The site exhibits a unique combination of undeveloped land and proximity to downtown Middlebury. Small New England farmhouse-style homes are located across the street from the site, with the rest of the site surrounded by a densely forested backdrop. The site is located approximately one mile south of the current Mary Hogan Elementary School and one-half mile east of the town's recreation center.

Figure 7. Proposed site of Middlebury Elementary in the context of the town.

Like much of Vermont, the 8,500-person town of Middlebury has a long history tied to its agricultural roots and rural setting. Due to Middlebury's rural nature, automotive travel remains the primary form of transportation to all parts of the town, including the current middle school site. The site is currently served by the Addison County Transit Resources (ACTR) bus, which provides easy and reliable access across the town. Furthermore, with the new school located adjacent to the existing middle school, the town's school bus network would be streamlined and parents with children at both schools would benefit from a more convenient pickup and drop off process.

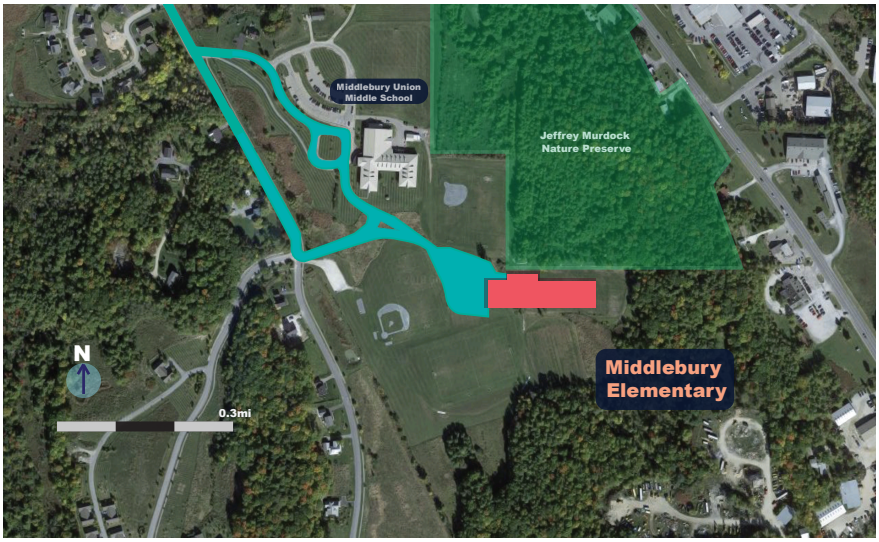
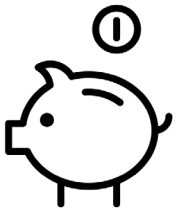


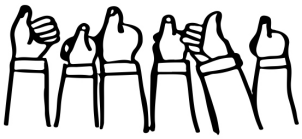
Figure 8. The proposed Middlebury Elementary is adjacent to the existing Middlebury Union Middle School.

The site's proximity to the Trail Around Middlebury provides easy walking access from multiple directions. A sidewalk extends to the site along the entirety of Middle Road North and continues to all sections of town along Route 7. While located only a mile from the current elementary school, the proposed site is slightly less centrally located, which initially raised walkability concerns. A 2013 study of Mary Hogan's walkability, however, found that parents' three top reasons for not having their children walk to school were amount of traffic, speed of traffic, and safety of intersections. It thus appears that the existing elementary school's location along the heavily-trafficked Route 7 actually discourages walking due to traffic and safety concerns. The minimal thru-traffic and extensive sidewalk network of the proposed site directly addresses the main walkability concerns of the new site. Furthermore, Vermont's Safe Routes to School Program is active in the Middlebury area, encouraging walking and biking to school and works to improve pedestrian accessibility to school sites.

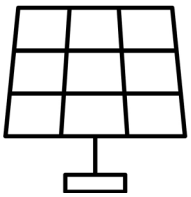
III. Middlebury Elementary Design Goals: Building Sustainable Learning Communities



Design a Zero Energy school that prioritizes efficiency and affordability.
Throughout the design process, our team regarded the goal of Zero Energy as a guiding principle, not just a requirement to be met. By incorporating cost-effective, efficient practices into each design decision, we aim to create a building that demonstrates the economic feasibility of Zero Energy design even in the coldest parts of the United States.



Promote an experiential and collaborative learning environment through shared and fluid learning spaces.
Our design aims to break down many of the educational barriers found in traditional elementary schools, while maintaining the importance of classroom spaces in a modern education. By designing around "neighborhoods" for each grade level, we seek to encourage student collaboration and maximize the use of space through flexible learning areas.



Inspire curiosity-driven learning through visible Zero Energy design features and connections to the natural environment.
By highlighting—not hiding—the inner workings of energy-efficient design features, we aim to provide students with an exciting building that serves as both an inspiration and a powerful educational tool. We see a Zero Energy school not just as a building that houses a learning environment, but as a learning environment at its very core.

Incorporate the character and needs of the surrounding community in order to create a vibrant hub for the town of Middlebury.
Our work is guided by the understanding that elementary schools are community centerpieces in small-town Vermont, and decisions about their design have profound effects on students and community members. Throughout our design process, we have striven to maintain continuity with the surrounding landscape while incorporating the specific needs expressed by the Middlebury community.

Ensure long-term success by incorporating adaptability, durability, and accessibility into every aspect of the school design.
Elementary schools must serve as a community and educational hub for many decades while adapting to the changing pedagogical needs of the 21st century. In order to ensure the school's continued success, we aim to maximize both the durability and reparability of the building's materials and mechanical systems while maintaining opportunities for future expansion. Through flexible learning spaces, accessible features, and minimal interior structural components, we strive for a school that adapts to the needs of individuals of all learning and physical abilities.

IV. Evaluation Parameters Narrative

i. Architectural Design

In order to maximize daylight and minimize energy loss, the building design is structured along a long east-west axis with few corners. The school is also designed to fit in with the surrounding forest and take advantage of fertile agricultural space to its south. The school's orientation also seeks to minimize the amount of site work required in order to limit negative environmental disruption. To address safety concerns, visitors must enter the school through the main entrance. The interior vestibule doors of the main entrance are locked outside of arrival and dismissal, forcing all visitors to check in at the front desk before being allowed access to the school through another door. All other exterior doors require keycard access which is only provided to faculty and staff. Once inside the building, faculty and staff have easy access to the lounge and offices and students can reach the nurse's office without having to navigate other administrative spaces.

Situated at the heart of the building, the town center provides a central gathering space for eager learners and ready educators. It serves as both an exciting and informative space where students can playfully interact with energy monitoring displays and learn about the Zero Energy design features within their school. Its proximity to the main entrance, multipurpose room, main staircase, and the education neighborhoods make it a meeting point and visual centerpiece for users of the school. The town center serves to aid with movement through the space, either towards the "neighborhoods" and learning spaces or towards the more active shared spaces. Exits are designed to both meet code and divide programmatic spaces, enabling access to the outdoors with minimal learning disruption. The building's northern and eastern facades border a mixed-wood forest of the to offer outdoor education opportunities just steps away from the classrooms.

Landscape Design

Our landscape outdoor elements are designed to express the natural geology and history of the local region and promote learning and engagement with the physical environment. Our design maximizes student's engagement with the natural world, extending classroom spaces to the outdoors while incorporating the physical features of our site to create low cost, low maintenance, and natural outdoor learning spaces.

Our site soil profile is predominantly composed of Vergennes Clay, so sand and clay pits have been integrated into the playground to allow children to explore the properties of the soils and the differences between them in a hands-on playful environment. The playground is covered with recycled wood chips, which provide a permeable, biodegradable, and easily replaceable flexible surface material for children to play on. The recently installed playground equipment at Mary Hogan Elementary has been used extensively by the current elementary school students and will be transferred to our playground, reducing cost and wasted materials.

The rock garden and amphitheater will utilize rocks that will be dug up during leveling and construction and from the nearby rocky outcropping in the forest. We have taken advantage of the natural rocky outcropping and created a natural playscape for climbing and exploration, close to the playground and amphitheater.

Parking is provided for up to 60 cars with 24' wide roads to provide double lane movement and backing. We have limited the parking spots to 60 to encourage carpooling and communal transportation use. To mitigate heat island effects, the parking lot is designed with bioswales, permeable paving and heavily planted with extensive natural vegetation. The roads are made up of recycled crushed pavement to ensure permeability.

The educational farm is situated on the south side of the building to maximize solar exposure and provide a space for students to learn about agriculture. The outdoor pavilion, is a lightweight wooden structure that provides shade and cover while working at the farm. It provides a communal gathering space for outdoor group projects.

ii. Interior Design, Lighting, Plug Loads, and Appliances

Our design includes many eddies which gives occupants the opportunity for casual interaction. Through liberal use of built-ins we have designed many levels into the school, allowing students of all ages to interact on the same plane or be above it all for a different perspective. The reading room/gallery is one of the spaces that will allow for building occupants to use the spaces as best fits their needs. The space is designed to provide quiet reading space for students if the collaboration spaces are too noisy. It can be used to showcase student work on particular projects.

Plug Loads and Lighting

Every educational and administrative space will utilize a smart, dimmable switch that controls both the lighting and outlets of the room. Our team has chosen the Insteon 6 button dimmer smart keypad due to its reliability, cost effectiveness, and programmability. Insteon switches offer several advantages over traditional light switches. First and foremost, the Insteon system allows for scheduled and occupancy-controlled lighting. Each individual switch can be programmed to shut down all lights and outlets at scheduled times, for example after classes conclude or even during scheduled breaks. In addition, each switch placed in a classroom will be paired with a motion activated occupancy sensor. The Insteon system is very programmable; teachers would be able to tweak their own schedules for their individual electrical systems and change the motion criteria that leads to lights being shut off. The choice of six buttons allows the users to choose between only adjusting the lighting and also shutting down the outlets. One switch will activate all the lights and outlets in the space. The next two switches will operate the light dimmer and outlets separately. The bottom two switches will set specific lighting schemes, and the last switch will shut down all lights and outlets.

Figure 9. Insteon six button switch.

Our chosen switching system is extremely robust, operating over a hardwired and RF dual band network. In contrast to a simple router system, each switch in the Insteon mesh network acts as a repeater, ensuring that as the system grows, the signals are still communicated to the farthest parts of the network. Unlike other Wi-Fi reliant systems, the Insteon switches communicate effectively instantaneously and can operate without an internet connection ensuring reliability around the clock.

Using smart switches and occupancy sensors will result in significantly less energy usage over time. The Insteon system has an easy to use interface that allows for labeled switches and energy monitoring. Each classroom can be individually monitored for its energy usage, and at the end of the day the interface allows for all non-essential electrical systems to be easily shut off from a central control panel. Less commonly used spaces such as bathroom or utility closets will use a Lutron Maestro Sensor Switch to reduce the total number of smart switches needed.

Light Fixtures

Middlebury Elementary uses a 100% LED lighting strategy. All luminaires are DLC premium listed. Illuminance levels in each space are designed to meet the ASHRAE Zero Energy Design Guide (ZEDG) targets. Fixtures were chosen to meet and exceed these values while keeping lighting power density below the ZEDG recommended levels. Except where otherwise noted, all luminaires are suspended from the ceiling 8' above the floor. In classrooms, 80/20 indirect/direct linear fixtures are specified to minimize glare but still provide some downlighting. Meeting rooms, lobbies, corridors, and other small to medium-sized spaces use 2' x 2' suspended flat panel lights.

Figure 10. Suspended Flat Panel Luminaire. These fixtures provide a large amount of luminance with low energy consumption.

Kitchen

At Middlebury Elementary, food nourishes students' bodies while providing opportunities to learn about Vermont's rich agricultural heritage. Food preparation at Middlebury Elementary is not seen as food "service": the kitchen is not a passive space for ensuring meal requirements are met, but is rather a dynamic classroom that strives to involve students, faculty, and staff in nourishing the community.

The school's food program takes advantage of the building's location directly adjacent to Middlebury Union Middle School. With a full kitchen designed for a student body far larger than its current enrollment, MUMS has the potential to provide valuable partnership and support to Middlebury Elementary's breakfast and lunch programs. In order to minimize energy waste from heating duplicate appliances in neighboring buildings, all hot food preparation at Middlebury Elementary will occur at MUMS' existing facility. This arrangement opens up the possibility for Middlebury Elementary's kitchen space to double as an interactive learning space for food preparation and preservation. The kitchen will contain preparation tables, refrigeration space, warming ovens, and small appliances, all of which can be used as both learning tools and supplements to MUMS' facilities. In combination with the school garden and MUMS, the space is able to provide complete, locally-sourced meals while teaching cooking skills and farm-to-table principles.

iii. Energy Analysis

Energy Model

Every design decision included in Middlebury Elementary has undergone extensive energy analysis and we have come to a final design in which energy efficiency is optimized without sacrificing comfort and the fun learning environment we envision for the school.

We started the design process by determining the optimal orientation and massing of the school. As a result, we prioritized a building with a long east-west axis to promote daylighting and rooftop photovoltaic panel energy production. The long, shallow form allows daylight to penetrate deep into the space, especially in the classrooms, reducing the lighting loads for the entire building. We also chose a very simple building shape with minimal corners and tried to minimize our surface area to volume ratio. In doing so, we limit the opportunities for heat loss from the envelope, especially in corners,which are difficult to insulate. We thus reduce the yearly heating and cooling loads, saving energy.

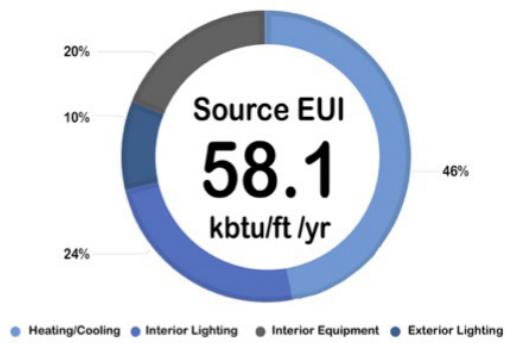


Figure 11. Site Energy EUI Breakdown per year.

Renewable Energy

With an EUI of 18.46 kBtu/ft^2, powering our building with a roof-mounted array becomes a possibility. In order to ensure the building meets the Zero Energy goal over time, we have accounted for the manufacturer-specified 10% decline in output over 25 years and any uncertainties in our energy model by sizing the PV array to produce 24.5 kBtu/ft^2. We thus expect to produce 514,069 kWh per year. This excess production will be used to offset the energy consumption at other Addison County Schools and help minimize the cost of operating the building.

To produce 24.5 kBtu/ft^2 of electricity, we will need a PV array that consists of 1,244 Panasonic HIT N330 photovoltaic panels with a total peak capacity of 410.5 kW. This panel was chosen for its longevity, high efficiency (19.7%), and snow drainage capabilities, making it perfect for a high latitude location with limited roof space. Each panel is rated for 330 Watts under standard conditions.

Factor	Value	Remarks
Temperature Coefficient	-0.258%/°C	
Average Daytime Ambient Temp.	12.9°C	
Temperature Derate Value	0.9358	Temperature Coefficient*(ambient + 30°C heat output from panels)
Soiling	0.98	
Shading	0.99	
Snow	98	
Mismatch (imperfections)	0.98	
Wiring	0.99	
Connections	0.995	
Degradation	0.9974	
Nameplate	0.99	
Availability of Power Grid	0.98	
General Derate Value	0.8882	Soiling*Shading*Snow*Mismatch*Wiring*Connections*Degradation*Namplate*Availability
Inverter Efficiency	0.96	Based on manufacturer specifications for 50 kW Solectria Renewables Grid-Tied Inverters
kWh/year Consumption	514,069	EUI*Square Footage
KWh/day Consumption	1408.41	
Average Peak Sun Hours/day	4.3	At 29° mounting angle (44° latitude - 15° for peak summer production and closer spacing)
Total PV Needed (kW):	410.4834	kWh/day ÷ peak sun hours/day ÷ temp derate ÷general derate ÷ inverter efficiency
Total HIT 330W Panels Needed	**1244**	PV kW/330W

Table 1. Calculations and factors used to determine the size of the PV array.

Of the 51,425 ft^2 of roof space on the building, approximately 46,000 ft^2 is usable when the shading from the parapets, shading from the building, and area required for the Solatubes is removed. Based on a two-hour solar window on December 21st (azimuth: 167.46, altitude: 21.61), there should be 6.23 ft. between each row. Including the panel, we thus need 45.14 ft^2 per panel. At this space requirement, we can fit 1,019 panels on the roof. Even though we have moved back our first row from the southern parapet, it may receive a fraction of winter shading, but the conservative sizing, and summer orientation (-15 degrees) makes the impact of this negligible. The final 225 panels required to meet our 1,244 total will be located on a canopy over the parking lot. The parking canopy will mimic the 29° pitch of the roof panels, and would be even more efficient because of lower operating temperatures due to the ventilation of an open air installation. The

Figure 12. Panasonic HIT N330 photovoltaic module.

Figure 13. Our specified 50kW inverter.

array will likely use nine 50 kW Solectria Renewables Grid-Tied Inverters. These inverters operate at 96-96.5% efficiency and are relatively affordable.

If the parking canopy PV is not desired, the 1,019 panels on the roof can provided exactly the amount of electricity required each year but there would be no margin of error or degradation. It would thus be ideal to find some additional area to install a small number of additional panels.

In terms of the feasibility of installing this array, the State of Vermont has a 500 kW cap on net-metered photovoltaic arrays. Our array is under that cap so we can develop the array through a Power Purchase Agreement with a permitting process similar to a net-metered array on the top of a house. We have chosen to have a third party finance and install the array using a Power Purchase Agreement because the upfront cost of this array would likely be around $1.03 Million dollars. This assumes a $2/Watt cost for PV and uses a quote of $22,000 per inverter. While this purchase will pay for itself over time, it will likely be more palatable to town voters for electricity to be a fixed cost paid out over the lifetime of the agreement rather than as a large upfront cost.

iv. Constructability

Constructability is perhaps the most important component of any architectural design. Our team of architects worked closely with both the mechanical electrical and plumbing team and engineering advisors who have experience in elementary school construction. The result is a school that is both beautiful and practical. Our floor plan designates spaces for necessary, decentralized mechanical systems and our envelope uses a steel support system that will help create a sturdy, 100-year building.

Design

Our most effective measure to prevent common problems in construction is simplicity in our design. By taking the "perfect wall" approach to our wall, slab and roof, we clearly and explicitly accounted for each control layer, and minimized the number of steps needed to apply each layer. For example, our continuous, fluid applied water, air and vapor barrier will be applied directly to our sheathing, covering our entire building in one simple application, while easily reaching areas that might otherwise be difficult to seal with a more traditional water and air control layer approach. We gave careful detail of each transition from wall to slab and wall to roof to ensure that the control layers are continuous. We plan to use sealant to ensure continuity of the water and air control layers. We incorporate a thermal break between our concrete slab and metal stud wall to combat the dangers of thermal bridging with a predominantly steel structure. Having two layers of insulation on either side of our vapor control layer presents the possibility of a condensation problem, however, our emphasis on exterior insulation will keep the dew point on the exterior of our structure through the year.

In our slab specifically, we will prevent issues of capillary action by providing many capillary breaks from the conditioning of the ground under our slab, draining bulk water away from the base of our building and installing a vapor barrier directly to our concrete, above the thermal insulation. While we accept that concrete is prone to irregularities, we expect that our multiple methods of protecting our slab will prevent common issues of frost damage, capillary movement of water and thermal bridging with the steel structure.

Our building design takes inspiration from several previous projects, and therefore uses many well-established practices. That said, some of our material choices push the current established practices of building science and are therefore relatively obscure. One example is our extensive use of mineral wool insulation instead of rigid foams on the exterior of our structure, a practice that has only recently become more common. However, with the growing popularity of this strategy, we expect resources for adapting installation techniques to improve in the coming years. Under-slab insulation is becoming a common practice in the US, and here we chose to specify XPS instead of mineral wool because mineral has not seen much use in this application.

For the construction of our wall, the use of a steel stud wall, with interior and exterior gypsum sheathing and loose fill cellulose inside the stud cavity is standard practice. The fluid applied R-guard water, air and vapor control layer is a product of Rutland, Vermont, so we expect local contractors to be familiar with the product. Exterior insulation is a little less common, particularly the use of the Armatherm Z-Girts, but we will build a mock-up of our wall construction on-site to train the contractors in the proper installation procedure. Full details on this construction can be found in Figure F.

Codes

Our team strove to design a school that exceeded safety requirements while still conforming to zero energy design goals. Early on in our design phase, our team contacted the building code inspector that would evaluate our school

should it be built. Communication with him ensures that our building exceeds the code requirements needed for a safe and accessible building. We have carefully read and applied the Vermont State Fire Code additions to NFPA 101, the International Building Code, and access codes to our design and building construction. Our final product is a building that rivals commercial skyscrapers in terms of fire safe construction. As a Type I Class B rated structure, our school would be built to withstand both major environmental events as well as interior room and contents fires. Not only will our school meet the stringent construction requirements that come with Type I building construction; our floor plan ensures rapid egress in case of emergency both through wide and centrally located exit corridors and appropriately installed ground floor windows. Our architecture team thoughtfully placed exits and egress routes throughout the building to exceed fire code regulations for evacuation while minimizing the total number of openings in the building envelope. Our final design features 8 ground level exits and 3 carefully placed stairwells to maximize the speed with which occupants can exit in case of emergency. Any point within the building is within 200 feet of at least two exits as allowed with our schools supervised automatic sprinkler system. 96% of the school is within 150 feet of at least one exit. Any room with the potential to hold more than 30 students has at least two remotely located exits. Centralized exit corridors exceed width requirements (6 feet or over), and the building has no dead-end corridors that could confuse evacuation. All stairways are designed to meet egress requirements with a minimum 44-inch width and landings twice the length of door intrusion. Stairways as well as all assembly occupancies of the building are equipped with fire rated doors and appropriately rated fire-resistant construction. Lastly, all doors along egress routes are equipped with panic hardware and swing outward towards the point of egress.

Our school will integrate a comprehensive supervised automatic sprinkler system to ensure the safety of its occupants. This addition is required for a two-story educational occupancy and allows for the maximum egress route to be increased to 200 feet from 150 feet. Furthermore, the entire complex will be equipped with a voice annunciator fire alarm system to facilitate evacuation for young children. A central fire alarm panel will be located immediately to the right of the main entrance for fire personnel, and annunciator panels will be located at the north and south pod exits as well as the rear east exit. Every room in the school will be equipped with a combination smoke and carbon monoxide sensor, labeled so that fire personnel can rapidly locate the source of an alarm. The entire school will be equipped with emergency lighting on a unique circuit that uses an emergency battery in the event of power loss. The fire alarm and sprinkler activation systems will use a separate circuit with emergency power as well.

v. Financial Analysis

Construction Costs

According to our construction cost analysis, we estimate the total construction costs of our elementary school to be $17,823,089. With the inclusion of costs for general requirements (e.g. contractor, architectural, engineering, and other design fees), the entire project is expected to cost a total of $23,399,334. As the figure above illustrates, the construction of the shell accounts for the most significant portion (57% = $10,163,973) of our construction costs. This is largely due to our use of a ballasted EPDM membrane on the building's roof. The EPDM and ballast cost is substantial, but if we had chosen another roofing material we would have had to spend a fair amount of money on the roof material and spend more money on the racking system for the PV array. While the PV is financed through a PPA, the cheaper racking system will result in a lower cost for the developer, meaning we will pay less per kWh of electricity.

With a square footage of 71,595 ft^2, our estimates indicate that our school's construction would cost around $249 per square foot. According to the 20th Annual School Construction Report, the median cost per square foot of elementary schools in VT was $400.36 in 2014. Adjusting for cost escalation of 5.3% over the last four years, the median cost per square foot

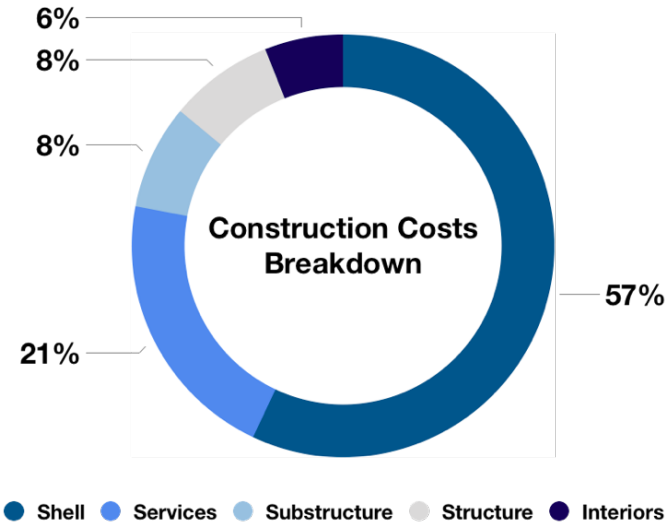


Figure 14. Construction Cost Breakdown by building component. Total Construction cost of $17,823,089 with a full project cost of $23,526,477.

of elementary schools in VT is $421.58 in 2018. This would mean that the cost per square foot of our school is only 59% of that of the median elementary school in the state of Vermont. We are thus meeting our affordability design goal that is crucial to making this project a reality.

We believe that our design is substantially cheaper than the average for many reasons. Wherever possible we have specified common building materials that are both durable and affordable. Another factor that proved crucial to achieve the cost-effectiveness of our design was our use of an integrated design process. We made it a priority to ensure that all the different teams were in constant communication and collaborated efficiently throughout the project. As a result, no systems were oversized and every decision was weighed against how it affected other parts of the process and the overarching design goals.

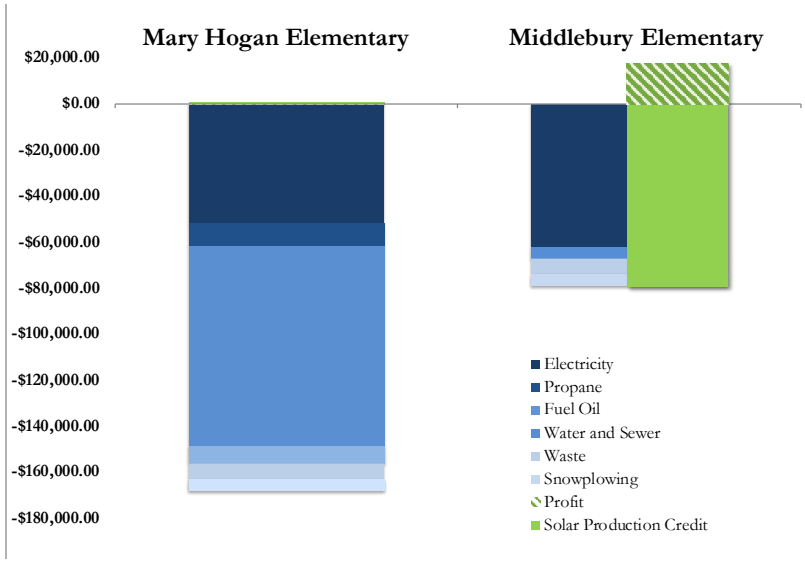


Figure 15. Operating Cost comparison of proposed school and the existing school.

Maintenance and Operations

Middlebury Elementary will not use any propane or fuel oil for heating or appliances, so even with energy efficiency upgrades the electricity usage of Middlebury Elementary is slightly higher than that of the current school (as seen in Table 2). This increase is minor compared to the decrease in costs that stem from eliminating propane and fuel oil usage. It must also be noted that the energy costs for the conventional school were calculated using $0.155/kWh (the cost for electricity on Green Mountain Power's (the local utility) Rate 6 for small-scale commercial buildings), while the energy costs for our school were calculated using $0.14/kWh. We are assuming this $0.14/kWh because this is the expected price paid for electricity bought through a PPA that we will use to finance the PV system used to get the building to Zero Energy. Broadly, a PPA refers to a power-purchasing agreement, a situation in which a developer pays for the installation of PV energy system and is payed back for this installation by the user (our school) over a period of time (usually 10-25 years). In such an arrangement, the user pays less for energy than the utility charges, in this case $0.14/kWh or less.

	Yearly Cost		Savings	
Category	Existing Elementary School	Zero Energy Middlebury Elementary	Yearly	Percentage
Electricity	$52,000.00	$70,369.28	-$18,369.28	-35.33%
Propane	$9,900.00	$0.00	$9,900.00	100.00%
Fuel Oil	$87,000.00	$0.00	$87,000.00	100.00%
Water and Sewer	$7,400.00	$4,933.33	$2,466.67	33.33%
Waste	$6,600.00	$6,600.00	$0.00	0.00%
Snowplowing	$5,000.00	$5,000.00	$0.00	0.00%
Facilities (salaries included)	$700,000.00	$700,000.00	$0.00	0.00%
Total	$867,900.00	$786,902.61	$80,997.39	9.33%

Table 2. Operating Cost Comparison.

As for water consumption, the current school's toilets and sinks date back to the 1960s. We conservatively estimate saving 33% on the building's water bill due to the use of new low-flow fixtures in our school. Most systems will require monthly filter changes that the existing staff can easily perform before or after the school day, limiting maintenance cost. We have thus assumed that all other categories (waste, snowplowing, facilities) will not change with the new school.

vi. Envelope Performance and Durability

Guiding Principles

Our envelope design balances several considerations in its arrangement and choice of materials. First and foremost, our school must strictly adhere to basic building science principles in order to achieve our goal of Zero Energy. Whenever possible, we chose the simplest solution to envelope challenges to facilitate construction and ensure long term reliability. We aim to create a durable "100-year" structure by choosing materials that last and construction plans that allow for passive protection of materials. Safety is also a driving concern in school design; all of our materials meet or exceed fire code regulations for a Type I Class B educational occupancy, and any material posing potential health hazards was avoided

altogether. Lastly, we took into account our building's impact on the greater environment and prioritized recycled and recyclable materials accordingly.

Water Control

Effective drainage is the single most effective way to reduce the risk of water damage to the inside of an assembly, as it moves the majority of water away from the building instead of allowing it to penetrate and damage assembly parts. Our drainage design begins at the roof in the form of scuppers, favored over drains for their reduction in potential problems and removal of thermal bridging. Next, a continuous water barrier protects all additional control layers from the roof all the way down to the foundation. This water control layer lies beneath our wall's cladding and serves as an additional drainage plane. This dual approach will keep water away from material susceptible to damage while also allowing materials to dry outwards. Only the cladding and mineral wool insulation remain outside this water control layer, both of which are resistant to water damage and able to dry easily. The ventilation layer beneath our cladding will also facilitate drying on the exterior side of the water and vapor control layer. Together, our cladding and water control layer work together to keep all water draining away from vulnerable materials while still allowing for potential drying.

Our window installation details call for many levels of flashings, both above the window and at its base, in order to control bulk water and move it away from the opening. Many levels of sealant on the interior and exterior of the window opening will ensure the continuity of the water control layer. In each of our diagrams (based on manufacturers recommended standards) we ensure that flashings and overhangs shed the majority of water away from our openings before sealant and caulk is affected. These sealing details as well as multiple layers of flashing ensure that any water that does reach the openings cannot pass through our continuous control layers. Air continuity is achieved using caulk and sealant at multiple stages, from inside an out.

The scuppers will direct the majority of water away from the foundation, but the surrounding ground will still be sculpted to resist the flow of water into our slab, with less permeable ground directly against our building and a slope of at least 5%. This design will also reduce the potential for insect problems at the base of our walls. Additionally, we plan to establish a capillary break at the base of our wall with a thin membrane strip, as well as at the bottom and edges of our slab with the stone base and polyethylene sheet. The polyethylene sheet is placed above the insulation and directly to the concrete to allow a drying profile inwards and outwards at either face of the sheet

Air Control

Similar to our methods for preventing water damage, our air control layer begins at the roof with a continuous roof membrane that connects directly to the fluid applied membrane on our walls. Throughout the parapet wall to roof transition and the roof itself, we maintain air, water and vapor control continuity. This is achieved by the branching of our fluid applied membrane in our walls to two separate layers: our water control roof membrane and air and vapor control applied directly to our exterior sheeting above our roof deck. Membrane strips ensure that this transition is continuous. This membrane lies underneath the water and thermal control layers for its own long-term protection. The air control layer continues on the face of the exterior gypsum board of our walls in the form of a continuous fluid applied membrane. By minimizing penetrations on our wall and sealing all openings, we aim to preserve the continuity of this air barrier. Windows of course pose a significant challenge, which we address with an interior sealant and our use of casement style to reduce leakage. The air control layer then runs beneath our building, sandwiched between our foundation and insulation. The transition between wall and slab is achieved using sealant at the thermal break of the wall and slab connection.

Vapor Control

We achieve most of the needed vapor control through our continuous air barrier. We have designed further protection in the form of an additional vapor impermeable coating and sheet in our wall and slab which will limit the vapor exchange across our envelope. Throughout the year, condensation will form on the exterior of our water control layer, allowing it to easily drain away. We achieve this by placing the thermal control layer on the exterior side of the vapor control layer. Humidity inside of our building will be carefully maintained through our advanced ventilation systems.

Thermal Control

Our three envelope sections (wall, roof and slab) use three individual thermal control strategies. We have taken advantage of our building's flat roof design to incorporate copious amount of mineral wool insulation that will aid our buildings overall efficiency. In addition, our roof will use three layers of staggered insulation to reduce air flow between layers at the joints. Our thermal control minimizes thermal bridging with exterior insulation in the majority of our

roof, and extra insulation in our parapets to reduce heat loss at edges where structural integrity necessitates thermal discontinuity. The parapets minimize this heat loss by allowing extra insulation above these high loss areas.

Our walls also use multiple layers of mineral wool to create a high level of thermal resistance on the outside of our other control layers. These layers will stretch continuously across the walls, with no thermal bridges. Behind our outside layer of insulation, we have incorporated loose cellulose stud cavity insulation to reduce the burden on our exterior sheeting from many layers of mineral wool insulation. We acknowledge that significant thermal bridging will occur through the steel studs, but the majority of our insulation will still remain outside of the structure, balancing this loss. Lastly, our use of more efficient products and strategies in our envelope penetrations will minimize heat loss from our structure. By using relatively high R-value windows and an air lock door system, we minimize heat loss through these inevitably vulnerable points.

Our slab will be just as effectively insulated, both beneath and on its edges to minimize heat loss into the ground. The wall to slab connection is a likely location for thermal bridges, especially when using steel studs instead of wood. We will employ a load-bearing foam thermal break here to minimize bridging, as well as significant under slab insulation. Our decision to not include a basement in our design significantly reduces heat loss through the foundation.

Durability and Material Choice

Our envelope team exclusively chose materials that exceed building code standards and contribute to our building's long-term durability. We chose to use materials that will likely reduce installation error and are resistant to fire, moisture, and insects such as mineral wool insulation. Our choice to use steel and concrete for our building makes for a long lasting, resilient structure. Our R-guard vapor barrier combines three control layers (water, air and vapor) into one fluid applied product, again minimizing room for error and ensuring continuity in these important control layers.

Vermont is lucky to have minimal threats from natural disasters, with no history of earthquakes, major wildfires, or tornadoes. Two potential hazards include blizzards, a relatively common occurrence in the Northeast, and the occasional hurricane. Middlebury's inland location already limits the impacts of a hurricane to flooding from overflowing rivers, and we have chosen a site that sits on high ground well away from the only nearby river. The most likely natural disaster that would impact Middlebury Elementary is a "Nor'easter" blizzard. Our structure is designed to handle the intense snow-loading that comes with our winters, including sudden increases in snow from major storms. Our heavily insulated envelope will protect against pipes bursting, the most common problem associated with long winter storms. Overall, our school could serve as a valuable assembly point in the event of a significant emergency. With ample space and effective insulation, our school would make an excellent shelter during prolonged natural disasters.

Windows

When designing our school's windows, we strove to balance the welcome benefits of natural daylight and significant drawbacks that come with many envelope penetrations. Our school utilizes Alpen Tyrol Series PH+ triple-pane windows. These windows are PHIUS certified and are made in the U.S. of fiberglass reinforced polymers. The frame is made of uPVC, an aerospace-grade fiberglass, minimizing thermal bridging through what is often the weakest thermal component of window systems. Whole-window U-factors range from (0.13 to 0.11) W/m^{2}K, depending on the type and glazing tuning. Even our lowest-performing windows are better than most existing windows on the market. We have a mixture of Tilt Turn/ Hopper windows and fixed windows. Every classroom has two operable windows, while the rest (one or two) are fixed. Labs and banks of windows in the library follow the same pattern. The second floor south-facing windows are all fixed. Exterior windows in administration offices are all operable. Our balanced strategy of operable and fixed windows gives teachers and students control over natural ventilation in their space while also incorporating higher-performance fixed windows.

Figure 16. Section of Alpen Tyrol PH+ Tilt/Turn and Hopper window.

Specification	Quantity
Alpen Tyrol TR-9 PH+ HighGain, Fixed 4' x 4', R-8.3, SHGC = 0.35	43
Alpen Tyrol TR-9 PH+ Balanced, Fixed 4' x 4', R-9.1, SHGC = 0.24	30
Alpen Tyrol TR-9 PH+ Balanced, Fixed Non-Tempered 2' x 4', R-9.1, SHGC = 0.24	146
Alpen Tyrol TR-9 PH+ HighGain, Tilt Turn/Hopper 4' x 4', R-7.7, SHGC = 0.30	32
Alpen Tyrol TR-9 PH+ Balanced, Tilt Turn/Hopper 4' x 4', R-7.7, SHGC = 0.21	36
Alpen Tyrol TR-9 PH+ Balanced, Fixed 4' x 8', R-9.1, SHGC = 0.24	2

Table 3. Window quantity and specification. See Figure G for more information.

Green and red LED indicators

next to the window tell occupants whether or not the outdoor air conditions are favorable for natural ventilation. Each window also has an integrated sensor that shuts off the ventilation and geothermal systems for that room when the windows are opened. This sensor is also tied into the Building Management System, and staff can see from the central display if windows are left open when the building is unoccupied. This central information display will help prevent burst pipes, a common occurrence in cold Vermont winters if windows are accidentally left open.

We have tuned glazing in our window design to get the best performance out of our glazing. The south-facing windows have a relatively high SHGC of 0.30 and 0.35 (operable and fixed, respectively). These windows take advantage of the low winter sun that gets in beneath our overhangs to provide passive heating to our building. The low winter sun is admitted through the windows and heats up the slab, providing a low-cost radiant heat system that reduces the load on our geothermal system. The north-facing windows use Alpen's "Balanced" glazing, with a SHGC of 0.21 and 0.24 (operable and fixed, respectively) since there is minimal direct sunlight to take advantage of on that side of the building. Our large west-facing PV viewing windows present a challenge as traditionally large east-facing glazing is not recommended. However, we deemed it a priority to enable students and visitors to see the PV system at work in all conditions. These windows use Alpen's SolarControl glazing with a SHGC of 0.15 to minimize unwanted late-afternoon heat gain, especially in the summer.

Figure 17. Solatube SkyVault M74DS.

In order to provide daylight to interior spaces without compromising the building envelope with skylights or large clerestories, we have specified Solatubes. Each SkyVault M74DS provides a 28.5" tube of light from the roof to key spots along the glass over the building's Main Street. These Solatubes will brighten up Main Street and provide daylight to the northern side of the first and second floor collaboration spaces. Additionally, we have designed in Solatubes over the first-floor hallway outside of the first and second grade classrooms, which will fill this space and the first-floor collaboration area with natural light. Using the manufacturer's added thermal insulation panel, these light tubes have a U-value of 0.45 W/m^{2}K. While worse than our window performance, they perform much better than skylights. We plan to install only 20 of them throughout the building, and the copious amounts of natural daylight they will provide makes them well worth the thermal bridging. Smaller Solatubes do have lower U-factors but would require significantly more penetrations negating their benefit.

Finally, in the gym we will use specified four-foot-tall Kalwall along the second story of both the southern and northern facades. Kalwall's thermally broken wall system has a U-factor of 0.05 W/m^{2}K and a SHGC of 0.10 with a VT of 0.17. From a thermal performance perspective, the Kalwall is more than twice as insulated as our best fixed windows and half as insulated as our walls. Kalwall provides a happy medium of filling our gym with daylight without the glare of windows and with lower heat losses in the winter. Each Kalwall panel is four feet wide and has a small section of wall in between it to minimize heat loss from mullions.

vii. Indoor Air Quality (IAQ) and Ventilation

In an elementary school setting, indoor air quality not only affects the health and comfort of the occupants, but can significantly impact students' abilities to learn. In Middlebury, VT we are fortunate to have some of the cleanest outdoor air in the country and we have designed our building to ensure that this translates to a similarly high quality of air within the school. Middlebury Elementary's airtight envelope both minimizes energy loss and provides more control over the air that enters and exits the building. The airtight design, however, demands an effective ventilation system to maintain healthy indoor air quality.

Ventilation

We have taken a decentralized approach that decouples the ventilation system from the heating and cooling system using a dedicated outdoor air system (DOAS) that provides fresh air to each zone based on demand. We have determined that the VS 500 SQ and VS 3000 RT units from Ventacity Systems are best suited to provide proper indoor air quality for the specific needs of our building. By separating the ventilation from the heating and cooling system, we can ensure that proper air quality will always be

Figure 18. VS 500 SQ Classroom Ventilation and HRV unit.

provided without sacrificing occupant comfort. Due to Vermont's cold outdoor air temperatures during the majority of the academic year, we have decided to use highly efficient heat recovery ventilators (HRVs) to transfer heat from the exhaust air to the fresh air supply. For colder winter days, the units have an electric pre-heater to aid in heat recovery and maintain comfort levels of the supply air.

Figure 19. VS 3000 RT Ventilation and HRV unit.

We determined that breaking the building into individualized ventilation zones would be the most energy efficient way to provide proper ventilation to each space. To ensure the best possible learning environment for the students we have designated classroom a single zone. Each classroom receives fresh air from a VS 500 SQ unit. The units measure 7 ft. wide, 3.5 ft. long, 1.5 ft. tall, and are hung from the ceiling along the exterior wall of each classroom with supply and exhaust vents directly connected to the outside. One of the primary advantages of these units is that they can distribute fresh air throughout an entire classroom without the need for any ductwork. The units include electronically commutated motors and back curving fan blades to reduce power requirements and maintain quiet operation (between 31 and 40 dB under typical operation). The VS 500 SQ units provide ventilation that is catered to classroom needs in real time, incorporating passive infrared (PIR) presence sensors and CO_2 sensors to adjust airflow based on occupancy. They include relative humidity (RH) sensors and volatile organic compound (VOC) sensors to monitor the condition of the air. Each unit has an individual control panel to allow for manual adjustments and is integrated into a Smart Building Gateway management system that allows for remote online monitoring, diagnostic reports, and preventative maintenance notifications.

With 25 classrooms served by VS 500 SQ units, the rest of the building will be served by five larger VS 3000 RT units. These units can be mounted on the roof or inside the building, providing the ventilation for many spaces via a ducted distribution system. The units have been strategically placed with the intent of limiting ductwork (which increases energy efficiency and decreases the cost of installation) and maximizing the space available for rooftop PV panels (the roof above the kitchen and part of the cafeteria is already shaded by the rest of the building). The ductwork itself will be circular with a 22-inch diameter and the duct runs will avoid sharp corners to reduce friction and increase overall efficiency. The VS 3000 RT units include room CO_2 sensors with adjustable dampers that adjust ventilation based on occupancy. They include room RH and VOC sensors to monitor the air quality and are similarly incorporated into the Smart Building Gateway management system. The units were sized based on the airflow requirements for each space type given in ASHRAE Standard 62.1. All systems have therefore been designed to operate within their most efficient airflow regions; however, they have the capacity to provide additional airflow that is 20% to 50% above the ASHRAE requirements.

To reduce sources of air contamination within the building, interior design selections have been made to emphasize natural materials in order to decrease off-gassing. In particular we have chosen to use no-VOC paints and wall finishes, as well as formaldehyde-free drywall throughout the interior. In addition, the use of mineral wool in our envelope design provides insulation without additional VOC contamination. The location of our water and vapor barriers ensures that the dew point is located outside of the barrier, preventing the growth of mold and bacteria within the building, which would otherwise reduce IAQ. The interior design includes air-filtering plants that will help to improve IAQ while reminding students of the role of living organisms as natural air filters. With two operable windows in each classroom and light indicating when they may be opened, we allow the occupants to take direct advantage of the clean outdoor air through natural ventilation without risking losses in energy efficiency.

Our decentralized approach leads to relatively large upfront equipment costs; however, the ductless units greatly reduce the building's ductwork and associated installation costs. These units simplify the overall design and lead to straightforward ventilation management, while providing completely customized ventilation for each learning environment.

Soil Gases

Radon and other naturally-occurring soil gases can pose a risk to occupants. In order to mitigate potential hazards to building occupants, our design incorporates soil gas management from the start. A gravel layer below the rigid XPS insulation layer allows for the free movement of soil gases. This layer includes perforated PVC pipes spaced every 40 feet that can collect radon and other soil gases as they build up, and vent them out above the roof line from under the slab. A polyethylene sheet will keep the radon from permeating into the building through any small cracks in the slab. To ensure that this sheet maintains a proper air barrier, all penetrations for plumbing and wiring will be sealed with gaskets made from the polyethylene sheet and taped.

viii. Mechanical, Electrical, and Plumbing Design

Every mechanical, electrical, and plumbing design decision was made to prioritize energy efficiency, visibility for the students, and occupant comfort. To best achieve these goals, our team decided to use a decentralized approach to our heating, cooling, ventilation, and hot water systems. Not only do decentralized MEP systems lead to greater efficiency, they allow for a new level of interaction and competition between students.

Mechanical

We have chosen to use a geothermal system with ground source heat pumps (GSHPs) to fulfill our heating and cooling needs. While geothermal systems require a substantial up-front investment, we have determined geothermal is the most energy efficient option and will lead to substantial paybacks over the lifespan of the building. With an entirely electric, geothermal-based heating and cooling system, we expect the heating costs alone to be one-third of Mary Hogan Elementary's current heating oil costs and we project a full return on investment within twenty to thirty years. Geothermal energy is particularly attractive in Vermont due to the stability of ground temperatures when compared to outside air. Furthermore, our site in Middlebury was selected for its lack of sheet rock and its limestone makeup that offers a significant, long-term geothermal potential.

We have chosen to use a closed loop geothermal system with vertical bore holes. Similar to the ventilation system, we have chosen to create individualized heating/cooling zones within the building to ensure occupant comfort in each space at all times. We have a dedicated, water to air heat pump for each classroom that will provide heating and cooling based on thermometer readings for that specific room. Our other spaces, such as the gym, cafeteria, corridors, and administrative offices are zoned with larger heat pumps dedicated to each of those spaces as well. This offers the advantage of having each space heated and cooled separately, leading to more balanced use of the geothermal energy. If one space requires cooling while other spaces require heating, the excess heat from the cooled space can be transferred to the refrigerant and used to heat the other spaces.

Our first step in making sure the building is properly conditioned was to design an energy-efficient envelope and reduce our infiltration rates to a target of 0.6 air changes per hour throughout the building. By starting with an energy efficient building construction, we are able to reduce the energy needed to condition the spaces. Based on our climate and building design, we have found that for most spaces our heating loads outweigh our cooling loads and therefore we have sized the majority of our heat pumps based on heating loads (with the exception of a few internal spaces that have higher cooling demands). The heating loads for each space were determined from spreadsheet calculations (which incorporated the R-values for the roof, slab, walls and windows, natural infiltration rates, mechanical ventilation rates and heat recovery efficiency) in conjunction with design heating loads determined by our model.

Figure 20. Climate Master Tranquility 30 Series (TE) Heat Pump.

With our heating loads calculated for the entire building, we determined that our bore field would be 20,000 square feet with 35 bore holes, each running 500 feet deep. The overall size has been increased by ten percent above the demand to make sure that there will be enough thermal energy available throughout the year. While 35 bore holes at 500-foot depth is the target, the true size will not be determined until drilling begins and preliminary ground temperature measurements can be made. Our refrigerant will be a mix of water and 25% food grade propylene glycol to prevent freezing. While ethylene glycol is a better heat transfer fluid, we have chosen propylene glycol because it is nontoxic and will pose less of a concern with our choice to make the piping exposed within the building. The piping for each bore hole is fed into a manifold vault where each pipe can be closed individually to allow for effective initial purging and to allow the system to continue operating if one of the pipes needs repair. From the vault, the main supply and return pipes run into the building's mechanical systems heart, which houses the circulation pumps, glycol fill tank, expansion tank, and hydraulic separator. This room is adjacent to the town square and has windows on two walls to encourage the students to learn about the systems. The refrigerant will then be circulated through

Model	Quantity	Operation	Cooling Capacity BTUh	EER BTUh/W	Heating Capacity BTUh	COP
TZ024	25	Part	19,400	22.2	14,700	4.0
		Full	24,600	16.0	17,800	3.6
TE049	8	Part	39,100	27.4	29,800	4.4
		Full	49,600	19.3	36,400	4.0
TE064	5	Part	51,200	26.7	38,100	4.4
		Full	66,200	18.8	48,700	3.9

Table 4. Heat Pump Specifications and Quantity.

four loops to all of the heat pumps within the building. By breaking the building into four loops based on heating demand, we are able to maintain lower flow rates within the pipes (< 64 gpm) and use smaller, more efficient circulation pumps.

Recognizing that a geothermal system is only worth its cost if the heat pumps themselves are highly efficient, we have chosen to use TZ024, TE049, and TE064 ClimateMaster heat pumps from the Tranquility 22 Ultra High Efficiency (TZ) Series and the Tranquility 30 Premier Efficiency (TE) Series. All three of these heat pumps have been designated as Energy Star Most Efficient Products for 2018 and we have chosen to use only three variations in order to maintain the operational and maintenance simplicity of the building.

The heating demands for the classrooms vary between 13.1 kBtu/hr and 17.4 kBtu/hr and we have chosen to use the TZ024 units for each classroom, which will ensure that they will always be properly heated or cooled. The units themselves will sit in heat pump closets within each classroom. The supply air will be distributed through ceiling ductwork to four diffusers evenly spread throughout the room and the ductwork will have at least two right angles to reduce sound concerns. The return air will be fed directly into the heat pump through a return air grill in the closet wall, which will include a sound baffle. The Tranquility 22 units are among the quietest units on the market with the compressors isolated from the cabinet base for maximized sound attenuation. Further sound attenuation will be accomplished by mounting the unit on a rubber isolation pad to reduce vibrational transmission into the structure of the building. The units include iGate control systems and variable flow technology to allow for constant monitoring of the performance of each unit and reduce overall energy consumption. The rest of the building will be heated and cooled by a combination of 8 TE049 and 5 TE064 units serving multiple spaces, with thermometers in each space to provide properly individualized conditioning.

Once installed, the heat pump units themselves do not require regular maintenance aside from visual inspection and occasional replacement of the filters every three months. This inspection schedule could easily be tied into the filter inspection schedule for the ventilation units allowing for a brief but thorough inspection of all of the mechanical systems four times a year.

We use thermometers to monitor the refrigerant temperature entering and exiting the ground loop system throughout the year. While we intend for the school to be occupied during the summer months allowing for a more balanced heating and cooling demand over the course of the year, we monitor the ground loop temperature to look for any thermal drift over time as there may be more energy extracted from the ground than put back in. Based on the performance of other geothermal systems in Vermont, we do not expect this to be a significant issue, but if it does become a problem, we would consider including other backup heating systems to provide a more balanced energy load and maintain consistent ground temperatures.

Electrical

Our team has developed a preliminary plan for the electrical layout of our building. Our system will utilize three-phase power, a requirement for our selected ventilation and ground source heat pump systems. To minimize the cost associated with large circuits, our team plans to install three 120/208 V feeders and three 480/277 V feeders from the main electrical rooms to centrally located breaker panels located on the first and second floors. Our use of large diameter feeders is designed to save both cost and energy by reducing the length of smaller diameter wiring and associated voltage loss. General purpose, mechanical, and lighting are all separated into their own panels to ensure that the irregularity or change in loads on the system does not carry across to other circuits. When possible, single pole general purpose circuits were designed to serve 10 receptacles, the maximum allowed under the NEC, to minimize wiring cost and increase the overall efficiency of the electrical system. All mechanical machinery, point source water heaters requiring more than 20 amps, and large appliances were assigned their own dedicated circuits to facilitate maintenance. Any pump or motorized appliance will be protected with a fuse corresponding to the amperage of the circuit, as well as its associated breaker.

Our team chose to use copper wiring due to its long term durability and fire safety compared to aluminum. Every general-purpose circuit will be AFCI protected to minimize fire risk. Every circuit on our building will use one size higher copper wire gauge then required for the amperage of that circuit. For example, 20-amp circuits will use 10-gauge wire as opposed to 12, 30-amp circuits will use 8-gauge as opposed to 10 and so on. The decision to use a larger wire size than that required by the NEC was based upon a study conducted by the Copper Development Association, which found that using one size higher wire than needed leads to significant energy and cost savings. For example, the simple change from 8 to 6-gauge wiring for the point source water heating circuits will reduce energy loss by 40 percent at full load with only a 42 percent increase in upfront material and installation fees. Taking into account the cost of energy, this simple change is expected to save our school 0.07 cents per kilowatt hour used, paying for itself in under two years.

When selecting outlets, our team prioritized safety and functionality above all else. For any outlet located near a plumbing fixture or space prone to getting wet, our team selected the Leviton 20-amp 125 volt Duplex Self-Test Tamper Resistant GFCI Outlet. All other spaces utilize standard 20-amp Leviton Tamper Resistant outlets, as required by NFPA 70

in educational occupancies. Floor and ceiling outlets are located in strategic positions to ensure flexibility of spaces as well as easy installation for short throw projectors. When possible, our team attempted to follow the residential guideline of installing one outlet per 12 feet or at least one per wall. A full layout of electrical outlets, as well as a table detailing the total number of each outlet, can be found in the construction documents.

Plumbing

When designing our building's plumbing, our team focused on minimizing the number of fixtures through thoughtful positioning, careful selection of low-flow and low-maintenance systems, and point source water heating to minimize energy loss associated with water heating. Early on, the MEP and Architecture teams collaborated to determine the location of centralized restrooms and sinks in order to minimize construction costs and total fixture counts while conforming to Vermont State standards. Keeping with the Vermont State school design standards, every Kindergarten classroom in our school has its own bathroom. Each other set of two grades shares one set of male and female restrooms with one additional single use restroom designed to be ADA compliant and gender neutral. In addition to the accessible single-person bathrooms, every restroom will have one ADA compliant 5' x 5' restroom stall. While the single use restrooms meet ADA guidelines, our team strove to ensure that our school's restrooms exceeded federal regulations in accessibility. Our standard ensured that every single space of our school was as accommodating to students with disabilities as those without. We designed each collaboration space to have one shared sink per four classrooms. The STEM lab and Arts room each have their own sinks to facilitate their needs.

All restrooms will utilize low flow toilets to promote water conservation. We selected the Toto Ultramax II low flow toilet due to its simple use and overall efficiency. We questioned whether elementary school students would be able to routinely remember how to operate a dual flush system and decided that a simpler low-flush system would save more water in the long term. Male restrooms will use Sloan WES-1000 waterless urinals, and one in each restroom will be ADA compliant. Proper maintenance and cleaning will be emphasized to ensure that the waterless urinals remain functional with extended use. We elected to use American Standard 0.5 GPM Innsbrook Electronic Proximity Faucets with Lucerne wall mounted sinks in all restrooms to further reduce water usage while still promoting adequate hand washing for hygiene.

Figure 21. Ecosmart point source water heater.

All of the hot water used in our elementary school will be point source generated, drastically reducing the energy loss associated with transporting hot water over large distances and storing hot water indefinitely. Our selected point source water heating systems boast 99.8 percent thermal energy efficiency, decreased heating delay, and endless hot water supply when sized appropriately. Each multi-person restroom will utilize a sized model of the EcoSmart Point Source water heater, capable of providing hot water to four taps simultaneously even with Vermont's relatively cold tap water temperature. Individual sinks will utilize the smaller model, the EcoSmart Pou 6, while the kitchen will have its own dedicated EcoSmart 27 to facilitate large scale dish washing. Bathrooms with 2 sinks will use the EcoSmart 11, and those with 4 will use the EcoSmart 18. Lastly, the shower in the administrative/nurses office will utilize an additional EcoSmart 18, capable of supplying the tap and shower simultaneously with hot water.

Our school will have three Elkay EDF 15R Non-Refrigerated Drinking Fountains, two centrally located on the first floor and one on the second floor. Refrigerated water is wholly unnecessary in Vermont, where tap water is rarely above 40 degrees. We chose to only meet the minimum code requirement for the number of drinking fountains because we want to encourage students to use reusable water bottles, a simpler solution that instills long term sustainability beyond the classroom. Every sink in the pods will have a simple tap from which students can fill their water bottles. We choose to use the American Standard Monterrey 4" Centerset Gooseneck Faucet in all of the collaboration spaces. The Art, STEM, Science, and Wet Lab classrooms will each have a Just Manufacturing ARB-2435-A-GR-T sink, and the kitchen will have two NSFB-345 3 compartment sinks.

All plumbing systems and fixtures were chosen based on efficiency, cost effectiveness, and durability. EcoSmart projects their systems to last over 20 years, a dramatic improvement over tank-based systems. All selected plumbing fixtures and heating systems are manufactured by American companies, promoting local economic growth and environmentally friendly sourcing.

Rainwater

All drainage from the roof occurs through scuppers located in the parapet that distribute water out and away from the building. Two rows of perforated PVC pipe below ground level provide additional drainage, collecting water and moving it away from the foundation. Outside the building, our design utilizes a natural approach to rainwater management. The current site already includes constructed wetlands to capture rainwater from the playing fields and Middle School. We plan to utilize additional bioswales around our building and parking lot to reduce the flow of water runoff from our site, allowing us to continue using the existing wetlands for water management. We will thereby reduce the school's impact on the soil and slow down the release of water after a storm. Additionally, we will include donated rain barrels to collect some of the runoff from the roof and use it for irrigation of the teaching farm.

ix. Innovation

A Flexible Building for a Changing Pedagogy

Middlebury Elementary is designed to bring early education into the 21st century. The traditional classroom design is poorly suited to accommodate new learning strategies, and Middlebury's current building, already bursting at the seams with students, has little flexibility. Our new school design will allow for constant adaptation and innovation as education standards change. We expect our building to encourage collaborative learning and crossovers between subjects. Our use of garage doors in the STEM, Art and Wet labs is designed to bring a liberal arts interdisciplinary approach to early education and encourage students to see the connections between the arts and sciences.

Visible Engineering

A building should not only be a shelter from the elements. So much thought and effort has gone in to our building's envelope and mechanical systems; it would seem foolish to hide those design choices from the students. Middlebury Elementary has been designed to be as much of a learning tool as a simple structure. Instead of hiding mechanical systems, our team has chosen to highlight and color code them so that students can begin to understand how and why they work. Students can monitor their energy usage at the town square, and learn about photovoltaic power using a small educational solar panel.

Decentralized Mechanical Design

Our MEP team has taken a decentralized approach to all of the mechanical systems of our building. Each aspect of MEP suffers from energy loss over large distances, whether it be friction loss over long duct runs or heat loss when transporting hot water. Not only do decentralized systems eliminate these problems, they also create a more robust and dependable system overall. Decentralization also facilitates student competition, as students can directly see how their everyday actions effect the mechanical systems in their particular zone.

A 21st Century School with a 19th Century Soul

Our team has designed an innovative and modern elementary school that pays homage to Vermont's rich history. We strove to take the small-town culture that makes our community so unique and incorporate it into our school's layout. Our exterior design is heavily influenced off of Vermont farm buildings, and we have made sure that Vermont's agricultural heritage will take center stage at our school with our proposed farm and wet lab. Our school will forever serve as a beacon to how a small town can retain its culture while incorporating modern design and construction principles.

V. Appendices: Energy Analysis

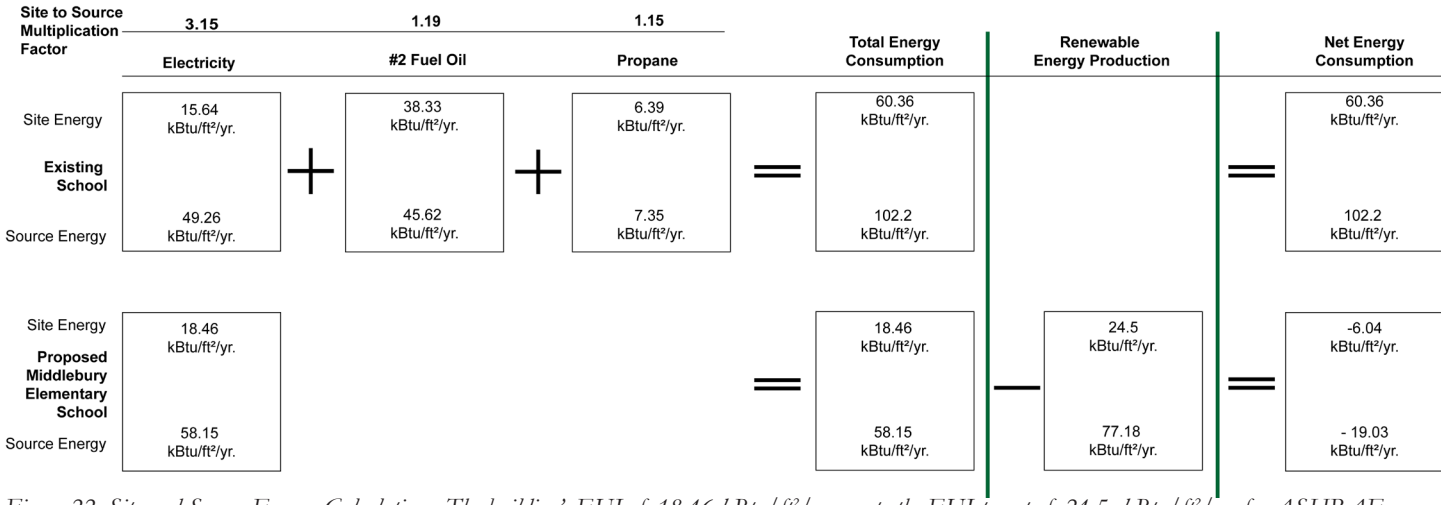


Figure 22. Site and Source Energy Calculations. The building's EUI of 18.46 kBtu/ft²/yr. meets the EUI target of 24.5 kBtu/ft²/yr. for ASHRAE Climate Zone 6A in the Technical Feasibility Study for Zero Energy K-12 Schools. Renewable energy production numbers are based off calculations in Table 1. Net energy consumption less than zero in the far right column indicates that the Zero Energy target is being reached.

Space	Lighting Power Density (W/ft2)	Plug Load Density (W/ft^2)	Heating sizing factor	Cooling sizing factor	COP	EER (Btuh/W)	Heat Pump Model
Classrooms	0.38	0.378	1	1	4	22.2	TZ024
1st Floor Collaboration Space	0.38	0.084	1	1	4.4	27.4	TE049
2nd Floor Collaborative Space	0.38	0.084	1	1	4.4	27.4	TE049
Collaboration Space Meeting Rooms	0.53	0	1	1	4.4	27.4	TE049
Gym	0.42	0.084	1	1	4.4	27.4	TE049
Lab spaces + library reading room	0.38	0.168	1	1	4	22.2	TZ024
Library	0.38	0.168	1	1	4.4	26.7	TE064
Multipurpose Room	0.38	0.756	1	1	4.4	26.7	TE064
Music Room	0.38	0.756	1	1	4.4	26.7	TE064
Administration	0.34	0.42	1	1	4.4	27.4	TE049
Front Entrance Corridor	0.19	0	1	1	4.4	26.7	TE064
Town Center (Lobby)	0.46	0.084	1	1	4.4	26.7	TE064
Kitchen	0.38	5.88	1	1	4.4	27.4	TE049
Mechanical Rooms	0.32	0.168	1	1	4.4	27.4	TE049
Restrooms	0.4	0.168	1	1	4.4	27.4	TE049

Table 5. Energy Model Inputs. Lighting Power Density, Plug Load Density, HVAC sizing capacities, and HVAC system efficiency.

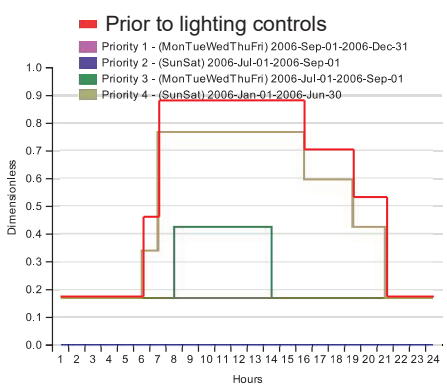


Figure 23. Interior Lighting Schedule from OpenStudio Model. Shows that controls reduce the energy required to light the building.

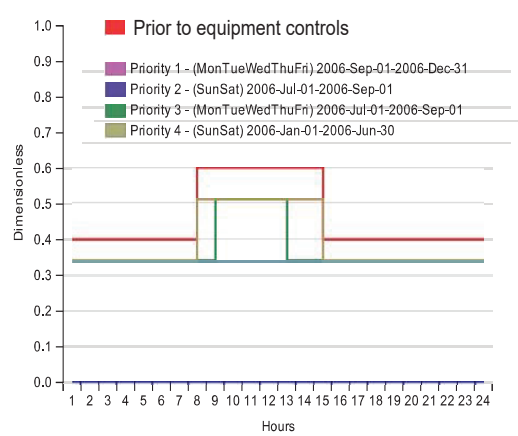


Figure 24. Building Equipment Schedule from OpenStudio Model.

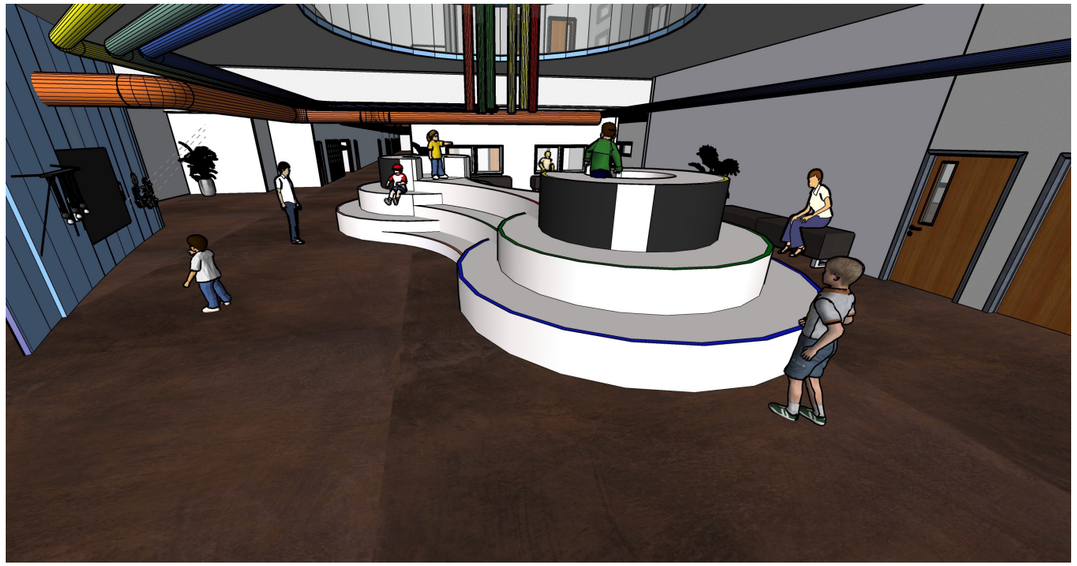


Figure 25. The systems heart is a unique gathering space formed by the ebbs and flows of movement around the school and the eager learners and ready educators. Its proximity to the main entrance, multi purpose cafeteria area, main staircase and main street make it a meeting point and frequent visual for users of the school. The LEDs represent each grades energy usage and students can push the coordinating color button for their grade to reveal their usage.

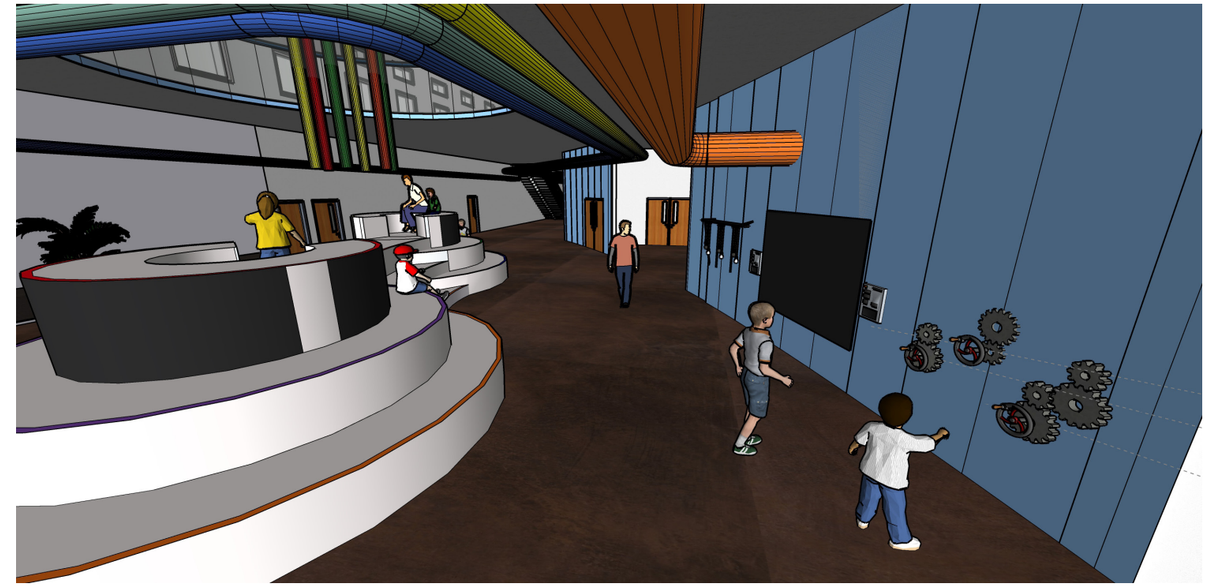


Figure 26. The interactive screen provides more detailed information on the schools energy usage and educates students on the types of systems in use and ways they can conserve energy. The levers and pulleys on the wall allow the students to experiment with energy production and the screen shows theoretical amounts produced and examples of systems that could be run with that amount.

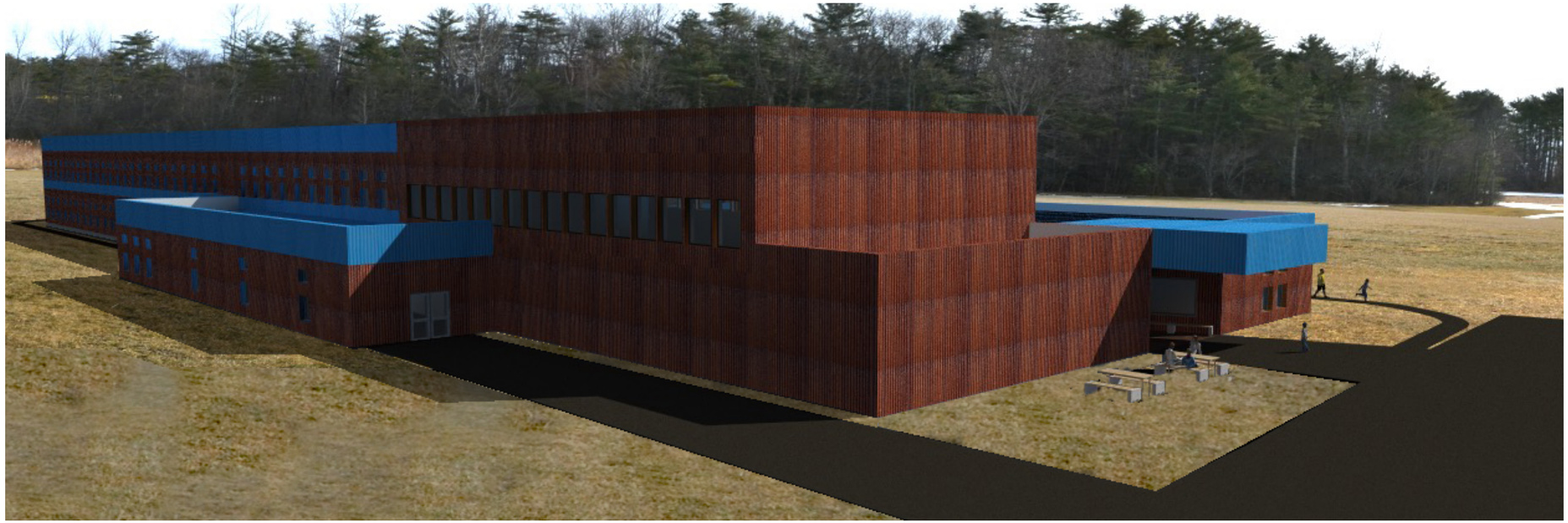


Figure 27. Middlebury Elementary looking Southeast. The educational farm will be located in the field just beyond the school.

Figure 28. The Cafeteria. All furniture is flexible (fold-able or stackable and on wheels) in order for the space to be converted to anything the school might need. This facilitates its use either as an extension of the town center or for a presentation in the music room.

Figure 29. Main Street. In the corridors and gathering spaces, cool and calm whites and blues are used to help revive students minds while not taking away from student work that is to be displayed.

Figure 30. Collaborative Learning Space. Each grade's collaboration space is color-coded (above the doors and in the central divider). All furniture is flexible and can easily be rearranged.

Figure 31. Collaborative learning space and the glass small meeting rooms for one-on-one instruction. Note the aquaponics system to take the

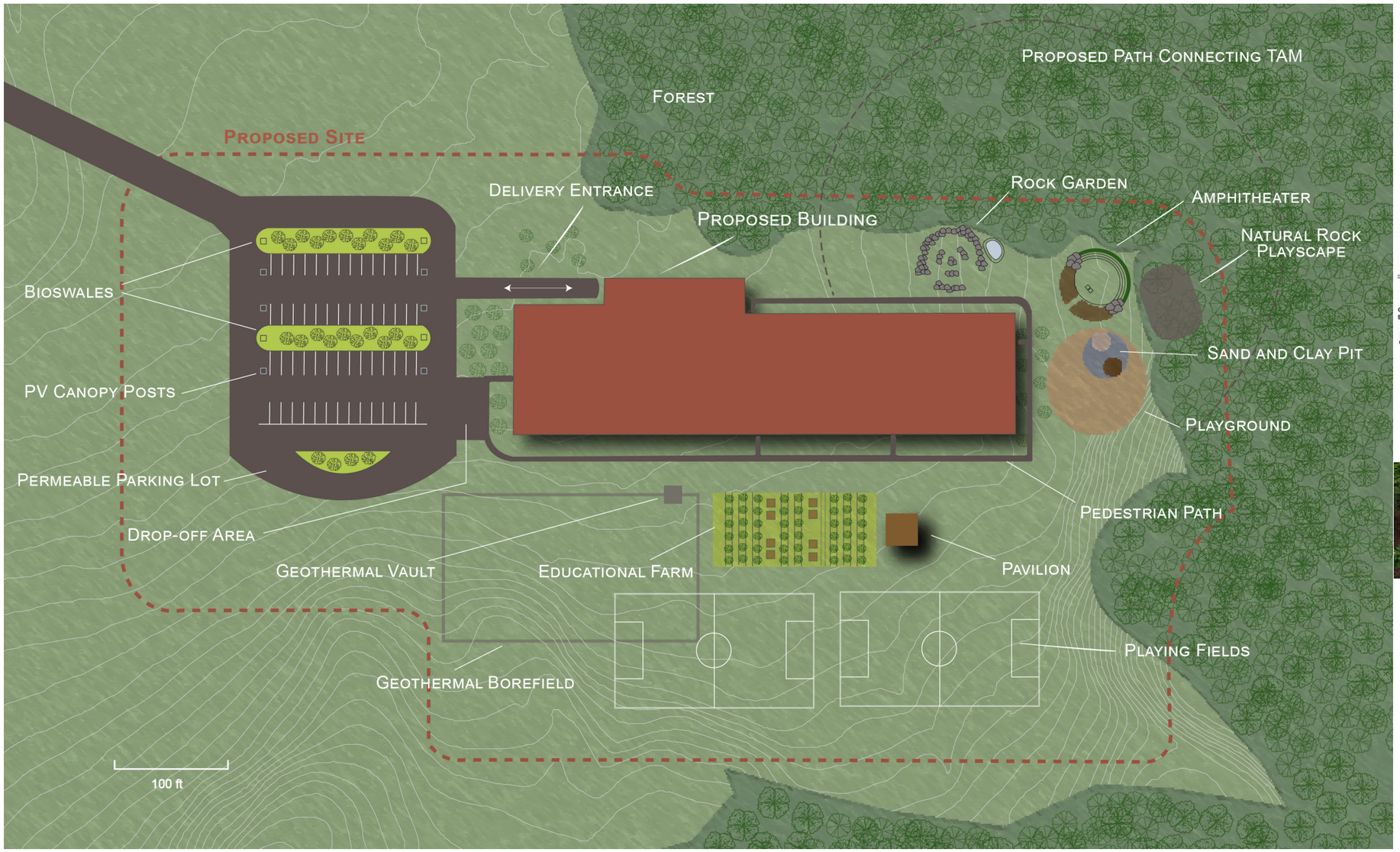
Figure 32. A typical first and second grade classroom. The classroom reinforces the flexibility and adaptability of the school and each is uniquely catered to each grade. This arrangement might be good for small group work. The upper window allows daylight to penetrate deep into the classroom while the lower window is at kid-height to allow for a connection with the environment.

Figure 33. A typical first and second grade classroom. Color schemes are targeted for different age groups. Younger grades have warmer tones to stimulate learning while older grades have calmer cool colors to help students focus. The cubbies allow for storage and flexible seating arrangements.

Figure 34. A typical first and second grade classroom. This arrangement might be used to watch a movie or a full class presentation. Note the integrated recycling and trash bins in the cabinetry. Windows above the cabinets are designed to allow the teacher to supervise the collaborative space without distracting the students.

Notes

- The parking lot is made of recycled and crushed asphalt with a gravel base to minimize the amount of impermeable surface
- The geothermal borefield has 35 500 foot deep wells
- The path connecting the forest is a nature walk but also connects into the Trail Around Middlebury
- Much of the exterior landscaping will be accomplished with hardscaping using local rocks to minimize the need for water
- The amphitheater and rock garden both function as outdoor classrooms
- Trees and shrubbery are limited to the East and West sides of the building to minimize the impact on daylight entering the building
- The playground will be brought from the existing school



Precedent

Figure 35. Precedent image of PV canopies over a parking lot.

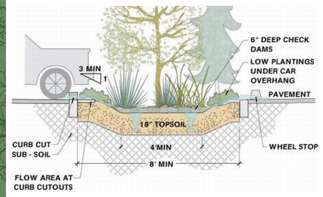
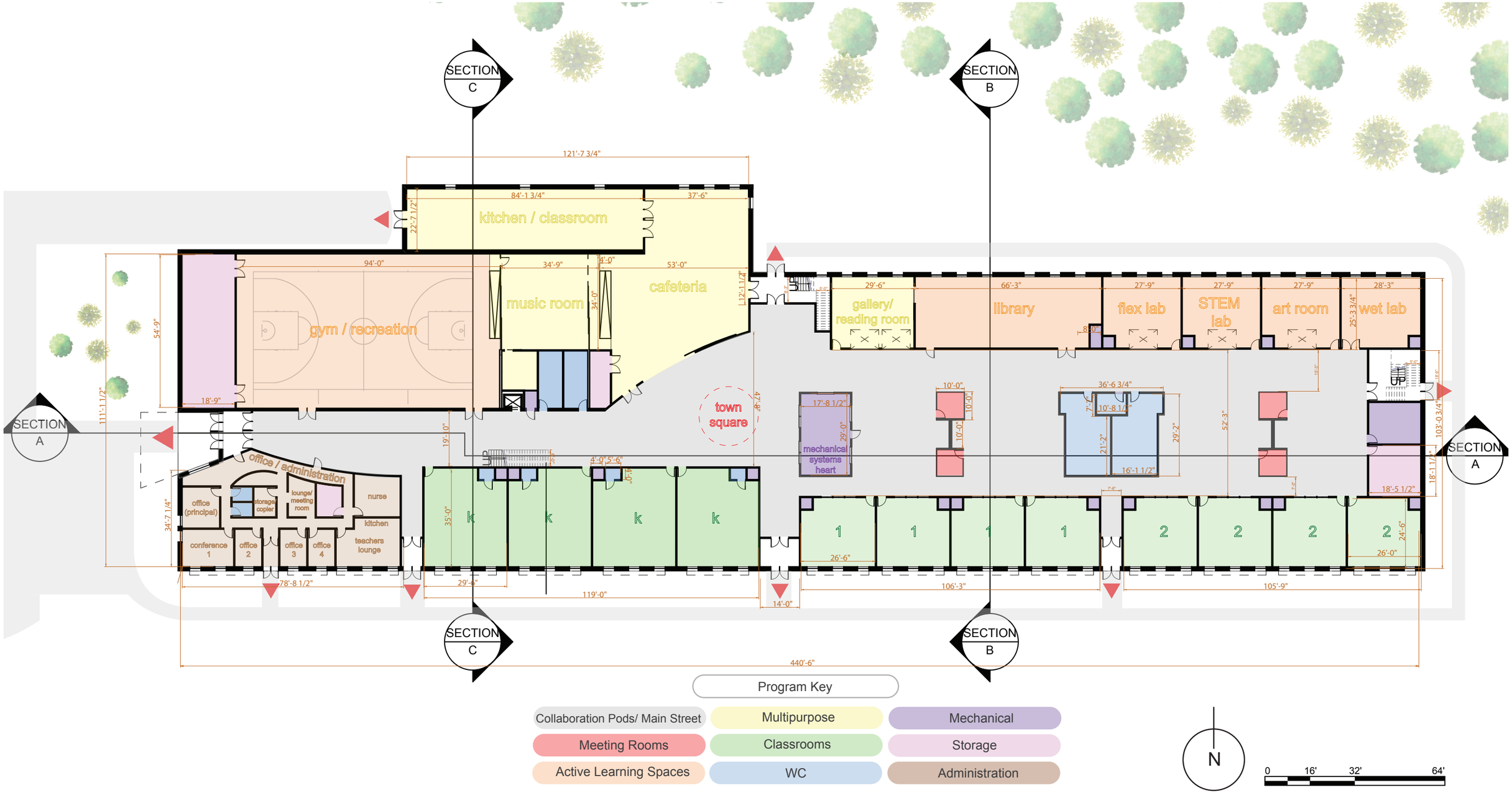


Figure 36. Precedent images of a cross-section of a bioswale. Cars can be parked on either side, just as in our design.

Figure 37. Precedent image of a man-made rock amphitheater.

Figure 38. Pavilion. The pavilion is a three-sided covered outdoor classroom.



Program Key

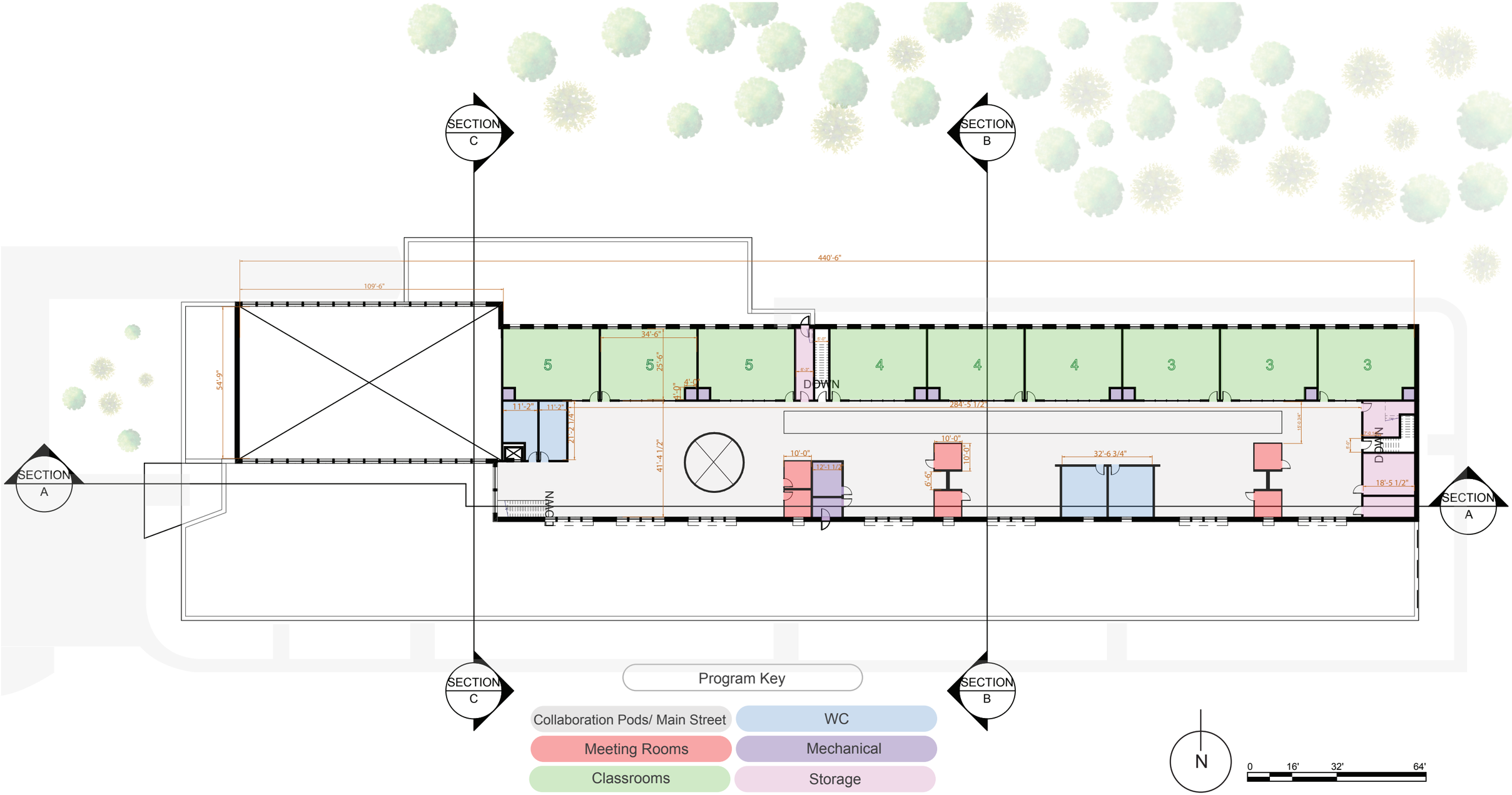
Collaboration Pods/ Main Street	Multipurpose	Mechanical
Meeting Rooms	Classrooms	Storage
Active Learning Spaces	WC	Administration

N

0 16' 32' 64'

First Floor

Figure B

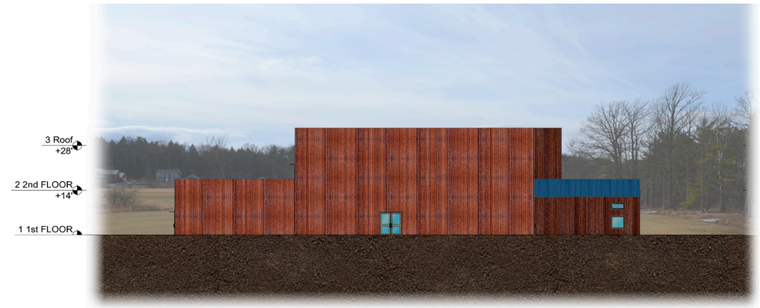


MiddZEST
Middlebury Elementary

Second Floor

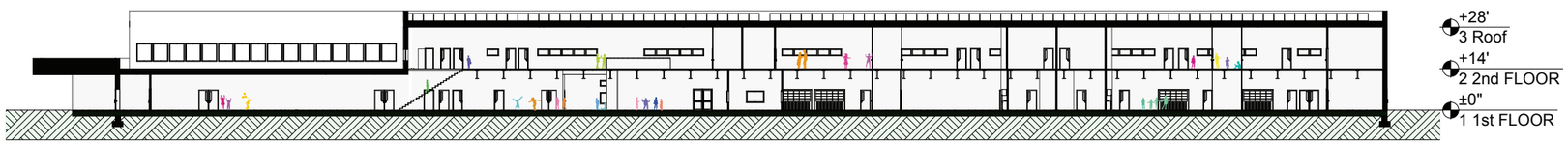
Figure C

NORTH ELEVATION
SCALE: 1/32" = 1'-0"
0 16' 32' 64'



EAST ELEVATION
SCALE: 1/16" = 1'-0"

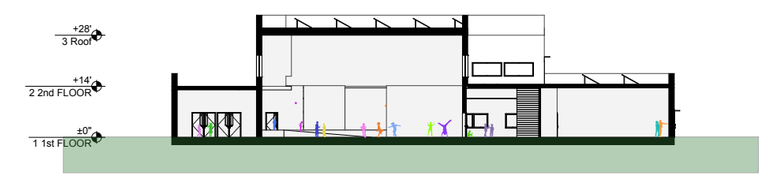
SECTION B
SCALE: 1/16" = 1'-0"



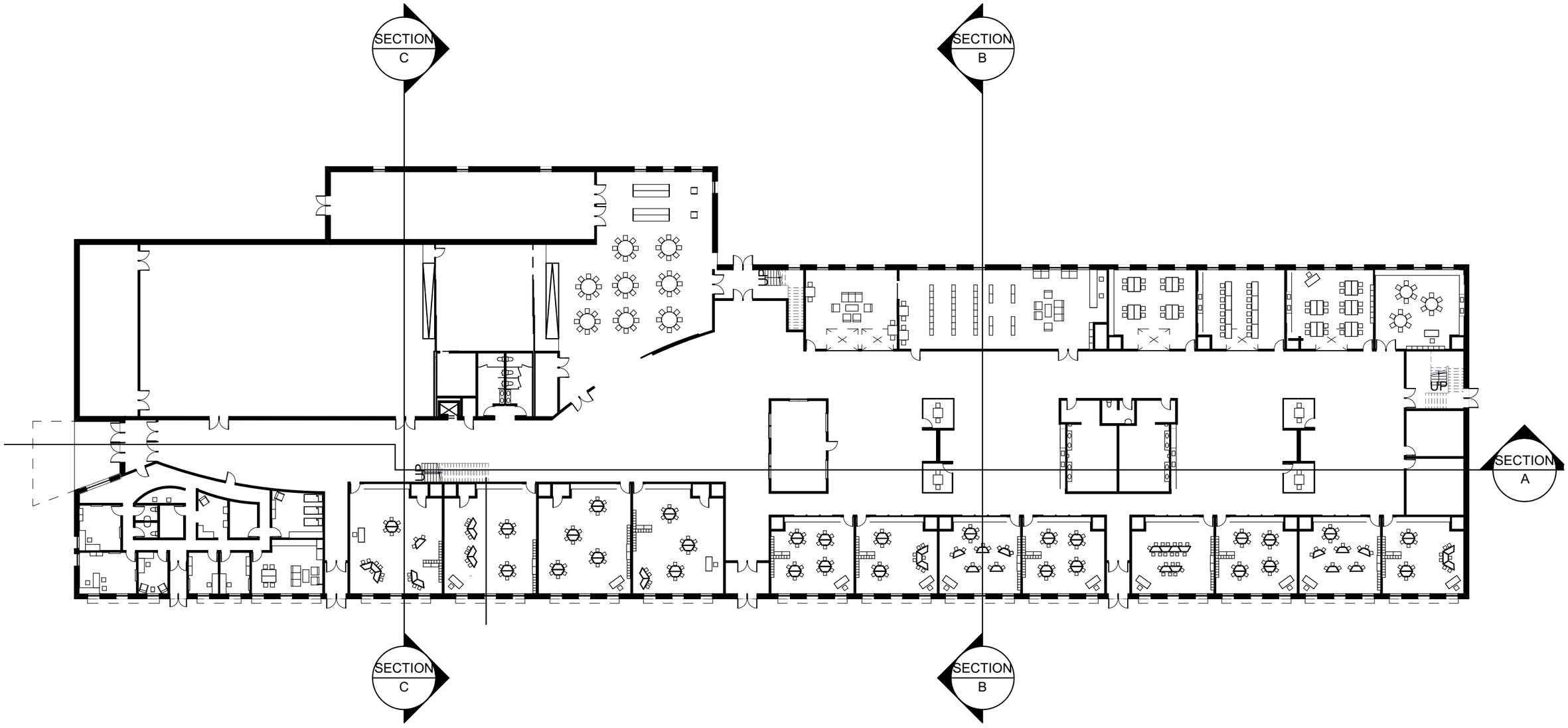
SECTION A
SCALE: 1/32" = 1'-0"
0 16' 32' 64'

WEST ELEVATION
SCALE: 1/16" = 1'-0"

SOUTH ELEVATION
SCALE: 1/32" = 1'-0"
0 16' 32' 64'



SECTION C
SCALE: 1/16" = 1'-0"



MiddZEST
Middlebury Elementary

Rendered First Floor Plan

Figure E

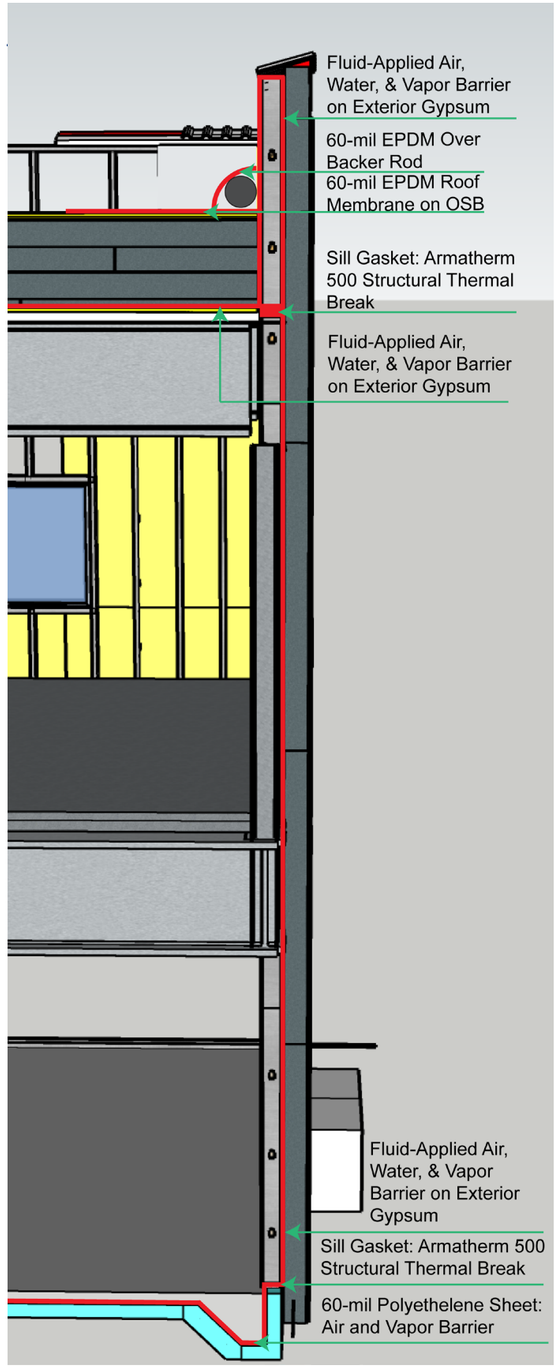
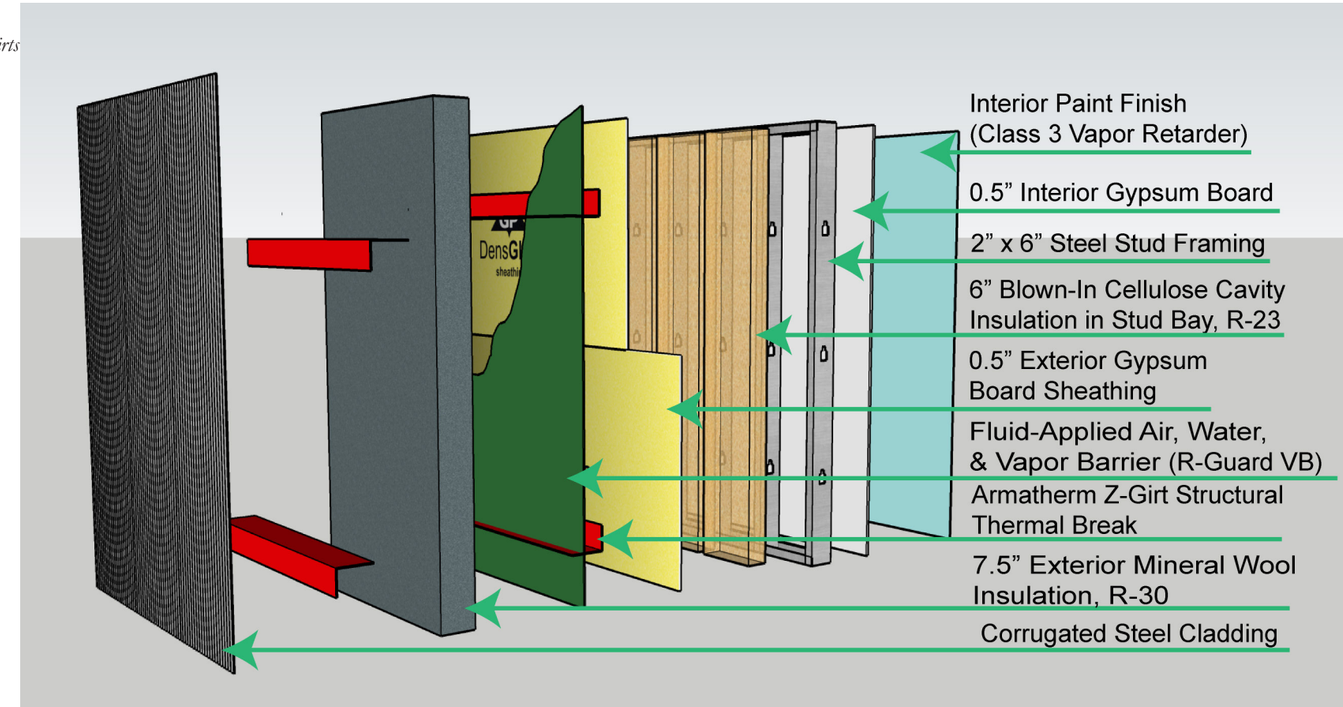


Figure 39. (Left) Continuous Air Barrier. The continuous layer is composed of a polyethylene sheet under the slab, to a fluid-applied air, water, and vapor barrier (R-Guard VB) on the exterior gypsum, and an EPDM roof membrane. Transitions are sealed with Armatherm 500 structural thermal break sill gaskets. A backer rod is used on the roof to hold extra roof membrane to prevent tearing if the membrane is stretched. The parapet is filled with blown-in insulation and has an additional layer of insulation capping it off underneath the flashing.

Figure 40. (Right) Wall Section. Armatherm Z-Girts are used to support the cladding and the exterior insulation.



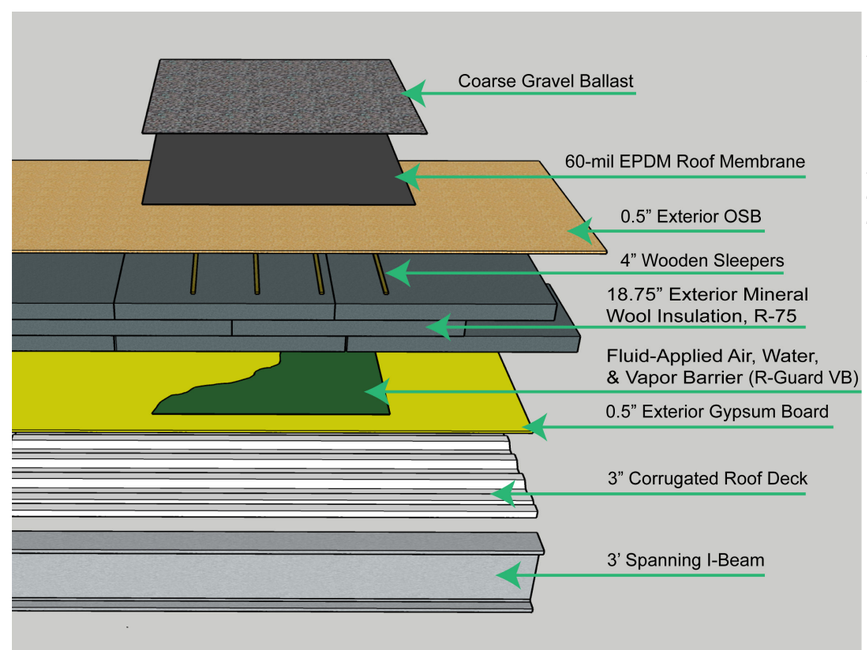
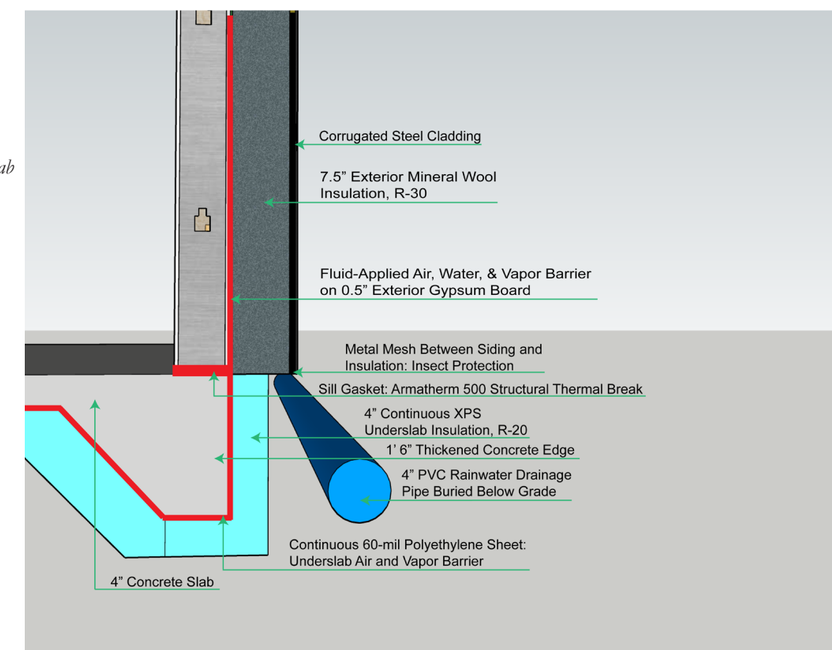


Figure 41. (Left) Roof Section.

Figure 42. (Right) Slab Section and Wall-to-Slab Connection.



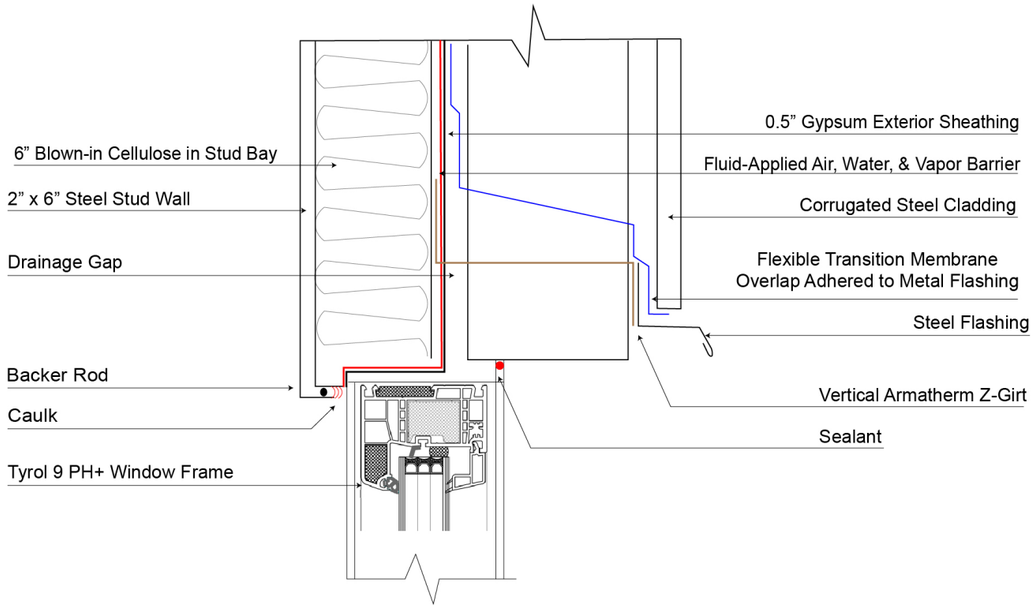


Figure 43. (Left) Window Head Section.

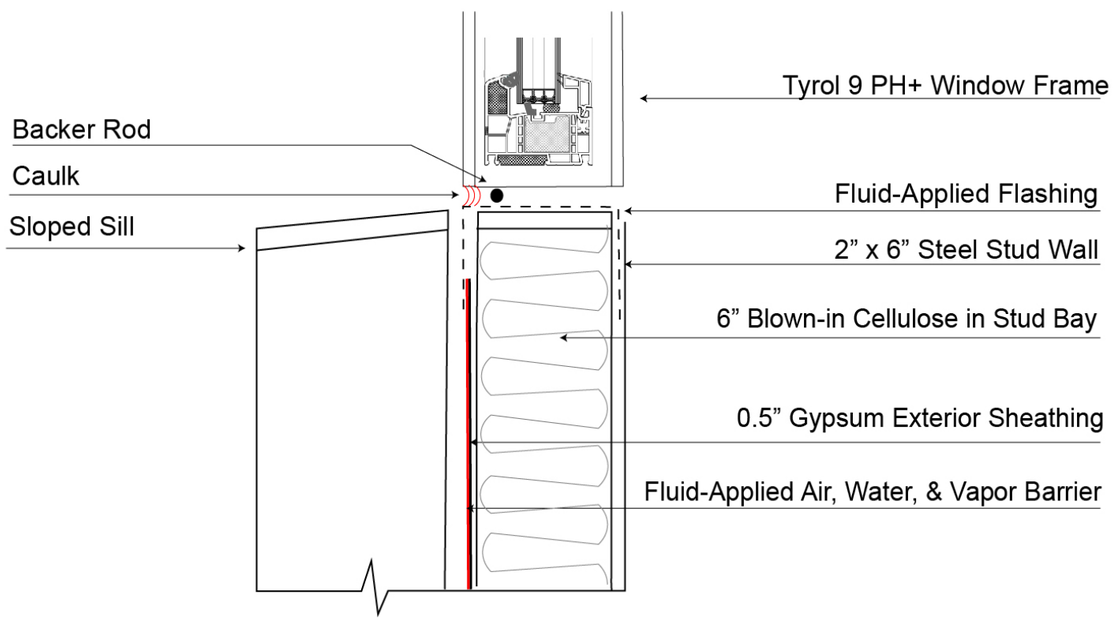


Figure 44. Window Sill Section.

Table 6. (Right) Window Schedule.

	Specification	Size (l x h)	Quantity	Remarks
South-Facing	Fixed	4' x 4'	43	Center windows in each South-facing classroom. All windows on the 2nd story South-facing wall.
	Operable Tilt Turn/Hopper	4' x 4'	32	Two outer-most windows in each South-facing classroom, all exterior windows in the Administration neighborhood.
	Fixed Daylighting	4'x 2'	77	Above all view windows. One additional window in each South-facing bathroom on the 2nd floor.
North-Facing	Fixed	4' x 4'	29	Two center windows in each North-facing 2nd floor classroom. Central window in groups of 3 on the 1st floor.
	Operable Tilt Turn/Hopper	4' x 4'	34	Outer-most windows in each North-facing classroom on the 2nd floor. Outer-most windows on the first floor groups of 3.
	Fixed Daylighting	4'x 2'	63	Above all view windows.
	Fixed	2' x 4'	2	Stairwell
East-Facing	Fixed	4' x 4'	1	Multipurpose Room
	Fixed Daylighting	4'x 2'	1	Multipurpose Room
	Fixed	2' x 4'	2	Stairwell
West-Facing	Fixed	4' 2" x 8' 2"	2	2nd floor above the main staircase to view the PV array
	Operable Tilt Turn/Hopper	4' x 4'	2	Administration neighborhood
	Fixed Daylighting	4'x 2'	2	Above view windows in Administration neighborhood

Table 7. (Right) Window Quantities and Specifications.

Specification	Quantity
Alpen Tyrol TR-9 PH+ HighGain, Fixed 4' x 4', R-8.3, SHGC = 0.35	43
Alpen Tyrol TR-9 PH+ Balanced, Fixed 4' x 4', R-9.1, SHGC = 0.24	30
Alpen Tyrol TR-9 PH+ Balanced, Fixed Non-Tempered 2' x 4', R-9.1, SHGC = 0.24	146
Alpen Tyrol TR-9 PH+ HighGain, Tilt Turn/Hopper 4' x 4', R-7.7, SHGC = 0.30	32
Alpen Tyrol TR-9 PH+ Balanced, Tilt Turn/Hopper 4' x 4', R-7.7, SHGC = 0.21	36
Alpen Tyrol TR-9 PH+ Balanced, Fixed 4' x 8', R-9.1, SHGC = 0.24	2

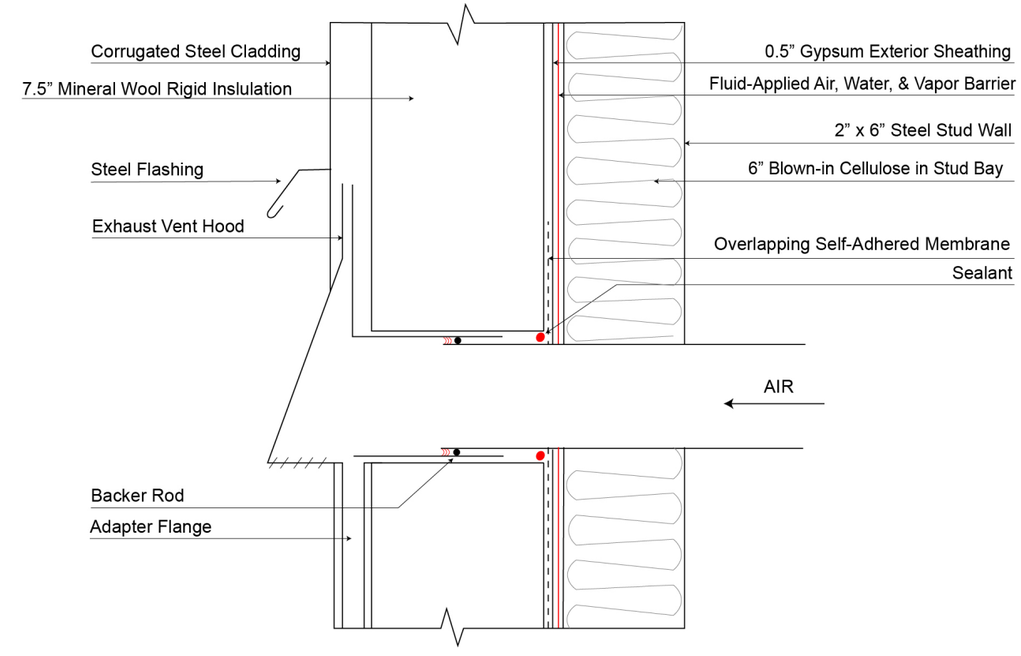


Figure 45. (Right) Vent Section. Vents are used for each VS 500 SQ classroom ventilation unit air intake and return.

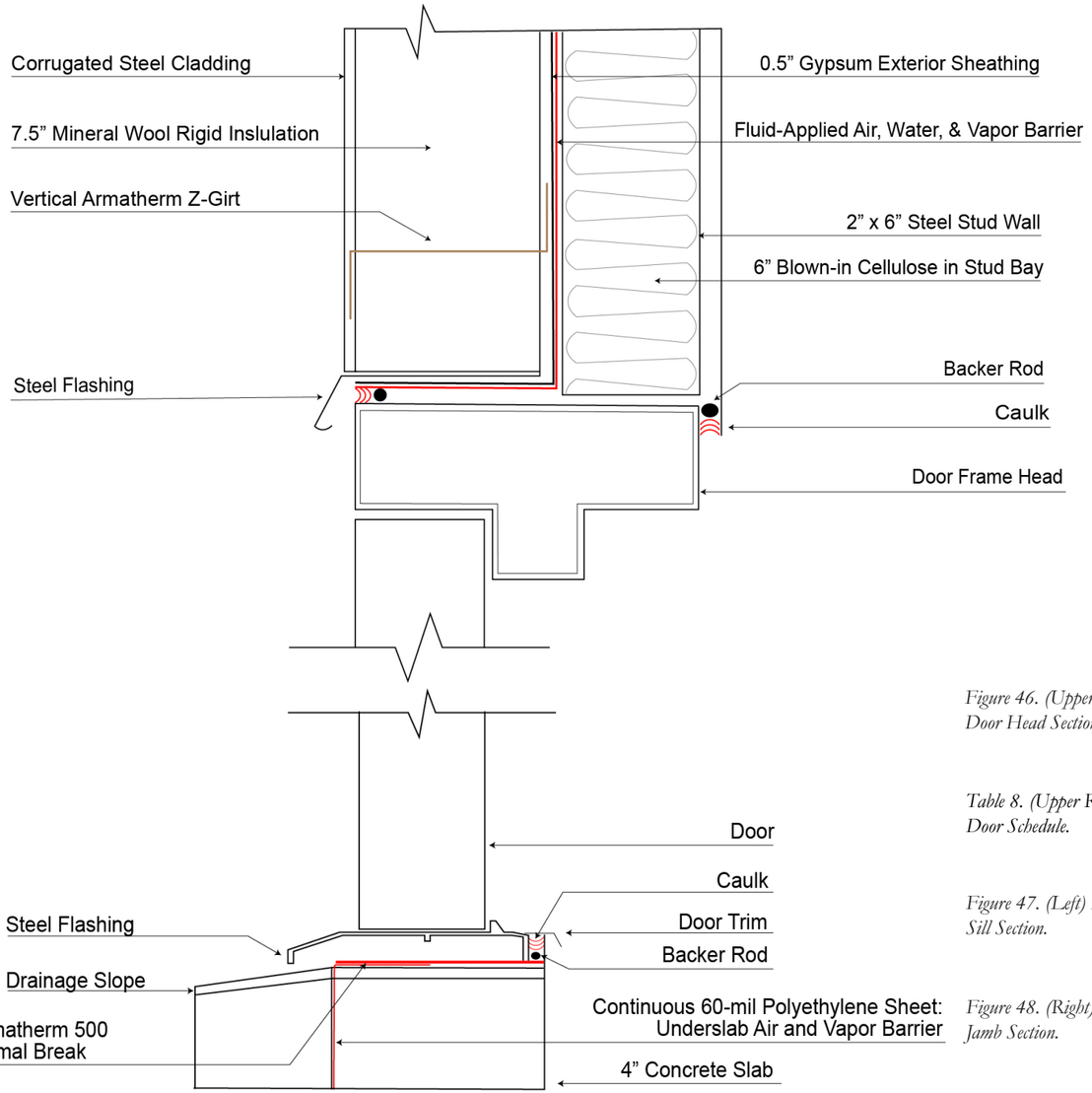


Figure 46. (Upper Left) Door Head Section.

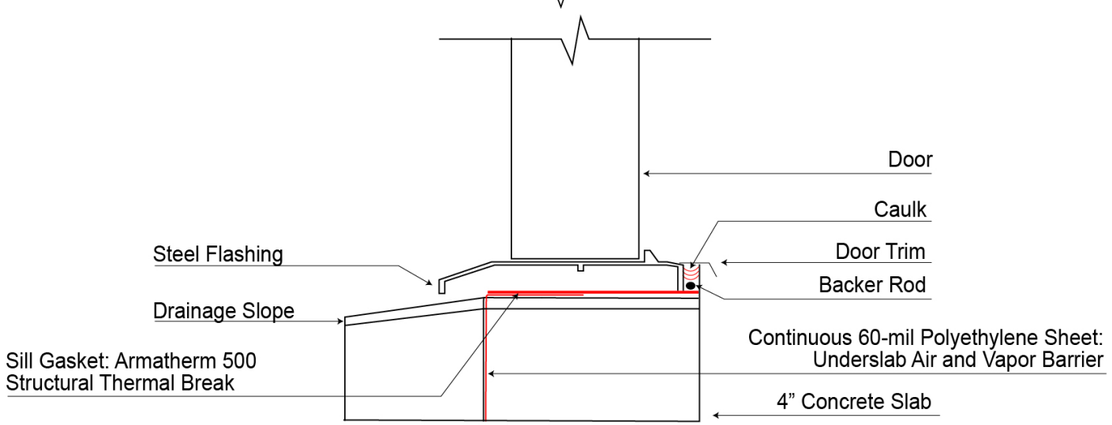
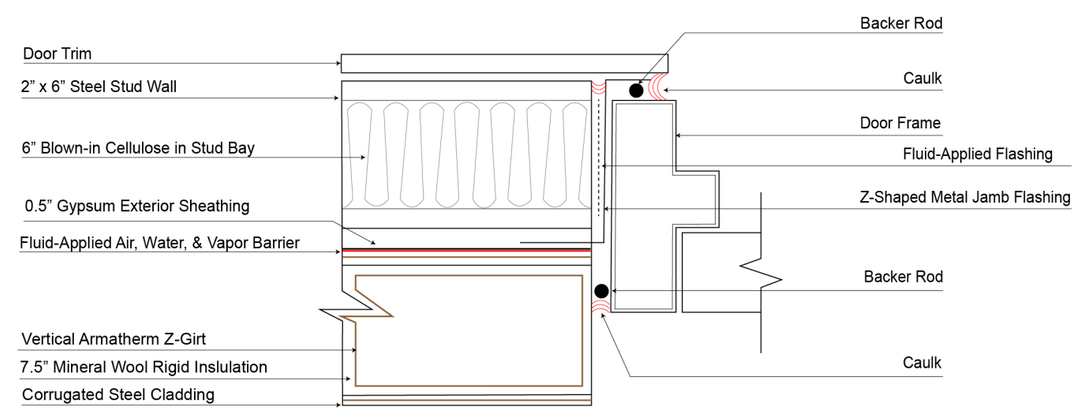


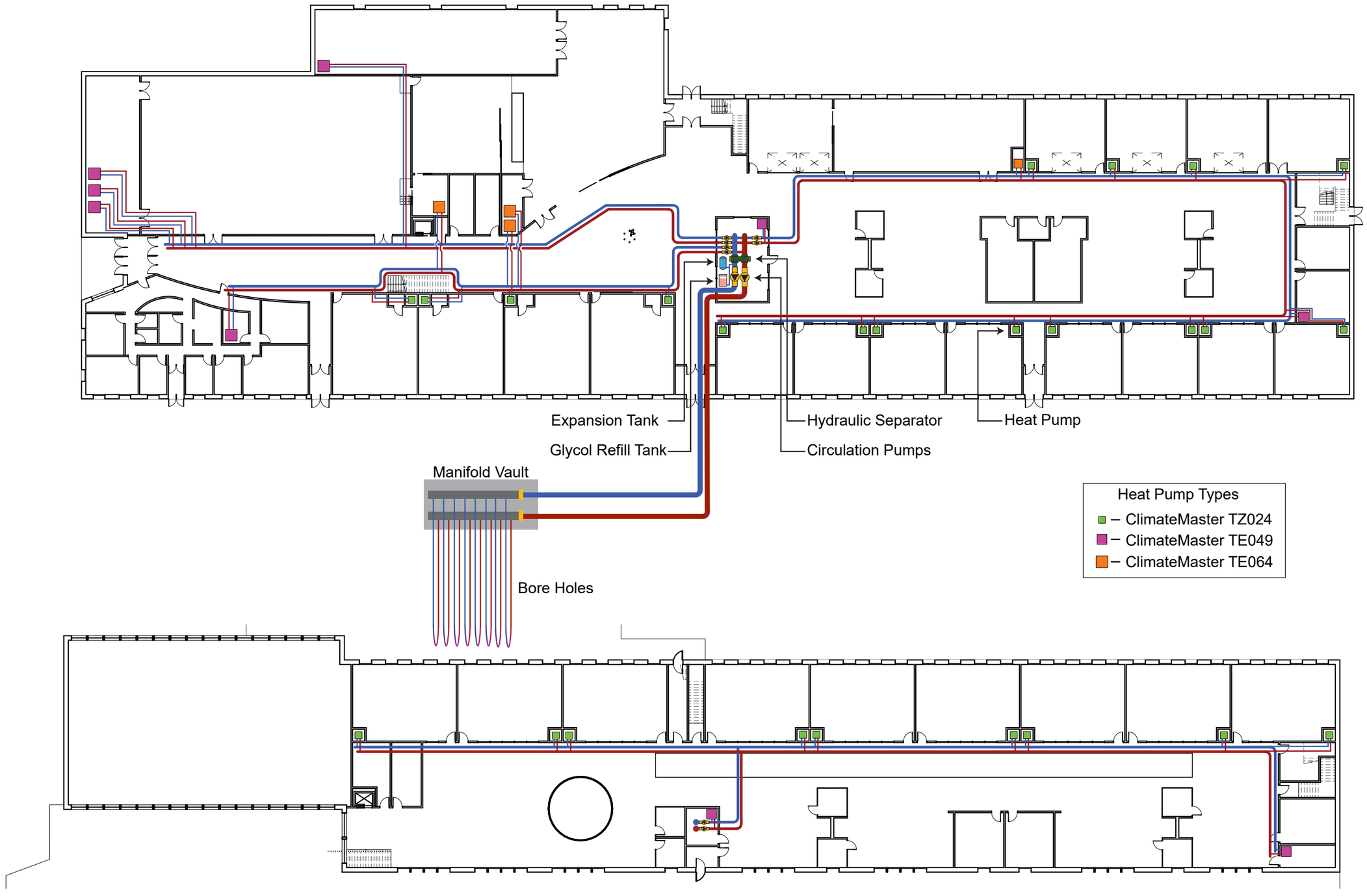
Table 8. (Upper Right) Door Schedule.

Space	Door Type	Quantity	Remarks
Admin	Interior Single Door	9	Excl. bathroom and dedicated storage doors
	Insulated Exterior Double Door	2	Exit: Center Wall Section, Panic Hardware
	Insulated Exterior Single Door	1	Remote-release lock from front desk
Classrooms	Interior Single Door with View Glass	21	
Gym	Interior 2 hr. Fire Double Doors	2	
Music Room	Sliding Partition, 34'	2	
	Interior Single Door	1	
Cafeteria	Sliding Partition, Curved, 20'	1	
	Interior 2 hr. Fire Double Doors	2	Center Mullion, Panic Hardware
Kitchen	Interior Double Doors	2	
	Insulated Exterior Double Door	1	Exit: Center Wall Section, Panic Hardware
Reading Room	Interior Single Door	1	
	8' Unpowered Overhead Garage Door	1	
	Sliding Partition, 5'	1	
Library	Interior Double Doors	1	
	Interior Single Door	1	
Flex Lab, STEM	8' Unpowered Overhead Garage Door	3	
LAB, Art Room	Interior Single Door	3	
Wet Lab	Interior Double Doors	1	
Bathrooms	Interior Single Door	15	
Closets	Interior Single Door	11	Storage and Mechanical
	Interior Double Doors	2	Gym, Cafeteria
	Insulated Exterior Single Door	1	Roof access doors, 2nd floor
Meeting Rooms	Interior Single Door	10	
Staircases	Interior 2 hr. Fire Single Door	2	Panic Hardware
	Interior 2 hr. Fire Double Door	2	Center Mullion, Panic Hardware
Main Entrance	Insulated Exterior Double Doors	4	Center Wall Section, Panic Hardware
South Exits	Insulated Exterior Double Doors	6	Center Wall Section, Panic Hardware
East Exit	Insulated Exterior Double Doors	1	Center Wall Section, Panic Hardware
North Exit	Insulated Exterior Double Doors	1	Center Wall Section, Panic Hardware

Figure 47. (Left) Door Sill Section.

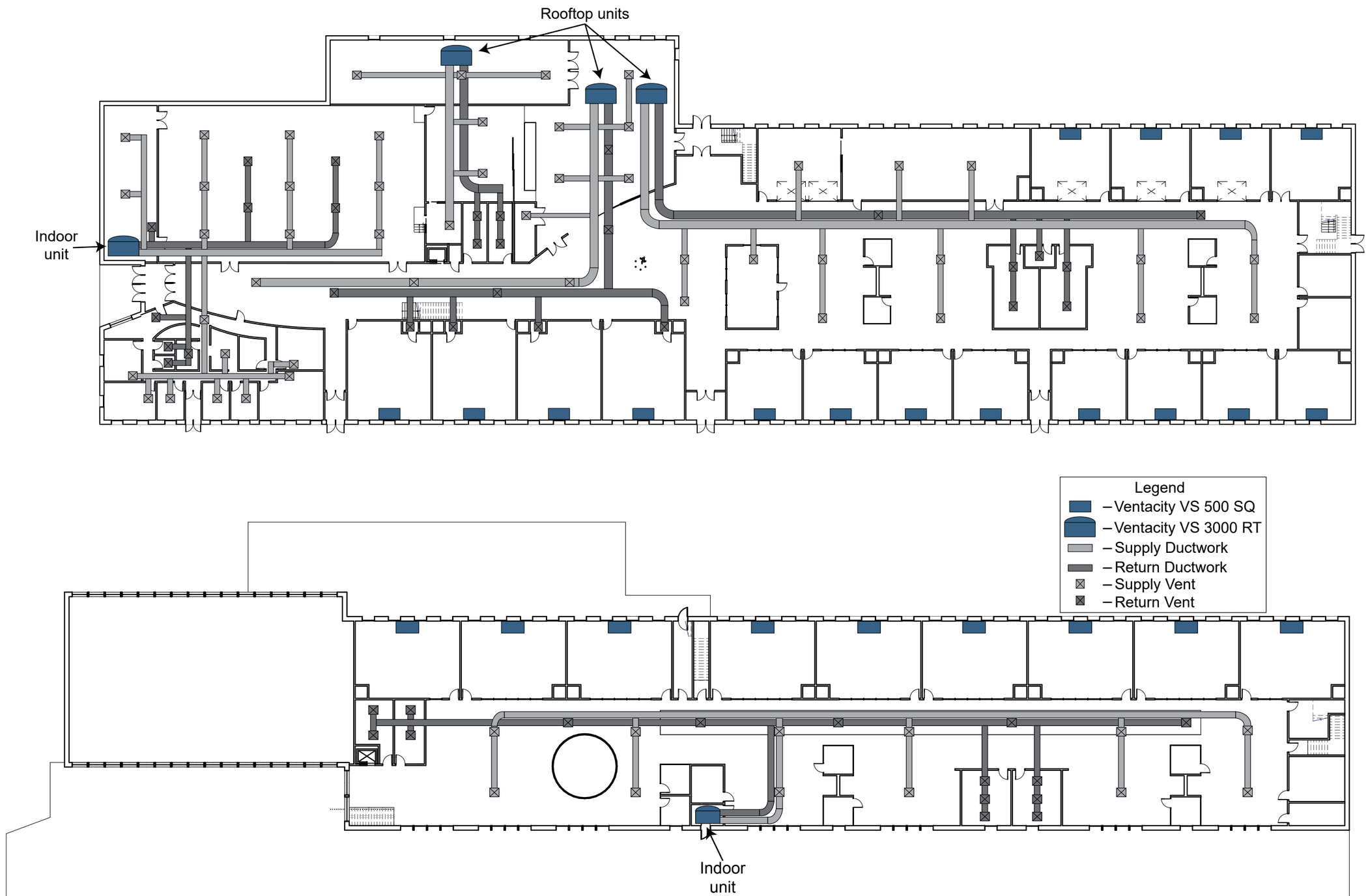
Figure 48. (Right) Door Jamb Section.



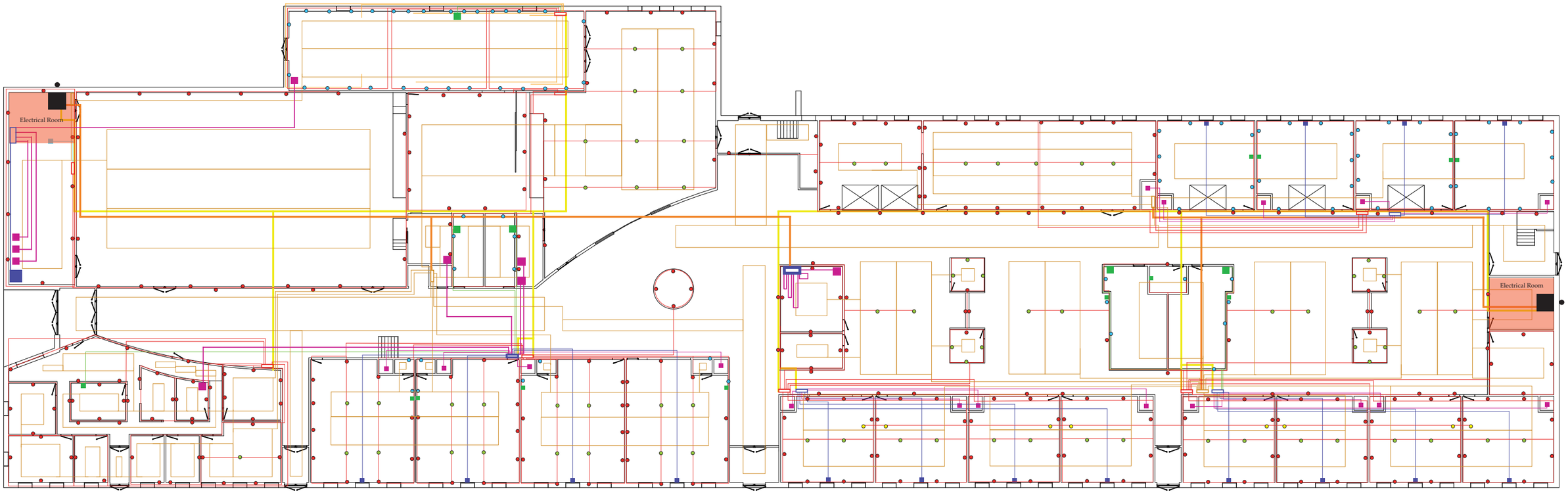


Ground Source Heat Pumps

Figure I



Dedicated Outdoor Air System And HRVs

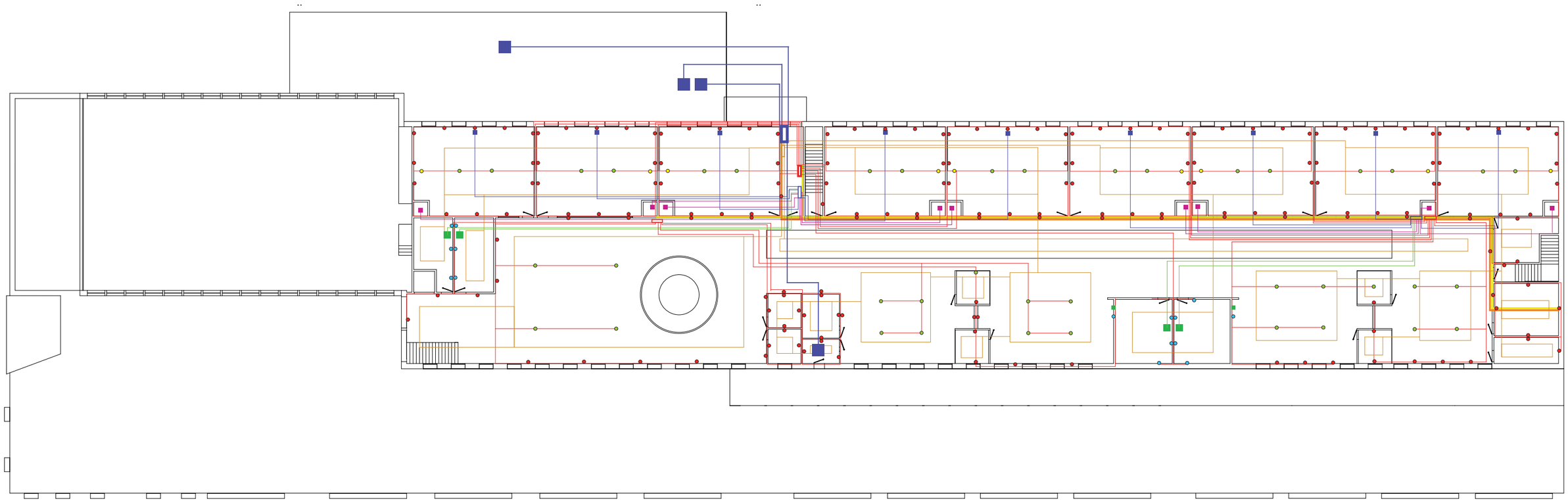


- 480/277 Feeder Lines to Breaker Panels
- 120/208 Feeder Lines to Breaker Panels
- 20 Amp Lighting Circuit, 10-Guage Wire
- 20 Amp General Purpose 1 Pole Circuit, 10-Gauge Wire, AFCI Protected
- Dedicated 20 Amp 2 Pole Heat Pump Circuit, 12-Gauge Wire, with Fuse
- Dedicated 40 Amp Heat Pump Circuit, 6-Gauge Wire, with Fuse
- Dedicated 20 Amp Ventilation 2 Pole Circuit, 10-Gauge Wire, with Fuse
- Dedicated 60 Amp Ventilation 3 Pole Circuit, 4-Gauge Wire, with Fuse
- Dedicated 30/40/60 Amp Point Source Water Heating Circuit, 8/6/4 Gauge Wire
- Dedicated 20 Amp Kitchen Circuit, 10-Gauge Wire
- Dedicated 20 Amp Air Compressor / Sprinkler System Circuit, 10-Gauge Wire, with Fuse

- 3 phase power transformer
- 100 Amp 3 Phase Power 120/208 General Purpose Breaker Panel (each circuit single pole)
- 100 Amp 3 Phase Power 480/277 Lighting Breaker
- 100 Amp 3 Phase Power 120/208 Small Mechanical System Breaker Panel
- 150 Amp 3 Phase Power 120/208 Small Mechanical System Breaker Panel
- 300 Amp 3 Phase Power 480/277 Large Mechanical System Breaker Panel

- 40 Amp Ground Source Heat Pump
- 20 Amp Ground Source Heat Pump
- 40 Amp Point Source Water Heater
- 20 Amp Point Source Water Heater
- Ventacity VS 3000 Ventilation System
- Ventacity VS 500 Ventilation System
- Leviton 20 Amp Duplex Tamper Resistant Outlet
- Leviton 20 Amp Duplex Ceiling Outlet
- Leviton 20 Amp Commercial Grade Self Grounding Duplex Outlet Floor Box
- Leviton 20 Amp 125-Volt Duplex Self-Test Tamper Resistant GFCI Outlet

First Floor Electrical System Plan



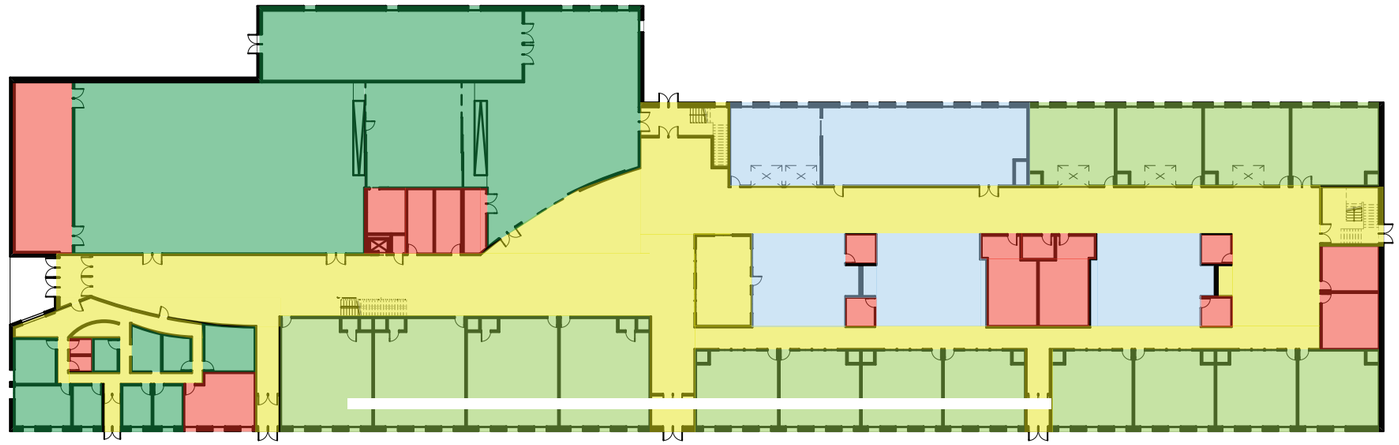
- 480/277 Feeder Lines to Breaker Panels
- 120/208 Feeder Lines to Breaker Panels
- 20 Amp Lighting Circuit, 10-Guage Wire
- 20 Amp General Purpose 1 Pole Circuit, 10-Gauge Wire, AFCI Protected
- Dedicated 20 Amp 2 Pole Heat Pump Circuit, 12-Gauge Wire, with Fuse
- Dedicated 40 Amp Heat Pump Circuit, 6-Gauge Wire, with Fuse
- Dedicated 20 Amp Ventilation 2 Pole Circuit, 10-Gauge Wire, with Fuse
- Dedicated 60 Amp Ventilation 3 Pole Circuit, 4-Gauge Wire, with Fuse
- Dedicated 30/40/60 Amp Point Source Water Heating Circuit, 8/6/4 Gauge Wire
- Dedicated 20 Amp Kitchen Circuit, 10-Gauge Wire
- Dedicated 20 Amp Air Compressor / Sprinkler System Circuit, 10-Gauge Wire, with Fuse

- 3 phase power transformer
- 100 Amp 3 Phase Power 120/208 General Purpose Breaker Panel (each circuit single pole)
- 100 Amp 3 Phase Power 480/277 Lighting Breaker
- 100 Amp 3 Phase Power 120/208 Small Mechanical System Breaker Panel
- 150 Amp 3 Phase Power 120/208 Small Mechanical System Breaker Panel
- 300 Amp 3 Phase Power 480/277 Large Mechanical System Breaker Panel

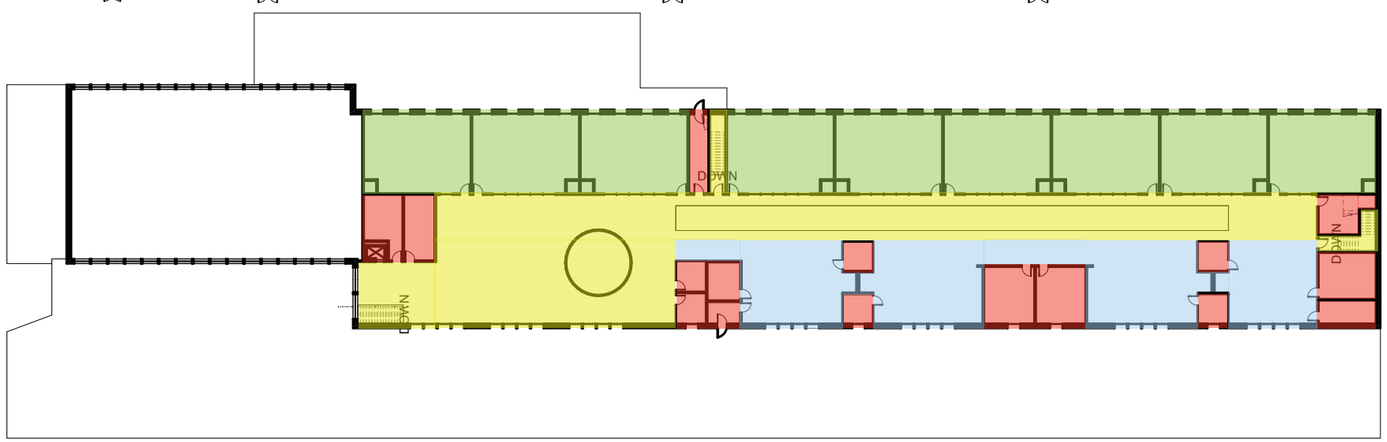
- 40 Amp Ground Source Heat Pump
- 20 Amp Ground Source Heat Pump
- 40 Amp Point Source Water Heater
- 20 Amp Point Source Water Heater
- Ventacity VS 3000 Ventilation System
- Ventacity VS 500 Ventilation System
- Leviton 20 Amp Duplex Tamper Resistant Outlet
- Leviton 20 Amp Duplex Ceiling Outlet
- Leviton 20 Amp Commercial Grade Self Grounding Duplex Outlet Floor Box
- Leviton 20 Amp 125-Volt Duplex Self-Test Tamper Resistant GFCI Outlet

Second Floor Electrical System Plan

First Floor



Second Floor



Centrally Contolled Corridor Lighting, Single Master Switch in Administration Zone

Individual Classrooms, Lights and Outlets Controlled by Insteon 6 Button Wall Keypad

Individual Rooms Controlled by Single Insteon Dimmable Light Switch

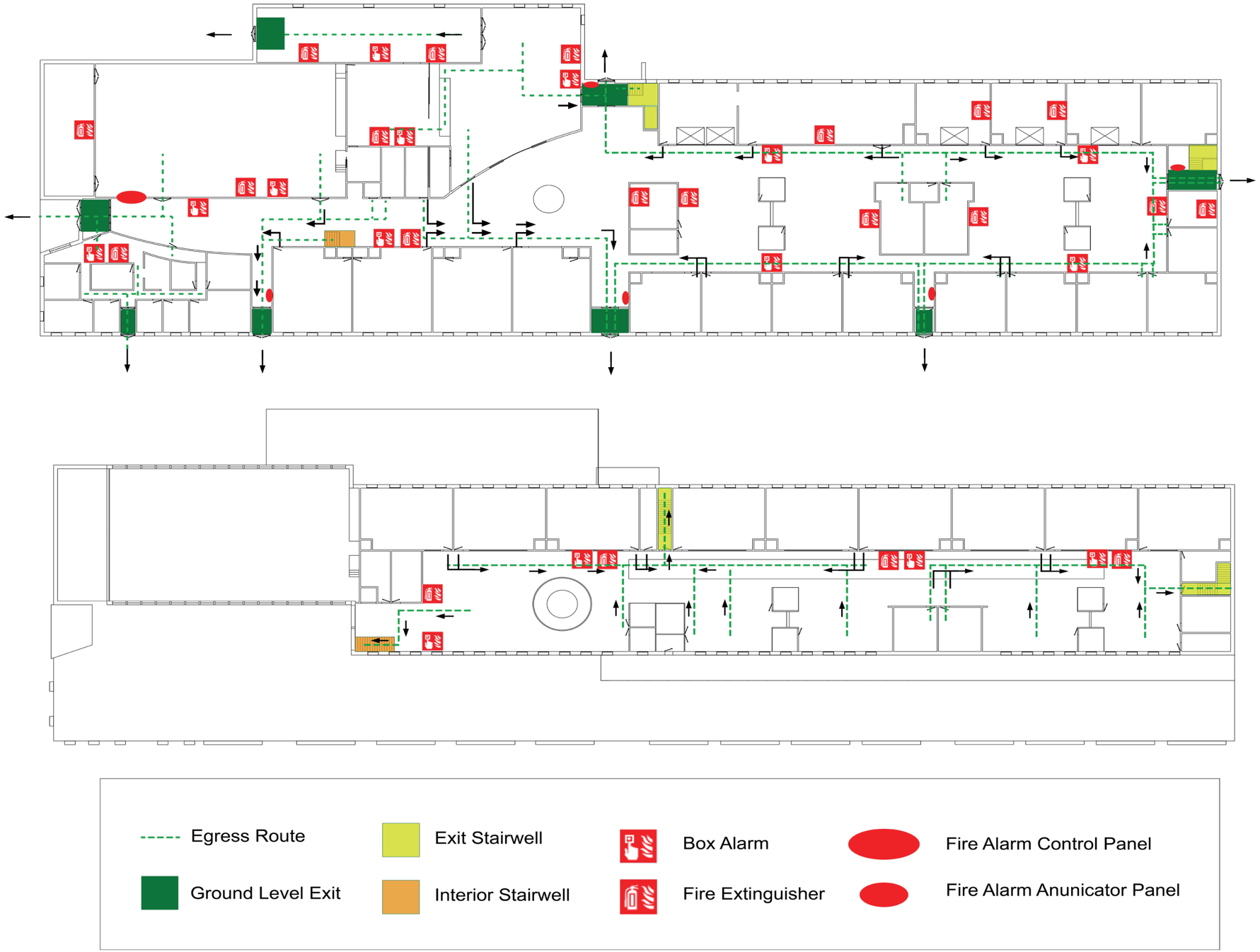
Common Spaces, Lighting Controlled by Insteon 6 Button Wall Keypad

Individual Rooms, Lighting Controlled by Lutron 30 Minute Sensor Switches

Lighting Zones

Heating and Cooling Zones

Heating Load (kBtu/h)
Cooling Load (kBtu/h)



Fire Protection Plan

Space	Fixture Type	Spec	per Room	# of Rooms	# of Fixtures	LPD (W/ft2)	Avg. Lux	Remarks
1st Floor Collaboration	Flat panel suspended	Lithonia EPANL 2' x 2	12	4	48	0.38	381	8' AFH, LHE model, 35K
2nd Floor Collaborative Space	Flat panel suspended	Lithonia EPANL 2' x 2	12	4	48	0.38	381	8' AFH, LHE model, 35K
Collaboration Space Meeting Rooms	Flat panel suspended	Lithonia EPANL 2' x 2	2	10	20	0.53	375	8' AFH, LHE model, 35K
Library	Flat panel suspended	Lithonia EPANL 2' x 2	24	1	24	0.38	377	8' AFH, LHE 35K
Administration	Flat panel suspended	Lithonia EPANL 2' x 2	35	1	35	0.34	415	8' AFH, LHE 35K
Front Entrance Corridor	Flat panel suspended	Lithonia EPANL 2' x 2	24	1	24	0.25	264	10.5' AFH, LHE model, 35K
Town Square (Lobby)	Flat panel suspended	Lithonia EPANL 2' x 2	24	1	24	0.46	470	10.5' AFH, LHE 35K
Mechanical Rooms	Flat panel suspended	Lithonia EPANL 2' x 2	5	4	20	0.32	300	8' AFH, LHE 35K
Restrooms	Flat panel suspended	Lithonia EPANL 2' x 2	6	8	48	0.4	339	8' AFH, LHE 35K
K Classrooms	Linear Suspended Indirect/Direct	Lithonia Grad Linear 4' 800L	15	4	60	0.36	331	8' AFH, 80/20, 27K
1st, 2nd Grade Classrooms	Linear Suspended Indirect/Direct	Lithonia Grad Linear 4' 800L	10	8	80	0.38	324	8' AFH, 80/20, 27K
3rd, 4th, 5th Grade Classrooms	Linear Suspended Indirect/Direct	Lithonia Grad Linear 4' 800L	14	9	126	0.4	353	8' AFH, 80/20, 27K
Lab spaces & Library Reading Room	Linear Suspended Indirect/Direct	Lithonia Grad Linear 4' 800L	12	5	60	0.43	301	8' AFH, 80/20, 27K
Music Room	Linear Suspended Indirect/Direct	Lithonia Grad Linear 4' 800L	18	5	90	0.38	316	12.5' AFH, 27K
Gym	Low Bay Suspended	Lithonia MSL 20,000L	12	1	12	0.42	306	20' AFH, 30K
Multipurpose Room	Low Bay Suspended	Lithonia MSL 8,000L	21	1	21	0.38	348	10.5' AFH, 30K
Kitchen	Low Bay Suspended	Lithonia MSL 8,000L	12	1	12	0.38	402	8.5' AFH, 30K

Table 9. Luminaire Schedule.

Fixture	Total Count
Lithonia EPANL 2' x 2'	291
Lithonia Grad Linear 4' 800L	416
Lithonia MSL 8,000L	33
Lithonia MSL 20,000L	12

Table 10. Luminaire Counts..

Space	Fixture Type	Quantity	Location
Lower Pods Male Bathroom	EcoSmart Eco 18 Point Source Water Heater	1	Beneath middle sink
	American Standard Lucerne wall mounted sink right faucet hole	3	West wall across from stalls, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	3	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	4	East wall, 1 in 5x5 stall, rest in 3x5 stalls
	Sloan Wes 1000 Waterless Urinal	2	South wall across from stalls, equally spaced, 1 ADA acessible
Lower Pods Female Bathroom	EcoSmart Eco 18 Point Source Water Heater	1	Beneath middle sink
	American Standard Lucerne wall mounted sink right faucet hole	3	East wall, across from stalls, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	5	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	5	West wall, 1 in 5x5 stall, rest in 3x5 stalls
Lower Pods Single Bathroom	EcoSmart POU 6 Point Source Water Heater	1	West wall, beneath sink
	American Standard Lucerne wall mounted sink right faucet hole	1	West wall, centered, ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	1	Fitted to sink
	Toto Ultra Max II Low Flush Toilet	1	South wall, Centered, with ADA rails
Lower Pod Common Spaces	EcoSmart POU 6 Point Source Water Heater	2	Beneath each sink
	Just Manufacturing CRACF -ADA-1923-A-GR-VRL-CT classroom sink, faucet/tap included	2	One on the outside of west and east walls of lower pod bathrooms
Cafeteria Male Bathroom	EcoSmart Eco 11 Point Source Water Heater	1	In between both sinks
	Lucerne wall mounted sink right faucet hole	2	West wall, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	2	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	3	East wall, 1 in 5x5 stall, rest in 3x5 stalls
	Sloan Wes 1000 Waterless Urinal	1	East wall, closer to door than stalls, ADA accessible
Cafeteria Female Bathroom	EcoSmart Eco 11 Point Source Water Heater	1	In between both sinks
	Lucerne wall mounted sink right faucet hole	2	East wall, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	2	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	4	West wall, 1 in 5x5 stall, rest in 3x5 stalls
Admin Single Bathroom w/ Shower	EcoSmart Eco 18 Point Source Water Heater	1	On south wall, between sink and shower
	Lucerne wall mounted sink right faucet hole	1	On south wall, centered, ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	1	Fitted to sink
	Toto Ultra Max II Low Flush Toilet	1	North wall, centered with ADA rails
	High Sierra 1.5 GPM High Efficiency Low Flow Shower Head	1	In shower, east wall
Admin Single Bathroom w/o Shower	EcoSmart POU 6 Point Source Water Heater	1	Beneath sink
	Lucerne wall mounted sink right faucet hole	1	South wall, centered, ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	1	Fitted to sink
	Toto Ultra Max II Low Flush Toilet	1	East wall, centered with ADA rails
Upper Pods South Male Bathroom	EcoSmart Eco 11 Point Source Water Heater	1	Between both sinks
	Lucerne wall mounted sink right faucet hole	2	East wall, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	2	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	4	West wall, 1 in 5x5 stall, rest in 3x5 stalls
	Sloan Wes 1000 Waterless Urinal	2	West wall, north of stalls, 1 ADA accessible
Upper Pods South Female Bathroom	EcoSmart Eco 11 Point Source Water Heater	1	Between both sinks
	Lucerne wall mounted sink right faucet hole	2	West wall, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	2	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	5	East wall, 1 in 5x5 stall, rest in 3x5 stalls
Upper Pod Common Spaces	EcoSmart POU 6 Point Source Water Heater	2	One on the outside of west and east walls of upper pod bathrooms
	Lucerne wall mounted sink right faucet hole	2	Fitted to each sink
	Just Manufacturing CRACF -ADA-1923-A-GR-VRL-CT, classroom sink, faucet/tap included	2	One on the outside of west and east walls of lower pod bathrooms
Upper Pods West Male Bathroom	EcoSmart Eco 11 Point Source Water Heater	1	Between both sinks
	Lucerne wall mounted sink right faucet hole	2	East wall, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	2	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	3	West wall, 1 in 5x5 stall, rest in 3x5 stalls
	Sloan Wes 1000 Waterless Urinal	1	West wall, south of stalls
Upper Pods West Female Bathroom	EcoSmart Eco 11 Point Source Water Heater	1	Between both sinks
	Lucerne wall mounted sink right faucet hole	2	West wall, 1 ADA accessible
	American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	2	Fitted to each sink
	Toto Ultra Max II Low Flush Toilet	4	East wall, 1 in 5x5 stall, rest in 3x5 stalls
Wet Lab / Art Room / STEM / Flex Lab	EcoSmart POU 6 Point Source Water Heater	4	Beneath each sink
	Just Manufacturing ARB-2435-A-GR-T Art Room Sink	4	Centered east wall STEM and flex labs, west wall art and wet lab
	American Standard Monterrey 4" Centerset Gooseneck Faucet	4	Fitted to each sink
Kitchen	EcoSmart Eco 27 Point Source Water Heater	1	Equidistant to each commercial sink, north wall
	EcoSmart POU 6 Point Source Water Heater	1	Beneath handwashing sink, north-east corner
	Just Manufacturing NSFB-345 3-Compartment Commercial Kitchen Sink	2	North wall, equally spaced between counters
	Just Manufacturing JPR-309 Commercial Sink Faucet	2	Fitted to each commercial kitchen sink
	Just Manufacturing CRACF -ADA-1923-A-GR-VRL-CT	1	North-east corner, handwashing sink
Kindergarten Classrooms	EcoSmart POU 6 Point Source Water Heater	4	Beneath each sink
	Just Manufacturing CRACF -ADA-1923-A-GR-VRL-CT, Faucet/tap included	4	Outside each single bathroom, east/west wall by bathroom, ADA
	Toto Ultra Max II Low Flush Toilet	4	Inside each single bathroom
Whole Building	Elkay EDF 15R Non-Refrigerated Drinking Fountains	3	Outside cafeteria, flex lab, and across from 2nd floor south bathroo

Fixture Type	Total
EcoSmart POU 6 Point Source Water Heater	15
EcoSmart Eco 11 Point Source Water Heater	6
EcoSmart Eco 18 Point Source Water Heater	3
EcoSmart Eco 27 Point Source Water Heater	1
Toto Ultra Max II Low Flush Toilet	39
Sloan Wes 1000 Waterless Urinal	5
American Standard Lucerne wall mounted sink right faucet hole	21
American Standard 0.5 GPM Innsbrook Electronic Proximity Faucet	21
High Sierra 1.5 GPM High Efficiency Low Flow Shower Head	1
Just Manufacturing CRACF -ADA-1923-A-GR-VRL-CT, classroom sink, faucet/tap included	9
Just Manufacturing ARB-2435-A-GR-T Art Room Sink	4
American Standard Monterrey 4" Centerset Gooseneck Faucet	4
Just Manufacturing NSFB-345 3-Compartment Commercial Kitchen Sink	2
Just Manufacturing JPR-309 Commercial Sink Faucet	1
Elkay EDF 15R Non-Refrigerated Drinking Fountains	3

Table 11. (Left) Plumbing Fixture Schedule.

Table 12. (Above) Plumbing Fixture Count.

Team Name	MiddZEST
Contest Category	Elementary School

Construction Cost Summary		
	RSMeans Estimate	**Team Estimate**
General Requirements	$ 4,404,693.89	$ 5,703,388.55
Substructure	$ 1,376,916.40	$ 1,376,916.40
Shell	$ 9,953,698.35	$ 10,260,294.15
Interiors	$ 911,517.13	$ 1,006,913.13
Services	$ 64,567.10	$ 3,720,996.10
Structure	$ 1,457,969.44	$ 1,457,969.44
Total Construction Costs	**$ 13,764,668.41**	**$ 17,823,089.21**
Total Project Costs	**$ 18,169,362.30**	**$ 23,526,477.75**

Project Summary Elementary School	
Sq. Ft	71,595
State	Vermont
City	Middlebury
Cost per Square Foot	$ 248.94
Location Factor compared to National Avg:	93.70%

Note: wherever possible, we completed our analysis using data from RSMeans. However, the unique design of our school meant that some of the items that we needed to make our vision a reality were not always available in standard cost databases. As a result, we were forced to look for cost data online or by directly contacting manufacturers. Whenever we did so, we made sure to factor any additional costs (e.g installation, overhead, etc.) into our analysis. Specifically, we assumed that an item's list price was only 60% of its final cost. Additionally, we included links to all of our external sources in an attempt to make our analysis as transparent as possible. Finally, our construction cost analysis differed from the template provided in that we expensed every item using the exact quantities needed as opposed to doing it as a function of the whole building's square footage. For example, since we had 52,046 square feet of exterior wall, we calculated the cost of all the exterior wall components using that measure as opposed to the school's square footage. We believe this allowed us to calculate the construction costs more accurately and avoid the risk of misrepresenting the expenses associated with our design.

Assemblies Category - Name	RS Means Line No.	Quantity (units)	Unit	Estimated Cost per Unit 2014	per Unit - Adjusted for escalation and location	RSMeans Estimated Subtotal	Team Estimate Cost Per Unit		Notes Required?	Justification/Notes (Required for values different than RSMeans Estimate)
Substructure				**$3,984.94**	**$3,931.78**	**$1,376,916.40**	**$3,931.78**	**$1,376,916.40**		
Footings: Concrete in place, including forms (40 uses), grade 60 rebar, concrete (Portland cement Type	03 30 53.40 0300	62.51	C.Y.	$1,325.00	$1,307.33	$81,720.94	$1,307.33	$81,720.94	NO	
Footings: Rigid insulation, Extruded polystyrene, 25 PSI compressive strength, 2" thick R10	07 21 13.10 1940	846	S.F.	$1.94	$1.91	$1,619.35	$1.91	$1,619.35	NO	
Footings: Armathon 500 thermal break	-	47	Ea.	-	-	-	-	-	-	
Underslab: Rigid insulation, Extruded polystyrene, 25 PSI compressive strength, 4" thick R20	07 21 13.10 1940	51570	S.F.	$3.88	$3.83	$197,422.58	$3.83	$197,422.58	NO	
Footings: Stormwater collection, polyvinyl chloride pipe, 20' lengths, SDR 35, B&S, 4" diameter	33 31 13.25 0200	2540	L.F.	$0.28	$0.28	$707.98	$0.28	$707.98	NO	
Slab: Concrete in place, including forms (40 uses), grade 60 rebar, concrete (Portland cement Type I), p	03 30 53.40 0300	636	C.Y.	$1,325.00	$1,307.33	$831,459.22	$1,307.33	$831,459.22	NO	
Slab Thick Edge: Concrete in place, including forms (40 uses), grade 60 rebar, concrete (Portland cemer	03 30 53.40 0300	63.44	C.Y.	$1,325.00	$1,307.33	$82,936.75	$1,307.33	$82,936.75	NO	
Slab: General fill, gravel fill, compacted, under floor slabs, 4" deep	31 23 23.17 0500	51570	S.F.	$0.77	$0.76	$39,179.22	$0.76	$39,179.22	NO	
Underslab: Stormwater collection, polyvinyl chloride pipe, 20' lengths, SDR 35, B&S, 4" diameter	33 31 13.25 0200	1500	L.F.	$0.28	$0.28	$418.10	$0.28	$418.10	NO	
Slab: Polyethelene Sheet, 60-mil	07 13 53.10 2200	51570	S.F.	$2.78	$2.74	$141,452.26	$2.74	$141,452.26		
Shells				**$4,608.86**	**$4,547.38**	**$9,953,698.35**	**$13,058.44**	**$10,260,294.15**		
Roof: EPDM, 60 mils, 0.40 psf, loose-laid & ballasted with stone (10psf)	07 53 23.20 4600	51425	S.F.	$160.00	$157.87	$8,118,246.71	$157.87	$8,118,246.71	NO	
Roof: Roof decking, made from recycled materials, open type, 3" deep, type N, 22 ga., 50-500 squares	05 31 23.50 3250	51425	S.F.	$3.36	$3.32	$170,483.18	$3.32	$170,483.18	NO	
Roof: Gypsum sheathing, gypsum, weatherproof, 1/2" thick	06 16 43.10 0020	51425	S.F.	$1.49	$1.47	$75,601.17	$1.47	$75,601.17	NO	
Roof: Mineral wool insulation (18.75")	-	51425	S.F.	$5.06	$4.99	$256,739.55	$4.99	$256,739.55	NO	
Roof: Fluid-applied membrane air barrier, spray applied vapor barrier, 25 S.F./gallon	07 27 26.10 0100	51425	S.F.	$0.37	$0.37	$18,773.45	$0.37	$18,773.45	NO	
Roof: Sheet metal flashing and counter flashing, including up to 4 bends, steel sheets, galvanized, 26 ga	07 65.10.10 9326	2463.75	S.F.	$4.56	$4.50	$11,084.84	$4.50	$11,084.84	NO	
Roof: Oriented Strand Board factory laminated WR Barrier 1/2" thick, on roof	06 16 36.10 4700	51425	S.F.	$1.49	$1.47	$75,601.17	$1.47	$75,601.17	NO	
Roof: Sleepers treated 2" x 4"	06 11 10.34 0340	10	M.B.F	$2,100.00	$2,071.99	$20,719.88	$2,071.99	$20,719.88	NO	
Windows, doors, and vents: Sheet metal flashing and counter flashing, including up to 4 bends, steel sh	07 65.10.10 9328	4000	S.F.	$4.20	$4.14	$16,575.90	$4.14	$16,575.90	NO	
Roof: Backer rod, polyethylene, 1" diameter	07 91 23.10 0090	1314	L.F.	$1.31	$1.29	$1,698.38	$1.29	$1,698.38	NO	
Roof: Solatube	-	30	Ea.	-	-	-	$1,126.06	$33,781.80	YES	Quote from manufacturer.
Exterior walls: Partition wall, stud wall, 8" to 12" high; exterior, 1/2" gypsum sheathing, 1/2" gypsum fir	09 21 16.33 9400	52045.8	S.F.	$6.35	$6.27	$326,082.41	$6.27	$326,082.41	NO	
Exterior walls: Poured loose-fill insulation, cellulose fiber, R3.8 per inch, 6" thick	07 21 23.10 0022	52045.8	S.F.	$1.02	$1.01	$52,378.59	$1.01	$52,378.59	NO	
Exterior walls: Fluid-applied membrane air barrier, spray applied vapor barrier, 25 S.F./gallon	07 27 26.10 0100	52045.8	S.F.	$0.37	$0.37	$19,000.08	$0.37	$19,000.08	NO	
Exterior walls: Mineral wool insulation (7.5")	07 21 23.10 0100	52045.8	S.F.	$2.03	$2.00	$104,243.67	$2.00	$104,243.67	NO	
Exterior walls: Steel siding, galv, corrugated or ribbed, on steel frame, 30 ga.	07 42 13.30 0080	52045.8	S.F.	$4.24	$4.18	$217,730.62	$4.18	$217,730.62	NO	
Exterior walls: Furring, wood strips, 1" X 2", on walls, on wood	06 11 10.42 0012	7435	L.F.	$1.29	$1.27	$9,463.21	$1.27	$9,463.21	NO	
Exterior walls: Steel louvers, 18 gauge, fixed blade, 12" X 12", galvanized	08 91 26.10 0100	25	Ea.	$100.00	$98.67	$2,466.65	$98.67	$2,466.65	NO	
Parapet: Partition wall, stud wall, 8" to 12" high; exterior, 1/2" gypsum sheathing, 1/2" gypsum finished	09 21 16.33 9400	6680	S.F.	$6.35	$6.27	$41,852.19	$6.27	$41,852.19	NO	
Parapet: Fluid-applied membrane air barrier, spray applied vapor barrier, 25 S.F./gallon	07 27 26.10 0100	6680	S.F.	$0.37	$0.37	$2,438.63	$0.37	$2,438.63	NO	
Parapet: Poured loose-fill insulation, cellulose fiber, R3.8 per inch, 6" thick	07 21 23.10 0022	6680	S.F	$1.02	$1.01	$6,722.71	$1.01	$6,722.71	NO	
Parapet: Steel siding, galv, corrugated or ribbed, on steel frame, 30 ga.	07 42 13.30 0080	6680	S.F	$4.24	$4.18	$27,945.40	$4.18	$27,945.40	NO	
Parapet: Fluid-applied membrane air barrier, spray applied vapor barrier, 25 S.F./gallon	07 27 26.10 0100	4600	S.F.	$0.37	$0.37	$1,679.30	$0.37	$1,679.30	NO	
Parapet cap: Poured loose-fill insulation, cellulose fiber, R3.8 per inch, 6" thick	07 21 23.10 0022	2956.5	S.F	$1.02	$1.01	$2,975.40	$1.01	$2,975.40	NO	
Exterior Doors: Standard hollow metal doors, insulated, 1-3/4" thick, full panel, 18 ga. 3'-0" X 7'-0'	08 13 13.13 1760	33	Ea.	$615.00	$606.80	$20,024.28	$606.80	$20,024.28	NO	
Exterior Doors: Standard hollow metal doors, vision lite	08 13 13.13 2000	33	Ea.	$104.00	$102.61	$3,386.22	$102.61	$3,386.22	NO	
Expansion control: Expansion joint assemblies, floor cover assemblies, 1" space, aluminum	07 95 13.50 0200	114	L.F.	$43.00	$42.43	$4,836.61	$42.43	$4,836.61	NO	
Expansion control: Expansion joint assemblies, wall and ceiling assemblies, 1" space, aluminum	07 95 13.50 0800	170	L.F.	$33.00	$32.56	$5,535.17	$32.56	$5,535.17	NO	
Exterior Windows: Alpen Tyrol TR-9 PH+ Balanced, Fixed 4' X 8', R-9.1, SHGC = 0.24	-	2	Ea.	-	-	-	$2,000.00	$4,000.00	YES	Quote from manufacturer.
Exterior Windows: Alpen Tyrol TR-9 PH+ HightGain, Tilt Turn/Hopper 4' X 4', R-7.7, SHGC = 0.30	-	32	Ea.	-	-	-	$1,250.00	$40,000.00	YES	Quote from manufacturer.
Exterior Windows: Alpen Tyrol TR-9 PH+ HightGain, Fixed 4' X 4', R-8.3, SHGC = 0.35	-	43	Ea.	-	-	-	$1,084.00	$46,612.00	YES	Quote from manufacturer.
Exterior Windows: Alpen Tyrol TR-9 PH+ Balanced, Tilt Turn/Hopper 4' X 4', R-7.7, SHGC = 0.31	-	36	Ea.	-	-	-	$1,250.00	$45,000.00	YES	Quote from manufacturer.
Exterior Windows: Alpen Tyrol TR-9 PH+ Balanced, Fixed 4' X 4', R-9.1, SHGC = 0.24	-	30	Ea.	-	-	-	$1,084.00	$32,520.00	YES	Quote from manufacturer.
Exterior Windows: Alpen Tyrol TR-9 PH+ Balanced, Fixed Non-Tempered 2' X 4', R-9.1, SHGC = 0.24	-	146	Ea.	-	-	-	$717.00	$104,682.00	YES	Quote from manufacturer.
Exterior Windows: Skyroofs, translucent panels, 2-3/4" thick, ridge and furrow units, over 4' O.C., doub	08 45 10.10 2750	128	SF Hor.	$75.50	$74.49	$9,535.09	$74.49	$9,535.09	NO	
Floor: Floor decking, made from recycled materials, non-cellular composite decking, galvanized, 2" dee	05 31 13.50 5200	22116	S.F.	$2.85	$2.81	$62,189.83	$2.81	$62,189.83	NO	
2nd Floor Slab: Concrete in place, including forms (40 uses), grade 60 rebar, concrete (Portland cement	03 30 53.40 0300	204.76	C.Y.	$1,325.00	$1,307.33	$267,688.04	$1,307.33	$267,688.04	NO	
Interiors				**$8,928.85**	**$8,809.75**	**$911,517.13**	**$43,095.35**	**$1,006,913.13**		
Interior walls: Partition wall, stud wall, 8" to 12" high, 1/2", interior, gypsum board, stg, tape & finish 2	09 21 16.33 1200	82066.28	S.F.	$4.75	$4.69	$384,615.09	$4.69	$384,615.09	NO	
Interior fire doors: Metal fire doors, flush, "A" label 3 hour, egress core, 18 ga., 3'-0" X 7'-0"	08 13 13.15 0680	8	Ea.	$890.00	$878.13	$7,025.03	$878.13	$7,025.03	NO	
Interior doors: Smooth wood doors, flush, interior, hollow core, lauan face, 1-3/4", 3'-0" X 7'-0"	08 14 16.09 0108	72	Ea.	$206.00	$203.25	$14,634.16	$203.25	$14,634.16	NO	
Interior doors: Smooth wood doors, flush, interior, hollow core, lauan face, 1-3/4", pair of 3'-0" X 7'-0"	08 14 16.09 0112	10	Pr.	$240.00	$236.80	$2,367.99	$236.80	$2,367.99	NO	
Interior doors: Wood doors, vision lite	08 14 16.09 5000	92	Ea.	$104.00	$102.61	$9,440.37	$102.61	$9,440.37	NO	
Interior metal frames: Standard hollow metal frames, 16 ga., up to 5-3/4" jamb dept, 3'-0" X 7'-0" sing	08 12 13.13 0100	77	Ea.	$236.00	$232.85	$17,929.60	$232.85	$17,929.60	NO	
Interior metal frames: Standard hollow metal frames, 16 ga., up to 5-3/4" jamb dept, 6'-0" wide, doubl	08 12 13.13 0140	28	Ea.	$295.00	$291.06	$8,149.82	$291.06	$8,149.82	NO	
Garage doors: Residential garage doors, overhead, sectional, incl. hardware, fiberglass, 9' X 7', standar	08 36 13.20 0200	5	Ea.	$1,250.00	$1,233.33	$6,166.63	$1,233.33	$6,166.63	NO	
Classrooms: Whiteboards	-	21	Ea.	-	-	-	$750.00	$15,750.00	YES	https://tinyurl.com/y7zondzs
Classrooms: PowerLite 680 XGA 3LCD Presentation Display	-	21	Ea.	-	-	-	$1,517.00	$31,857.00	YES	https://tinyurl.com/yb6eqtlo
Classrooms: 3.5" wooden peg	-	420	Ea.	-	-	-	$0.60	$252.00	YES	https://tinyurl.com/y7dfvtnd
Classrooms: Plywood, 3/4" thick with lumber edge, 12" wide	-	1575	L.F.	$9.50	$9.37	$14,762.92	$9.37	$14,762.92	NO	
Art room: Whiteboards (4' X 20')	-	1	Ea.	-	-	-	$750.00	$750.00	YES	https://tinyurl.com/y7zondzs
Art room: PowerLite 680 XGA 3LCD Presentation Display	-	1	Ea.	-	-	-	$1,517.00	$1,517.00	YES	https://tinyurl.com/yb6eqtlo
Art room: Multi-Section Cabinet w/ 15 Bins	-	2	Ea.	-	-	-	$602.00	$1,204.00	YES	https://tinyurl.com/yb8rgove
Music room: Partitions, sliding, acoustic air wall, 1-5/8" thick	10 22 43.10 0020	1576	S.F.	$52.50	$51.80	$81,636.33	$51.80	$81,636.33	NO	
Cafeteria: Crathco D35-3 Triple 5 Gallon Bowl Stainless Steel Refrigerated Beverage Dispenser	-	1	Ea.	-	-	-	$2,194.00	$2,194.00	YES	https://tinyurl.com/ya22cbff
Kitchen: 23 Cu Ft Super Deluxe 1 Section Solid Door Reach In Refrigerator	-	2	Ea.	-	-	-	$3,460.00	$6,920.00	YES	https://tinyurl.com/y7922gzd
Kitchen: Maxx Cold 49-cu ft Frost-Free Freestanding Commercial Upright Freezer (Stainless Steel)	-	2	Ea.	-	-	-	$6,417.00	$12,834.00	YES	https://tinyurl.com/ybpr2nml
Kitchen: Hoshizaki CR2S-FS 55" 2 Solid Door Reach-In Refrigerator, Commercial Series	-	2	Ea.	-	-	-	$5,040.00	$10,080.00	YES	https://tinyurl.com/yb4jqjvl
Kitchen: Bakers Pride BCO-E1 Cyclone Series Single Deck Full Size Electric Convection Oven - 208V, 1 Ph	-	1	Ea.	-	-	-	$5,327.00	$5,327.00	YES	https://tinyurl.com/ybl7x2ce
Kitchen: Avantco MX10 10 Qt. Gear Driven Commercial Planetary Stand Mixer with Guard - 110V, 3/4 ł	-	1	Ea.	-	-	-	$949.00	$949.00	YES	https://tinyurl.com/ycygzenf
Kitchen: Vitamix 62826 Vita-Prep 3 Food Blender - 64 oz. Capacity - 3 HP	-	1	Ea.	-	-	-	$932.00	$932.00	YES	https://tinyurl.com/ydzxhndf
Administration: Appliance Cabinet w/ Hutch Set	-	1	Ea.	-	-	-	$1,915.00	$1,915.00	YES	https://tinyurl.com/y8nwbxz7
Administration: Cabinet With Right Hand Sink & Wall Cabinet	-	1	Ea.	-	-	-	$2,915.00	$2,915.00	YES	https://tinyurl.com/y8nwbxz7
Multi-purpose room: Partitions, sliding, acoustic air wall, 1-5/8" thick	10 22 43.10 0020	299	S.F.	$52.50	$51.80	$15,488.11	$51.80	$15,488.11	NO	
Interior glass: Sheet glass, 3/16" thick, tempered	08 81 55.10 0700	5085	S.F.	$12.35	$12.19	$61,962.06	$12.19	$61,962.06	NO	
Cabinetry: Manufactured wood casework frames, base cabinets, counter storage, 36" high, two bay, 3(	12 32 23.15 0400	180	Ea.	530	$522.93	$94,127.46	$522.93	$94,127.46	NO	
Cabinetry: Manufactured wood casework frames, wall mounted cabinet, two bay, 24" high, 54" wide	12 32 23.15 6800	180	Ea.	425	$419.33	$75,479.57	$419.33	$75,479.57	NO	
Cabinetry: Manufactured wood casework frames, wall mounted cabinet, two bay, 30" high, 36" wide	12 32 23.15 9000	60	Ea.	430	$424.26	$25,455.85	$424.26	$25,455.85	NO	
Stairs: Floor plate stairs, shop fabricated, steel stringers, custom steel stairs, 4' wide, medium priced	05 51 16.50 0810	48	Risers	$871.50	$859.88	$41,274.00	$859.88	$41,274.00	NO	
Stairs: Floor plate stairs, shop fabricated, steel stringers, custom steel stairs, 6' wide, deluxe	05 51 16.50 0900	24	Risers	$1,236.25	$1,219.76	$29,274.23	$1,219.76	$29,274.23	NO	
Railing: Railings, Pipe, shop fab'd, 3'6" high, posts @ 5' O.C., aluminum, 2 rail, satin finish, 1-1/4" diame	05 52 13.50 0020	64.9	L.F.	$58.50	$57.72	$3,746.01	$57.72	$3,746.01	NO	
Air barrier curtains, incl. motor starters, transformers, and door switches, environmental separation, d	23 34 33.10 3150	9	Ea.	$2,025.00	$1,997.99	$17,981.90	$1,997.99	$17,981.90	NO	
Services				**$60,880.00**	**$60,067.92**	**$64,567.10**	**$183,584.92**	**$3,720,996.10**		
Plumbing: Toto Ultramax II toilets	-	39	Ea.	-	-	-	$1,309.00	$51,051.00	YES	https://tinyurl.com/y8u2ul44
Plumbing: Sloan WES-1000 waterless urinals	-	7	Ea.	-	-	-	$854.00	$5,978.00	YES	https://tinyurl.com/yb7k5gzm
Plumbing: Elkay EDF 15R Non-Refrigerated Drinking Fountains	-	3	Ea.	-	-	-	$677.00	$2,031.00	YES	https://tinyurl.com/ydgktcoh
Plumbing: EcoSmart Pou 6	-	13	Ea.	-	-	-	$265.00	$3,445.00	YES	https://tinyurl.com/y9df8tq3
Plumbing: EcoSmart Eco 18 (0160 on page 498)	-	1	Ea.	-	-	-	$715.00	$715.00	YES	https://tinyurl.com/ybxnyhjs
Plumbing: EcoSmart Eco 27	-	9	Ea.	-	-	-	$842.00	$7,578.00	YES	https://tinyurl.com/yd48d2ah
Plumbing: American Standard 6055.205.002 0.5 GPM Innsbrook Electronic Proximity Faucet	-	25	Ea.	-	-	-	$865.00	$21,625.00	YES	https://tinyurl.com/yb69huz4
Plumbing: Lucerne wall mounted sink right faucet hole	-	25	Ea.	-	-	-	$217.00	$5,425.00	YES	https://tinyurl.com/y98qagzc
Plumbing: American Standard Monterrey 4" Centerset Gooseneck Faucet	-	8	Ea.	-	-	-	$344.00	$2,752.00	YES	https://tinyurl.com/ycSbxe6y
Plumbing: High Sierra 1.5 GPM High Efficiency Low Flow Shower Head	-	1	Ea.	-	-	-	$67.00	$67.00	YES	https://tinyurl.com/y7gxd5ft
Plumbing: Commercial Kitchen Sink NSFB-345 3 Compartment	-	2	Ea.	-	-	-	$6,875.00	$13,750.00	YES	https://tinyurl.com/ybdtvc9q
Plumbing: ARB-2435-A-GR-T	-	4	Ea.	-	-	-	$2,690.00	$10,760.00	YES	https://tinyurl.com/ybk42ncr
Electrical: Insteon 6 button dimmable switch	-	33	Ea.	-	-	-	$127.00	$4,191.00	YES	https://tinyurl.com/y8dn8663
Electrical: Insteon Wireless Motion Sensor	-	25	Ea.	-	-	-	$63.00	$1,575.00	YES	https://tinyurl.com/yarxej3q
Electrical: Lutron Maestro Sensor Switch	-	32	Ea.	-	-	-	$30.00	$960.00	YES	https://tinyurl.com/y7uko9bu
Electrical: Insteon Garage door kit	-	5	Ea.	-	-	-	$113.00	$565.00	YES	https://tinyurl.com/yd4s9j3n
Electrical: Insteon Hub	-	1	Ea.	-	-	-	$134.00	$134.00	YES	https://tinyurl.com/yke7uopn
Electrical: Leviton 20 Amp 125-Volt Duplex Self-Test Tamper Resistant/Weather Resistant GFCI Outlet,	-	104	Ea.	-	-	-	$42.00	$4,368.00	YES	https://tinyurl.com/yba6g6f3
Electrical: 20 Amp Tamper Resistant Duplex Outlet, White	-	488	Ea.	-	-	-	$6.00	$2,928.00	YES	https://tinyurl.com/yao6bdr4
Electrical: Homeline 100 Amp 20-Space 40-Circuit Indoor Main Breaker Plug-On Neutral Load Center wi	-	25	Ea.	-	-	-	$114.00	$2,850.00	YES	https://tinyurl.com/ykcfnwm
Electrical: Leviton 88003 Electrical Wall Plate, Duplex Receptacle, 1-Gang - White (10-pack)	-	60	Ea.	-	-	-	$4.00	$240.00	YES	https://tinyurl.com/yaws6dtd
Electrical: 20 Amp Commercial Grade Self Grounding Duplex Outlet Floor Box Brass	-	110	Ea.	-	-	-	$99.00	$10,890.00	YES	https://tinyurl.com/y7v3lg6f
Electrical: Homeline 40 Amp Single Pole GFCI Circuit Breaker	-	1	Ea.	-	-	-	$163.00	$163.00	YES	https://tinyurl.com/yawags9q
Electrical: Transformer, 240V, 480V Wye/277V, 15kVA	-	1	Ea.	-	-	-	$2,324.00	$2,324.00	YES	https://tinyurl.com/y6qhrr2j
Electrical: Homeline 20 Amp AFCI Single Pole Circuit Breaker	-	1	Ea.	-	-	-	$74.00	$74.00	YES	https://tinyurl.com/ycqz5csu
Elevator: Hydraulic passenger elevators and options, hyd. pass, base unit, 1500 lb., 100 fpm, 2 stop, std	14 24 23.10 2050	1	Ea.	$60,500.00	$59,692.99	$59,692.99	$59,692.99	$59,692.99	NO	
Mechanical: Ductwork	-	4000	L.F.	-	-	-	$35.00	$140,000.00	YES	based on quote from J.W. and D.E. Ryan
Mechanical: Piping	-	-	-	-	-	-	-	$105,100.00	YES	based on quote from J.W. and D.E. Ryan
Mechanical: Piping insulation	-	-	-	-	-	-	-	$48,515.00	YES	based on quote from J.W. and D.E. Ryan
Mechanical: Equipment costs	-	-	-	-	-	-	-	$263,020.00	YES	based on quote from J.W. and D.E. Ryan
Mechanical: Condensate drains	-	-	-	-	-	-	-	$18,450.00	YES	based on quote from J.W. and D.E. Ryan
Mechanical: Bore hole excavation and installation	-	-	-	-	-	-	-	$446,250.00	YES	based on quote from J.W. and D.E. Ryan, 35 bore holes at 500 ft. deep
Mechanical: Startup and comissioning services for 1 year	-	-	-	-	-	-	-	$20,400	YES	based on quote from J.W. and D.E. Ryan
Fire protection: Portable fire extinguishers, CO2, with hose and "H" horn, 15 lb.	10 44 16.13 0160	13	Ea.	$380.00	$374.93	$4,874.11	$374.93	$4,874.11	NO	
Fire protection: Fire panel system	-	71595	S.F.	-	-	-	$6.00	$429,570.00	YES	based on national averages
Fire protection: Automatic sprinkler system	-	71595	S.F.	-	-	-	$3.00	$214,785.00	YES	based on national averages
Fire protection: Smoke and CO2 detectors	-	65	-	-	-	-	$60.00	$3,900.00	YES	https://tinyurl.com/y6uwzw58
Ventillation: Ventacity VS 500 SQ Equipment + Install	-	25	Ea.	-	-	-	$14,400.00	$360,000.00	YES	based on quote from J.W. and D.E. Ryan
Ventillation: Ventacity VS 3000 Equipment + Install	-	5	Ea.	-	-	-	$90,000.00	$450,000.00	YES	based on quote from J.W. and D.E. Ryan
Contingency for lighting, wiring, and plumbing	-	-	-	-	-	-	-	$1,000,000.00	YES	We added this line to include items that are outside of the scope of our design
Structure				**$265.95**	**$262.40**	**$1,457,969.44**	**$262.40**	**$1,457,969.44**		
Structure: Bracing, shear wall X-bracing, per 10' x 10' bay, one face, metal strap, 20 ga. X 6" wide	05 41 13.05	30	Ea.	$95.00	$93.73	$2,811.98	$93.73	$2,811.98	NO	
Structure: Columns, structural, steel, concrete filled, extra strong pipe, 8" diameter	05 12 23.17 0940	8122	L.F.	$90.50	$89.29	$725,236.29	$89.29	$725,236.29	NO	
Structure: Structural steel members, shop fab'd for 100-ton, 1-2 story project, bolted connections, bea	05 12 23.75 1520	11179.25	L.F.	$64.00	$63.15	$705,928.32	$63.15	$705,928.32	NO	
Structure: Open web joists, K series, 30' to 50' spans, 26K10, 13.8 lb./L.F.	05 21 19.10 0640	1478.25	L.F.	$16.45	$16.23	$23,992.85	$16.23	$23,992.85	NO	