Designing for Zero Carbon

Volume 3

Case Studies of
All-Electric K-12 Schools

Written by
Edward Dean, FAIA
Bernheim + Dean Inc.

Foreword by
Ida Clair, FAIA
California State Architect

Additional Contribution by
Anna LaRue
Founder and Principal
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September 2025

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Foreword

In 1933, the Long Beach earthquake caused significant damage to schools in the area. Within a month, the California Legislature passed the Field Act, establishing stringent standards for public school buildings to withstand earthquakes, and today California school buildings are the safest in the nation. Addressing the climate crisis is just as urgent as preparing for the next earthquake, yet many California school districts remain unprepared to ready their school buildings to withstand the effects of climate change.

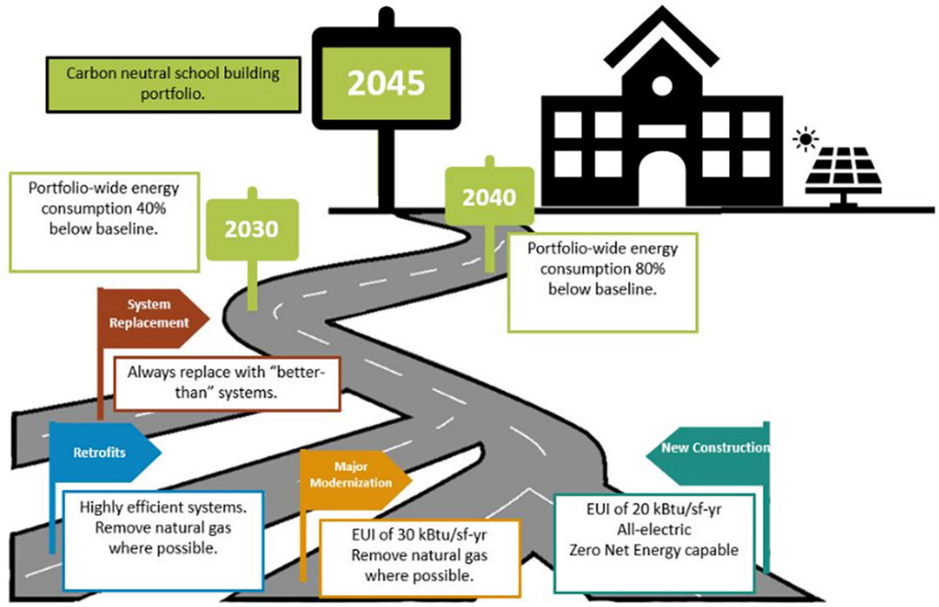
The age of the average public school building in California is 45 years. Yes, that's old, considering that any technology that is 45 years old today can be found in most museums. Commodities that have technologically evolved, such as automobiles, are more fuel efficient today than 45 years ago, yet a greater number of automobile owners still make their selection based on the bells and whistles in newer fossil fuel powered models and hesitate to make the evolutionary change to more planet-friendly choices such as a battery electric car. Whether it is the unfamiliarity, the cost, or the lack of experiencing significant personal impact of climate change, transformational change is hard for many. Often, it takes a community that prioritizes a commitment to a zero-carbon future to deliver a zero-carbon school. Inversely, a district that prioritizes a zero-carbon school can transform a community.

The environmental concerns school districts must address are numerous: waste management, water use reduction, stormwater management, energy management, extreme heat, and indoor air quality are just to name a few. State agency regulations addressing conservation and advancing healthy school facilities are scattered in disparate departments, leading to a piecemeal approach in resolving the goal of school facility sustainability. Furthermore, many school buildings are designed to minimum regulatory requirements when newly constructed or modernized, leading to a piecemeal approach to facility sustainability, instead of districts approaching sustainability through an intentional district-wide plan. Most of the funding for school construction in California comes from state and local bonds, and responsible stewardship of funds translates into designing to meet regulatory minimums so that funding can be extended to as many facility improvements as possible. Often, innovative technologies that support zero-carbon objectives are not considered, let alone prioritized, even if zero-carbon facilities deliver quantifiable cost savings and educational benefits from occupancy into the future.

School facility construction budgets are required to be robust enough to deliver regulatory minimums. Similarly to the Field Act which established structural minimums for school facilities, it would reason that establishing requirements for zero embodied carbon and zero operational carbon would hasten the transition of schools to net zero. However, the regulatory process involves public participation, so if the market is not ready to deliver widespread low carbon materials, green energy, or sustainable technologies at reasonable cost, or if understanding the methods to achieve net zero facilities is complicated, the public resists. For public schools, educational resources and financial incentives through state grants spur implementation of sustainability objectives, as was demonstrated by the California Schools Healthy Air, Plumbing, and Efficiency Program (CalSHAPE) and the Cal Fire Green Schoolyards Grant Program, and utility grant programs also aid in the transition; however, districts can't rely on grants alone to implement sustainability measures. To meet established goals of zero carbon by 2045, regulations need to be adopted. Unfortunately, when regulations are adopted, incentives typically cease.

In 2020, the Division of the State Architect (DSA) established the *Getting to Zero in California Schools Program* with a goal to "educate before we regulate." Since the program's inception, DSA has seen an increase in the engagement of districts in our regulatory development and interest in DSA's educational resources and programs. Since the pandemic in 2020, student health has been prioritized, and as the high level demand for grant funds demonstrate, the will to build sustainably is high. A sea change takes time, and the process is gradual: first, educa-

Roadmap to Zero



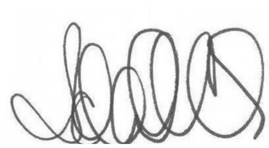
(Left) Illustrative graphic for *Getting to Zero in California Schools Program* (New Buildings Institute)

tion; second, increasing availability of monetary, professional, and material resources; and then, when the market is ready, regulation.

The building standards in the 2022 edition of the *California Energy Code (Title 24, Part 6)* have advanced carbon reduction through the operation of building systems, ushering in a transition from fossil fuel use to all-electric heat pump technology, requiring solar photovoltaics, and establishing a threshold for the implementation of batteries for storing energy. The 2022 Title 24, Part 6, sets the stage to achieving near net zero operational carbon for schools and increasing facility sustainability and resiliency.

With a call to action by Governor Newsom to double the state's efforts to achieve net zero, state agencies committed to advance the next level of net zero. On July 1, 2024, California became the first state in the nation to mandate embodied carbon requirements for nonresidential buildings. Utilizing a modest approach, the embodied carbon building standards in the 2022 *California Green Building Standards Code (CALGreen)* apply to public schools with an aggregate new or improved area of 50,000 square feet. The embodied carbon regulations provide three pathways to achieve compliance: (1) building reuse, (2) whole building life cycle analysis, and (3) prescriptive global warming potential limits for five materials, namely structural steel, concrete reinforcing steel, mineral wool insulation, glass, and concrete. Providing a school district options towards compliance gives them the flexibility to choose the best means to lower the embodied carbon footprint of the project, while managing program, costs and schedule. In future code cycles, the thresholds for area and material *Global Warming Potential (GWP)* will decrease, leading to a significant sustainability shift.

The case studies presented in this book celebrate the early leaders in public school facility sustainability in California. By addressing both embodied carbon and operational carbon, these schools have transformed their communities and have inspired the students to become future sustainability leaders. The initiative and leadership of their districts demonstrate to other districts the possibility and promise of a zero-carbon future for the next generation.



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State Architect of California

GETTING TO ZERO OVER TIME
DIVISION OF THE STATE ARCHITECT
DEPARTMENT OF GENERAL SERVICES

Introduction

This book of case studies is the *third* volume in the series *Designing for Zero Carbon,*[1] which focuses on the *electrification of buildings*, a current objective of California government policy to combat climate change and all its now-evident societal impacts.

- *Volume 1* was published in March 2022 and provided case studies of projects that were *non-residential*, both new and renovation projects.
- *Volume 2* was published in July 2023 and focused on case studies of *multifamily residential* projects, also new and renovation.
- This *Volume 3* presents case studies of *all-electric K-12 school* projects, identified as a building type with unique issues in making such a transition in the energy source used.

As pointed out in the Introductions to both Volume 1 and Volume 2, "…full decarbonization of the building sector will only be realized when the use of carbon sources of energy in buildings such as natural gas is eliminated and the electric power grid is itself fully decarbonized. The latter goal is mandated to be achieved in 2045."

This 100% decarbonization of the California electric power grid by 2045 is the result of SB-100, passed in 2018 by the California state legislature and the driving force behind this major change in building systems design throughout California.

The other part of this transition to fully-decarbonized energy use in buildings will occur when the building sector adopts the all-electric design mandate for all new and renovated buildings. The transition is well underway for some building types, as noted in *Volume 1* and *Volume 2*. For other building types, such as the focus of this *Volume 3*, K-12 schools, there are institutional and organizational impediments to that transition. These impediments can be overcome, as demonstrated in particular by these case studies, and the outcomes often exceed expectations.

Issues and Challenges with K-12 School Projects

One of the surprising things learned during the research for this case study book is the relative dearth of candidate projects to feature as case studies of all-electric K-12 school projects. Very few examples were found in many highly populated areas of California. The indication was, therefore, that there were serious impediments for schools to plan new building or renovation ("modernization") projects that would abandon the use of fossil-fuel energy sources. This was, of course, of great interest to the researchers of these case studies.

In California, Proposition 13 (approved by voters in 1978) limits increases to property taxes, which had been a primary source of local school funding. As a general result, the state government now provides the majority of school funding for operations (but not facilities), with formulaic allocations based on specific needs and requirements.[2] Some school districts have additional local funding measures and additional private support from parent associations or local fundraising organizations.

Construction and other facility improvement is funded through state and local bonds, which must be approved by voters. The process[3] to receive funding through state agencies can take three or four years and requires substantial process management. "Districts that do not have sufficient

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[1] The full series of eight case study books covers an expansive range of building types to support the adoption of energy-efficient, low-carbon building design practices in California. These books can be found and downloaded for free from https://calbem.ibpsa.us/resources/case-study-books/. They are also available on Amazon in softcover print form at: https://www.amazon.com/s?k=zero+net+energy+case+study+buildings&i=stripbooks&ref=nb_sb_noss.

[2] https://edsource.org/wp-content/publications/Booklet_2-00.pdf

[3] https://www.dgs.ca.gov/-/media/Divisions/OPSC/Resources/Flowchart.pdf

local funds to cover a project's costs while waiting for the state backlog are at an enormous disadvantage".[4] It is easier for more urban, wealthier areas to pass bond measures[5] and assign resources to navigating the state funding approval process, resulting in higher-income students receiving more school new construction and also modernization funding, which has historically been allocated as match funding and on a first-come, first-served basis.[6]

In addition to securing funding, planning for school construction is a lengthy process that includes design and significant reviews and approvals from state agencies including the California Department of Education, the Division of the State Architect, the Department of Toxic Substances Control, the Office of Public School Construction, the California Geological Survey and the Department of Industrial Relations, depending on type of project.[7] Districts must adhere to specific rules and regulations throughout the design and construction process that add to the steps necessary for project completion including, community engagement, engagement with local agencies, commitments to workforce development and local hiring, and department of labor prevailing wage requirements for construction labor. Schools also must adhere to stricter construction schedules as completion must align with expected dates of a new school year or term.

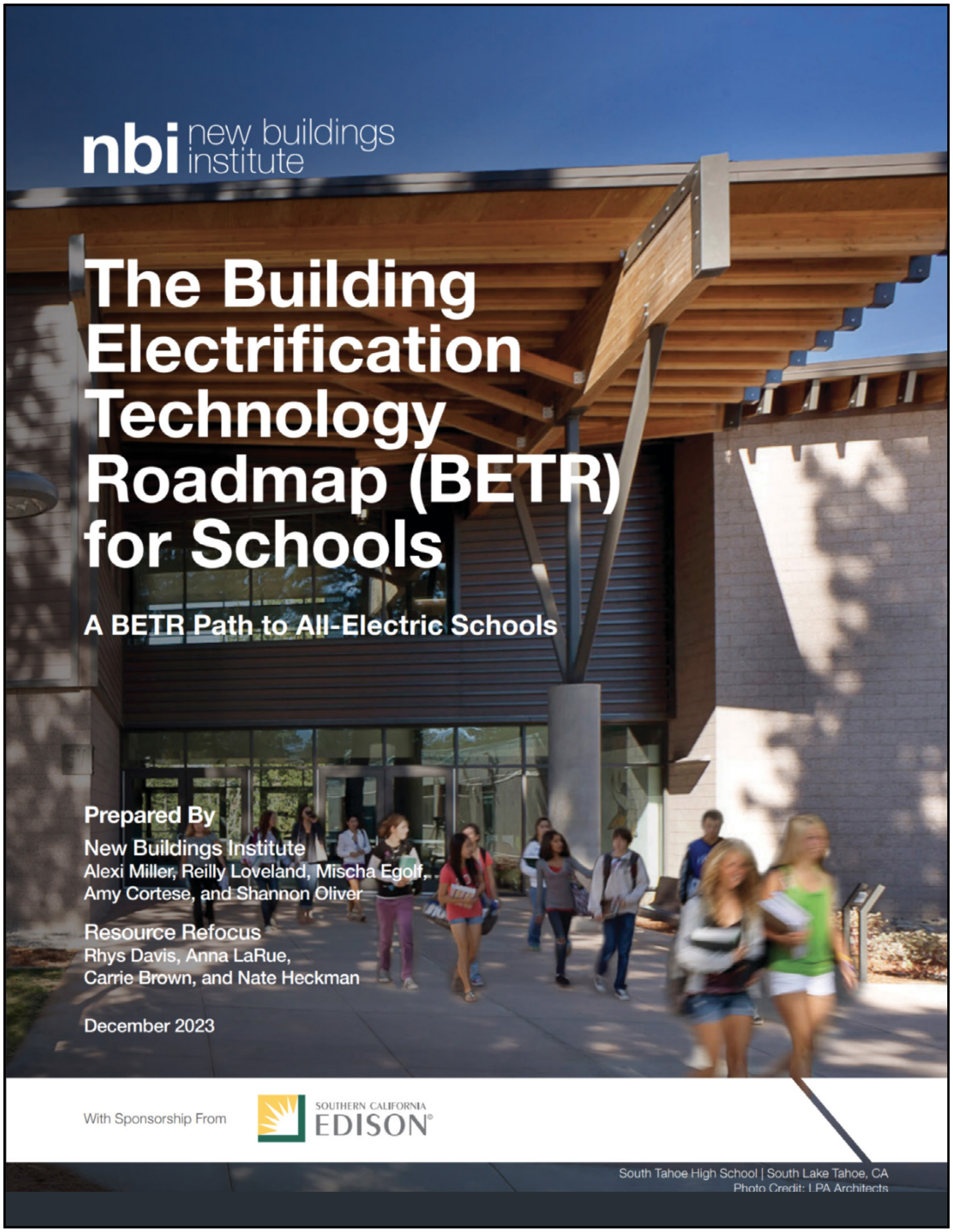
For schools with limited space, constructing a new school or even modernizing an existing facility may require initial demolition of an existing building in order to construct the new one in its place. Students still need to attend school during the often multi-year construction process, and this poses substantial logistical challenges for both the school district[8] and families. Finally, as with all construction projects, schools need to contend with construction labor shortages and changes in costs for building materials.

Another challenge is that California is experiencing declining public school enrollment; the 2023-24 school year was the seventh consecutive decrease.[9] This trend is expected to continue. Modest enrollment gains are expected in places like Placer County, which is fairly rural, and the highest decline in enrollment is likely to be in Los Angeles County, which has by far the largest number of enrolled students.[10] These declines have implications for school finances and planning needs. While there are new all-electric schools being designed and constructed, a number of districts are also closing and consolidating schools.

A number of school districts are opting to plan for electrification retrofits, though these also face challenges. Existing schools in California have struggled to keep up with basic health and safety system maintenance in the last few decades, let alone additional modernization upgrades. In 2018-19, 38% of California students attended schools that did not meet minimum facility standards. In the four years prior to that school year, 108 schools had to temporarily close due to facility conditions.[11] Keeping up with deferred maintenance is one of the largest barriers to the electrification of existing school buildings, as any funding that might have been available for

[4] https://edsource.org/2025/let-the-scramble-begin-for-a-short-supply-of-state-construction-money/725109
[5] https://calmatters.org/education/2023/11/school-construction-2/
[6] https://citiesandschools.berkeley.edu/blog/moving-to-equity-california-school-facility-program-reform/
[7] https://www.dgs.ca.gov/OPSC/Resources/Cal-School-Construction
[8] Example of school board meeting notes discussing relocation options during construction: https://piedmont.granicus.com/DocumentViewer.php?file=piedmont_21b9218609fb8ba298e11612e66e7180.pdf&view=1
[9] https://dof.ca.gov/forecasting/demographics/public-k-12-graded-enrollment/
[10] https://experience.arcgis.com/experience/7fb99fb05b4c4fb6a19e70d7b827d9d2/
[11] https://www.ppic.org/wp-content/uploads/improving-k-12-school-facilities-in-california-august-2020.pdf

(Right) Publication cover, *The Building Electrification Technology Roadmap (BETR) for Schools*, available at website indicated.



https://newbuildings.org/resource/the-building-electrification-technology-roadmap-for-schools/

electrification would need to start with any existing systems that are failing before additional modernization can be undertaken.

In general, there are four pathways that electrification retrofits can take, not all of which are applicable or possible for all schools. The first is ***Emergency Replacement***. This pathway requires the immediate replacement of the failed fossil fuel equipment with an electric replacement. This pathway is only feasible if the building is electric-ready, meaning prepared for electrification retrofits within the underlying systems like electrical panels and wiring, physical space and structural support. It also requires readily available electric replacement equipment, which may not be feasible in every school district. Ultimately, unless prior projects have been done to ensure electrification readiness, this pathway is not usually feasible for most existing school buildings.

The second pathway is ***Planned/Routine Capital Improvement and Deferred Maintenance***. This pathway focuses on using any opportunity for funding that improves systems that use fossil fuels to electrify. This pathway only allows for upgrades that have minimal incremental costs above the existing system; for example, a *Heating, Ventilation and Air-Conditioning (HVAC)* electrification project tied to capital improvement or deferred maintenance projects is only feasible if minimal additional ductwork, piping or electrical infrastructure is needed compared to the fossil fuel HVAC system that would otherwise be installed. This pathway can unlock electrification projects that cannot be funded on their own, but not all electrification projects are feasible without deeper system improvements and modernization.

The third pathway is an ***Efficiency & Cost Savings Project (Deep Efficiency Retrofit)***. This pathway requires dedicated funding for modernization, energy efficiency, or building decarbonization, which is not often available to every school district, but can lead to the best outcomes for electrification retrofits. If considering the energy, air quality, and decarbonization benefits of electrified and efficient HVAC, water heating, and cooking systems, this pathway can allow electrification retrofits to add more value to the districts and to unlock the ability to update important related systems such as electrical infrastructure.

The final pathway is an ***Addition to Existing Building***. This pathway requires the school to be undergoing or planning for an addition or other retrofit already, but it can be an opportunity to improve key systems such as mechanical piping and ducting as well as electrical infrastructure. This may only get school buildings to electric-ready, but that can unlock other pathways to electrification in the future.

Whether or not the pathways above are feasible, they are directly impacted by the following variables that need to be considered for any electrification retrofit:

- ***Equipment remaining useful life***. This is the average amount of time a certain piece of equipment is expected to be operational. If a fossil fuel system still has remaining useful life, it is unlikely that a district would target it for electrification.

- ***Project scale.*** This is the magnitude of a potential electrification retrofit in terms of cost and complexity, which obviously affects the likelihood of any of the above pathways being feasible. For example, If a single zone packaged furnace and *Air-Conditioning (A/C)* unit needs to be replaced for a classroom, a packaged heat pump would likely have a small enough project scale that the retrofit could be completed with minimal funds and labor. However, if a school's central boiler fails, it is unlikely that a central heat pump could be slotted in without significant additional upgrades.

- ***Equipment availability***. Standard package heat pumps and smaller heat pump water heaters are generally readily available in California. However, larger custom central heat pump systems, induction cooking equipment for specific purposes and electric transformers can sometimes require long lead times for ordering and installation, affecting the feasibility of a complete electrification retrofit project.

When school districts consider new all-electric construction projects, there are a number of considerations and challenges. Districts need clear goals and direction from the school board and other district decision-makers. Recent successful projects show that the project will benefit from an internal champion who consistently advocates for attention to specific electrification aspects of the project. These projects require long-term thinking, motivated stakeholders, and the ability to create funding opportunities.[12]

Another major consideration is ongoing utility costs. Electric rates in California are higher than in other parts of the country and also appear high when compared to natural gas rates. For many schools, this is addressed through the addition of a solar PV system to offset increased electric costs. However, some schools, especially in urban areas, may not have adequate solar access due to surrounding buildings. Also, dense urban sites may not have adequate roof space. Existing schools that have large portions of their roof space occupied by rooftop HVAC equipment can be further limited in the ability to provide a new or added on-site solar PV system. For schools where a solar PV system is not feasible, a focus on efficiency and careful equipment selection may sufficiently reduce utility costs.

For schools that are able to utilize a solar PV system, there may be special challenges related to raising funds for installation and maintenance, leading to a contractual arrangement such as a third-party *Power Purchase Agreement (PPA)*.[13] There is yet another issue of the timing of when the solar PV system is approved for interconnection with the utility grid, as well as the ongoing debate about feed-in-tariffs and *Net Energy Metering (NEM)*,[14] all of which impact the later value of the electricity produced by the on-site system.

One other potential challenge to note is that many school districts have bidding and procurement rules requiring or encouraging local supplier, designer and construction firm participation.[15] While these rules are often effective for standard projects, it can take time to establish a consistent pool of knowledgeable bidders and can be a hurdle to cost-effective achievement of new project goals or inclusion of new technologies and systems.

Within this challenging framework, there are a number of schools that have nevertheless developed successful all-electric school construction projects. These are described in detail in this book.

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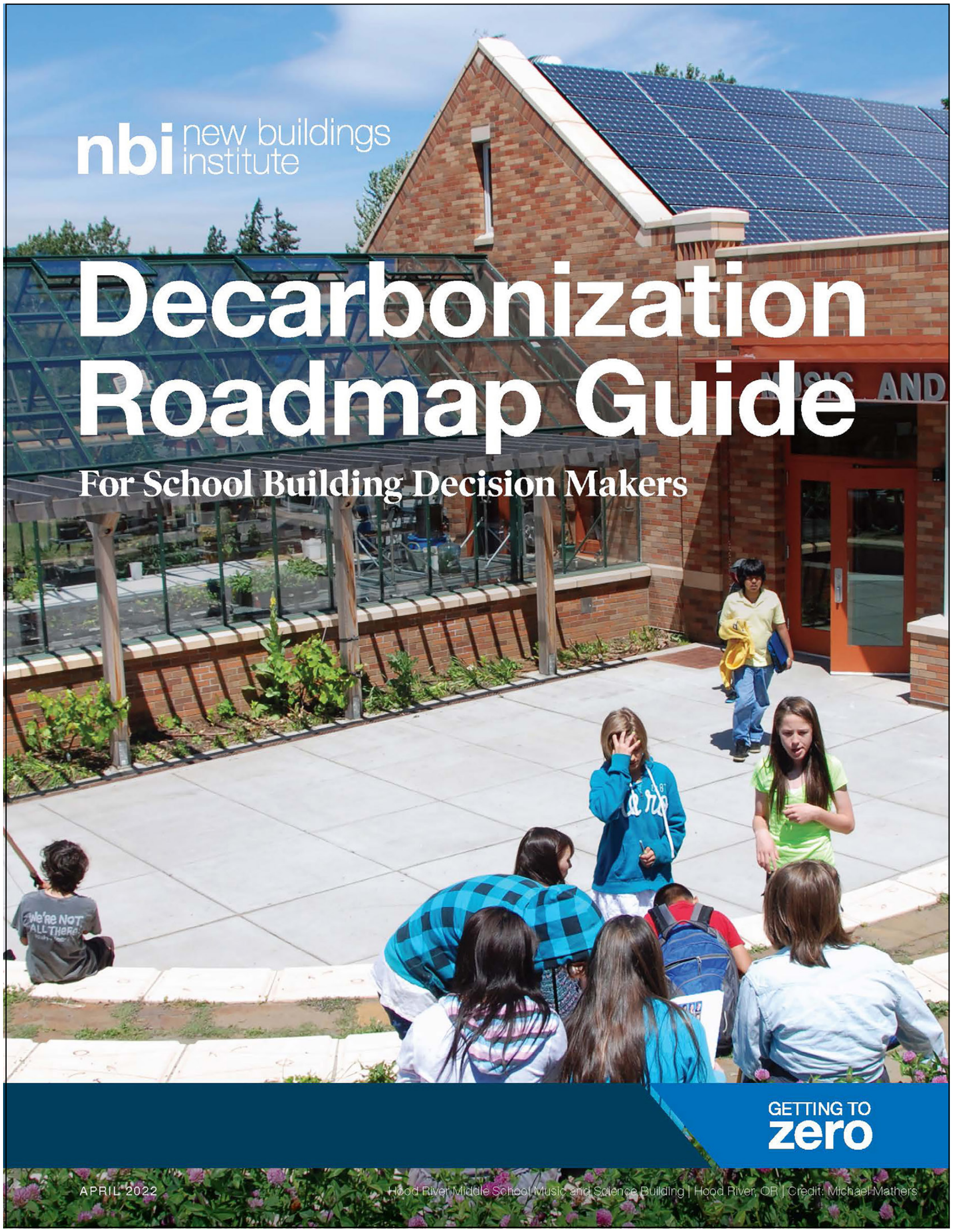
[12] Resources for schools - https://www.dgs.ca.gov/DSA/Resources Then Search for: *Achieving Net Zero Energy, Net Zero Carbon and Sustainable School Facilities*

[13] https://betterbuildingssolutioncenter.energy.gov/financing-navigator/option/power-purchase-agreement#:~:text=A%20Power%20Purchase%20Agreement%20(PPA,output%20for%20a%20predetermined%20period

[14] https://thecleanenergyalliance.org/net-energy-metering-explained/#:~:text=What%20is%20Net%20Energy%20Metering,than%20is%20used%20on%2Dsite

[15] As an example, see Oakland USD's bidding policies: https://www.ousd.org/community/requests-for-proposals-rfps



(Left) Publication cover, *Decarbonization Roadmap Guide for School Decision Makers*, available at website indicated.

https://newbuildings.org/resource/decarbonization-roadmap-guide-for-school-building-decision-makers/

The Case Study Projects in This Book

Similar to previous volumes in this series, five recent all-electric K-12 school projects were selected as both representative of exemplary design for both public and private schools and also as examples of the successful solutions to the types of problems and issues described earlier in this Introduction. As noted above, the list of candidate projects to be featured was clustered in one area of the state, but those selected are representative of the types of projects that could be initiated in other municipalities and locations in California. They include both new facilities and modernization projects, and the grade ranges from elementary to high schools.

Furthermore, nine additional completed projects are featured and summarized in a special section, *Additional Noteworthy Projects*. These projects have a particularly unique aspect of their program, building design or financial constraints that make them successful in their realization. Though not detailed case studies like the featured projects, the summary information provides comparative data and leads to follow-up with further study.

Additional Noteworthy Projects also has a special subsection describing the planning work being done in Los Angeles Unified School District (LAUSD), the largest K-12 school district in California, to introduce electrification of its facilities. Because of the size and complexity of the district, the issues described above are greatly magnified. However, significant progress is being made, as described and as highlighted in some detail for three projects in the planning stages.

Lastly, *Additional Noteworthy Projects* incorporates a *Peek at the Future* of all-electric K-12 schools in California with a sample of the winning results of the recent *Architecture-at-Zero Competition*[16], announced in January 2025. The competition site and program focused on a new facility for the Griffith Middle School of the LAUSD, using its existing site in East Los Angeles. The competition entries were required to be a design for an all-electric facility and to provide energy performance analysis for the innovative systems designs. Excerpts from the top three winning designs in the professional category are shown in this section.

We hope that all the projects discussed in this volume will provide both educational planners and facility designers with models for the successful process of achieving the ultimate goal: K-12 school facilities with fully decarbonized operational energy systems.

[16] See: https://aiacalifornia.org/news/twelfth-architecture-at-zero-competition-winners-announced/

Case Study Projects ▷

CASE STUDY NO. 1

Ocean View Elementary School

PHOTO: KYLE JEFFERS

Ocean View Elementary School

Case Study No. 1

Data Summary

Project Type: Public School
Location: Albany, CA
California Climate Zone: 3
Gross Floor Area: 49,040 sq.ft.
Occupied: August 2021
Grades: Pre-K - Grade 5

Modeled EUI (Site):
24.9 kBtu/sq.ft. per year
Measured EUI (Site):
24.0 kBtu/sq.ft. per year
Modeled On-Site Solar PV System:
220 kW (DC)
Modeled On-Site Energy Production:
322,000 kWh
On-Site Solar PV System Installed:
None
On-Site Battery Storage:
None

Client Organization:
Albany Unified School District

Design-Build Team

Contractor:
C.Overaa & Co., Richmond, CA
Architect:
Multistudio, San Francisco, CA
Mechanical-Electrical Engineer and Energy Modeling:
Interface Engineering, Oakland, CA
Mechanical Engineer of Record:
TEEB Inc., San Ramon, CA
Structural Engineer:
Salas O'Brien, Oakland, CA
Landscape Architect:
BASE, San Francisco, CA

Bridging Documents

Architect:
Hibser Yamauchi, Oakland, CA

Facility Master Plan

Architect:
WLC Architects, Berkeley, CA

New public school facilities in California are generally funded through public bond measures ("general obligation" bonds) created for that specific purpose, which are approved by the voters of a particular city or county. State funds are sometimes made available and the local jurisdictions providing funding may also include funds from local development fees, but public bond measures are the main source of funding for major building projects. Similarly, renovation and addition projects, usually called "modernization" projects, are usually funded in the same manner as new facilities and are often included with new facility projects proposed by the school district as part of a bond measure placed before the voters of that locality.

As a result of the institutional and legal procedures required, the process from initial planning to approved funding typically requires years to complete. Public school projects in California also uniquely come under the jurisdiction of the *Division of the State Architect (DSA)*, the state agency that provides design and construction oversight for public schools and other state buildings to ensure that they comply with California building codes and standards.

This first case study is a typical example of a public elementary school (in this case, a facility serving Pre-K through fifth grade) that went through the entire process from facility master plan to a new school campus at the site of an existing sub-standard and outmoded facility, with the funding provided by a local bond measure. As is often the case, the need to provide a seismic safety upgrade and programmatic improvement also gives the opportunity to introduce features that enable the transition to an all-electric facility and zero-carbon operation by 2045.

Background

Aware of the seismic safety deficiencies of many Albany (California) public schools, the Albany Unified School District (AUSD) Board of Education established a steering committee in June 2013 to study and evaluate the facilities at each of the AUSD school sites. Through a series of public meetings, input was solicited from the Albany community about each of the schools. At the same time, a team of experienced K-12 building design professionals led by WLC Architects was hired to evaluate all the buildings and sites, while participating in the community meetings to assist in development of the building programs for the new and modernized facilities.

After many meetings and much discussion about priorities and cost implications, a detailed Facilities Assessment[1] was developed by the consulting team, which laid out the extent of the work that had to be done at each of the school sites. The overall Facility Master Plan[2] was completed in December 2013 and adopted by the AUSD Board at its March 2014 meeting.

The AUSD then worked with the City of Albany to determine the extent of this work that would be cost feasible for a first bond measure, which would be placed on a future ballot for voters' approval. Several of the project sites were selected, including the Ocean View Elementary School.

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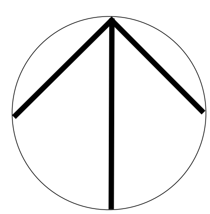
[1] Albany Unified School District Facilities Assessment, December 2013, https://1.cdn.edl.io/quR5ZaFUXKcVs0SFjNU89Q55LP3adpu8N7IKWTf7w6U6Zc5c.pdf.
[2] Albany Unified School District Facilities Master Plan, March 2014, https://1.cdn.edl.io/MeJXmLU8U-VlXZnNmRtxM3ja1fcHj23MXYdJJ7Wwbh5s8jXMi.pdf

Ocean View Elementary School - General Vicinity Plan



Project Process and All-Electric Facility Design
Phase 1 - Facilities Master Plan

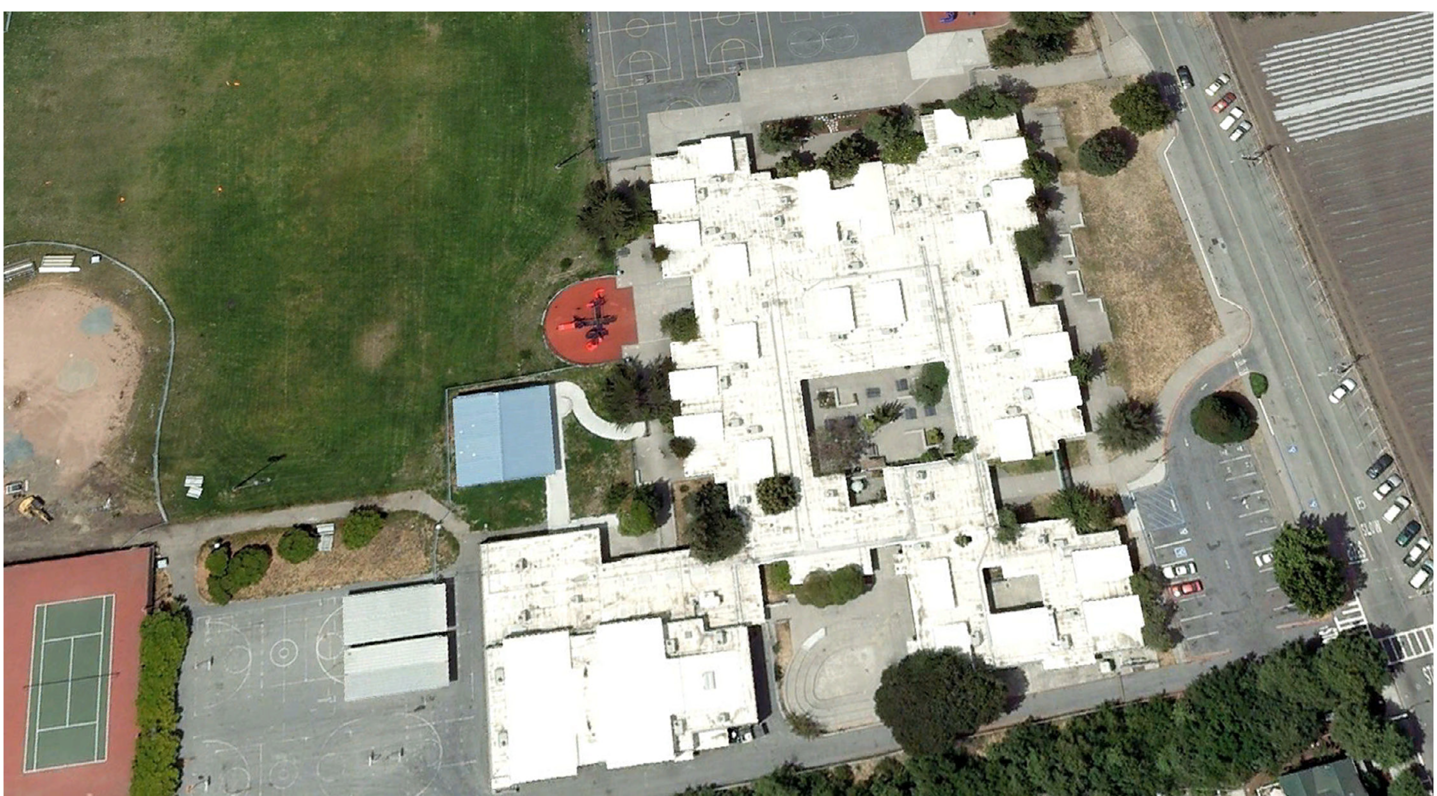
For the Ocean View Elementary School facility and site, the Facility Master Plan noted severe code deficiencies of multiple types, poor seismic design and energy inefficient features and systems. The 46,000 GSF[3] school was built in 1975, before the adoption of California building energy standards and the Title-24 (Part 6) energy code. The existing building structures and energy systems reflected this. For all these reasons, this was a priority project for the City of Albany.

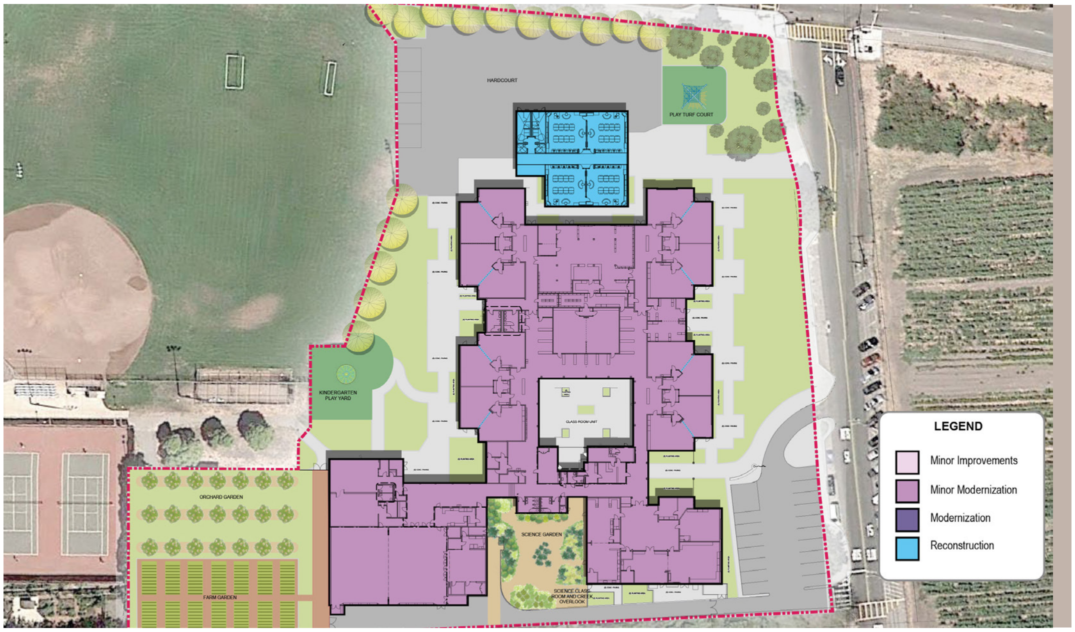
The Facility Master Plan provided three different options for the new design of Ocean View Elementary School in order to meet the goals that were determined during the 2013 public process: (1) renovation/modernization of all existing structures plus a new classroom building; (2) all new buildings along the southern and western sides of the site plus renovation/modernization of the existing multipurpose building; (3) all new buildings along the northern and eastern sides of the site. The first option (renovation/modernization) was estimated to have a (2013) construction cost of $24 million while the other two options (new buildings) were estimated at $30 million.

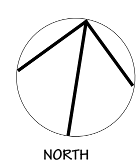
At this point, the transition to all-electric facilities was not yet set as a principal goal. That, as it turns out, would be established after the next step in the process: selection of the preferred scheme option and the development of corresponding design documents and a cost estimate that would be part of the basis for the public bond measure to finance all the school projects identified as the most urgent.

[3] GSF = “gross square feet”. This is the total floor area of a building including all ancillary spaces such as mechanical equipment rooms and user circulation spaces such as corridors, stairways and elevators, measured to the outside surface of enclosing exterior walls.

(Below) Satellite photo of the existing facility at Ocean View Elementary School before project construction (2018-19)







Facilities Master Plan design options for Ocean View Elementary School: *(Top)* Option 1, *(Middle)* Option 2, *(Bottom)* Option 3

(Opposite Page) Design for Ocean View Elementary School as part of the City of Albany school bond measure, passed by voters in June 2016. *(Courtesy of Hibser Yamauchi Architects)*

Phase 2 - Bridging Design Documents and All-Electric Design Mandate

In the fall of 2014, Albany USD selected the design team of Hibser Yamauchi Architects to lead the district project team in the development of a single design proposal for the Ocean View Elementary School campus based on the options described in the 2013 Facilities Master Plan. This design would be developed through the schematic design phase and corresponding preliminary cost estimate, which would be the basis for this project's part of the proposed bond measure. Also, if the bond measure were passed by the Albany voters, these documents could serve as the *bridging documents* for a design-build contractor[4] to construct the final facility.

While these preliminary design documents were being developed through 2015, the Albany USD Board created a *Sustainable and Integrated Design Committee* (now called the *Environmental Action Plan Committee*) to advise about the forthcoming school projects, in particular regarding the bond measure that was being planned for the June 2016 ballot, which would fund the Ocean View Elementary School project along with a number of others.

Among several significant innovative actions recommended by this advisory committee was a proposed mandate that all of the bond-supported projects *be designed as all-electric facilities*, which therefore would automatically become zero-carbon operational in 2045 when the California power grid is scheduled to be 100% decarbonized. This mandate was adopted by the AUSD Board in January 2016 and the design teams were directed to make the necessary adjustments to the proposed bond-funded projects. Funding for the Hibser Yamauchi design team to do the corresponding energy modeling, daylighting analysis and study for the solar PV system for Ocean View Elementary School was also recommended to the AUSD Board and approved.

The final schematic-level design (opposite page) and preliminary specifications for the project were subsequently approved by the AUSD Board in the spring of 2016.

A number of factors led to a significantly modified design from the options of the Facilities Master Plan. Among these was the discovery of a large storm drain through the site that could not be practically reconfigured or relocated; this divided the site with a 25-foot wide easement. The new design is primarily new construction focused on a central courtyard and some renovation to the buildings housing a multipurpose room and administrative offices. The design totaled 61,143 GSF for both new and renovated construction.

This design for the Ocean View Elementary School was placed on the June 2016 City of Albany ballot with the other K-12 school projects under Measures B and E and received voter approval. With the passage of the bond measure, the City of Albany became the first municipality to mandate all-electric schools for all of its new and modernization projects going forward from 2016.

Furthermore, to complete the comprehensive policy directive about sustainable design for schools, after this school bond measure was passed, the AUSD Board adopted Board Resolution #2016-17-01, *Sustainability & The Design and Construction of High Performance Schools*, which set the "Collaborative for High Performance Schools (CHPS)[5]-Verified" standard and the "Net-Zero Energy (NZE)-Ready" standard for all new school construction and major modernizations, including those funded by the recently passed bond measures.

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[4] *Design-Build* is a project delivery method where a construction firm is the prime contractor for the design and construction under one contract with the Owner. The professional architectual and engineering team is hired by the construction firm. The final price of the project is usually established at the end of the design phase.

[5] See: https://chps.net

ABBREVIATIONS

A	AFTER SCHOOL CARE
BRR	BOYS RESTROOM
C	COUNSELOR
CL	CLASSROOM
CLO	CLOSET
EL	ELEVATOR
ELD	ENGLISH LANGUAGE DEVELOPMENT
EVA	EMERGENCY VEHICLE ACCESS
GRR	GIRLS REST ROOM
K	KINDER CLASSROOM
N	NURSE
O	OFFICE
OT	OCCUPATIONAL THERAPY
P	PRINCIPAL OFFICE
RES	RESOURCE
SAU	STAFF ACCESSIBLE UNISEX TOILET ROOM
SDC	SPECIAL DAY CLASS
SP TH	SPEECH THERAPY
STOR	STORAGE
SU	STAFF UNISEX TOILET ROOM
U	ACCESSIBLE STUDENT UNISEX TOILET ROOM

SECOND FLOOR PLAN

FIRST FLOOR PLAN

(Opposite Page) Preliminary design plans for Ocean View Elementary School, approved Albany Board of AUSD in January 2019. *(Courtesy of Multistudio, formerly Gould Evans)*

(Following Pages) Final design-build plans for construction of the Ocean View Elementary School, begun in 2020. *(Courtesy of Multistudio, formerly Gould Evans)*

Phase 3 - Design-Build an All-Electric K-12 Elementary School

With the funding in place, the AUSD scheduled the work for the approved projects and solicited proposals for the Ocean View Elementary School project from design-build teams in October, 2018. The team of Overaa Construction and the architecture firm Gould Evans (now Multistudio) submitted a proposal together as a design-build team and was selected in November 2018 through a competitive process.

The *Request for Proposal (RFP)* documents included the bridging documents developed by Hibser-Yamauchi Architects and meetings were held with the bidding teams as part of the RFP response. The new project preliminary design was presented to the Albany USD Board in January 2019, just two months later. (See opposite page.)

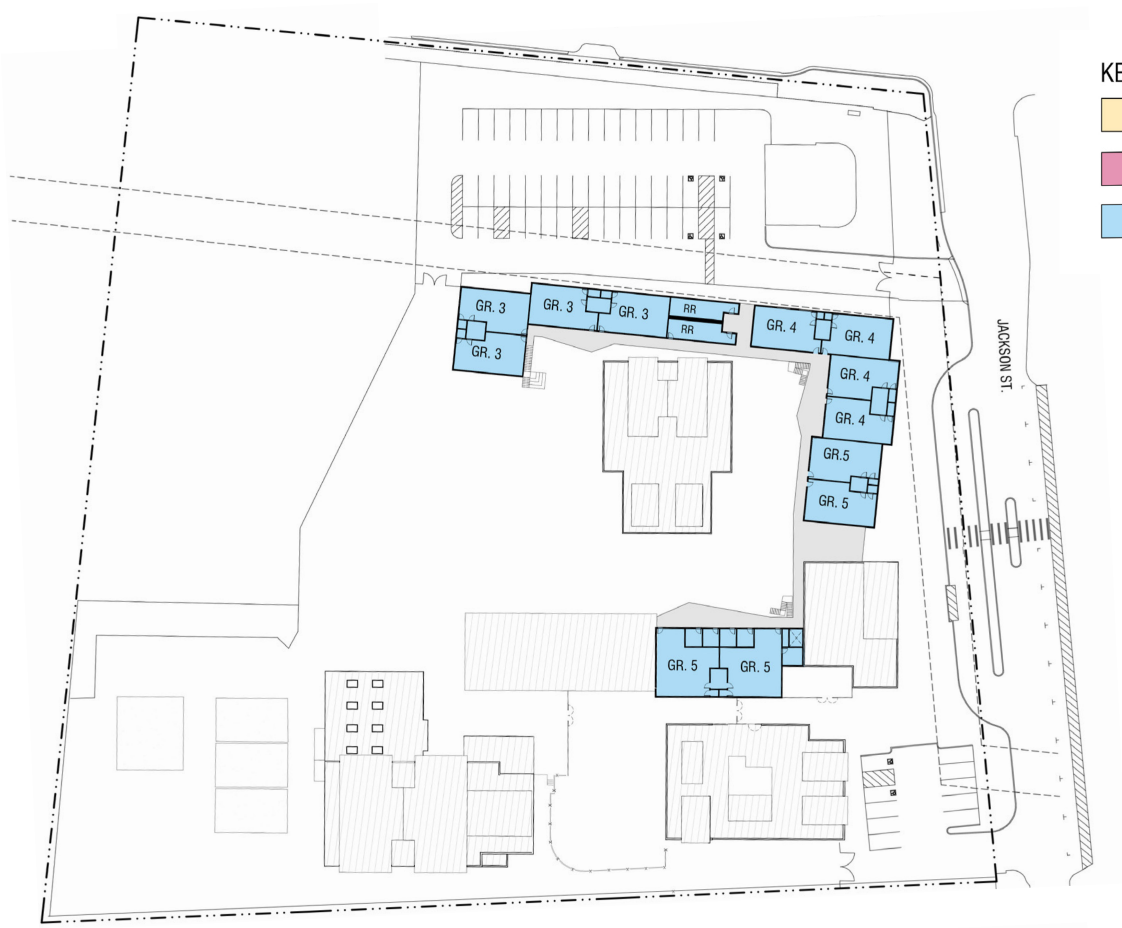
With the school board's approval, the project proceeded into final design and permit documents, as well as the DSA approval process. The project was strategically submitted for permit in two parts so that construction could begin as early as possible. Site work was permitted as the first increment and began in December 2019. The remaining overall building work was permitted in March 2020 as the second increment.

The design plans for construction were further slightly modified and finalized in 2020. (See the pages following.) Construction of the entire project was completed in June 2021.

(Below) Rendering of view of entry to the new Ocean View Elementary School from Jackson Street from design-build team in January 2019. *(Courtesy of Multistudio, formerly Gould Evans)*

KEY

- EXISTING TO REMAIN
- EXISTING TO MODERNIZE
- NEW CONSTRUCTION



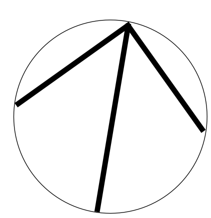
SECOND FLOOR PLAN

FIRST FLOOR PLAN

1. CLASSROOM
2. WORKROOM
3. MECHANICAL
4. ELECTRICAL
5. STORAGE
6. RESTROOM
7. MECHANICAL
8. LIBRARY/MKR SPACE
9. KINDERGARTEN
10. ADMIN
11. AFTERCARE
12. SCIENCE
13. KITCHEN
14. MULTIPURPOSE
15. MUSIC /CHOIR
16. COUNSELING SUITE
17. RESOURCE ROOM
18. READING
19. SPECIAL DAY CLASS
20. OCCUPATIONAL THERAPY
21. ENGLISH LANGUAGE DEV

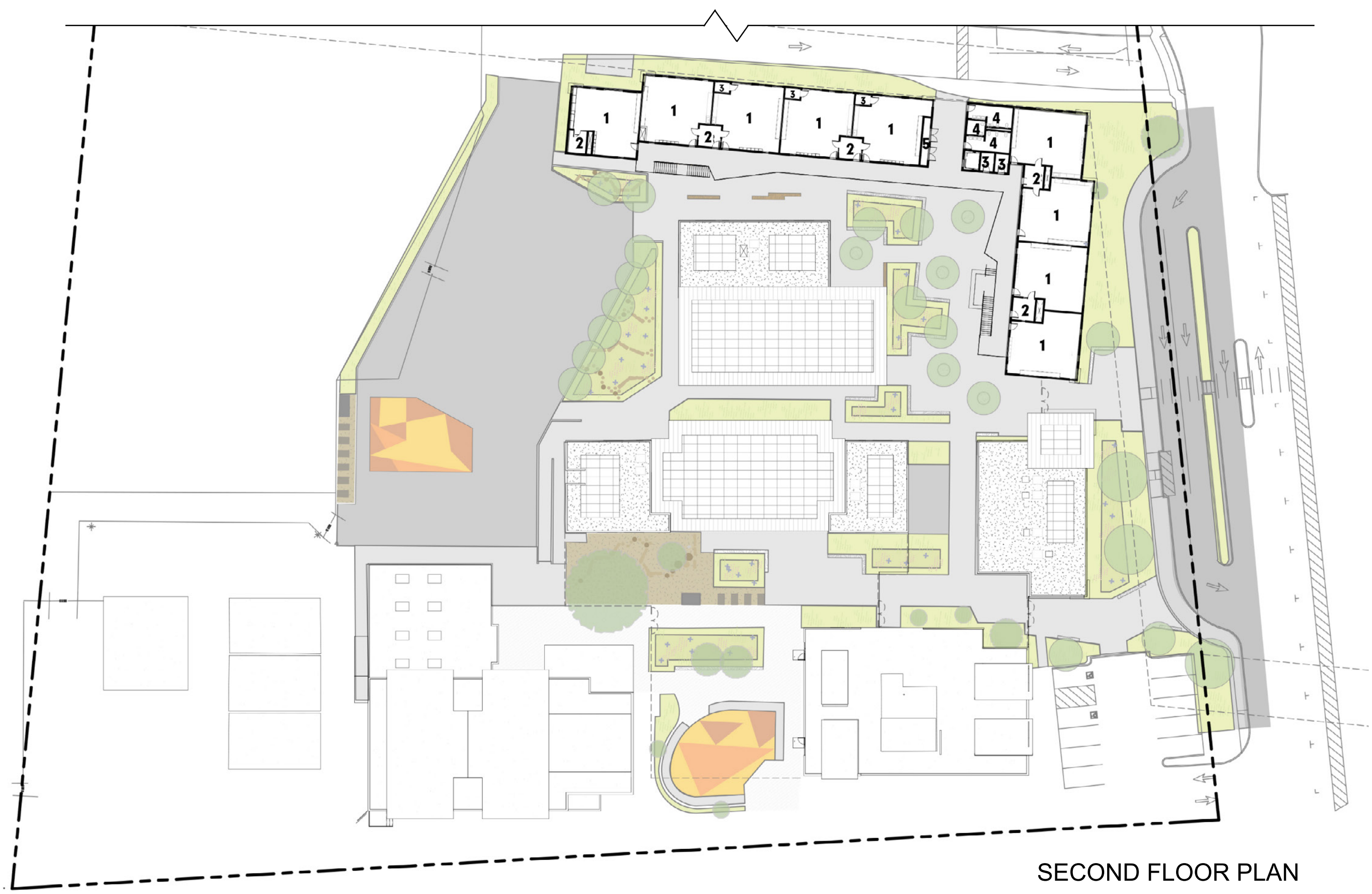
SITE AND GROUND FLOOR PLAN

0 20 40 60 100 200 FT

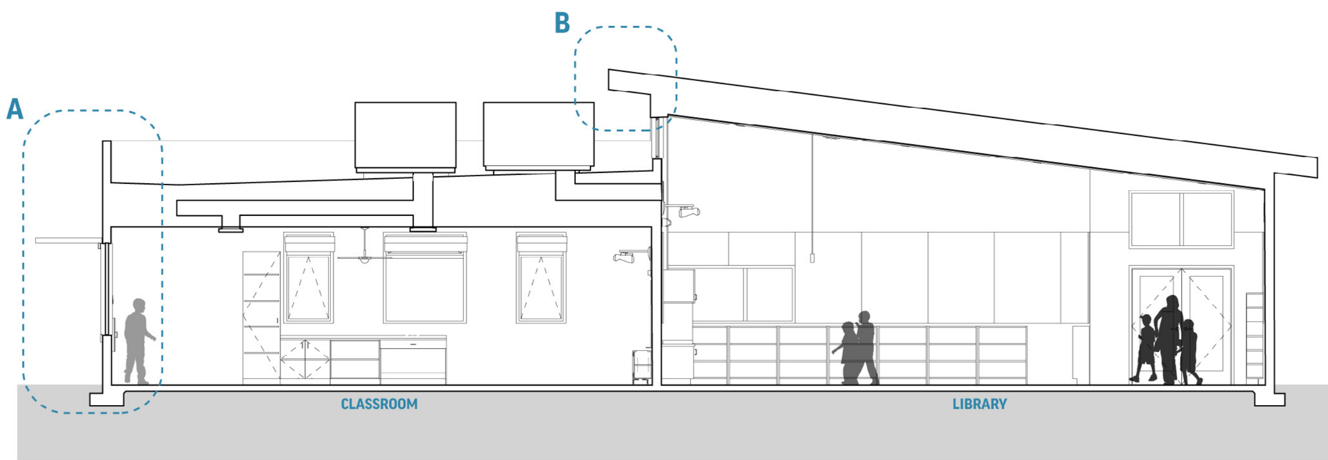


OCEAN VIEW ELEMENTARY SCHOOL — FLOOR PLANS

ROOF PLAN

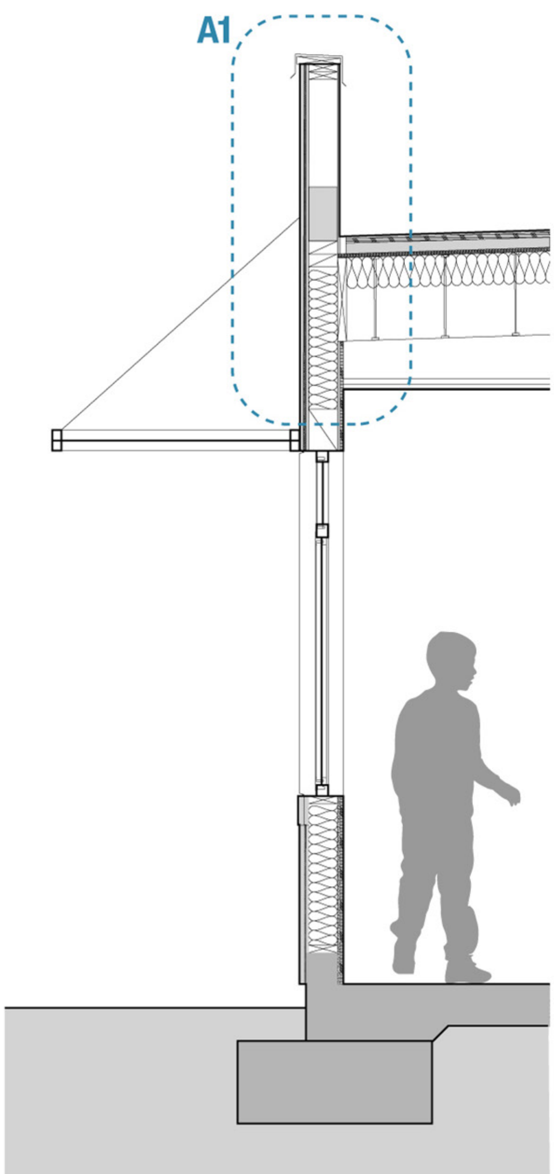


SECOND FLOOR PLAN

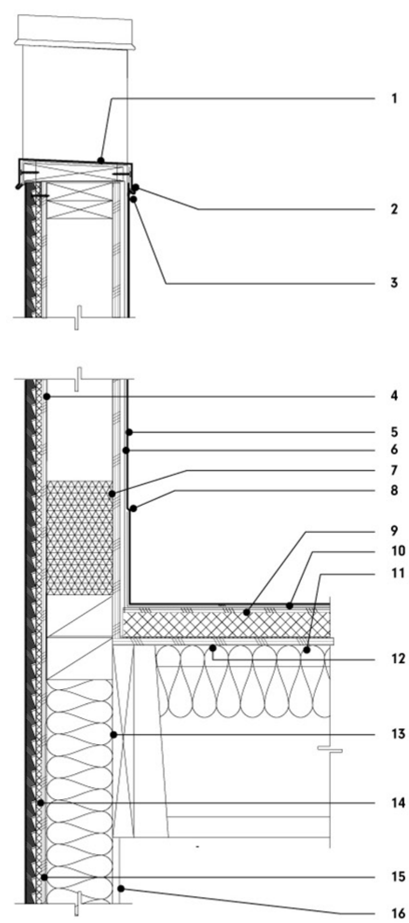


BUILDING SECTION AT LIBRARY AND CLASSROOM

OCEAN VIEW ELEMENTARY SCHOOL — BUILDING SECTION



A - WALL SECTION PARAPET AT CLASSROOM



A1 - STUCCO PARAPET @ ROOF, TYP.

1. LAP ROOF MEMBRANE OVER TOP OF PARAPET
2. 16 GA. CAP FLASHING
3. SEALANT, TYP
4. PLYWOOD SHEATHING AS REQ'D FOR SHEAR
5. WATERPROOFING MEMBRANE
6. EXTERIOR SHEATHING
7. SPRAY POLYURETHANE FOAM AIR BLOCK
8. LAP ROOF MEMBRANE AS INDICATED
9. 2" RIGID INSULATION
10. 1/2" PROTECTION BOARD
11. 6" - 6 1/2" THERMAL BATT INSULATION R-19
12. 1/2" EXTERIOR GRADE PLYWOOD SHEATHING
13. THERMAL BATT INSULATION R-19
14. 3-PART STUCCO SYSTEM OVER DRAINAGE MAT
15. PLYWOOD SHEATHING AS REQ'D FOR SHEAR
16. GYPSUM BOARD AT INTERIOR

Design Process and Low-Energy, Zero-Carbon Design Strategies

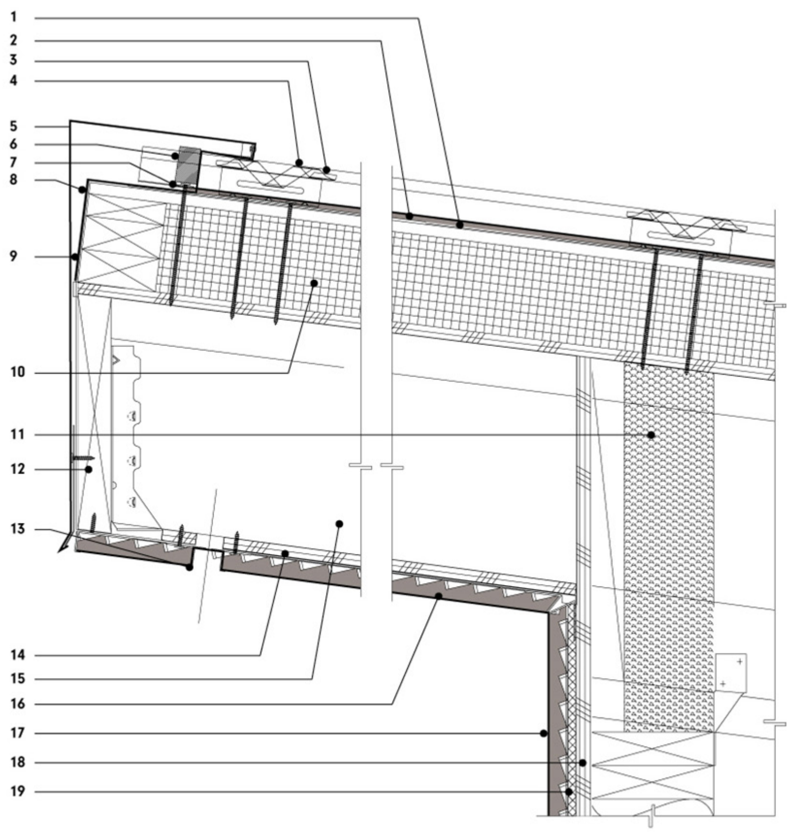
The design of the facility for Ocean View Elementary School evolved during the lengthy time period from the initial Facilities Master Plan through the funding, approvals and construction processes. That period of time (2014-2020) also coincided with the shift in California from an emphasis on ZNE design for buildings to all-electric (and energy-efficient) design and with the passage of SB-100 by the state legislature in 2018. (SB-100 set 2045 as the year that California's electric utility grid would be required to be 100% decarbonized.) The 2018 passage of SB-100 introduced additional design considerations, as discussed below.

The AUSD had already mandated an all-electric design in 2016, partly because the health of the community and the students were seen as important for this project. Having an all-electric campus eliminates gas-related pollution on site. Daylighting, fresh air and covered outdoor spaces were seen as creating a focus on healthy learning spaces for K-6 students.

As described above, during Phase 2 of the project process, the AUSD Board also adopted the "Net-Zero Energy (NZE)-Ready" standard for *all* new school construction and major modernizations, including those funded by the 2016 bond measures, in addition to the all-electric design mandate. The following sections describe these aspects of the design features.

Building Envelope - Insulation, Windows and Air-Tightness

Since the structure is maximum two-stories, it is built using typical 2X6 wood-frame construction. R-19 batt insulation is installed in the walls and roof, plus 2" rigid insulation on the roof to meet R-30, complying with minimum Building Energy Efficiency Standards Title 24 (Part 6) requirements. (See figures below and on opposite page.)



B - HIGH EAVE/COPING AT METAL ROOF

1. 1/2" COVERBOARD
2. METAL ROOF UNDERLAYMENT MEMBRANE
3. 1-1/2" STANDING SEAM MOVABLE CLIP
4. STANDING SEAM ROOFING PANEL
5. VENTED SHED RIDGE CAP
6. NEOPRENE CLOSURE
7. BUTYL TAPE
8. LAP HIGH-TEMP ROOF UNDERLAYMENT OVER WATERPROOFING, TYP.
9. WATERPROOFING
10. 4" RIGID INSULATION
11. SPRAY POLYURETHANE FOAM AIR BLOCK
12. 2x12 FASCIA
13. VENT SCREED
14. PLYWOOD SUBSTRATE
15. 2x10 RAFTER
16. STUCCO FINISH SYSTEM AT SOFFIT
17. EXTERIOR STUCCO WALL ASSEMBLY
18. PLYWOOD SHEATHING
19. DRAINAGE MAT

(Opposite page) Typical wall section and parapet detail. *(Left)* Typical roof detail. *(Courtesy of Multistudio, formerly Gould Evans)*

The concrete slab floor is uninsulated below or at its edges. The thermally-broken metal frame windows are Title 24 compliant: low-e Solarban-70 double-glazing (U = 0.45, SHGC = 0.25 with a visual transmission of 0.55). The width of the new classroom building is narrow enough to provide good daylighting from windows on both sides, so no skylights or solatubes were utilized. A clerestory window is added in the locations where the building width exceeds the ideal dimension for natural daylight penetration.

The building envelope employs air-sealing measures, but no air-tightness testing was done using blower-door testing techniques[6] to determine possible air leakage locations and whether the buildings were achieving the Title 24 standard of 5 ACH50 [7]. Testing was not required at the time of permit approval for this project.

As a result of the limitations of these design features, dictated primarily by budget constraints, the building envelope is minimally compliant with the prescriptive requirements of Title 24.

Heating, Ventilating and Cooling Systems

Heat pump units are located in louvered closets in most classrooms. These eliminate equipment from the roof location, providing space for future solar PV panels. For some buildings, including the administration and library buildings, rooftop package heat pump units utilize higher-efficiency *Variable Refrigerant Flow (VRF)*[8] systems. (See diagrams on opposite page.)

The mild marine climate of this location permits cooling with outside air using an economizer cycle for most of the year, but the heat pump technology provides air-conditioning when needed for the rare but increasing occurrence of relatively extreme weather events, an added benefit of this electric climate-control system. An *Energy Recovery Ventilator (ERV)*[9] sub-system was studied and deemed unnecessary because of the mild local climate.

Domestic Hot Water System

Electric resistance water heaters are used in the restrooms and in the warming kitchen located adjacent to the Multipurpose Room since the hot water demand is low in these spaces.

Appliances

The warming kitchen in the teachers' breakroom has an ENERGY STAR® rated refrigerator and electric induction range.

Lighting and Plug Loads

All indoor and outdoor lighting use *Light-Emitting Diode (LED)* sources with occupancy sensor controls. The lighting controls also respond to daylighting levels per California code requirements. The overall installed lighting electrical load averages 0.41 watts/sq.ft., significantly less than Title 24 code maximum.

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[6] For a description of the *Blower Door Test*, see: https://www.energy.gov/energysaver/blower-door-tests.

[7] ACH50 is the unit of measurement of the number of air changes per hour at 50 pascals of pressure. As noted, the California Title-24 standard is 5 ACH50. As a comparative reference, the *Passive House* standard is 0.6 ACH50. See: *Zero Net Energy Case Study Homes-Volume 1*, p. 12. https://calbem.ibpsa.us/resources/case-study-books/

[8] See: https://en.wikipedia.org/wiki/Variable_refrigerant_flow

[9] See: https://en.wikipedia.org/wiki/Heat_recovery_ventilation

(Below) Heat pump units are two types: Vertical units located in closets in each classroom (top diagram below) and Rooftop package units (bottom diagram below)
(Courtesy of Multistudio, formerly Gould Evans)

(Following Pages, pp. 18-19) Aerial view of completed Ocean View Elementary School from the west.
(Photo: Kyle Jeffers Photography)

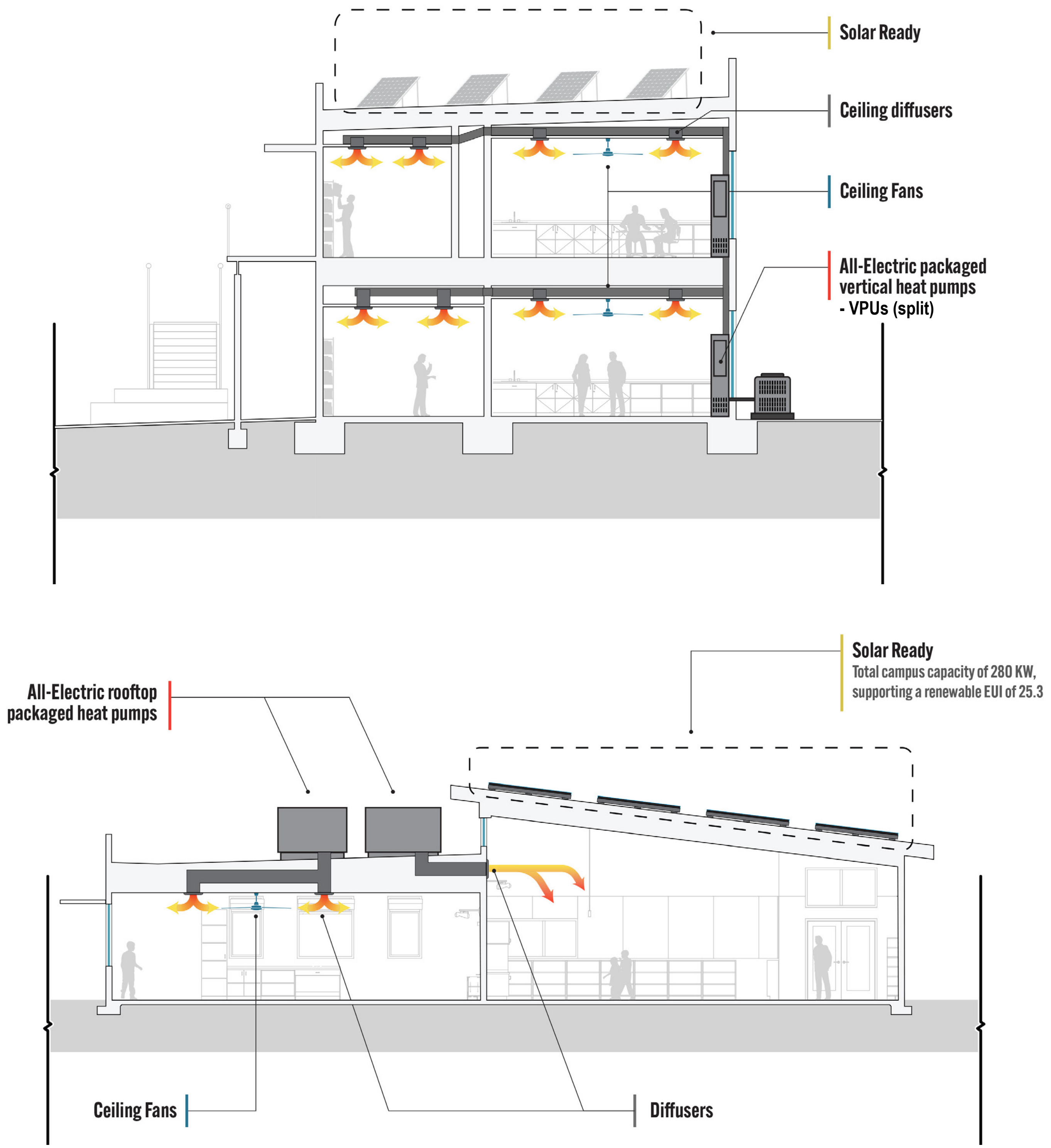


PHOTO: KYLE JEFFERS

Renewable On-Site Energy Supply

Solar Photovoltaic System

The principal issue for the solar PV system was the limitation on available roof area for the solar panels required. The energy modeling done by Interface Engineering in 2019 for the final design showed that 844 panels with a production rating of 320 watts per panel were needed to offset the predicted annual energy demand for the buildings and site in order to achieve the design goal of *zero-net-energy (ZNE)* use annually. This would have required the use of the roofs of both the new and existing buildings to accommodate enough panels to offset some but not all of the predicted total annual energy use.

The school board instructed the design-build team to utilize only the new buildings for the installation so that the expense of extensive additional work required on the existing buildings would not be incurred and excessively impact the project budget. To make the new buildings ready for the installation of the new solar PV system, the design-build team provided the infrastructure necessary in each location for the future solar PV panel connections.

The layout of solar PV panels on the roofs of the new buildings was rendered in the final design-build documents as shown in the figure at the bottom of the opposite page. The solar PV panels were to be installed by a solar subcontractor. As of the date of occupancy in the summer of 2021, the installation of the solar PV panels at all the bond-funded school projects was put on hold for budget reasons.

In 2023, the Albany USD decided to re-evaluate the installation of solar PV systems at the six schools funded by the 2016 bond measure. The district therefore commisssioned a study to re-conceptualize the siting and sizing of solar PV systems. The study also estimated the financial performance of a solar PV system financed through a *Third Party Power Purchase Agreement (PPA)*[10] for the installation and operation of the solar PV system.

In the case of the Ocean View Elementary School, the study assumed the use of 450-watt solar PV panels, which reduced the system size to 489 panels. These panels could effectively be accommodated on the newly built roofs plus one large canopy structure above some of the parking. This new, more advanced design, is shown in the figure at the top of the opposite page.

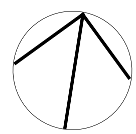
The study showed a payback period of about 12 years for the combined six schools. The Albany USD subsequently decided not to install the solar PV systems in the six district schools due to initial cost and the potential positive environmental impact of California SB-100 legislating 100% decarbonization of the state electric power grid by 2045.

On-Site Energy Storage: Batteries

No battery storage was included in the design, although this could be added in the future for load management and resilience if the solar PV system is ultimately installed.

[10] See: https://www.epa.gov/green-power-markets/solar-power-purchase-agreements

(Top Left) Roof plan of Ocean View ES from the 2023 *Solar PV Feasibility Study* showing solar panels installed on new building roofs and a new car canopy.



NORTH

(Bottom Left) Roof plan of final design showing solar panels installed on new building roofs *(Courtesy of Multistudio, formerly Gould Evans)*

Design Analysis: Optimizing Zero-Carbon Design

Design Analysis: Embodied Carbon

An embodied carbon analysis was not done as part of the design process because the analytical tools were not fully developed when the project was being initially planned. The relative simplicity of the structure (wood-frame rather than concrete and steel) and building components also led to a likely low embodied carbon set of solutions.

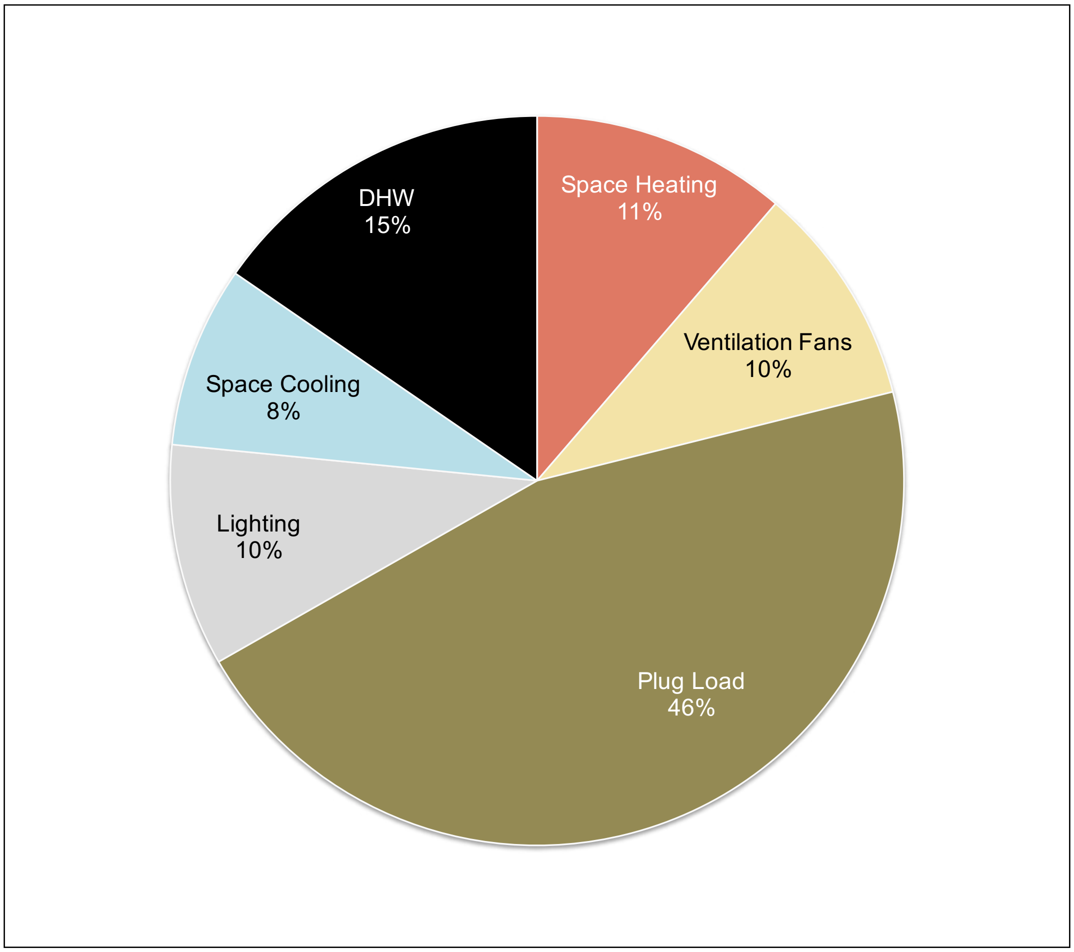
Design Analysis: Energy Modeling and Operational Carbon

The new Ocean View Elementary School buildings were analyzed during the design-build development phase using *CBECC-Com* building energy modeling software for Title 24 compliance. The modeled energy use for the 31,443 sq. ft. of new buildings (only) by category of use for prescribed conditions over the course of a year is given in the charts on the opposite page.

The results of the modeling show that the new buildings would consume a total of 230 MWh annually (upper chart), with an *Energy Use Intensity (EUI)* = 24.9 kBtu/sq.ft. per year. Because of the relatively mild climate and the good daylighting design, the predominant energy demand was predicted to be the plug load. The lower chart on the opposite page shows the monthly breakdown of the modeled energy use. The 15,870 sq. ft. of renovated exisiting buildings were separately estimated to have an EUI = 32.0 kBtu/sq.ft. per year.

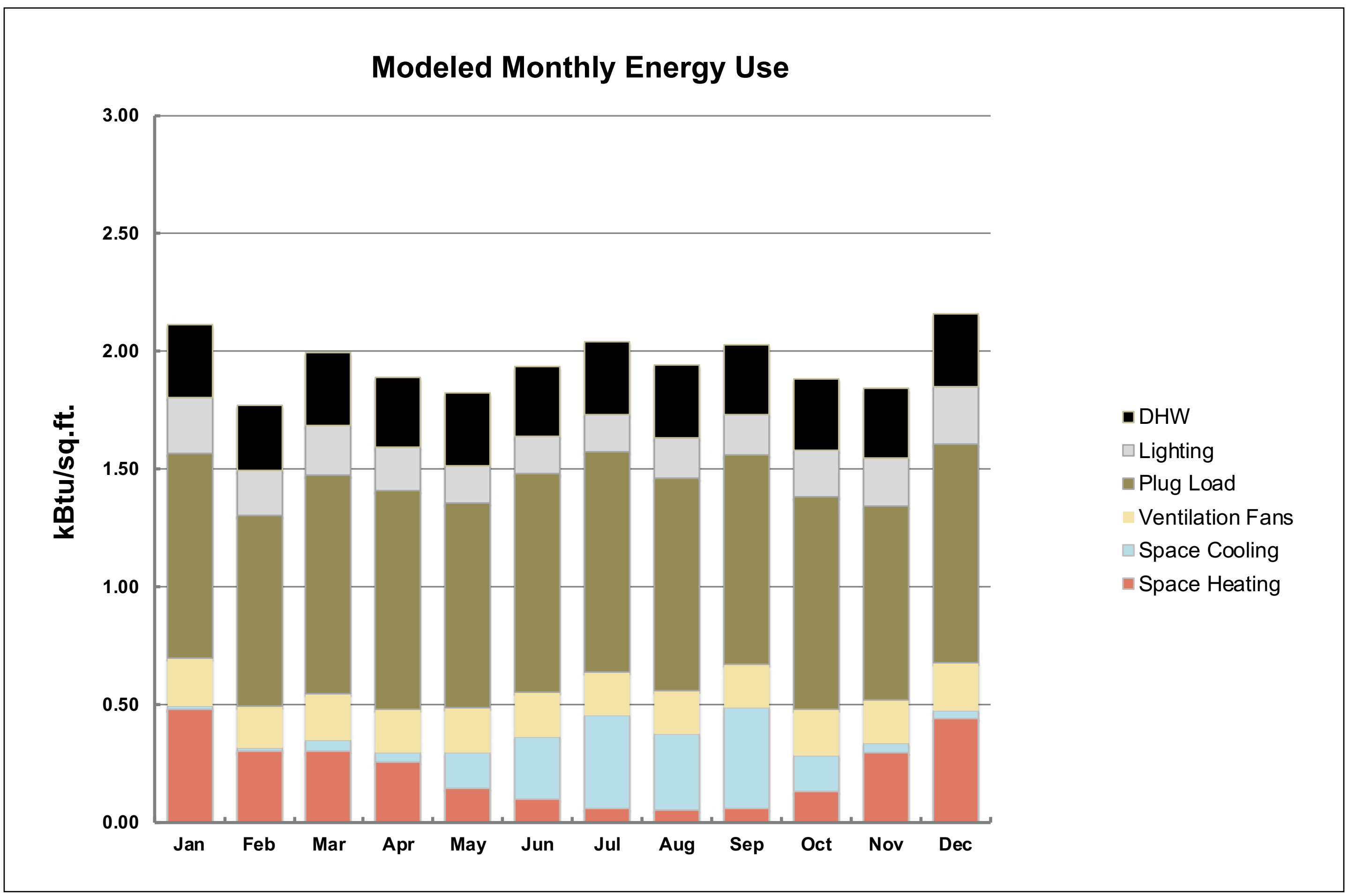
As described in the previous section, the modeling of the energy production by the initially-planned solar PV system was not adequate to offset the modeled annual energy use. This energy production modeling is not shown here because of the subsequent change in the proposed type of solar PV panel, followed by the Albany USD decision not to install any solar PV system. The design of any future solar PV system will be able to utilize actual energy use data for the site.

(Below)
View of outdoor spaces in center of Ocean View Elementary School. *(Photo: Kyle Jeffers Photography)*



Modeled Energy Use (Annual)

230,000 kWh/year
Modeled EUI = 24.9

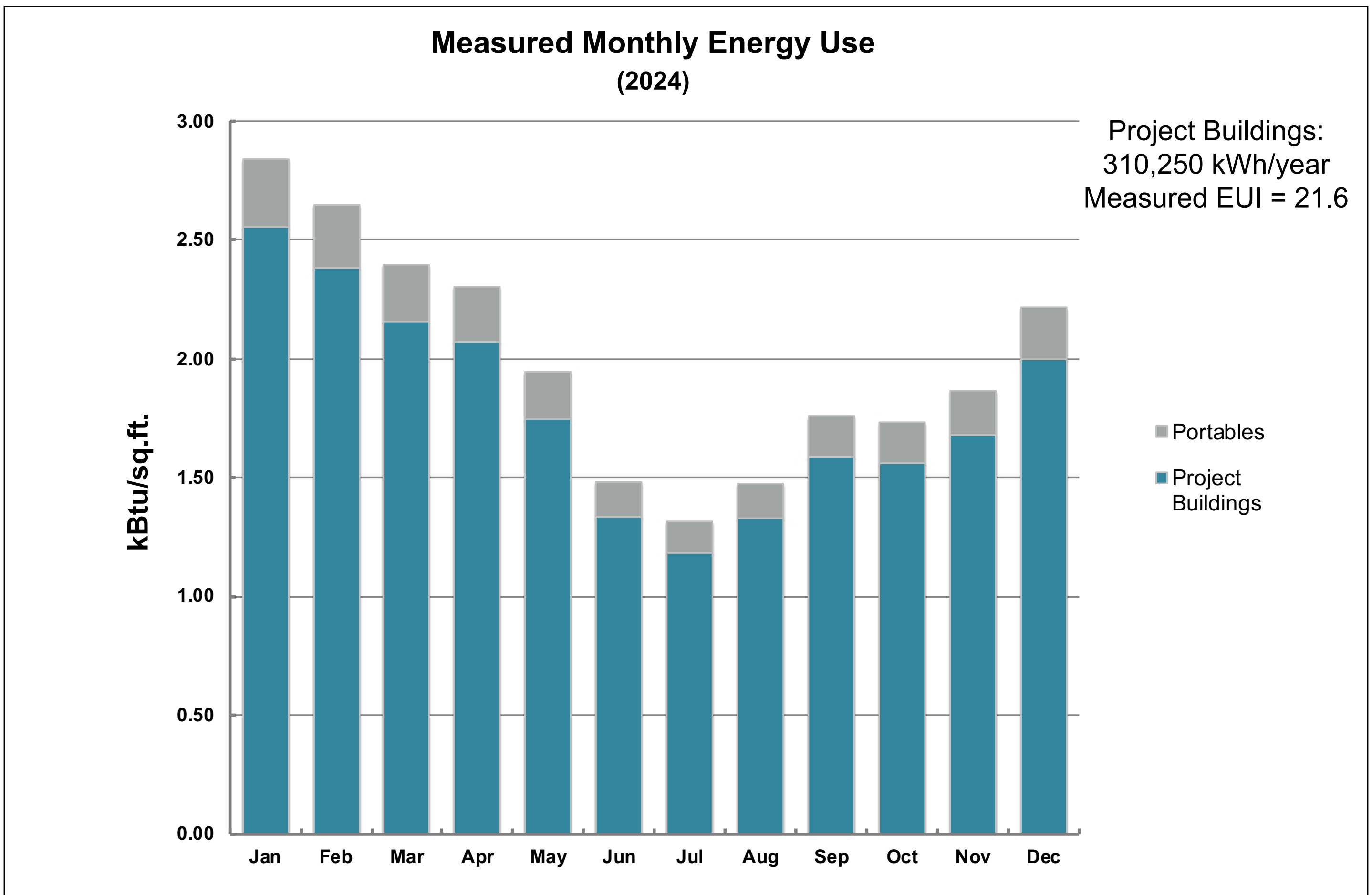


Energy Use — Post-Occupancy Measurement

There is only one electric utility meter for the entire Ocean View Elementary School site, including the temporary buildings (portables) that remained after the project was completed. It is estimated that these portables account for 10% of the measured energy use. Since no solar PV system was installed, the recorded data represents the electric energy use only of the entire campus—site electrical, new buildings, renovated buildings and portables.

Energy use data was recorded for the three most recent years and totaled 345 MWh for 2024. Deducting the estimated 10% for the energy used by the portables, the total energy use in 2024 for the remaining buildings (new and existing) and site was 310 MWh.

The 2024 monthly data for the entire site is shown in the bar chart graph below. As noted in the previous paragraph, because of the difference in sources of the recorded energy use for the entire site, the energy use data in this bar chart cannot be directly compared to the modeled monthly energy use for the new building project area shown in the bar chart on the previous page. However, the actual EUI in 2024 for the entire site (using the floor area of *all* structures) was 24.0 kBtu/sq.ft., roughly comparable to that predicted for the new building project area alone: 24.9 kBtu/sq.ft. The conclusion: in 2024, the Ocean View Elementary School was more energy-efficient than the design model estimated.



Post-Occupancy: Observations and Conclusions

This project was one of several that the AUSD undertook as part of the bond-funded program that was approved by Albany voters in 2016. It was not until 2021 that the project was completed and occupied. As part of the process along the way, the goal was adopted of an *all-electric* facility, eliminating all on-site carbon emissions from fossil fuels used in on-site systems to provide heating, hot water and cooking. Furthermore, when the State of Californa passed SB-100 in 2018, which set a target date of 2045 when the state's public electric power grid would be 100% fossil-fuel free, the school was set to have a zero-carbon footprint for all of its operational energy in 20 years.

This total operational decarbonization of the facility will be achieved without necessarily incorporating a solar PV system into the design, which remains as a possible addition at the site. The decision about whether to follow through with one of the original concepts for the facility will now be based solely on the cost, since the zero-carbon operational goal will be realized.

All-Electric Design Objective

The all-electric design objective (i.e., design for zero-carbon operation) was demonstrated to be practical, effective and feasible in this case for both a school retrofit project and new buildings. While energy-efficient design of the building envelope, daylighting and natural ventilation is still necessary with its well-understood features and methodologies, the design of electric systems that replace fossil-fuel based systems presents a new challenge to designers. This project successfully implemented electric technologies and demonstrates a design pathway that can be replicated by other school districts.

Lessons Learned

The design team for this project mentioned several "lessons learned" as they developed their design:

- For the renovated buildings, the rooftop commercial-grade heat pump package units were required to be a certain weight so that the existing structure would not need any additional strengthening. Package heat pump units are generally heavier than gas-fired units.

- Rooftop heat-pump units with VRF were originally planned for all buildings, but less-costly vertical heat pump units without VRF were placed in closets within the individual classrooms to reduce initial cost.

- Ordinarily, there may be a significant cost to a required upgrade to site service equipment depending on the existing level of service and the extent of work required for the planned upgrade. This was not needed for the Ocean View Elementary School site.

Design team final comment:

"Overall it was a successful project. Priority was set early to allow time and collaboration to resolve constraints to achieve the goal of full electrification."

CASE STUDY NO. 2

Blue Oak Middle School

PHOTO: SASHA MORAVEC

Blue Oak Middle School

Case Study No. 2

Data Summary

Project Type: Private
Location: Napa, CA
California Climate Zone: 2
Gross Floor Area: 24,298 sq.ft.
Occupied: August/2024
Grades: 6th - 8th

Modeled EUI (Site):
22.4 kBtu/sq.ft. per year
Measured EUI (Site):
No data yet available

On-Site Renewable Energy System Installed:
None
On-Site Storage Battery:
None

Client Organization:
Blue Oak School

Design Team
Architect:
Ratcliff, Emeryville, CA
Structural Engineer:
IDA Structural Engineers, Oakland, CA
Mechanical Engineer (Concept)
McCracken and Woodman, Oakland, CA
Mechanical Engineer of Record
Iron Mechanical, Sacramento, CA
Electrical Engineer:
O'Mahony & Myer, San Rafael, CA
Energy Modeling:
Streamline Green, Berkeley
Landscape Architect:
O/CB Studio, San Francisco

General Contractor:
Davis Reed Construction, Napa, CA

Private schools in California are registered with the State Superintendent of Public Instruction, California Department of Education, and consist of approximately 10% of the total school enrollment in California. These private schools generally include some portion of the grades K-12, usually mirroring the public school categories of elementary, middle and high schools. Some private schools combine elementary and middle school grades in a single facility or campus, while others focus on one of these educational groupings (K-5, 6-8, 9-12).

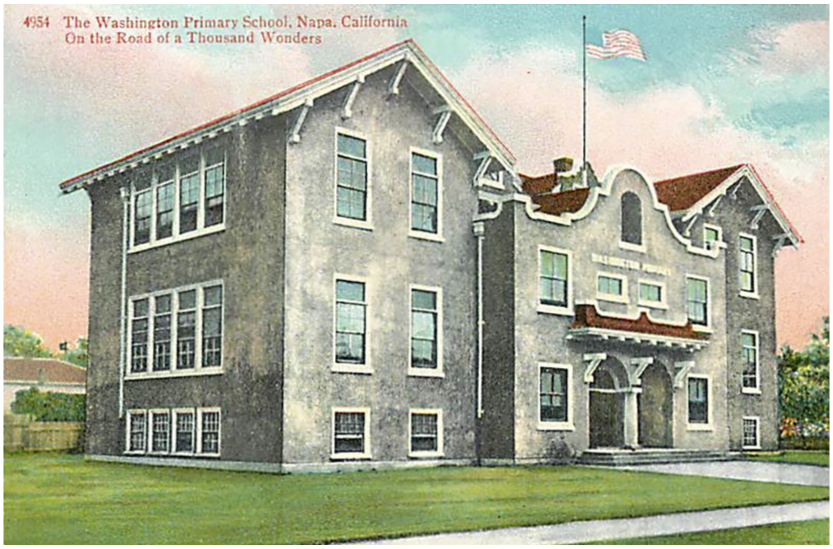
This second case study is an example of a private middle school, grades 6-8, for which an entirely new facility was designed and built adjacent to the school's existing elementary school building. (See *General Vicinity Plan* on opposite page.) New private school facilities are generally funded through private sources and as a result do not require oversight by state educational administrative offices. The result can be a shorter design and construction schedule as well as programmatic features of the facility that may be special or unique to the private school organization.

Background

The Blue Oak School was created in 2000 by some early tech entrepreneurs who, two years prior, had started a winery in Napa, California, and wanted to establish a high-quality elementary school in that area for their growing families and community.

They found a building near downtown Napa that was essentially abandoned, but it had formerly served both as an elementary school, the "Washington Primary School" from 1909 until 1933, and the "Manual Art & Science School" where home economics classes were taught until 1953. Then the school structure was converted to office space, used by the County of Napa for administrative offices until the early 1990s, when the old school building was basically abandoned, with the empty structure only occasionally being used by the Napa Fire Department as a training structure.

The Blue Oak School founders purchased this building in 2000 and proceeded to renovate it to accommodate their K-5 elementary school program. The new *Blue Oak Elementary School* opened in the fall of 2002.



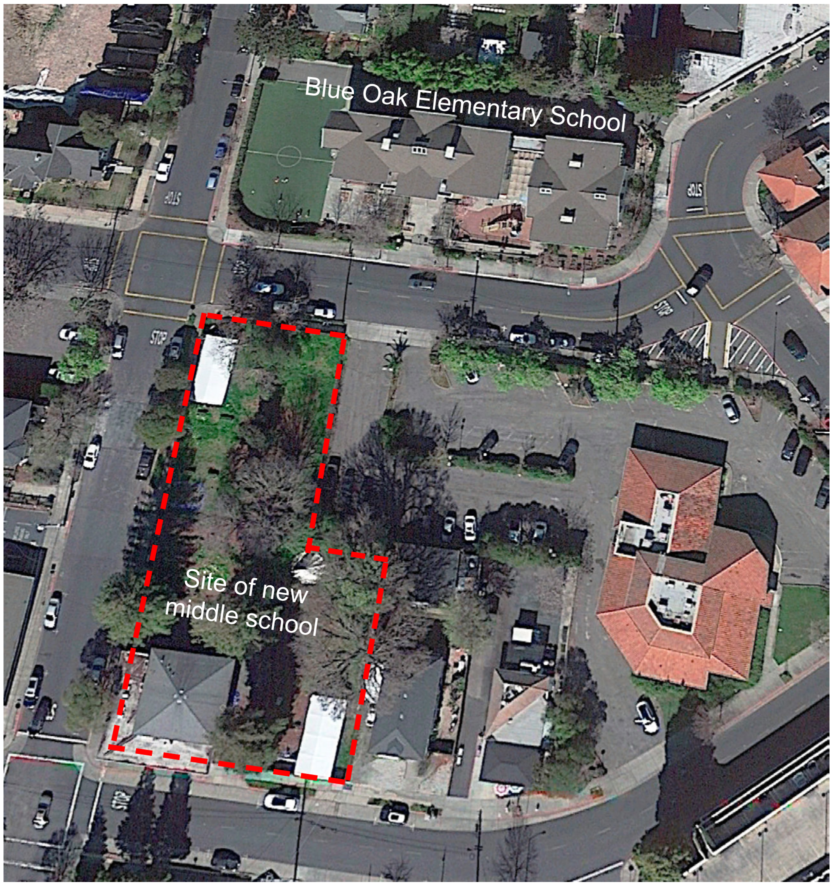
(Above) Postcard from 1910 showing original school building that was renovated in 2001-2002 to become the Blue Oak Elementary School.

Blue Oak Middle School - General Vicinity Plan

(Right) The Blue Oak Elementary School in the renovated historic structure, completed in 2002. (Courtesy of Ratcliff Architects)

The 2001-2002 renovation of the historic building was designed by Ratcliff Architects and McCracken & Woodman MEP Engineers. As part of this historic renovation, the engineers incorporated an innovative energy-efficient design feature—a ground-source heat pump that utilized the geothermal site characteristics beneath that location in the city. The founders of the Blue Oak School were so pleased with this energy-efficient, historic renovation that they engaged the same team to design the new middle school when the site directly across the street became available in 2019.

This site of the new middle school was relatively undeveloped for a downtown site, containing one house and a large garden area on five parcels. The original founders of Blue Oak School purchased the five lots and engaged their design team to develop a new modern facility for grades 6-8.



(Right) Aerial view of The Blue Oak School sites prior to 2019.

Design Process and Low-Energy, Zero-Carbon Design Strategies

In this case study, the fundamental goal of a zero-carbon operation through an all-electric design was chosen by the school leaders, while at the same time introducing certain innovative features to the classroom and program design. In fact, there was also a suggested stretch-goal of *Zero Net Energy (ZNE)* performance for the completed facility, which would require heightened energy-efficiency of the design of the facility as well as introduction of an on-site solar PV system. An all-electric design would maximize the impact of the addition of the solar PV system and there would also be a cost-saving result of avoiding the need for constructing a natural gas supply infrastructure at the site.

Building Program

The middle school building program was developed to include classroom space for the expected student enrollment, administration and shared school community spaces. The latter would include a school library and a new gymnasium. Eventually, the size of the site and other design constraints permitted a 27,000-square-foot facility in two buildings: a 17,500-square-foot academic building that includes eight classrooms, along with a 9,500-square-foot gymnasium building with indoor athletic courts, a culinary arts teaching kitchen and theater capability.

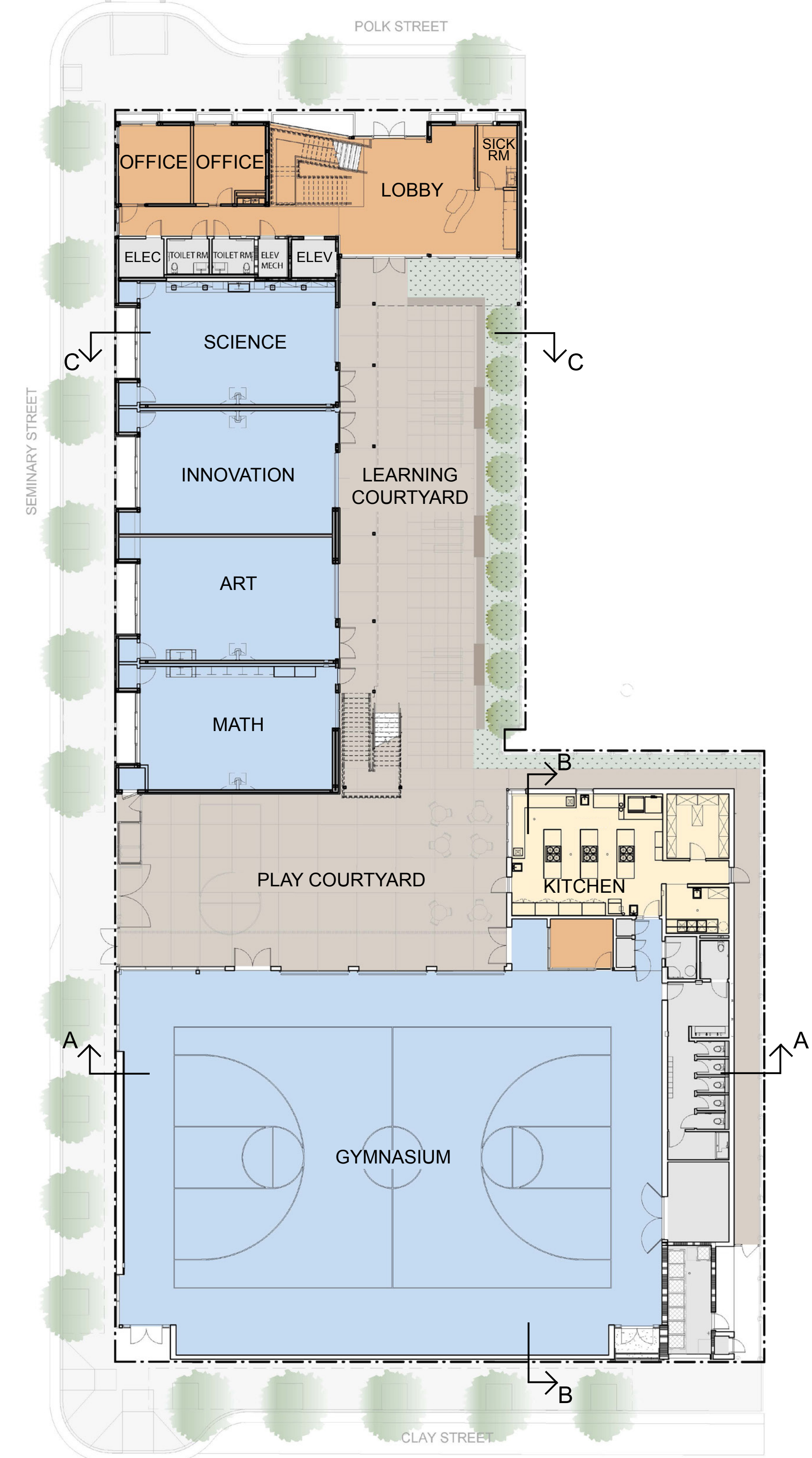
The new academic building includes art, humanities, social studies, math and music classrooms, a collaborative conference area that also serves as the school library and an administration space. The gymnasium can be transformed into a modern theater facility with seating, lighting and sound systems. The large commercial kitchen facility in this building is designed for instruction about food and cooking as well as serving events taking place in the large gymnasium space or the adjacent exterior courtyard.

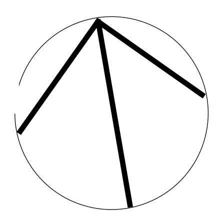
Site Constraints

The site was able to accommodate the desired building program on two levels. The local climate allowed innovative ideas about the connection between indoor and outdoor learning spaces, using roll-up garage doors as the wall adjacent to the outdoor area.

An interesting design constraint that resulted from the permeability of the ground in the area was the discovery of gas vapors from a nearby dry cleaning facility percolating through the soil at the site. The project construction was paused for six months in order to install a vapor mitigation system under the future concrete slab. A monitoring system was also included in the design of the enclosed spaces.

(Following Pages) The site plan, floor plans and building sections of the Blue Oak Middle School.

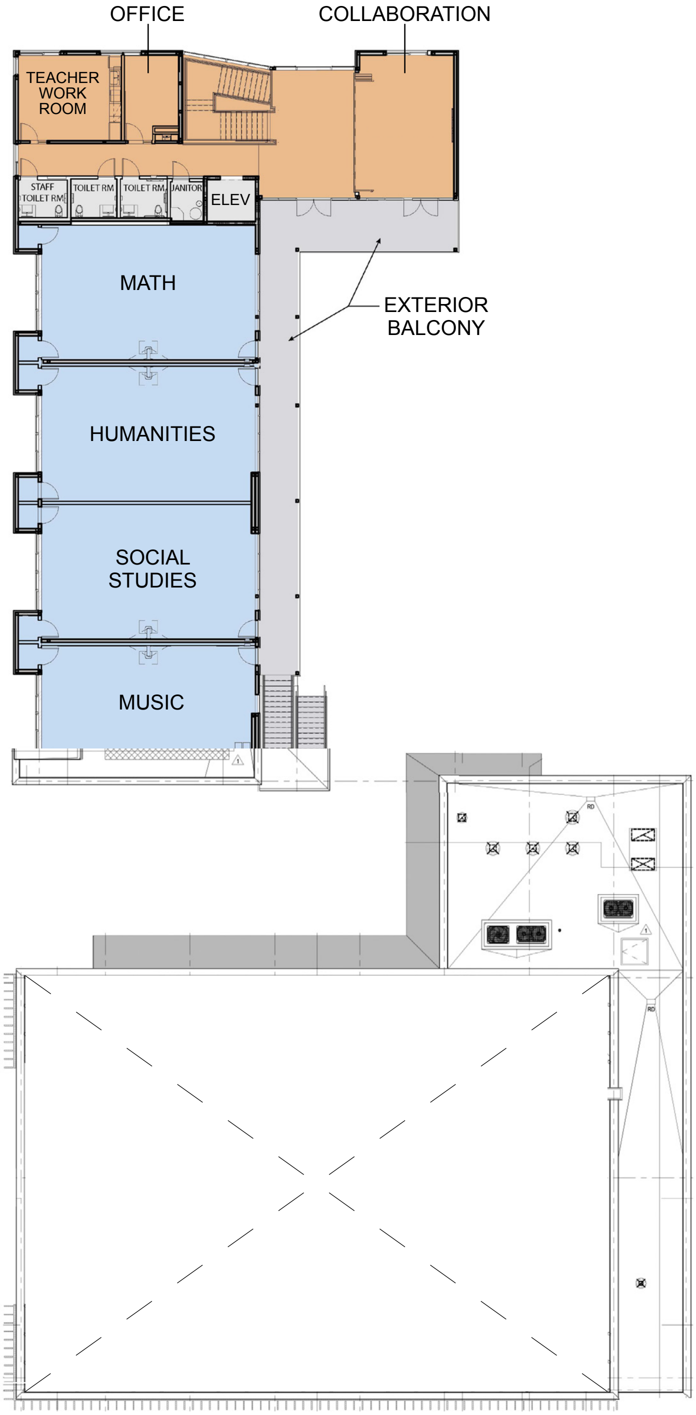




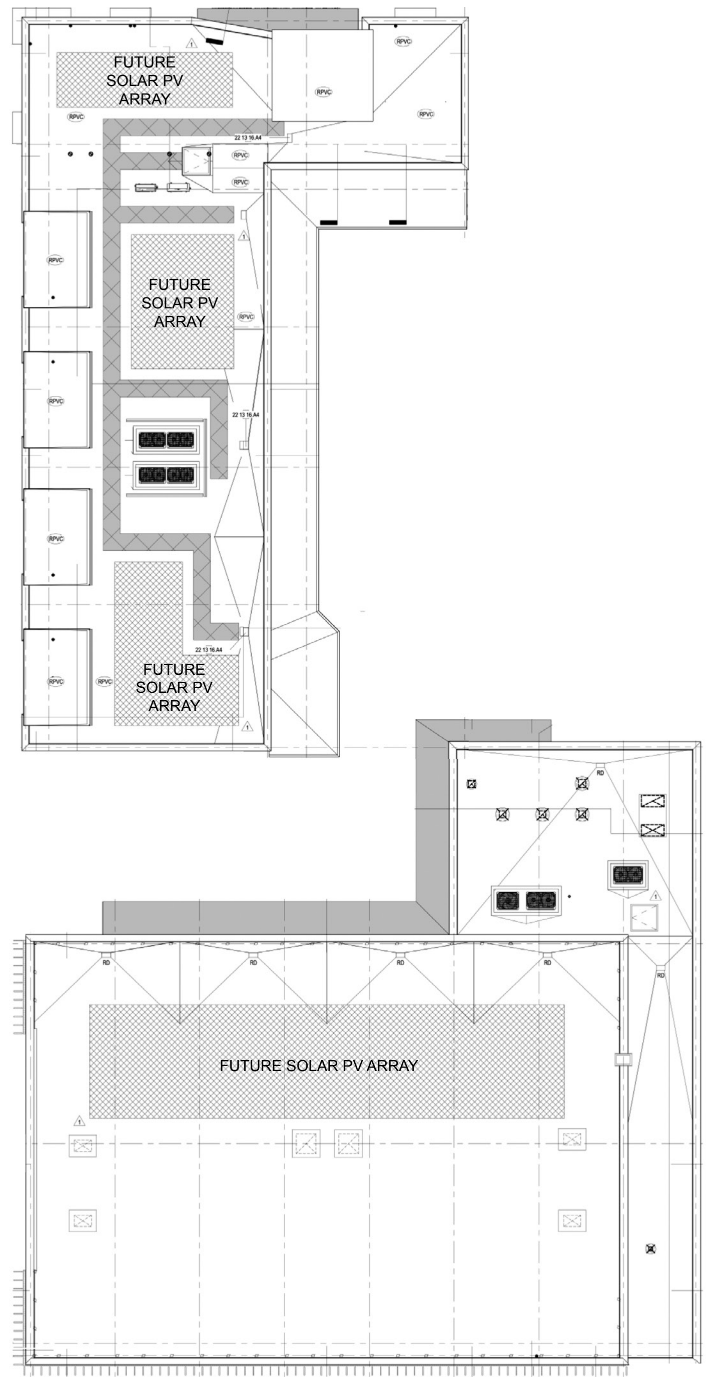
SITE AND GROUND FLOOR PLAN

0 10 20 30 50 100 FT

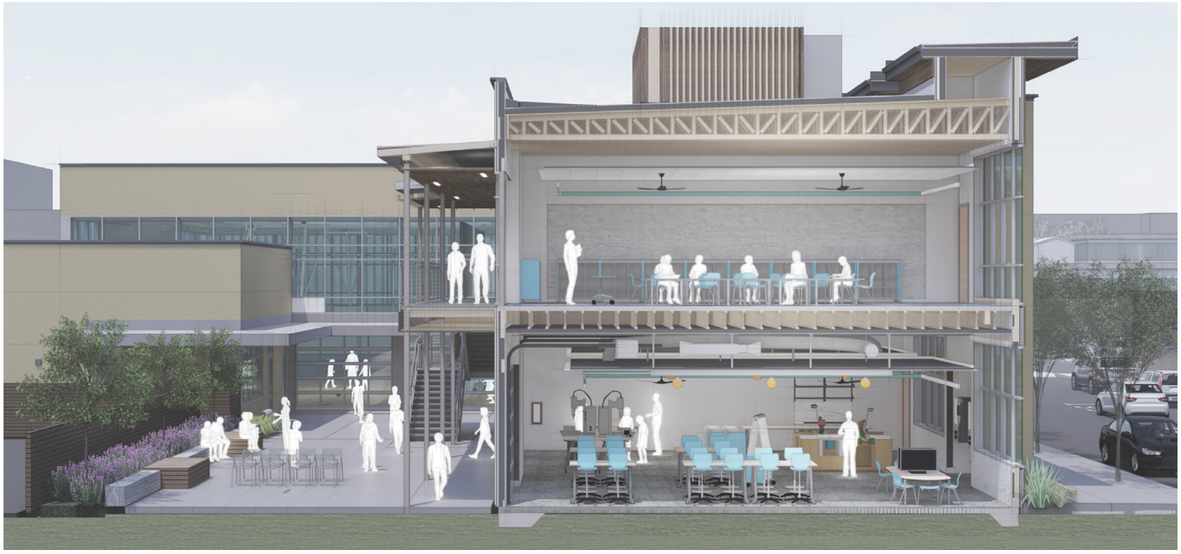
BLUE OAK MIDDLE SCHOOL — FLOOR PLANS



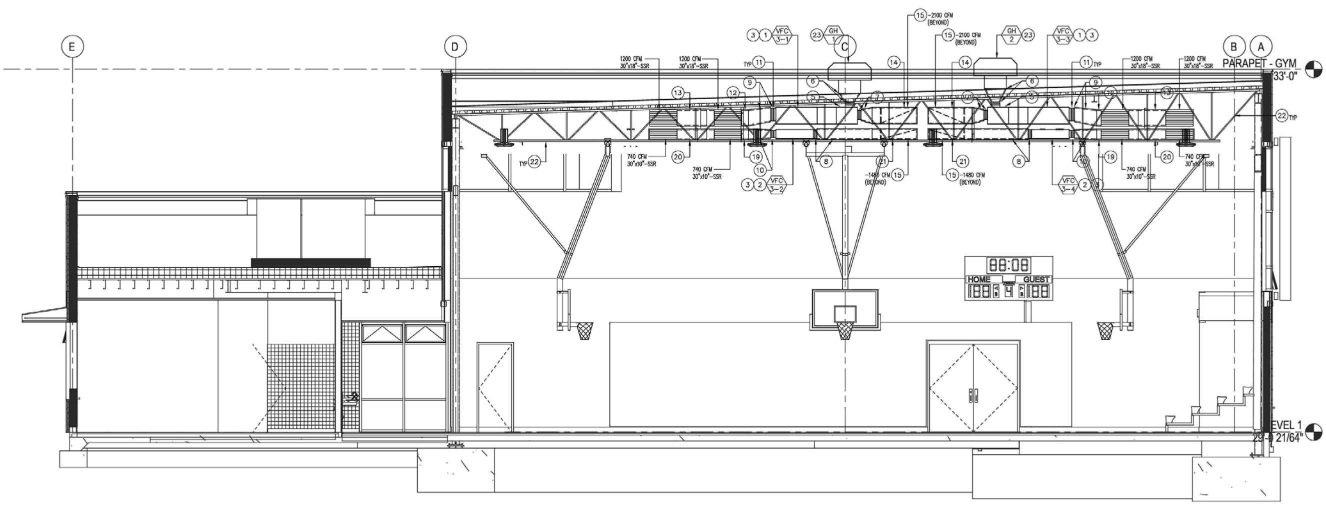
SECOND FLOOR PLAN



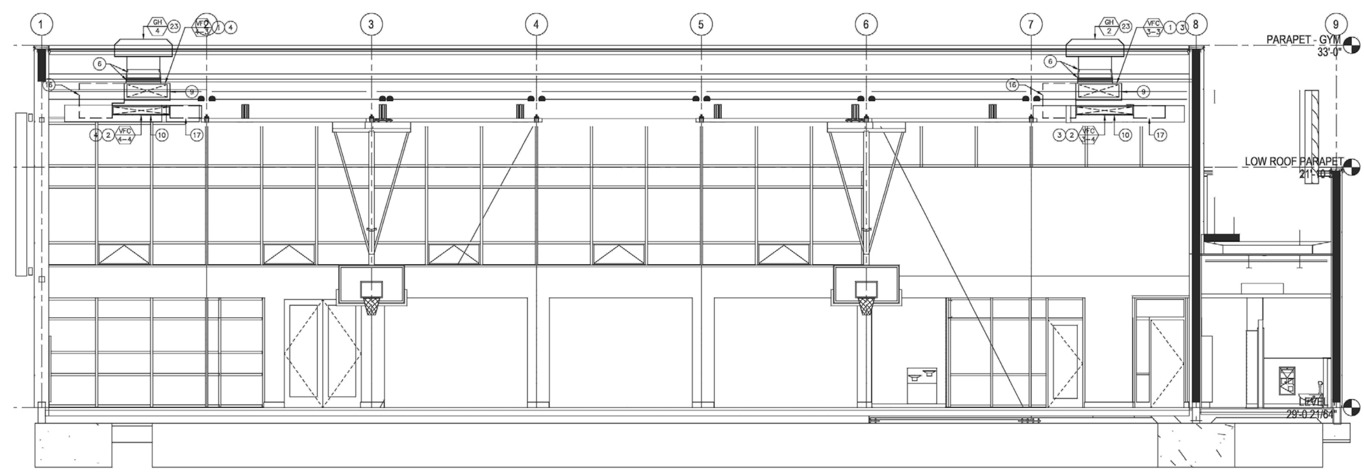
ROOF PLAN



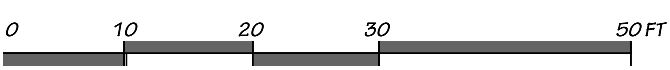
SECTION C - C   CLASSROOM BUILDING, LOOKING SOUTH



SECTION B - B   GYMNASIUM AND KITCHEN, LOOKING EAST



SECTION A - A   GYMNASIUM, LOOKING NORTH



BLUE OAK MIDDLE SCHOOL — BUILDING SECTIONS

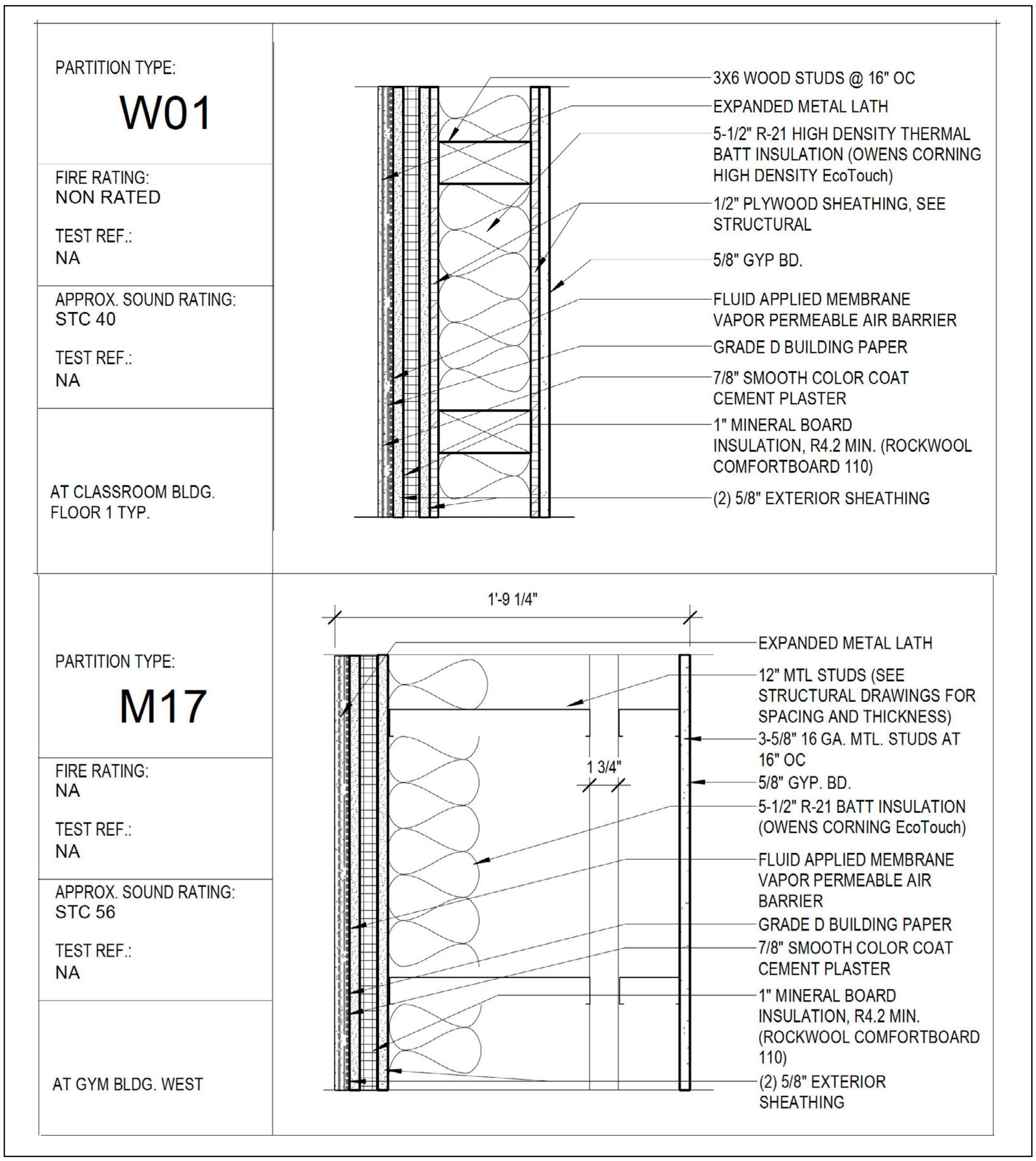
PHOTOS: SASHA MORAVEC

(Opposite Page) Typical west-wall sections of the two-story classroom building (left) and the gymnasium building (right). (Courtesy of Ratcliff Architects)

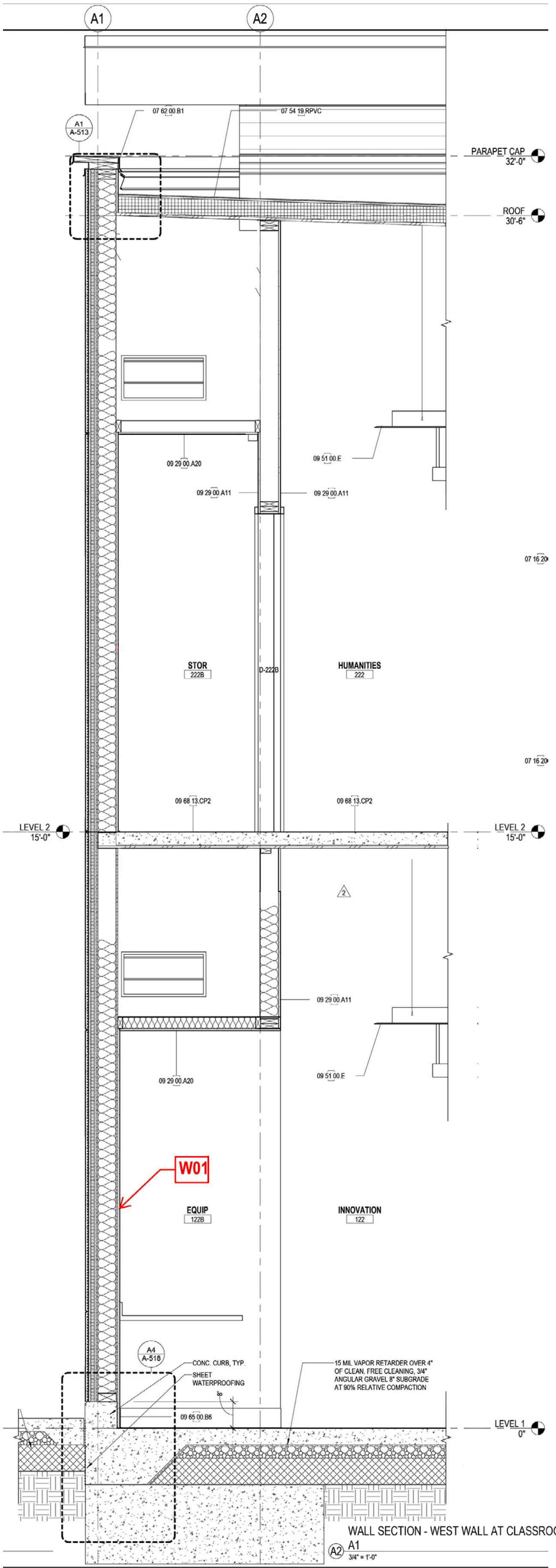
Building Envelope: Insulation and Windows

The classroom building was framed using standard wood-frame construction with 2X6 studs and 5-1/2” fiberglass batt insulation. (See detail W01 below.) A one-inch layer of mineral board insulation was applied over the plywood sheathing to prevent thermal bridging at the studs. The U-value for this wall is 0.049.

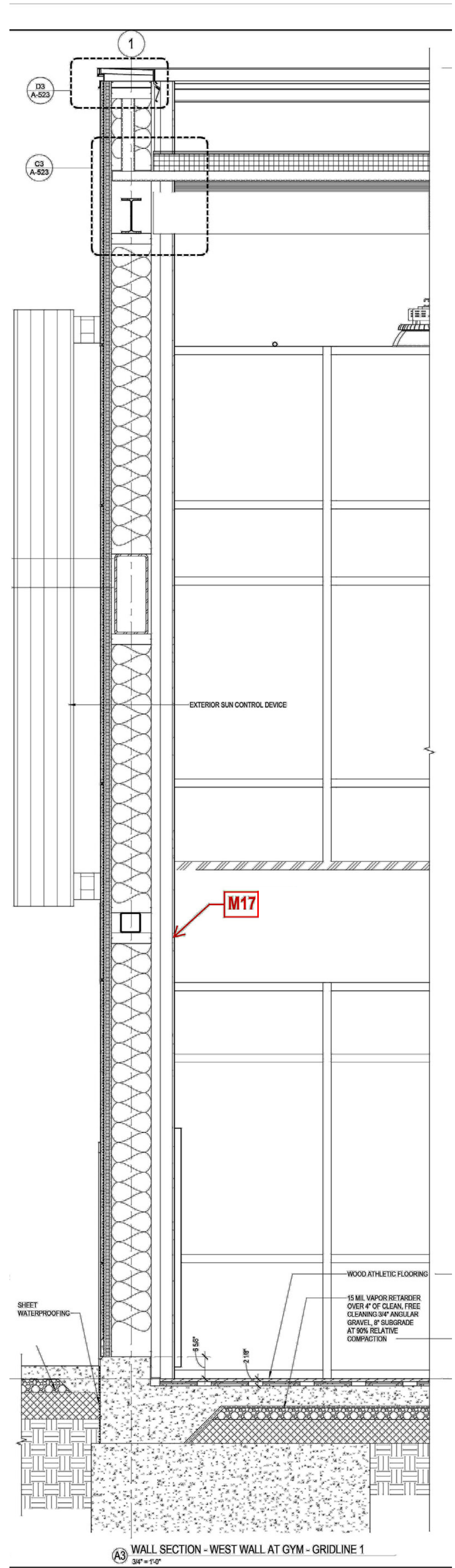
The gymnasium building was framed using deep steel studs because of the wall height. (See detail M17 below.) The same insulation material was used in this wall, though the total thickness of the batts was doubled in some places for acoustic reasons. (See wall section on the opposite page.) Again, one-inch mineral insulation board was added to the outside of the framing to eliminate severe thermal bridging at the metal studs. The U-value for this wall as shown in detail M17 is 0.087.



(Right) Wall details called out in the wall sections on the opposite page. Detail W01 uses 2X6 wood studs. Detail M17 uses 12” metal studs for structural reasons. (Courtesy of Ratcliff Architects)



WALL SECTION - WEST WALL AT CLASSROOM - GRIDLINE A1
A2
3/4" = 1'-0"



A3 WALL SECTION - WEST WALL AT GYM - GRIDLINE 1
3/4" = 1'-0"

The concrete floors are uninsulated. The roofs generally are insulated with 5”-thick rigid cellular polyisocyanurate sheets. The gymnasium roof, constructed of steel decking, is sloped to drain and is covered with uniform rigid insulating sheets having an overall U-value of 0.036. The classroom building roof consists of standard wood framing with tapered sheets of insulation to provide the necessary drainage and has an overall average U-value of 0.032.

Window system is a framing system[1] that provides thermal breaks between the exterior and interior of the frame. The double-glazing has a low-e coating[2] on the interior surface of the exterior pane. The classrooms also have a roll-up window-wall[3] that has an insulated frame and 1/2” tempered low-e glass units. (See photos on opposite page and below.)

Building Envelope — Air-Tightness

The buildings were not designed with a continuous air-tight membrane for the structure and there were no corresponding air-tightness tests.

PHOTO: SASHA MORAVEC

[1] Kawneer Trifab 451T thermal framing system. https://www.kawneer.us/products/storefront-framing/trifab-versaglaze-451-451t-framing-system/
[2] See: https://energyeducation.ca/encyclopedia/E-coating#:~:text=E%2Dcoatings%20or%20Low%2Demissivity,the%20passage%20of%20visible%20light.
[3] See: https://www.chiohd.com/garage-doors/full-view-aluminum/3297

(Below and Opposite Page) The ground-level classrooms are designed with roll-up window walls that allow connection directly with the outside for expanded instructional use.


PHOTO: SASHA MORAVEC

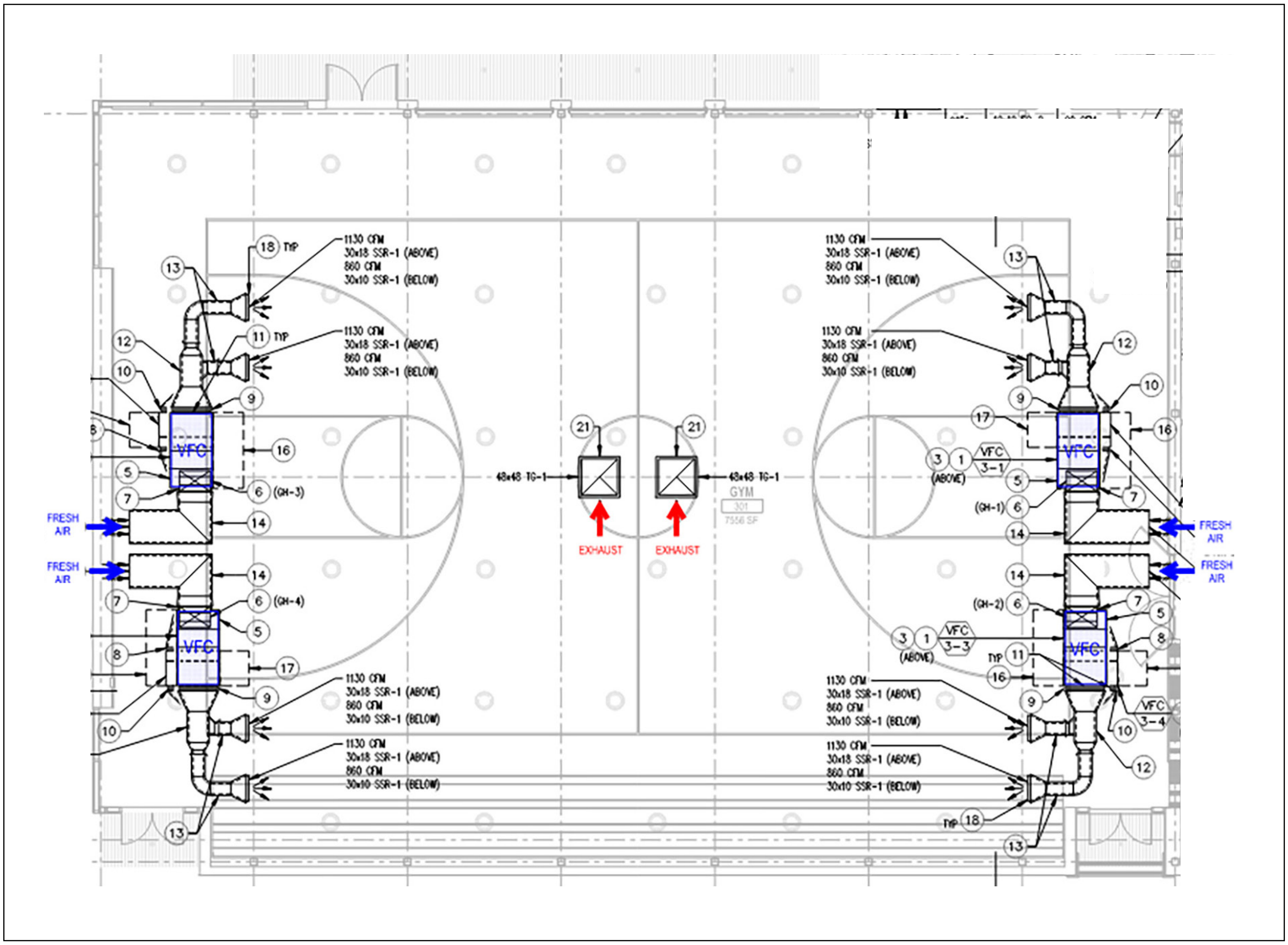
Heating, Ventilating and Cooling Systems

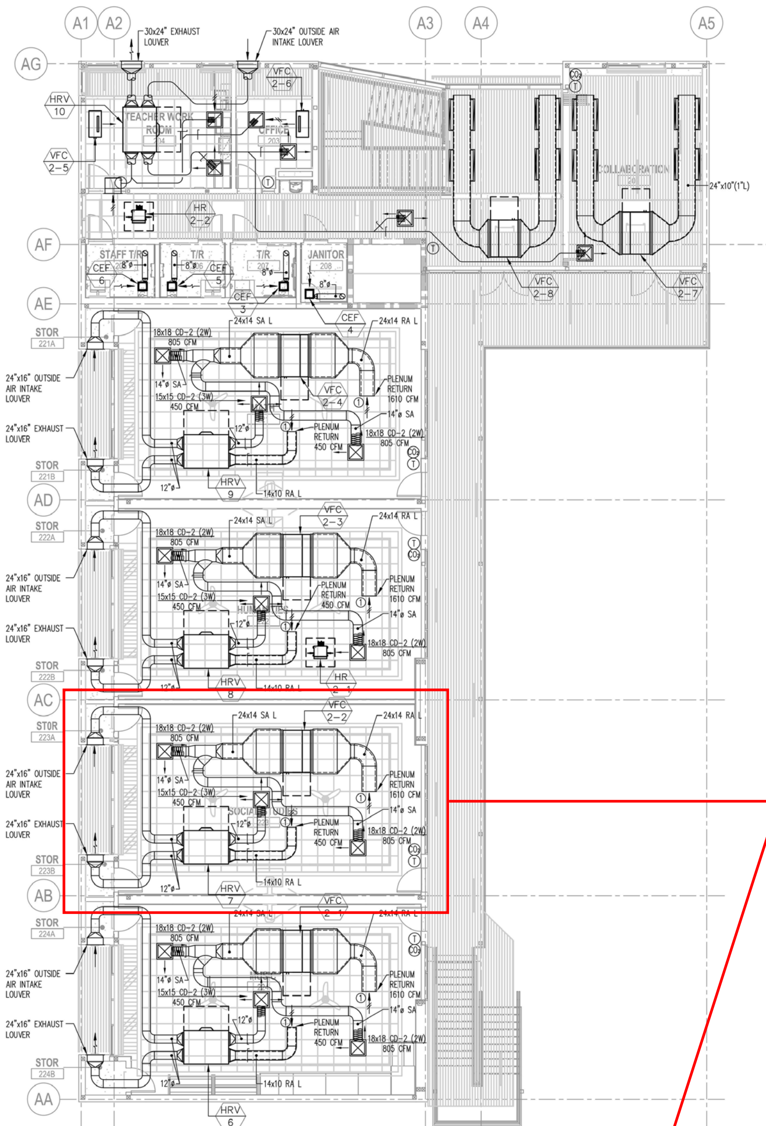
The key components of the all-electric heating and cooling system for the campus are the heat pumps located on the roof of each building. These heat pumps utilize a refrigerant that is pumped to individual *Vertical Fan Coil (VFC)* units located above the ceiling in each space. By keeping the VFC units below the roof structure, the roof space is kept relatively free of obstruction for the future installation of the solar PV system.

In the classroom building, each VFC is paired with a *Heat Recovery Ventilator (HRV)* attached to the fresh air intake for the space. (See diagram on the opposite page.) This design increases the energy-efficiency of the system by preheating or precooling the incoming air stream with the exhaust air flow.

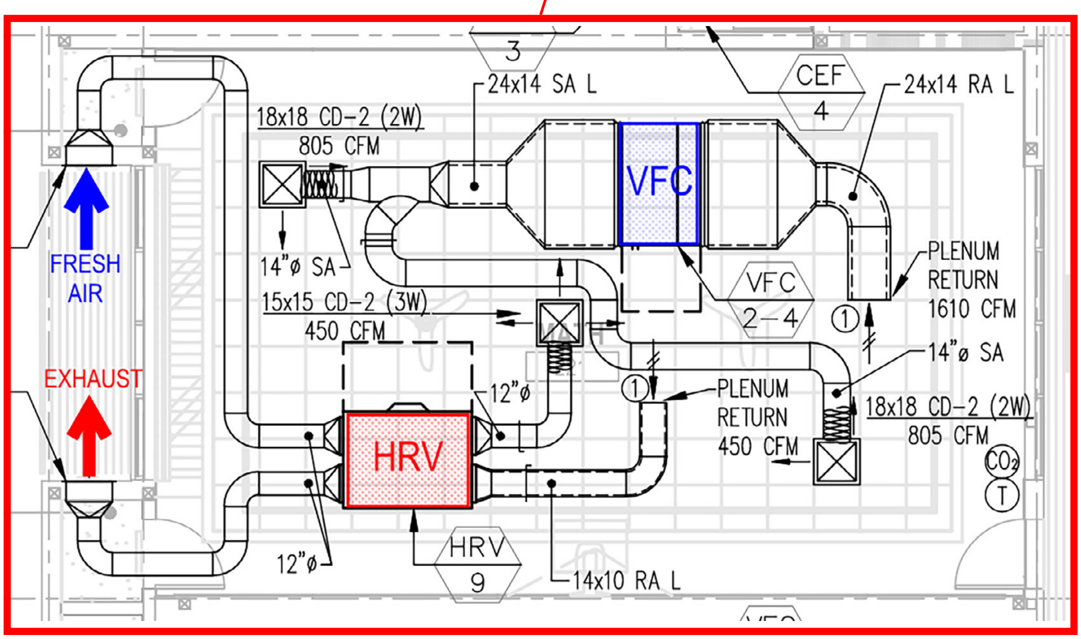
In the gymnasium building, the VFC units are suspended below the roof structure and the exhaust air is simply removed by fans in the middle of the large volume. (See diagram below.)

(Below) Mechanical systems diagram for the gymnasium, featuring VFC units and a simple exhaust air system in the middle of the space. (Courtesy of Ratcliff Architects)





(Left) Mechanical systems diagram for the second floor of the classroom building. (Courtesy of Ratcliff Architects)



(Left, Below) Mechanical systems diagram for a typical classroom, featuring a VFC and HRV. (Courtesy of Ratcliff Architects)

PHOTO: SASHA MORAVEC

(Opposite Page) View of the school library and common study space, with Blue Oak Elemenary School partially visible through the windows.

Domestic Hot Water Systems

Separate heat pump water heaters with recirculation pumps are located in a special closet in each building. In the gymnasium building, this closet is adjacent to the kitchen.

Lighting and Control Systems

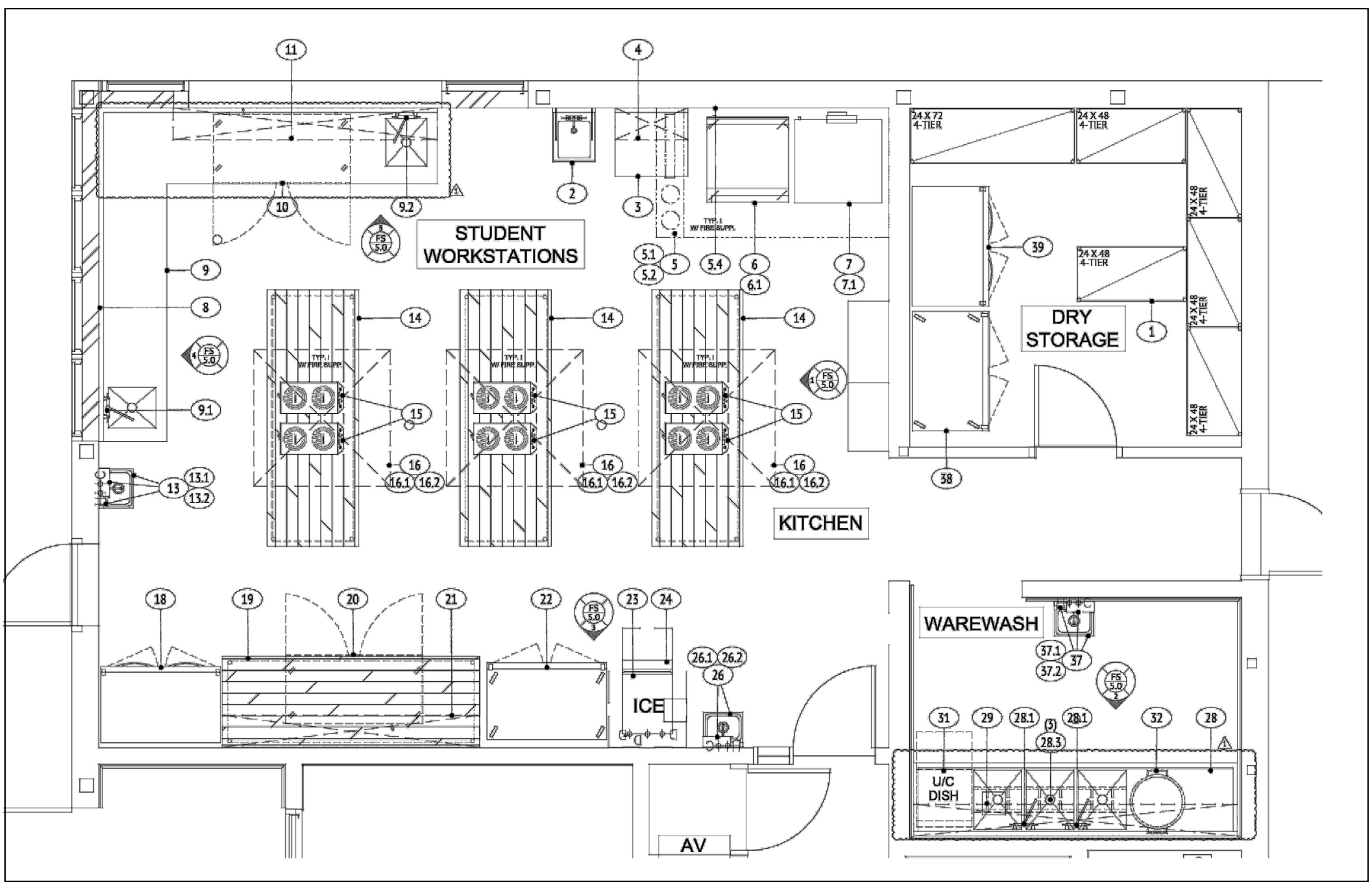
Lighting controls set the minimum lighting level based on the measured amount of daylight available in the individual space. In the classrooms, automated mechoshades are used when direct sun is detected incident on the glazing. For the gymnasium space, fixed vertical fins are utilized on the south and west sides of the main space to partially control the direct sun.

Appliances

The intent of the school founders was to have both a teaching kitchen for the middle school students to learn about healthy foods and their preparation and also to provide the meals for the school population. Induction cooking appliances were specified since they were safest and easiest to clean for this type of joint use. A 15-year contract was initiated with a food vendor to provide this induction food service equipment and the staff to operate and maintain this type of commercial kitchen. The kitchen was designed with the necessary exhaust hoods and electrical hook-ups for the vendor-supplied equipment.

(Below) Floor plan of school kitchen. Principal components:

- Exhaust Hoods: 5, 16
- Induction Cooktops: 15
- Electric Ovens: 6, 7
- Electric Griddle: 6
- Refrigerators: 10, 20, 22, 38
- Freezers: 18, 39



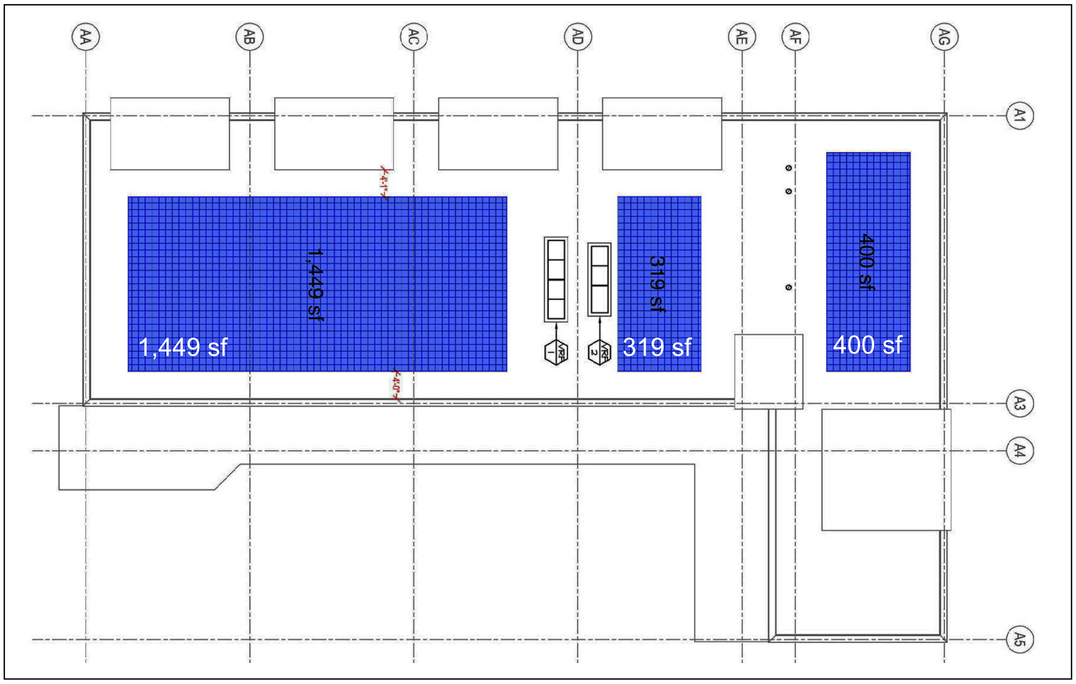
Renewable On-Site Energy Supply

Solar Photovoltaic System

Since the original intention was to design a ZNE building, the installation of a solar PV system was planned to offset the modeled energy demand. This required that a certain amount of roof space be left free of equipment so that the solar panel arrays could fit on the roofs of both buildings. A study for the classroom building is shown below.

Neither the solar PV panels nor battery storage were included in the final building plans for cost reasons. The State of California's decarbonization of the electric utility grid was also a factor, with the high energy efficiency of the buildings effectively keeping electric energy costs low. The school directors are expected to evaluate this again as the early years of occupancy reveal actual energy use patterns.

(Right) Study of the area of solar panel arrays that can fit on the classroom building roof.



Design Analysis: Optimizing Zero-Carbon Design

Design Analysis: Embodied Carbon

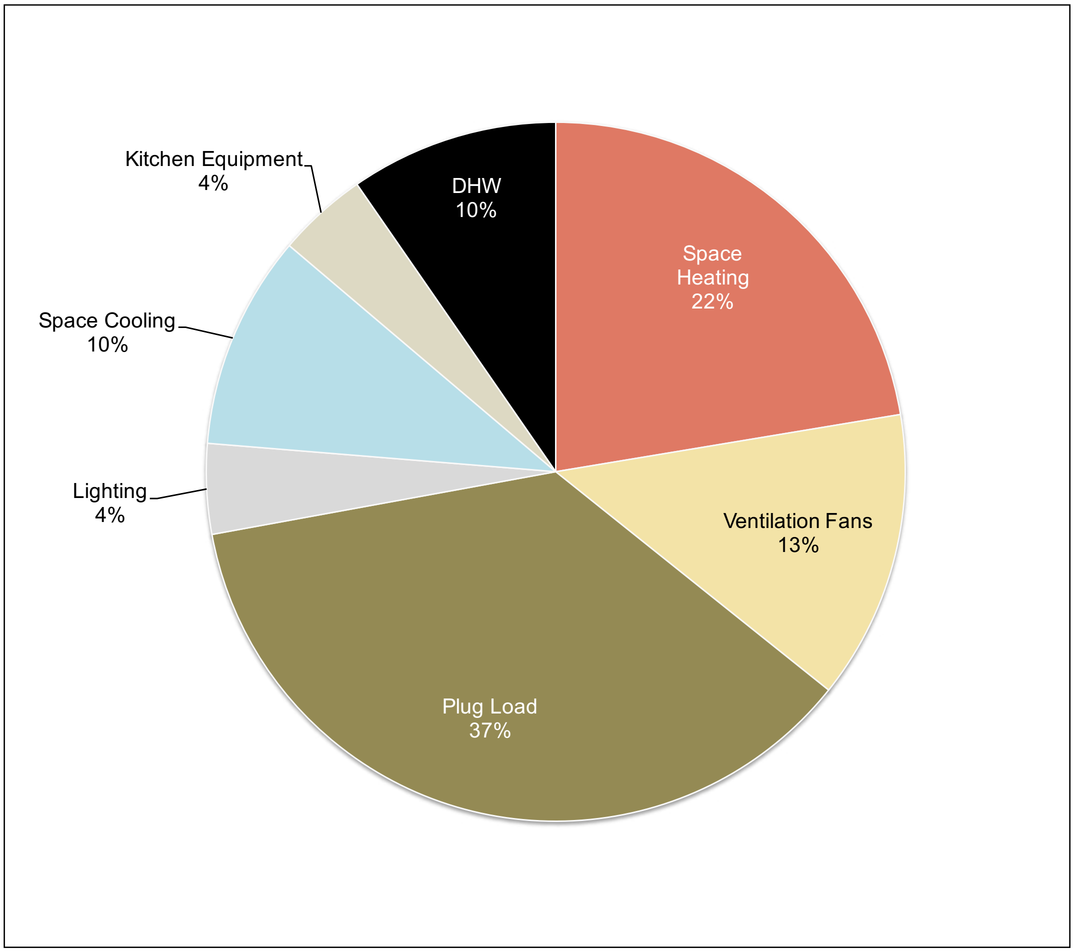
Embodied carbon was analyzed using the Tally software tool in Autodesk Revit during the Design Development phase for the classroom building only. Some specified products were identified as having high embodied carbon and replaced with lower carbon content products. The analysis was not done for the gymnasium building and was not repeated for the final design.

Design Analysis: Energy Modeling and Operational Carbon

The energy use of the final design for the entire project was modeled using the State of California Title-24 compliance software *CBECC-Com*[4]. The modeled energy use for the 24,296 sq. ft. of new buildlings by category of use for prescribed conditions over the course of a year is given in the charts on the opposite page.

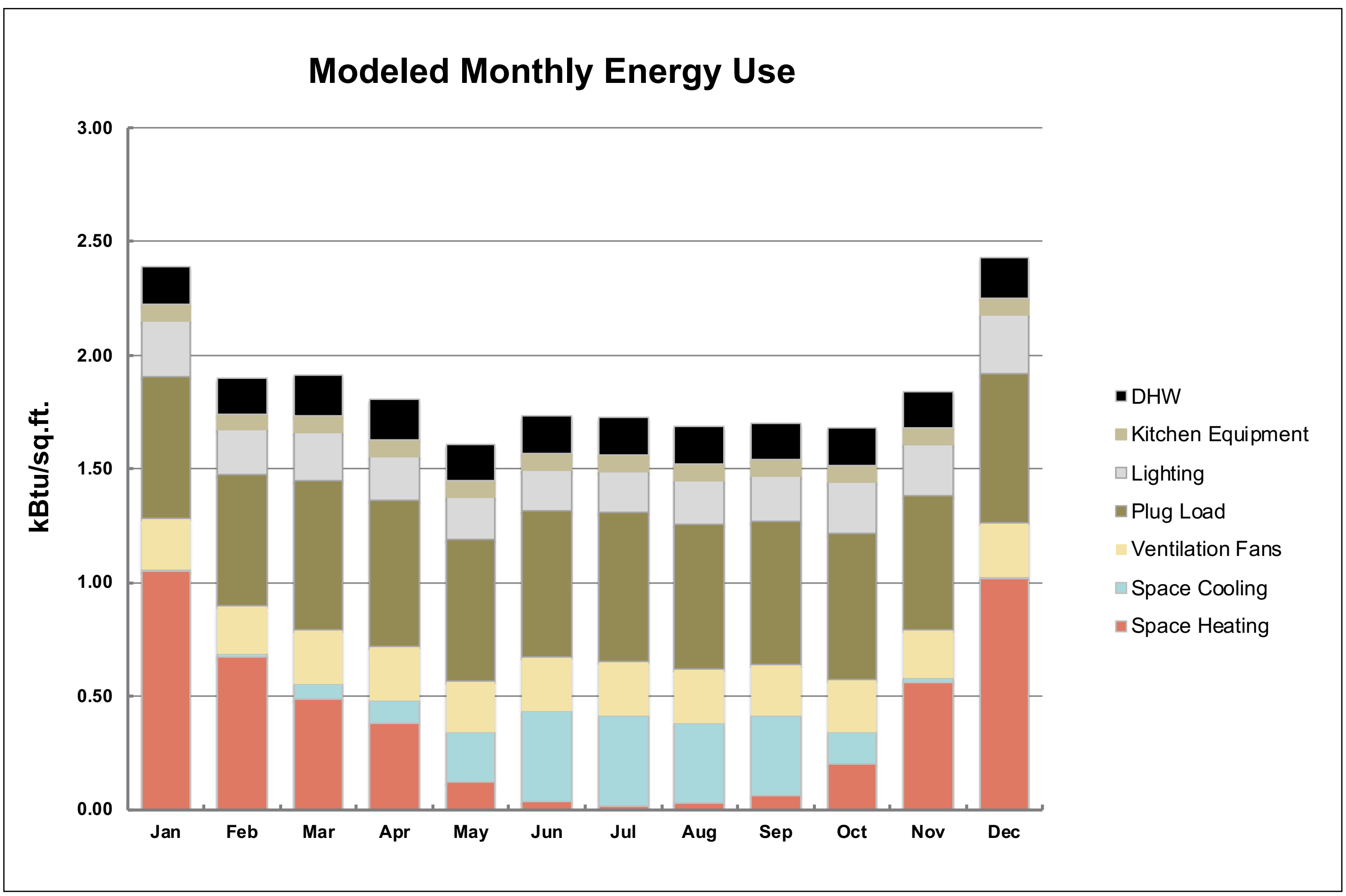
The results of the modeling show that the new buildings would consume a total of 160 MWh annually (upper chart), with an EUI = 22.4 kBtu/sq.ft. per year. Because of the relatively mild climate and the good daylighting design, the predominant energy demand was predicted to be the plug load. The lower chart on the opposite page shows the monthly breakdown of the modeled energy use.

[4] https://bees.noresco.com/#:~:text=CBECC%20(California%20Building%20Energy%20Code,%2C%20standards%2C%20or%20efficiency%20programs.



Modeled Energy Use (Annual)

160,000 kWh/year
Modeled EUI = 22.4



(Opposite Page, Top) View of the second-floor of the classroom building from the outdoor circulation balcony.

(Opposite Page, Bottom) View of the entry to the gymnasium at the southwest corner of the site.

Energy Performance and Operational Carbon: Post-Occupancy Measurement

Energy Use — Post-Occupancy Measurement

There is no metering of the energy use of the two middle school buildings other than the site totals recorded at the utility meter. This data is not available at the current time, so the monthly energy use totals cannot be provided for comparison with the modeled totals.

Post-Occupancy: Observations and Conclusions

An *all-electric* facility that eliminates all on-site carbon emissions from fossil fuels that are used in systems to provide heating, hot water and cooking was a principal design goal of this project. Furthermore, when the State of California passed SB-100 in 2018, which set a target date of 2045 when the state's public electric power grid would be 100% fossil-fuel free, the school was enabled to have a zero-carbon footprint for all of its operational energy in 20 years even without an on-site solar PV system.

This total operational decarbonization of the facility will in fact be achieved without necessarily incorporating the solar PV system into the design, which still remains as a possible addition at the site. The decision about whether to follow through with one of the original design concepts for the facility will now be based solely on the cost, since the zero-carbon operational goal will be realized in 2045 because of its all-electric nature.

All-Electric Design Objective

The all-electric design objective (i.e., design for zero-carbon operation) was demonstrated to be practical, effective and feasible. While energy-efficient design of the building envelope, daylighting and natural ventilation is still necessary with its well-understood features and methodologies, the design of electric systems that replace fossil-fuel based systems presents new challenges and opportunites for K-12 school clients and designers.

Lessons Learned

The design team for this project mentioned several "lessons learned" as they developed their design:

- The best practical aspect of the all-electric design of the project was the cost savings achieved due to the elimination of the natural gas infrastructure at the entire site.
- The induction kitchen equipment is extremely easy to keep clean and to maintain. This is highly desirable in an instructional kitchen.
- If the heating and cooling control system had been connected to the operable windows, the system could have stopped heating or cooling the air flowing into the spaces when the windows were opened. Such an interlock system was not installed.
- For sun and glare control in the morning from April through September, vertical fins should have been added to the north side of the gymnasium building.
- The addition of motorized operable windows in the gymnasium building would have improved operation and climate-responsiveness.

PHOTOS: SASHA MORAVEC

CASE STUDY NO. 3

Garfield Elementary School

PHOTO: KYLE JEFFERS

Garfield Elementary School

Case Study No. 3

Data Summary

Project Type: Public
Location: San Francisco, CA
California Climate Zone: 3
Gross Floor Area: 33,638 sq.ft.
Fully Occupied: August/2021
Grades: Pre-K - Grade 5

Modeled EUI (Site):
31.2 kBtu/sq.ft. per year
Measured EUI (Site) 2023-24:
15.5 kBtu/sq.ft. per year

On-Site Renewable Energy System Installed:
None
On-Site Storage Battery:
None

Client Organization:
San Francisco Unified School District

Design Team
Architect:
LDP Architecture, San Francisco, CA
Structural Engineer:
Murphy Burr Curry, San Francisco, CA
Mechanical, Electrical and Plumbing Engineering:
Engineering 350, San Francisco, CA
Energy Modeling:
Engineering 350, San Francisco, CA
Landscape Architect:
SWA, San Francisco, CA
Commissioning/Sustainability:
Harrison Thomas Group, Pacifica, CA
General Contractor:
E. F. Brett & Company, Petaluma, CA
Construction Manager:
Vanir, San Francisco, CA

San Francisco voters approved the passage of four successive ballot measures, known collectively as *Proposition A*, in each of the years 2006, 2011, 2016 and 2024. These measures each authorized the San Francisco Unified School District (SFUSD) to issue general obligation bonds for the renovation ("modernization") and new construction of K-12 schools throughout the city. The district had been studying the introduction of new energy design standards for all modernization and new building projects, including *Zero-Net-Energy (ZNE)* features, as well as the replacement of fossil-fuel energy systems with an all-electric energy supply. The passage of these bond measures provided the opportunity for SFUSD to incorporate these standards and begin to make the transition to a zero-carbon building stock.

The City of San Francisco was already in the process of legislating a 2016 update to its building code with new ZNE and zero-carbon design standards in municipal construction, so the SFUSD planned to introduce at the same time its corresponding new requirements for the projects funded by the 2016 and 2024 *Proposition A* bond measures. The district had been developing these requirements through feasibilty studies consisting of energy modeling of the different types of school buildings, establishing EUI benchmarks and sizing corresponding solar PV systems for ZNE performance. These feasibility studies included an emphasis on all-electric systems so that eventually the buildings would be fully zero-carbon when built.

The district tested the full implementation of these comprehensive requirements in one of these feasibilty study projects prior to 2016, namely in the construction of a new building for the *Claire Lilienthal Middle School*. The new building was a replacement for some temporary trailers located on-site and was the first ZNE project undertaken by SFUSD. This landmark K-12 project is described in detail as "Case Study No. 5" in the previous book of all-electric case study buildings, *Designing for Zero Carbon, Volume 1*.[1]

With the completion of this successful project in 2019, SFUSD then proceeded to apply these ZNE and zero-carbon design standards to the projects funded by the 2016 and 2024 *Proposition A* bond measures, including the renovation of *Garfield Elementary School*, an existing school building located in an historic neighborhood of San Francisco. For this project, SFUSD specifically prescribed a zero-carbon design approach, which meant incorporating all-electric energy systems throughout.

Background

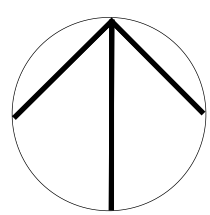
Garfield Elementary School has a relatively long history that follows along with the story of the development and growth of the City of San Franciso itself. It was one of the first public elementary schools in the city, built during the pre-Civil-War and post-Gold-Rush period in 1854 on the western slope of historic Telegraph Hill.

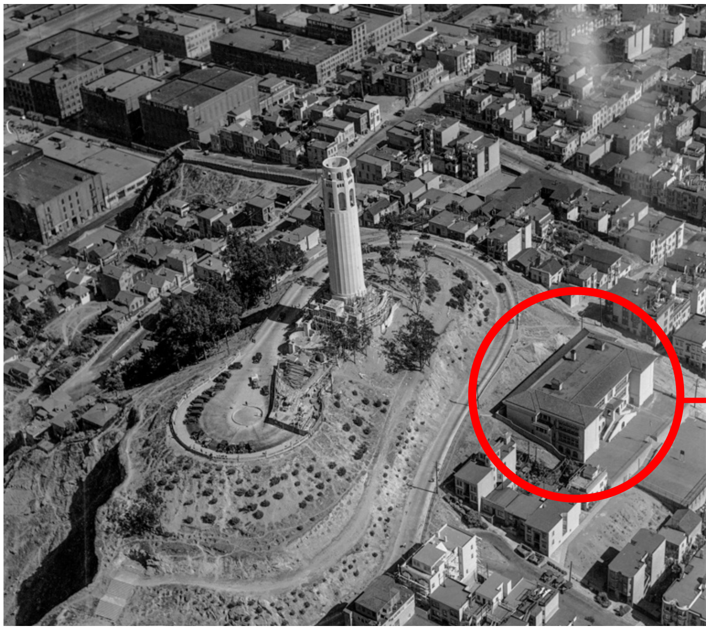
Early History

Originally known as Union Street School, it was later renamed Garfield Primary School in 1881 to honor the recently assassinated U.S. president, James Garfield. Twenty-five years later, the building was completely destroyed in the cataclysmic earthquake of 1906. During the recovery period from the devastation, San Francisco rebuilt the school in 1910 on the same site at 420 Filbert Street, apparently salvaging parts of the original structure. The replacement building was a three-story structure built in the Mediterranean Revival-style of the period. Thirty years later, the earthquake memorial monument, Coit Tower, was built on the peak of Telegraph Hill, immediately behind Garfield School. (See photos on following p.52.)

[1] Available for free download at https://calbem.ibpsa.us/resources/case-study-books/.

Garfield Elementary School - General Vicinity Plan





(Below) Garfield School as rebuilt after the 1906 San Francisco Earthquake and *(Left)* when the neighboring Coit Tower memorial structure was completed in 1933.

Modern History - 1981 Rebuild

The large, institutional design for the post-earthquake school building, shown above in a photo taken shortly after it was built in 1910, was a collection of formal classrooms with bare outdoor play yards located on the downhill west side. It was not considered for an upgrade in its seismic design until the 1970s. At that time, State of California had not only developed more stringent seismic codes but also had initiated a new energy code under the name Title 24 (Part 6). SFUSD scheduled several older schools in the district for renovation to meet these latest codes, including Garfield School, and hired the architectural firm Esherick Homsey Dodge and Davis for that project.

During the design phase, it was determined that the cost of renovation would be the same as a new building, so the district opted for a new design with a contemporary educational program. The architects, attempting to have a more residential scale and massing of the design in order to fit into the surrounding neighborhood, proposed a four-level building that stepped down the hill. They also flipped the main outdoor play yard to the east side, adjacent to the park surrounding Coit Tower, giving the children a space with a more park-like setting. In addition, they added one small outdoor space in the southwest corner of the site for the first floor kindergarten and an alley connection to the north to Greenwich Street.

The entry to the school is located on the second floor, with the same arched doorway as the 1910 Beaux-Arts-style building, and the access to the large park-adjacent outdoor space is from several doorways at the third floor and Filbert Street. The principal characteristic of the 1981 rebuild of Garfield School is its residential scale of the 33,638 sq. ft. institutional building modestly set in the historic residential neighborhood.

In 1982, the American Institute of Architects (AIA) named Garfield School as a winner of a *National AIA Honor Award* for that year and it was published in the May issue of the AIA Journal.[2]

Modern History - 2021 Modernization

As described in the introductory paragraphs to this case study, Garfield School was approved for a modernization design and construction utilizing *Proposition A* 2016 bond funds. This scope included the remodeling of the entire interior of the building, with improved seismic strengthening and conversion to an all-electric facility. The exterior of the building remained essentially the same.

The building that resulted from this modernization work, designed by LDP Architecture, is the focus of the remaining part of this case study. (See p.54ff.)

[2] AIA Journal, mid-May 1982, p. 210. https://usmodernist.org/AJ/AJ-1982-05-mid.pdf

(Left) Garfield School viewed from Filbert Street in 1981 after being completely rebuilt, with Coit Tower in the background. (Photo: George Homsey, courtesy of EHDD Architecture)

(Left) Garfield School in 1981, as viewed from the park to the east, below Coit Tower. (Photo: courtesy of EHDD Architecture)

Design Process and Low-Energy, Zero-Carbon Design Strategies

The renovation of Garfield School, completed in 2021, was truly a “modernization” project. According to the planned scope, the interior walls and stairs designed in 1980 were largely removed and new interior spaces built to accommodate the new organization of educational and service spaces. The existing gas-fired heating and hot water systems were replaced with all-electric heat pump systems, requiring new ductwork and piping throughout. Given a design mandate by SFUSD of ZNE performance, the accommodation of a sufficiently large solar PV array was initially required.

Building Program

The principal addition to the architectural program is a new cafeteria space for the entire school. Located in the two former kindergarten spaces on the ground floor, the cafeteria opens to a shared outdoor space formerly associated with those two rooms. The kindergarten spaces are relocated to the third floor, where they have immediate access to the larger shared play yard to the east. To accommodate these two rooms, the media center and library space was relocated to the first floor, adjacent to the cafeteria. The administrative and staff spaces were similarly moved up to the third floor next to the play yard, reinforcing this as the main entrance to the school.

Besides this interior reorganization, the fourteen classrooms were redesigned as separate rooms, with desirable sound separation and ease of access as a result.

Building Envelope – Insulation and Windows

The exterior walls had been well-insulated per the California energy code requirements in 1980. Typical exterior wall and roof assemblies were not required to be upgraded in terms of the R-values. The concrete floors remain uninsulated (same as the original 1980 detail). The seismic code that came into effect in 2019 required some structural strengthening and the opening of the wood-framed exterior walls in certain locations. Insulation was carefully replaced in these places. The net result is that the insulation levels of exterior walls, roofs and floors remain basically compliant with current Title-24 minimum prescriptive requirements.

Windows throughout the project were replaced with improved double-glazing, featuring a low-e coating for better thermal performance. Doors were also replaced by modern school entry doors with good thermal performance features (thermal break frame, R=3.0 insulation, gasketed for air-tightness).

Building Envelope – Air-Tightness

Since this was a modernization project and the exterior envelope essentially remained unchanged, no special air-tightness membranes were installed. There were no corresponding air-tightness tests done.

Heating, Ventilating and Cooling Systems

Standard rooftop gas-fired package units were replaced with electric heat pump units. Each rooftop package unit includes a heat pump with *Variable Refrigerant Flow (VRF)*. There are a total of twelve such rooftop units providing both heating and cooling to the spaces below the roofs of each of the four levels. The individual systems have full economizer cycle capabilities.

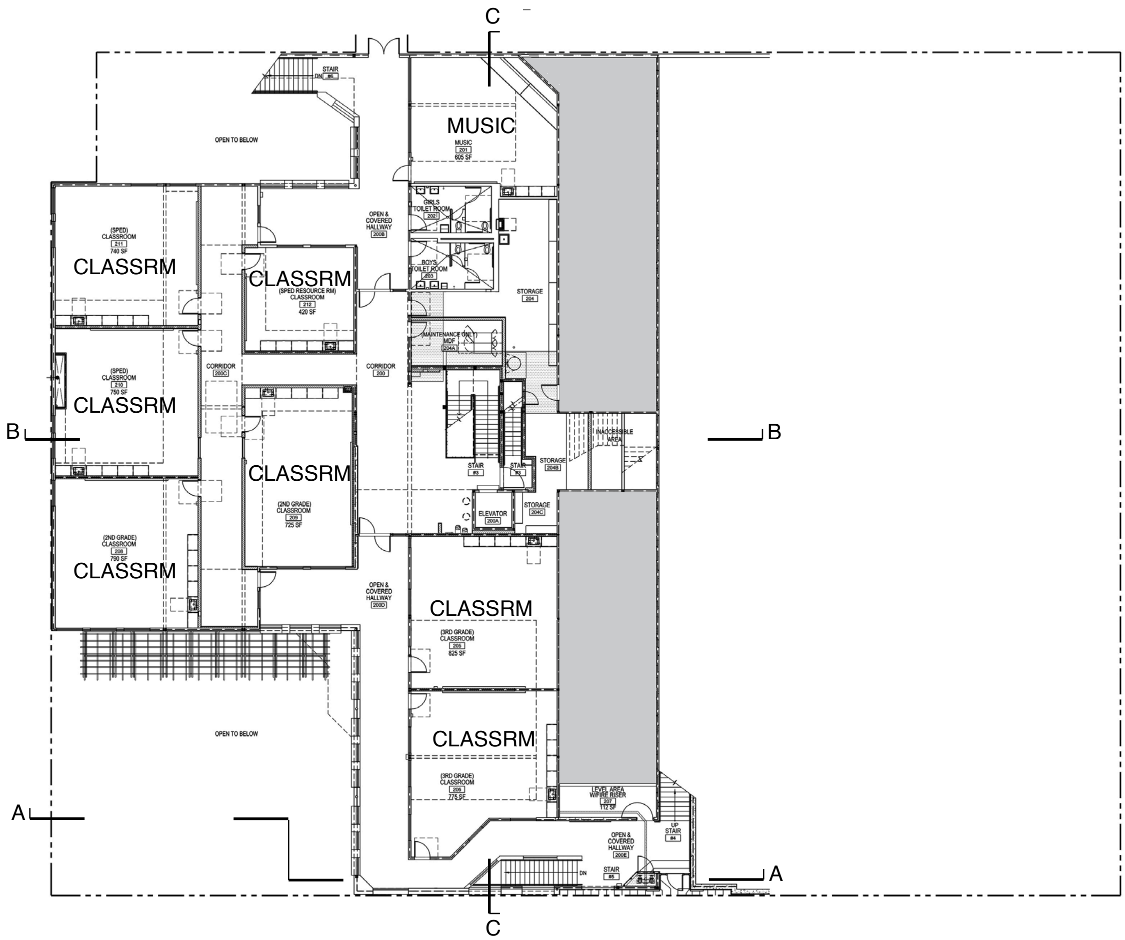
No additional energy-efficiency system such as an *Heat Recovery Ventilator (HRV)* is utilized in the standard rooftop package units.

(Following Pages) The floor plans, landscape plan and building sections of Garfield Elementary School.

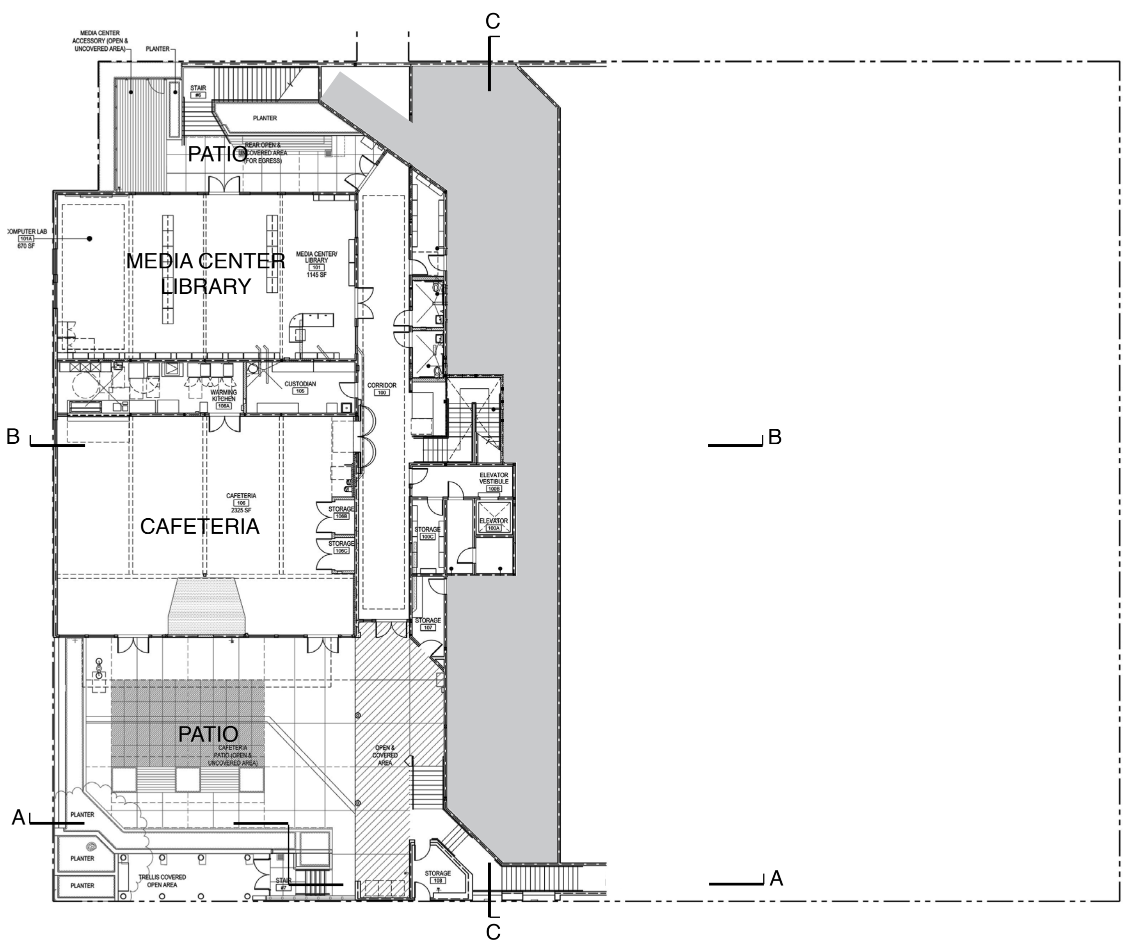
(Left) Garfield School viewed from Filbert Street after the 2021 modernization project work, with Coit Tower in the background. (Photo: Kyle Jeffers)

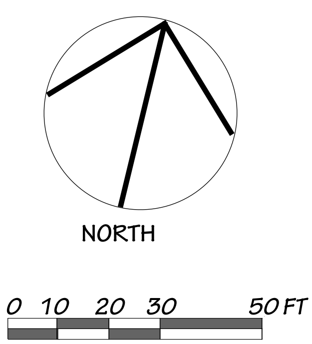
(Left) Garfield School play yard after the 2021 modernization project work.
(Photo: Kyle Jeffers)

SECOND FLOOR PLAN



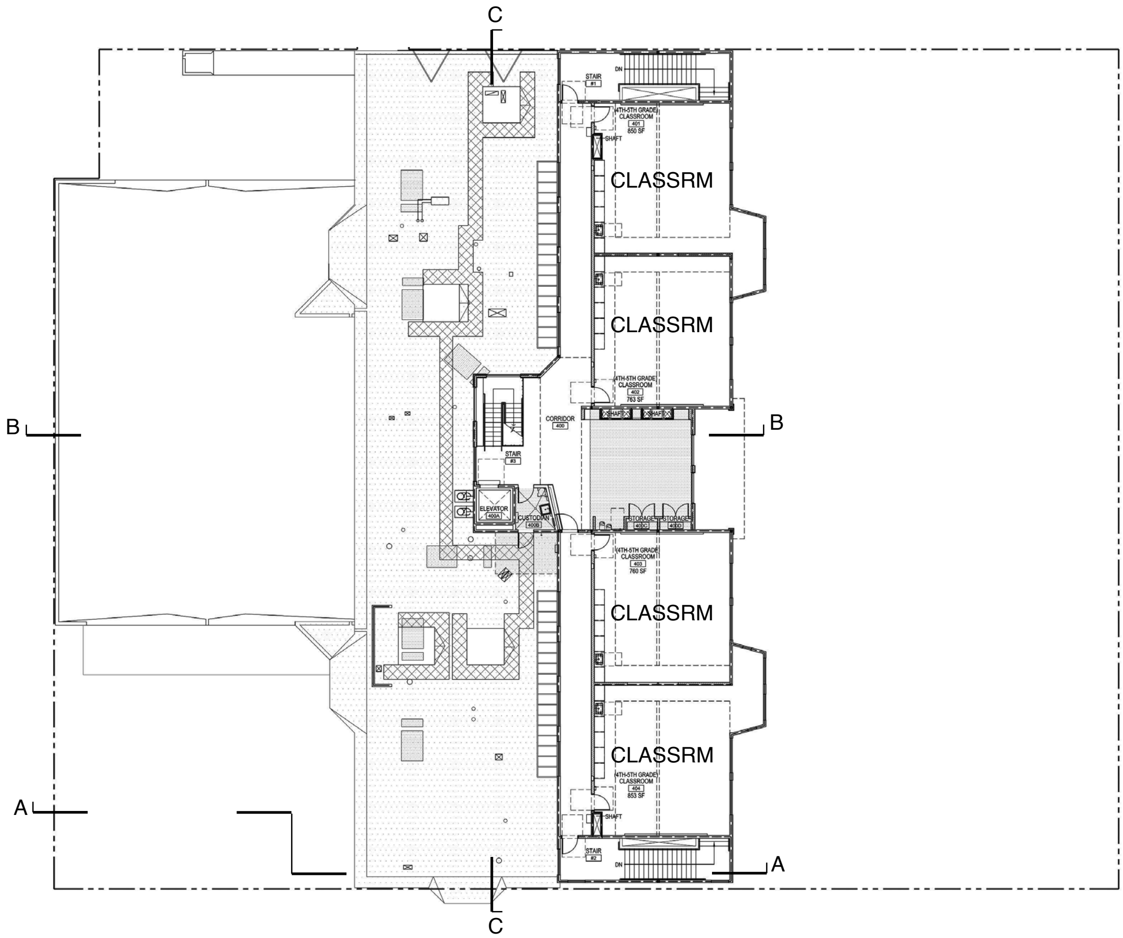
GROUND FLOOR PLAN



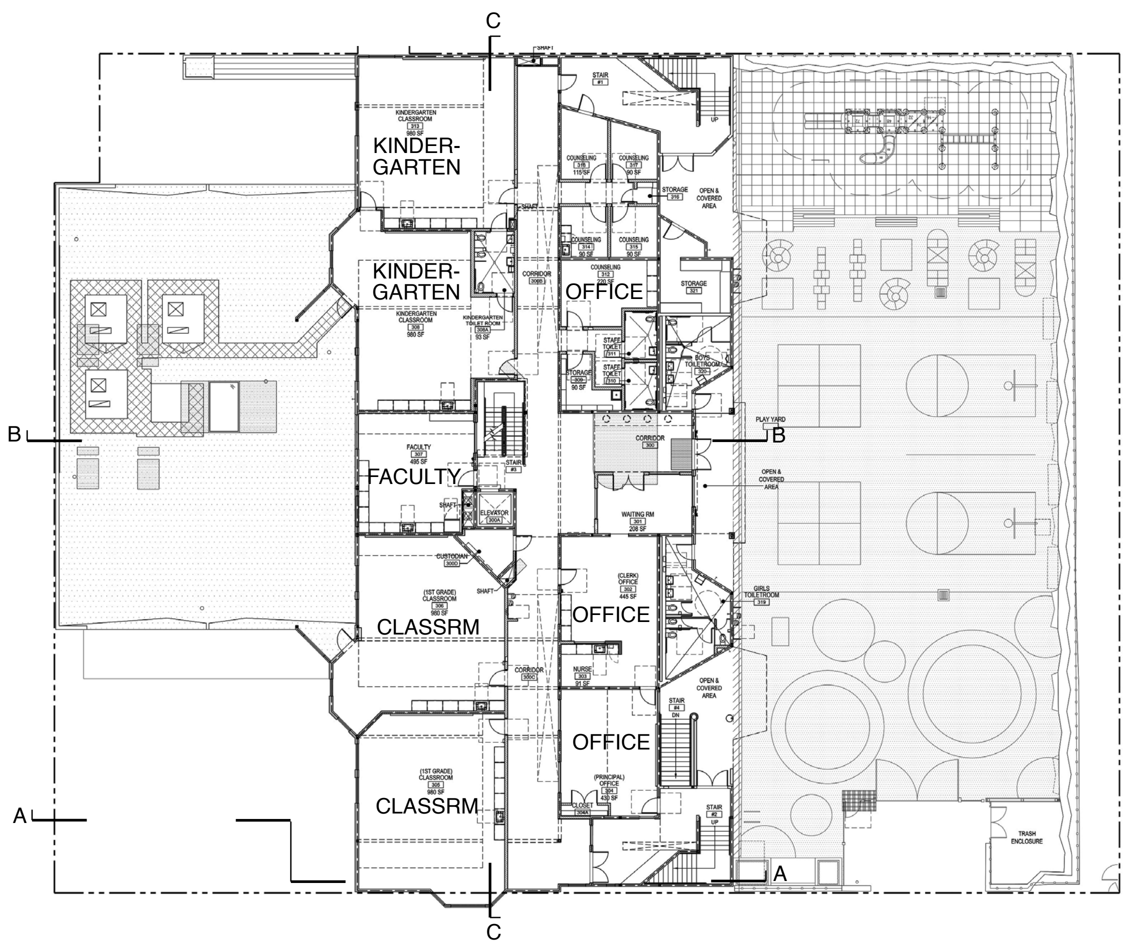


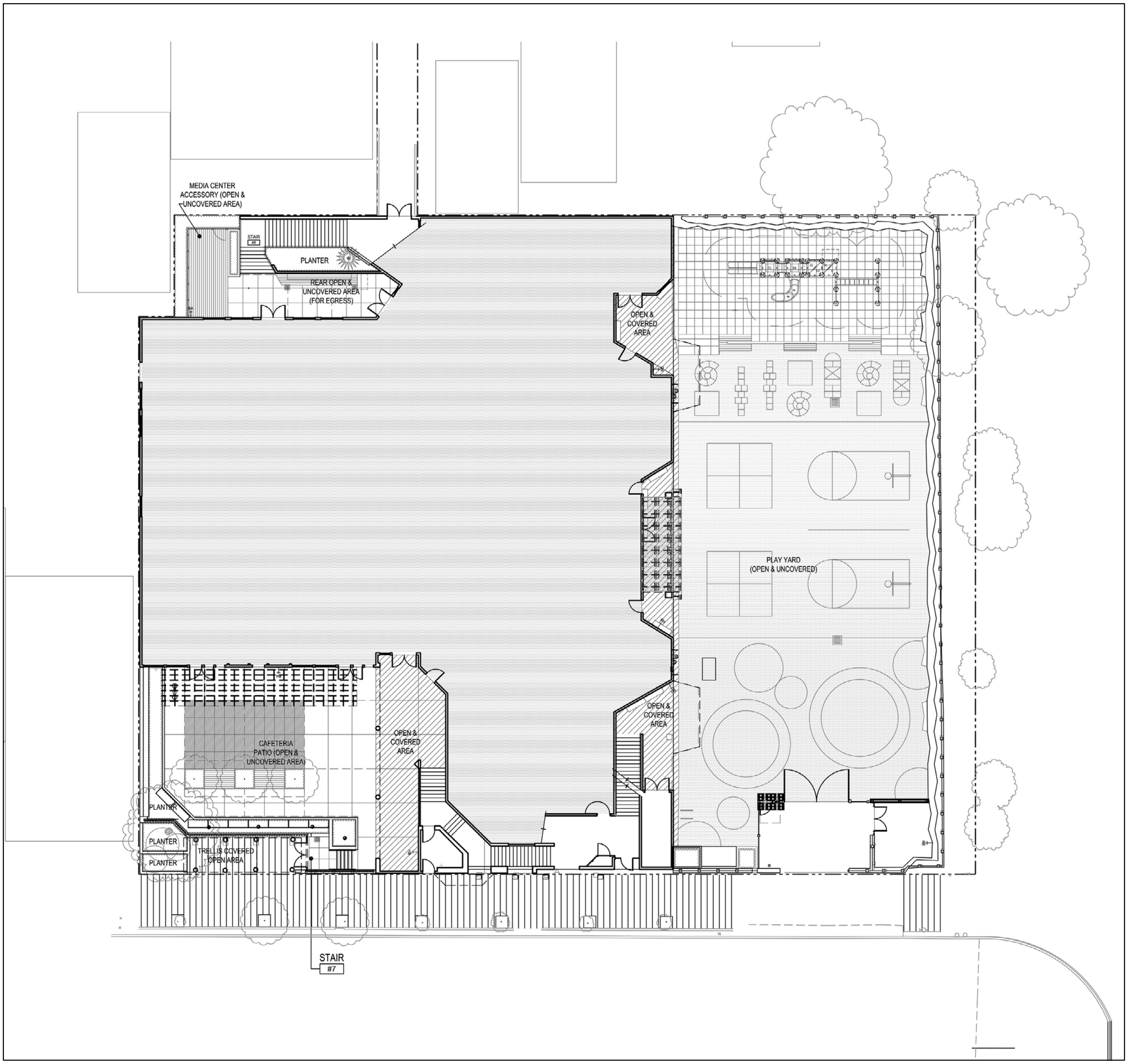
GARFIELD ELEMENTARY SCHOOL — FLOOR PLANS

FOURTH FLOOR PLAN

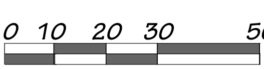


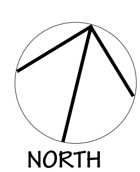
THIRD FLOOR PLAN



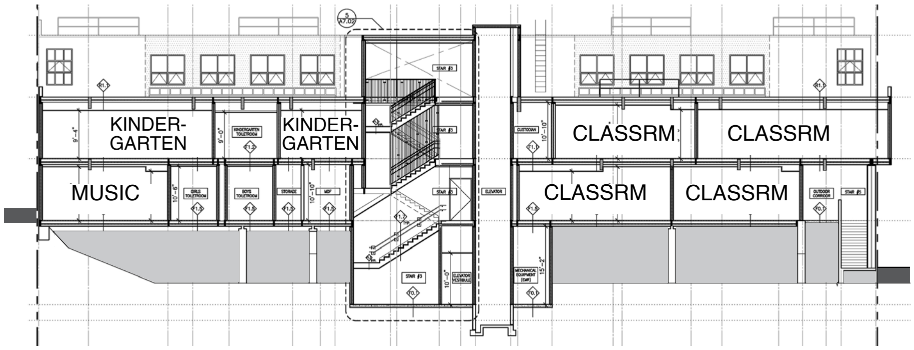


SITE PLAN / LANDSCAPE PLAN

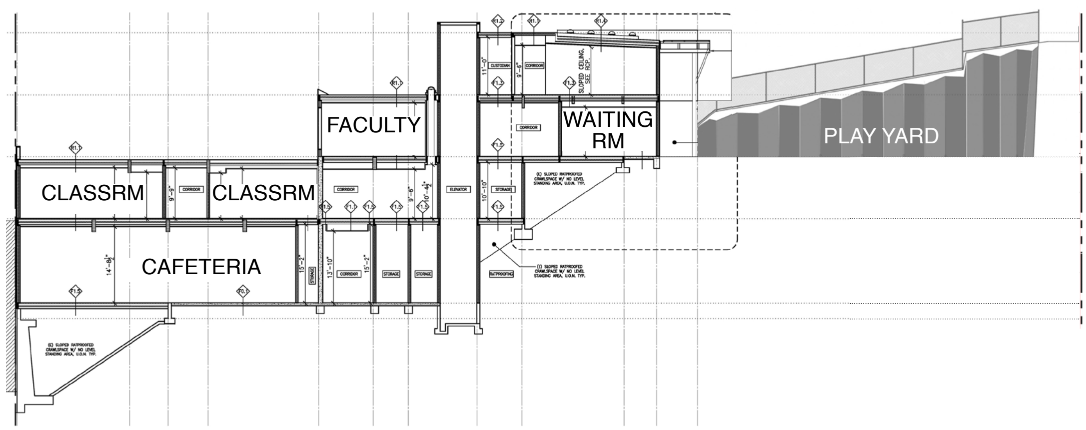




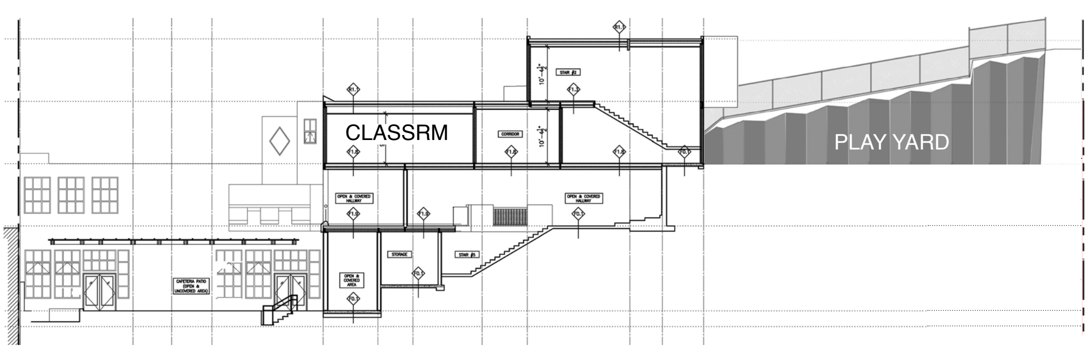
GARFIELD ELEMENTARY SCHOOL — SITE PLAN AND BUILDING SECTIONS



SECTION C - C



SECTION B - B



SECTION A - A

PHOTOS: KYLE JEFFERS

(Opposite Page - Top) Typical renovated classroom interior. *(Opposite Page - Bottom)* New Cafeteria room interior.

Domestic Hot Water Systems

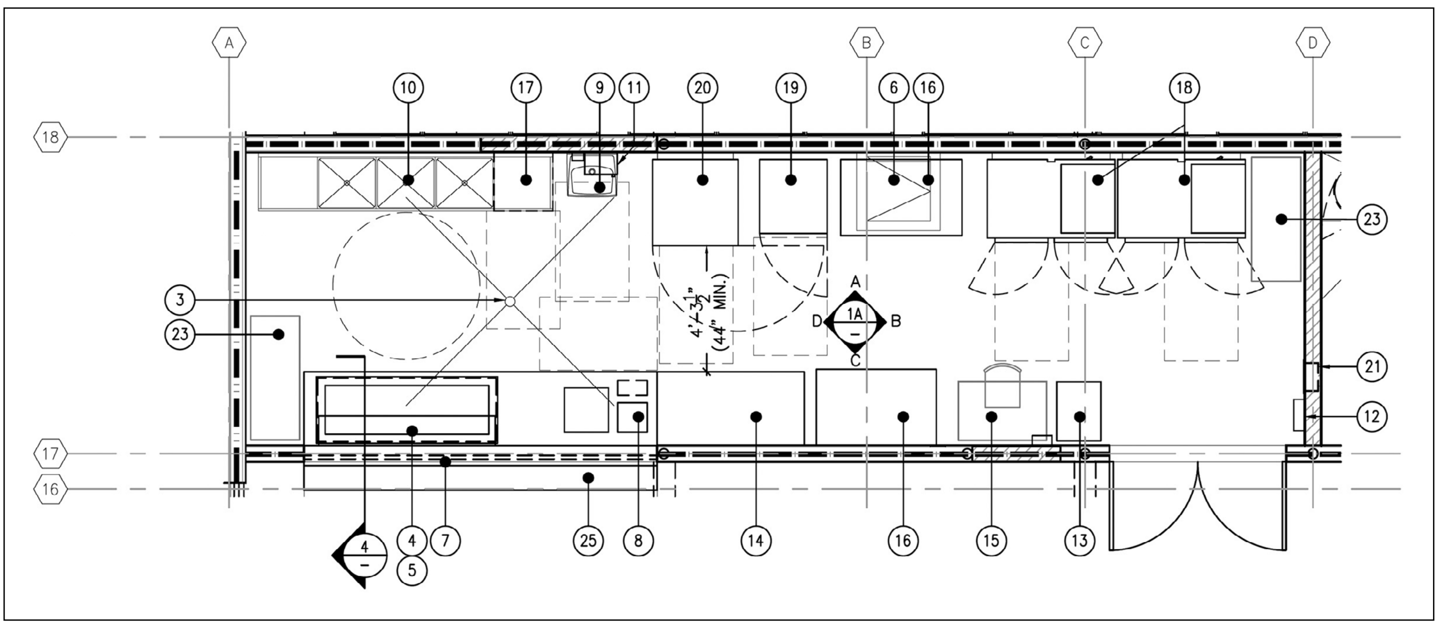
Hot water for the entire building is provided by a separate electric resistance water heater that had recently been installed before the modernization project. Because it was in good condition, this basic water heater was reused for cost reasons. A new, standard-size electric water heater was installed near the new warming kitchen space to provide high temperature water required in that space.

Appliances

Electric appliances are included in the new warming kitchen, which serves the new cafeteria space on the ground floor. (See floor plan below.) Food is actually prepared each day at an off-site facility and delivered to the warming kitchen. As a result, no induction stove is required. Other standard electrical appliances are installed, as noted below.

(Below) Floor plan of warming kitchen. Principal components:

- Milk Cooler, 16
- Dishwasher: 17
- Refrigerator: 18
- Freezers: 19
- Rewarming Oven: 20



Lighting and Plug Loads

The design of the building envelope in 1981 included a large number of skylights for extensive daylighting within the school spaces. Some skylights required repair as part of the modernization project and some solatubes were added to make daylighting a hallmark feature of the energy-efficient design.

All indoor and outdoor electric lighting fixtures use LED sources with occupancy sensor controls. The lighting controls throughout the building respond to the daylighting levels.

Control Systems

No special control systems were specified for the HVAC system operation.

(Following Pages, pp. 62-63) Relocated Media Center and Library Interior.


READ · READ · READ · READ · READ
MY PAPI HAS A MOTORCYCLE
CHATO'S KITCHEN

PHOTO: KYLE JEFFERS

Renewable On-Site Energy Supply

Solar Photovoltaic System

As noted above, the SFUSD had been developing new requirements for the projects funded by the 2016 and 2024 Proposition A bond measures, which included ZNE performance standards and zero-carbon design standards. The Garfield Elementary School Modernization project was one of the first to be required to meet these standards.

In 2019, the district confirmed that the school would be required to be "solar-ready", with the facility infrastructure for the right-sized solar PV system for ZNE performance included in the design and construction. The installation of the solar PV system would be a future project, depending on funding made available by a city agency or department such as the San Francisco Public Utilities Commission (SFPUC). "Facility infrastructure" included roof and/or site area for the future solar PV panels, structural capability for support of the panel arrays, electrical conduit in place for all future electrical circuitry and identified inverter/utility locations. As part of this modernization project, such an infrastructure was designed into the structure and a solar zone area was indicated on the drawings for the future installation of the solar PV panels.

On-Site Energy Storage: Batteries

No battery storage was included in the design, although this could be added in the future for load management and resilience if the solar PV system is ultimately installed.

Design Analysis: Optimizing Zero-Carbon Design

Design Analysis: Embodied Carbon

An embodied carbon analysis was not done as part of the design process primarily because the project was *modernization* of a Type-5 (wood-frame) building and did not substantially involve the exterior building envelope.

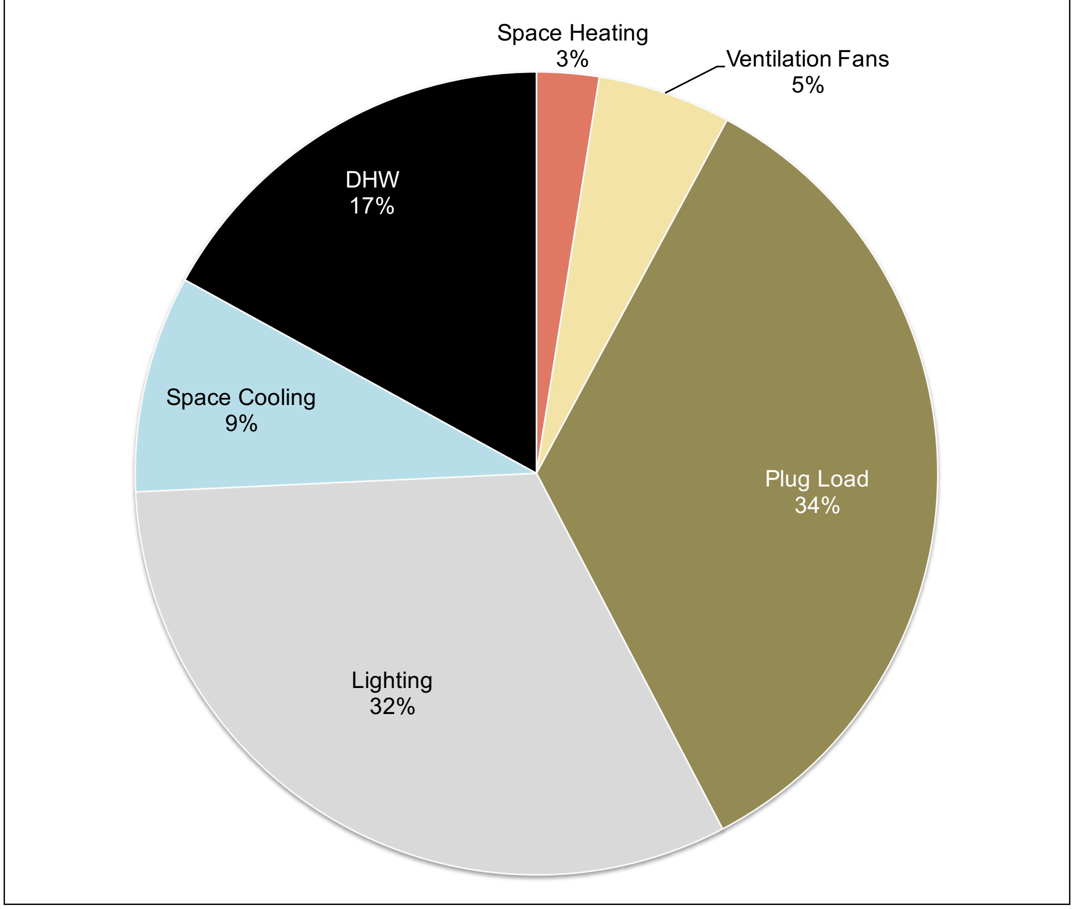
Design Analysis: Energy Modeling and Operational Carbon

For much the same reason, there was no energy modeling of the building design done in the early phases of design since the project involved primarily interior renovation and the replacement of the gas-fired HVAC and hot water systems with new all-electric components. Basically, the principal energy-consuming features and systems were fixed and no alternatives were possible for comparison.

Given that the solar PV system would be analyzed, selected and installed at some future time, there was no need to determine the monthly energy demand in order to size the system. Actual energy use data could be used to more accurately size the future solar PV system and verify ZNE performance.

Energy modeling is required, however, as part of the Title 24 energy standards, to demonstrate compliance of the final design with the California energy code. This energy model is required to be done using Title 24 (Part 6) prescribed compliance energy modeling software with many built-in prescribed features. The resulting performance numbers are applicable only to the demonstration of compliance with Title 24 code and not as a predictive tool for actual performance. This energy modeling software is therefore not used as a tool for design decision-making.

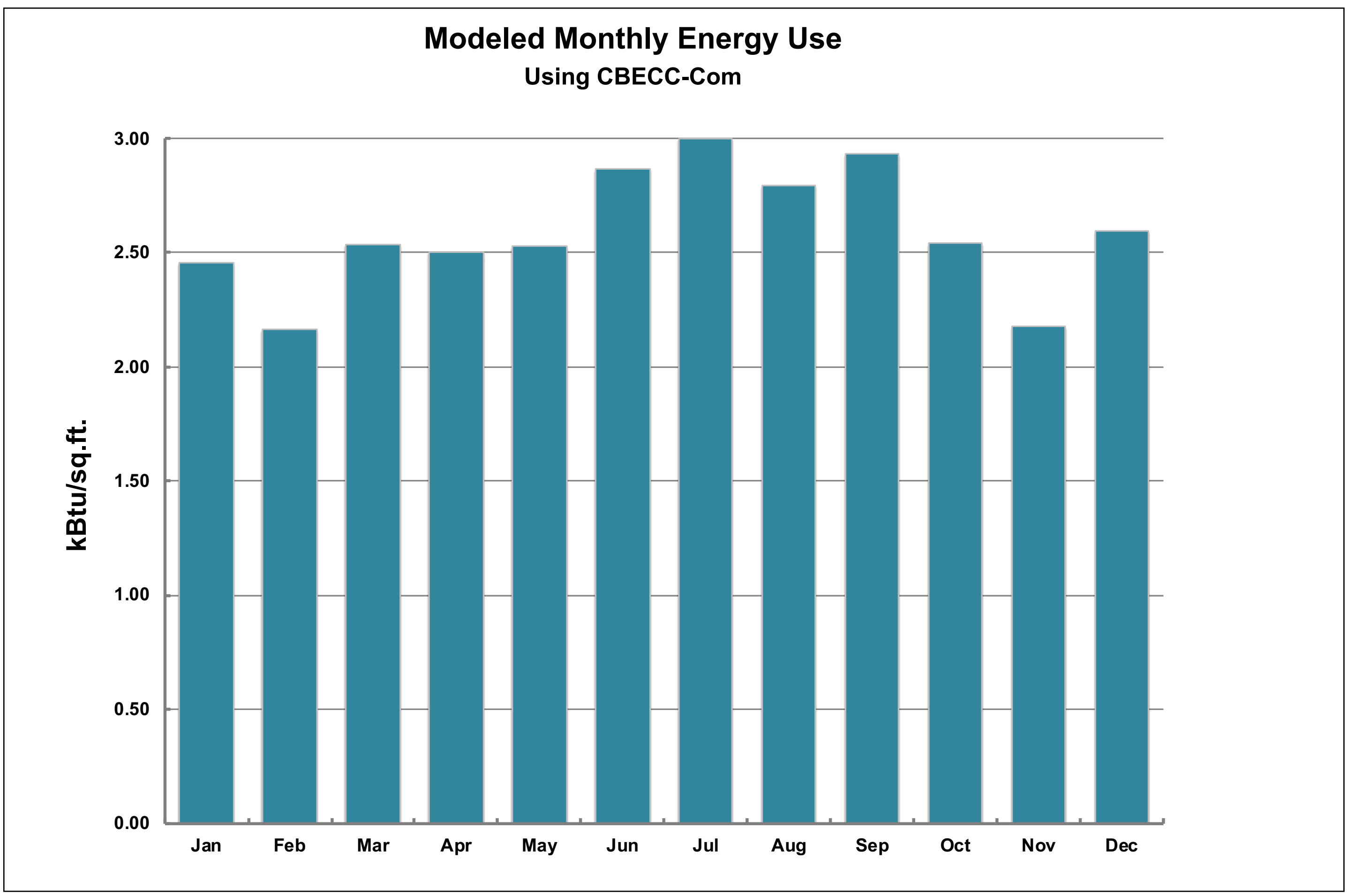
Charts showing annual and monthly energy use as modeled with this software, however, are shown on the opposite page for completeness.

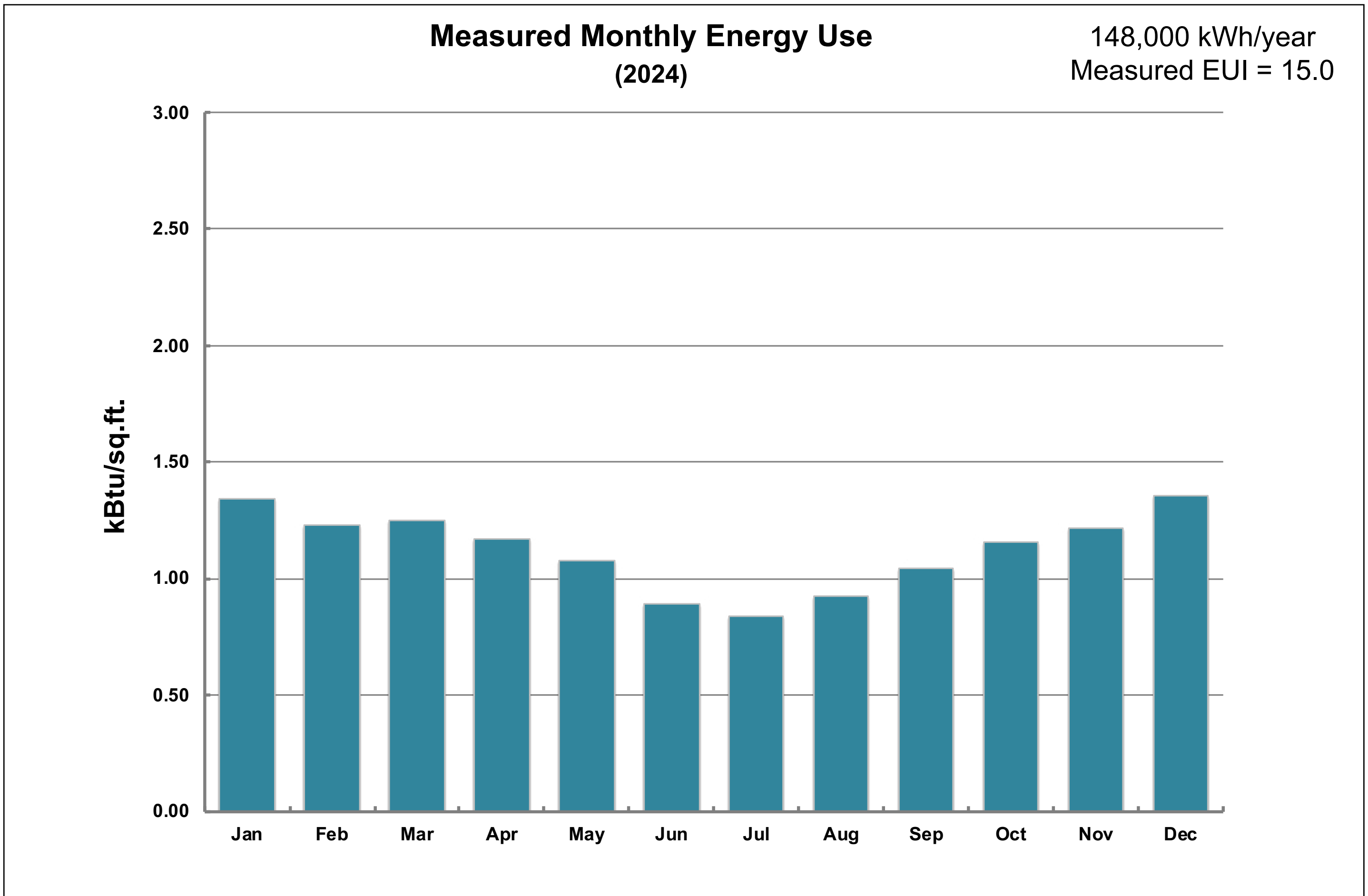


Modeled Energy Use (Annual)

Using CBECC-Com

307,600 kWh/year
Modeled EUI = 31.2





Energy Use — Post-Occupancy Measurement

Monthly energy use data was recorded at the site electrical meter for 2024 and is shown in the bar chart graph above. This data represents a full year at normal operation and is considerably below the energy use modeled using the required assumptions of the energy code compliance software. This large difference could be additionally attributed to conservative assumptions about building use, such as the assumed lighting and plug loads of the building. Also, in 2024, the Garfield Elementary School was apparently using energy more efficiently than assumed in the required code inputs. Actual measured site energy use for 2024 was 148,000 kWh/year, which is an EUI = 15.0. This is just less than half the modeled energy use using code-required software.

Post-Occupancy: Observations and Conclusions

All-Electric Design Objective

The all-electric design objective (i.e., design for zero-carbon operation when the electric grid is totally decarbonized in 2045) was demonstrated to be practical, effective and feasible for this modernization project. The gas-fired rooftop package units were easily replaced by the electric heat pump units and the building envelope was sufficiently energy-efficient to require no significant upgrade. The cafeteria was a new program space so that the new electric equipment could be added in a straightforward manner.

Lessons Learned

(Opposite Page) View of courtyard adjacent to new school cafeteria space on the ground floor (formerly the Kindergarten rooms)
*(*Photo: Kyle Jeffers*)*

The design team for this project mentioned several minor “lessons learned” as they reflected on the design process. An example: the design team would opt for heat pump water heaters instead of retaining the existing electric resistance water heater because of readily available compact types of units designed for schools. Also, the development of a simple booklet or short manual about the operation of the operable windows and the heating/cooling system would have been useful for the teachers and staff.

CASE STUDY NO. 4

Food Literacy Center at Floyd Farms

PHOTO: HMC ARCHITECTS

Food Literacy Center at Floyd Farms

Case Study No. 4

Data Summary

Project Type: Public
Location: W. Sacramento, CA
California Climate Zone: 12
Gross Floor Area: 4,096 sq.ft.
Fully Occupied: 2022

Modeled EUI (Site):
164.6 kBtu/sq.ft. per year
Measured EUI (Site):
65.9 kBtu/sq.ft. per year

On-Site Renewable Energy System Installed:
135 kW (DC) Solar PV
On-Site Storage Battery:
None
Measured On-Site Energy Production:
196,000 kWh per year
163 kBtu/sq.ft. per year

Client Organization:
Sacramento City USD

Design Team
Architect:
HMC Architects, Sacramento
Structural Engineer:
Buehler Engineering Inc., Sacramento, CA
Mechanical, Electrical and Plumbing Engineering:
LP Consulting Engineers Inc., Roseville, CA
Energy Modeling:
LP Consulting Engineers Inc., Roseville, CA
Landscape Architect:
Quadriga, Sacramento, CA

General Contractor:
Landmark Construction, Rocklin, CA
Solar Contractor:
Sac Valley Electric Co., Sacramento, CA

Public school districts sometimes establish a specialized educational facility that offers a program in subjects that are not usually available in standard school curricula. Such a program is made available to all district schools on a scheduled basis at this facility so that these special subjects can be incorporated into the regular curriculum offerings of all the schools in the district easily and inexpensively. Food and nutrition is such a specialized program and the district facility contains many different types of energy-consuming equipment and instructional spaces. The electrification of such facilities is therefore relevant to the discussion for K-12 schools.

Background

In 2012, the Jedediah Smith Elementary School of the Sacramento City Unified School District (SCUSD) was renamed *Leata'ata Floyd Elementary School*, in honor of the community advocate of Samoan descent who lived and worked in the surrounding public housing project in West Sacramento. Then, in 2018 the City of Sacramento and SCUSD entered into the *Leata'ata Floyd Elementary School Farm and Community Garden Project Agreement*, which allowed the School District to use excess land at the school site to establish an urban farm and a community garden to benefit the surrounding community, including the students who attend the school and their parents. Named *Floyd Farm*, this was to be an urban farm facility for the purpose of educating students about agriculture, environmental protection, health and nutrition. The SCUSD had already approved the *Food Literacy Center*, a non-profit corporation, as operator of the new Floyd Farm.

The Food Literacy Center was founded in July 2011 and its mission is to bring healthy food knowledge (and "farm-to-table" information) to underserved communities. Its founder, Amber Stott, had a lifelong career in nonprofit management and a personal passion for improving our food system and helping individuals improve their knowledge, attitude and behavior towards real food. As a food writer and blogger, Ms Stott spent years researching and writing about the need for increased education about the food system of our modern society. Issues of obesity among children and poor nutrition among large segments of the population provided motivation for the creation of this hands-on educational center about food.

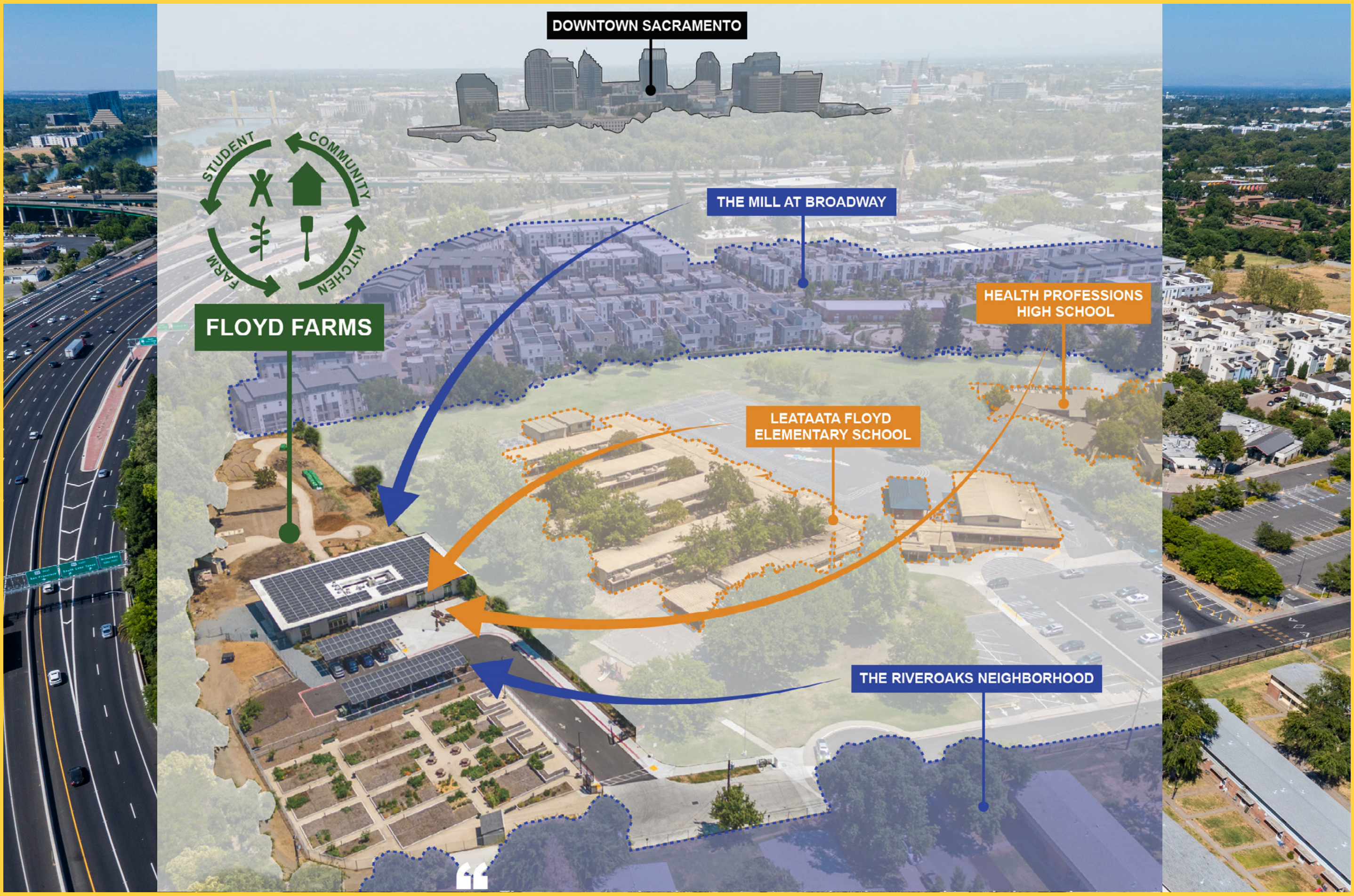
The Food Literacy Center had been working out of a portable building near the site of the new Floyd Farm when the project was approved in 2018. The SCUSD asked HMC Architects to assist the Food Literacy Center in developing a building program for the new facility at the Floyd Farm. (HMC Architects had already been selected in 2017 to design the central food service kitchen for SCUSD, a 50,000 sq. ft., $60 million project serving the entire district.) The Food Literacy Center would use this new facility in its mission to educate students, their families and the larger community about how sustainable gardening provides health and nutrition benefits.

HMC Architects developed such a building program for a 4,500 sq. ft. facility along with some drawings to be used in a fund-raising campaign. The Food Literacy Center successfully raised the funds to build the new facility at the Floyd Farm and then hired HMC Architects through SCUSD to produce the construction documents and manage the construction.

SCUSD regarded this facility as a demonstration project, programmatically and for its sustainability goals. The City of Sacramento committed $1 million to the development of this project, funding the underground utility construction and connections, and the developer of an adjacent housing project, *The Mill at Broadway*, contributed funds ("Quimby fees") that were normally earmarked for adjacent community development in the form of parks and recreation facilities. SCUSD covered the maority of funds to cover the cost of the entire project, which reached $7 million as its final total cost.

The project was completed and occupied in 2022. The design process for this unique educational facility from programming through occupancy is described in the following section.

Food Literacy Center at Floyd Farm - General Vicinity Plan


DOWNTOWN SACRAMENTO
STUDENT
COMMUNITY
FARM
KITCHEN
FLOYD FARMS
THE MILL AT BROADWAY
HEALTH PROFESSIONS HIGH SCHOOL
LEATAATA FLOYD ELEMENTARY SCHOOL
THE RIVEROAKS NEIGHBORHOOD

(Facing Page) Aerial photo of the Floyd Farms with surroundings in West Sacramento *(Top),* and a corresponding diagrammatic overlay identifying principal neighboring structures *(Bottom)*.
(Courtesy of HMC Architects)

(Following Pages) The floor plans, site plan, building elevations and building sections of Food Literacy Center at Floyd Farms.
(Courtesy of HMC Architects)

Design Process and Low-Energy, Zero-Carbon Design Strategies

While the main building program for the academic spaces was being established, ancillary program elements as design objectives and design features were also developed pertaining to the demonstration of all aspects of sustainable design for K-12 schools that SCUSD wanted to incorporate. In particular, the client and design team prescribed *Zero-Net-Energy (ZNE)* performance and an all-electric facility design to avoid any on-site fossil-fuel use. As such, the Food Literacy Center at Floyd Farms is a unique case study in designing for both zero-carbon and for zero-net-energy performance.

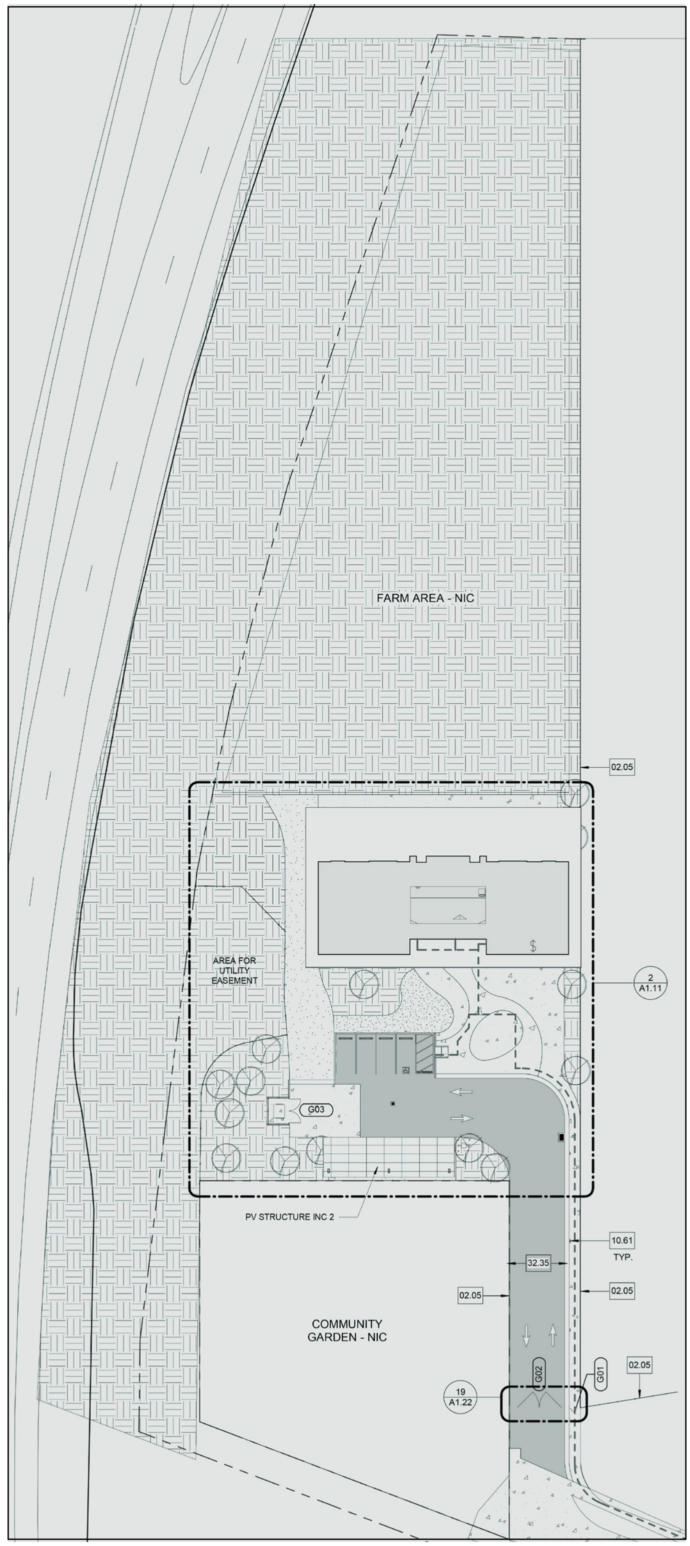
Building Program

The building program is relatively simple and consists of three basic indoor spaces and one major outdoor space adjacent to the large garden. The Headquarters Office for the administration and staff of the Food Literacy Center is designed principally as one flexible open office space with a conference room and one private office. The Commercial Kitchen is contained in the second space and contains the kitchen equipment for all class meal preparation and food-based community events. The large third room is the Cooking Classroom, which has separate cooking stations for smaller groups of students to engage in hands-on cooking lessons.

The outdoor space is meant to be a roof-covered teaching and demonstration “room” that can accommodate large groups from the community as well as regular school classes, utilizing the immediately-adjacent kitchen equipment on one side and the large community garden on the other.

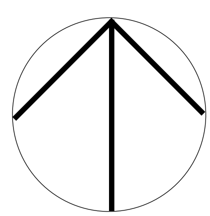
These program elements require special equipment and facilities, contributing to the uniqueness of the facility requirements. The mandate for an all-electric building that incorporates a large enough on-site solar PV system for a ZNE energy performace leads to an additional set of unique building features.

(Left) South entrance to Food Literacy Center.
(Photo: HMC Architects)

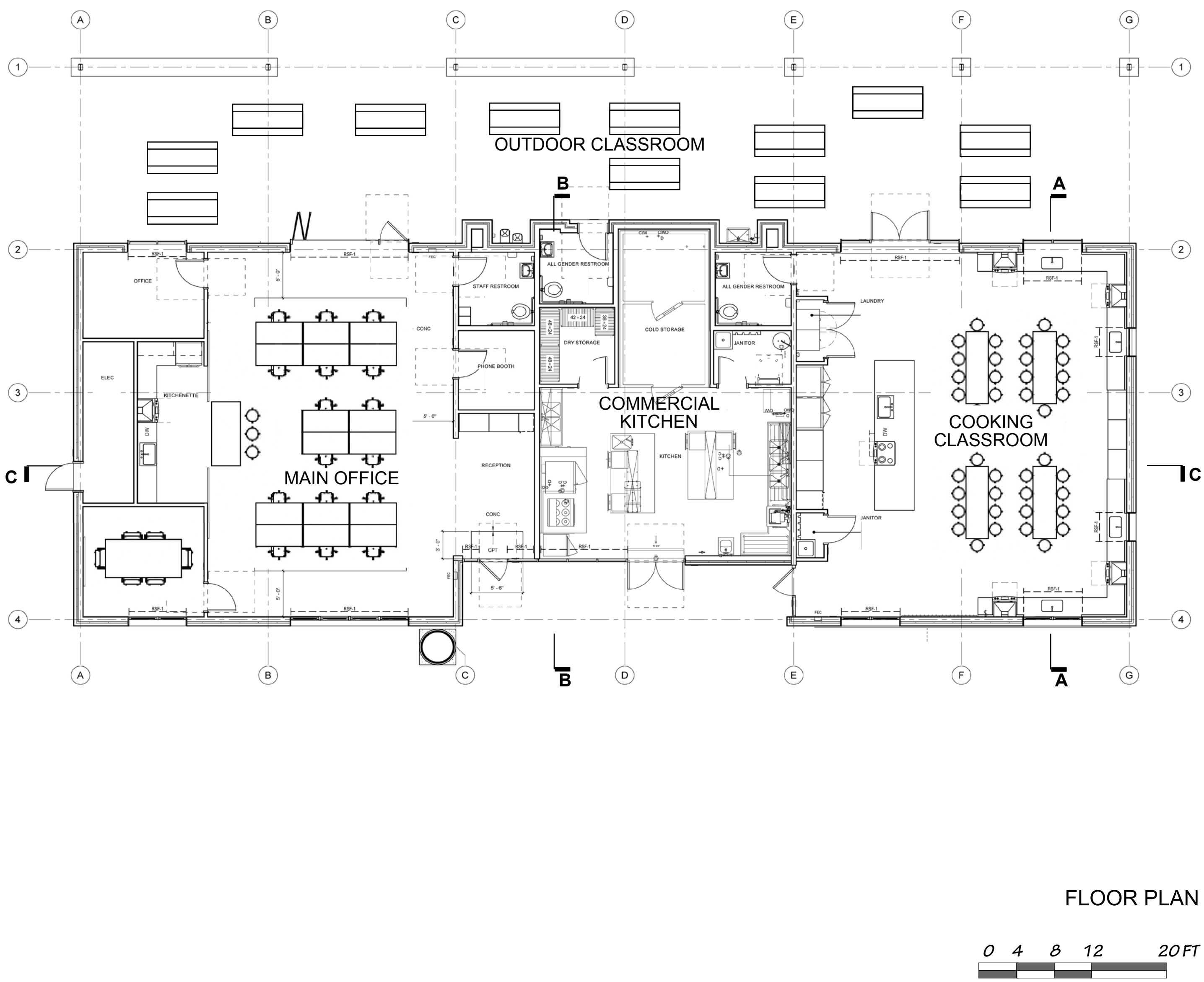


SITE PLAN

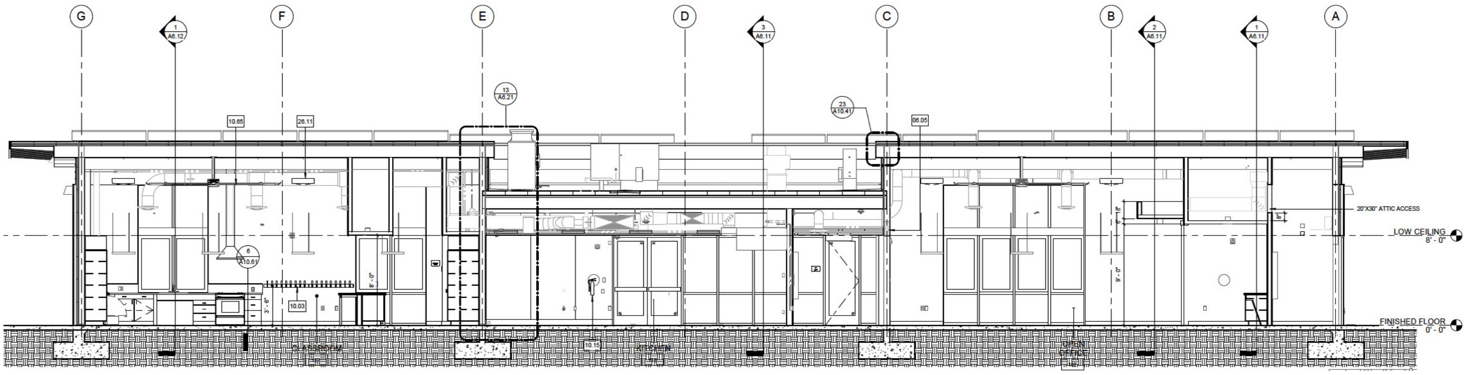
0 20 40 30 100 200 FT


NORTH

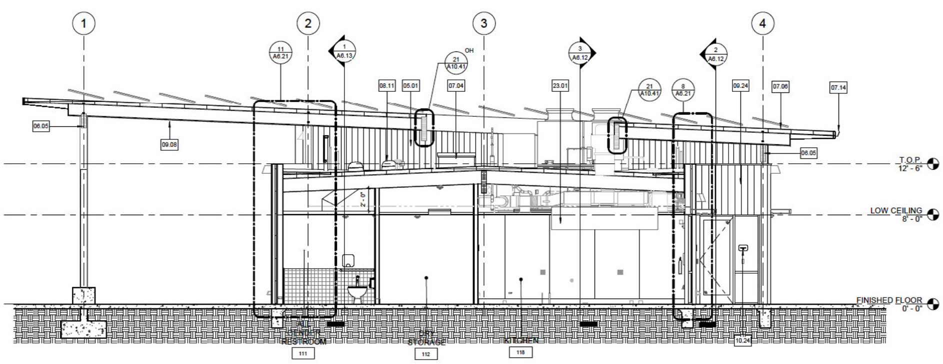
FOOD LITERACY CENTER AT FLOYD FARMS — SITE PLAN AND FLOOR PLAN


OUTDOOR CLASSROOM
MAIN OFFICE
COMMERCIAL
KITCHEN
COOKING
CLASSROOM
OFFICE
ELEC
KITCHENETTE
STAFF RESTROOM
ALL GENDER RESTROOM
PHONE BOOTH
RECEPTION
DRY STORAGE
COLD STORAGE
JANITOR
LAUNDRY
KITCHEN
0 4 8 12 20 FT

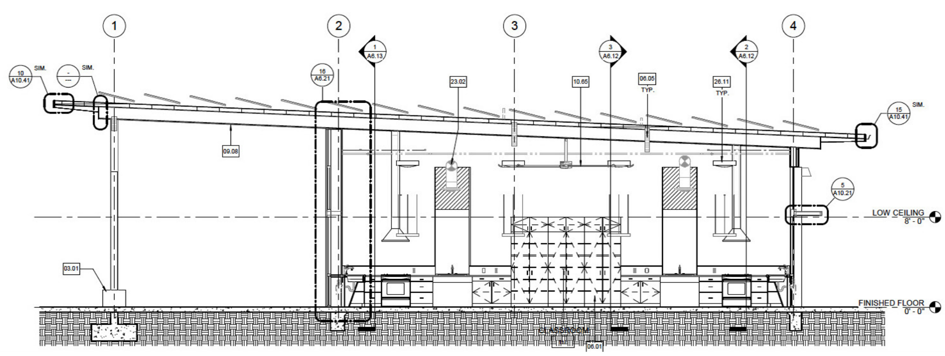
FLOOR PLAN



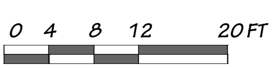
SECTION C - C



SECTION B - B



SECTION A - A



FOOD LITERACY CENTER AT FLOYD FARMS— BUILDING SECTIONS

Building Envelope

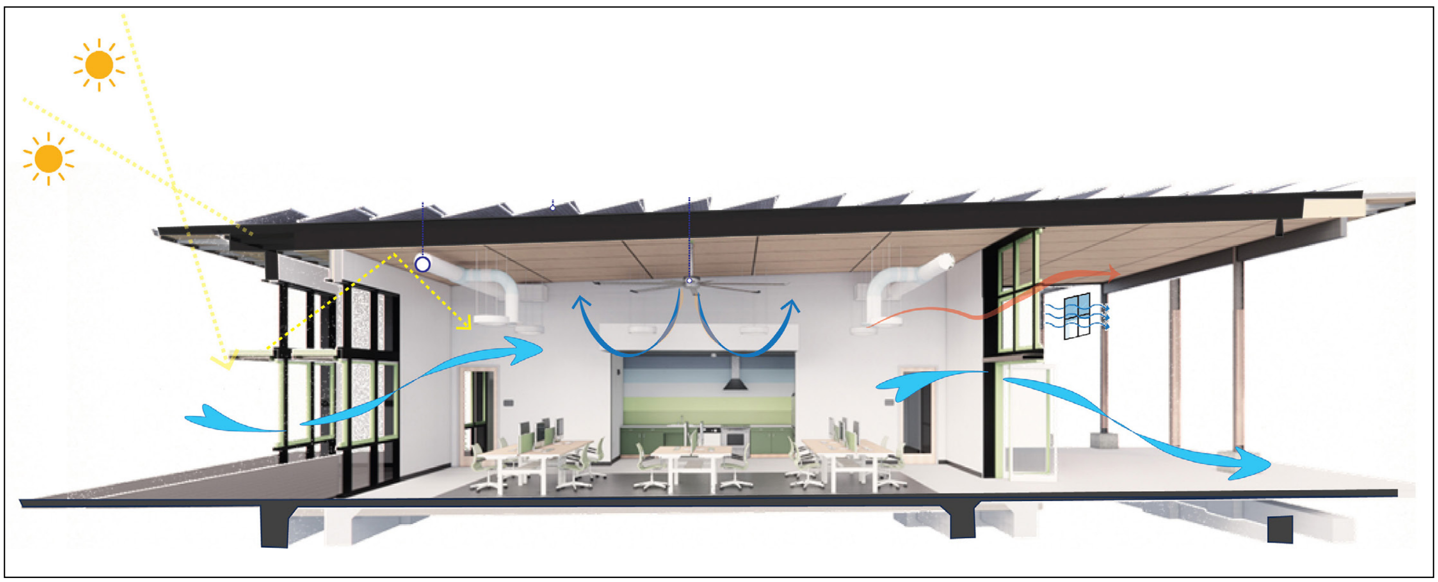
The local Central Valley climate requires both heating and cooling in winter and summer, respectively, with a fairly broad period of time when indoor comfort can be maintained through natural ventilation and careful shading for windows. The building design reflects this, with high insulation values for the walls and roof, roof overhangs and other fixed shading for windows.

The insulation levels meet the requirements of California's energy code with an additional 1.5"-thick layer of rigid insulation[1] on the exterior of the wood-framed walls to prevent thermal bridging. The roof has a 5.2"-thick layer of rigid insulation[2] across the uniformly sloped plane of the roof. The concrete slab floor is uninsulated.

Windows are doubled-glazed with a low-e coating. The operable windows and doors are placed to optimize cross ventilation for cooling during the moderate climate periods.

No special measures were taken to ensure air-tightness of the building envelope since so much building-use activity involves the coincidental use of the adjacent outdoor spaces.

(Below) Diagrammatic building section showing openable windows for natural ventilation air flow and a roof overhang design for optimal shading of south-facing glazing.
(Courtesy : HMC Architects)



Daylighting and Electric Lighting

The building is designed for good daylighting, with the optimized 40-foot building width and tall glass areas on both sides of the main spaces. Because the roof is sloped to the south to optimize the performance of the solar PV panels, the windows on the north facade are able to be exceptionally tall, providing extra daylight for the internal spaces. Several tubular skylights[3] are utilized in the commercial kitchen space in the center of the building to bring daylight to that relatively enclosed area.

Light fixture controls respond to measured daylight levels to turn off electric light fixtures when these levels exceed the programmed minimum.

[1] https://www.rmax.com/ecomaxci-fr

[2] Hunter H Shield polyiso board https://www.hunterpanels.com/products/roof-products/h-shield/

[3] Solatube commercial skylights, https://solatube.com/commercial

(Opposite Page, Top) Typical use of outdoor classroom space; *(Opposite Page, Bottom)* Typical use of indoor classroom space. (Photos: HMC Architects)

Heating, Ventilating and Cooling Systems

The three main spaces of the building are heated and cooled by a heat pump system that utilizes fan-coil units for air distribution to each of those spaces. (See system diagram below.) The system provides either heating or cooling to each zone by using *Variable Refrigerant Flow (VRF)*[4] to heat or cool the room air passing over the coils. Note also in the diagram (below) that large ceiling fans are utilized in the two major spaces to provide additional natural cooling.

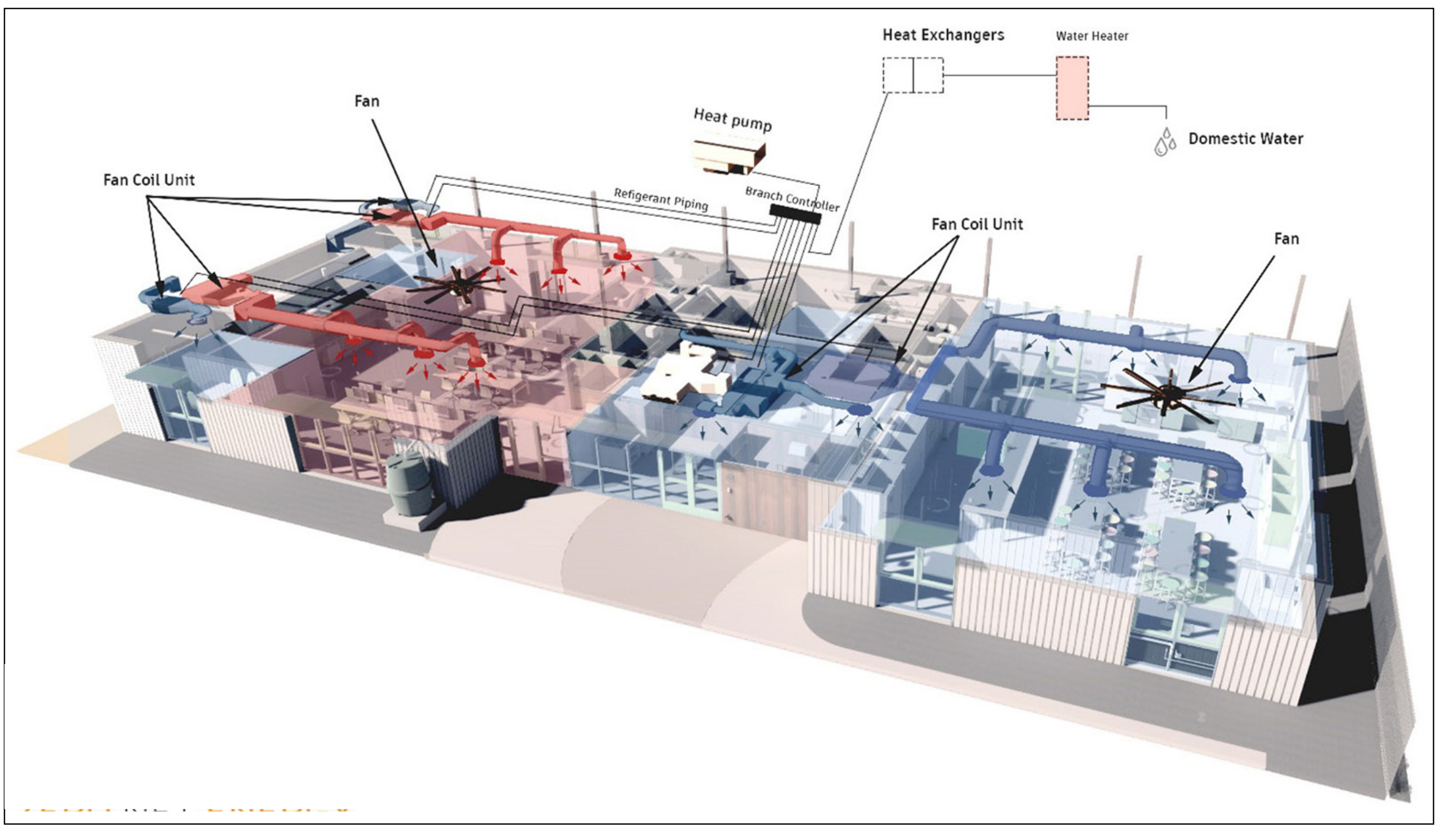
Because of the functioning cooking equipment and variability of load, heating one space may occur at the same time as cooling is required in the other spaces. The system is therefore designed with a strong heat recovery design, utilizing the waste heat from one space by moving it to another space as needed. This system also maximizes the thermal comfort control by allowing the simultaneous heating and cooling of the three different zones.

Domestic Hot Water Systems

The *Domestic Hot Water (DHW)* system is integrated with the VRF heat pump system via heat exchangers to allow the waste heat from the building system to be used to pre-heat the DHW. The intense level of food preparation in the kitchen and classroom spaces creates a high demand for hot water. The heat pump system preheats the DHW and, if there is space cooling occurring in any space in the building, the rejected heat from that space is also captured to provide additional preheating of the DHW. Any remaining requirement for heating the DHW is then done by the electric-resistance hot water storage tank itself. (See diagram below.)

[4] See: https://en.wikipedia.org/wiki/Variable_refrigerant_flow

(Below) Three-dimensional diagram of the heating, ventilating, cooling and hot water systems. (Courtesy: LP Consulting Engineers)




FOOD LITERACY CENTER
Our mission is to inspire kids to eat their vegetables.
THANK YOU
STRAWBERRY STATION

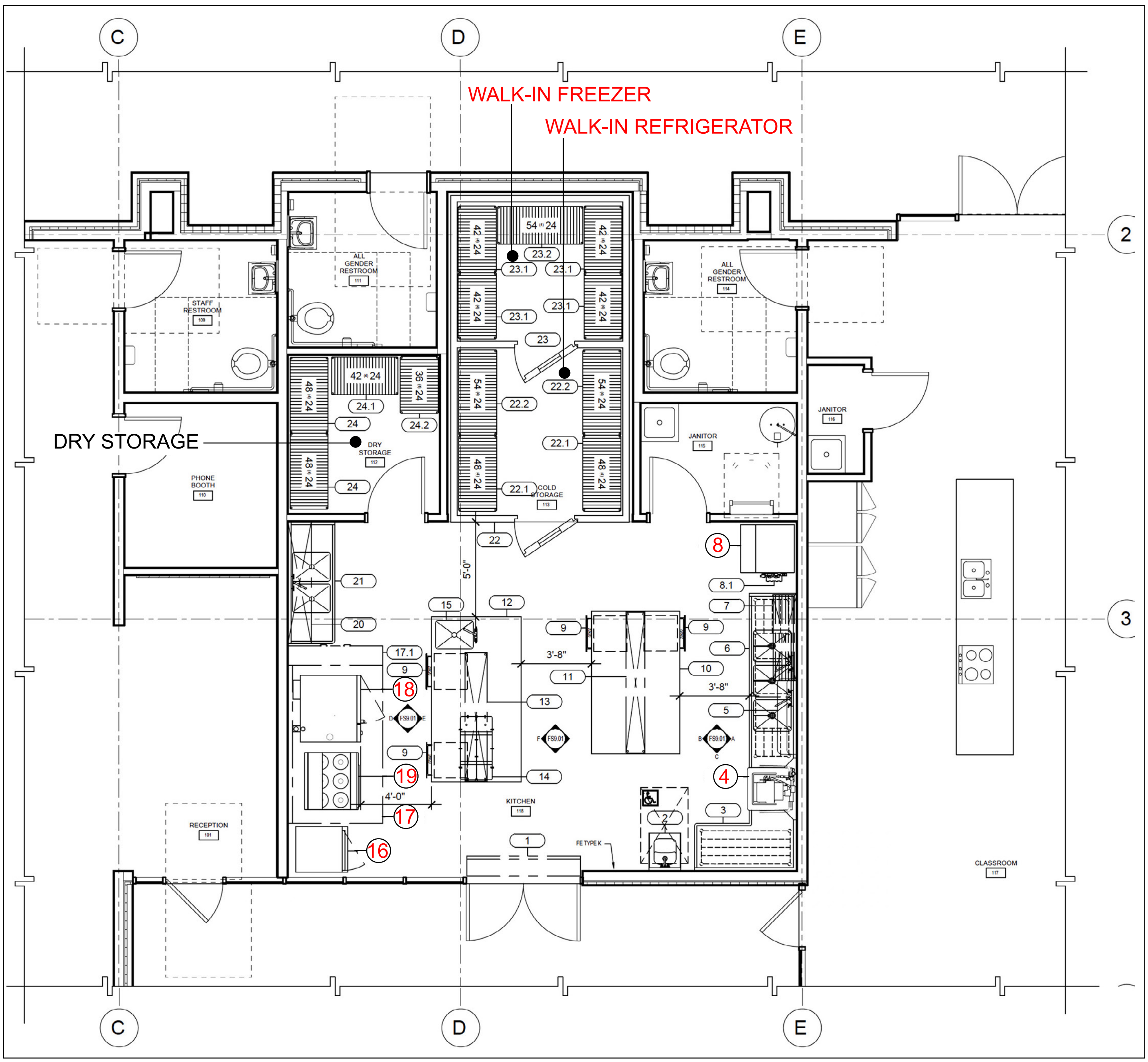
(Opposite Page) Electric cooking equipment in Commercial Kitchen (#16 - #19 in floor plan below.)
(Photo: HMC Architects)

(Below) Floor plan of Commercial Kitchen. Principal electric equipment:

- WareWasher, High Temp: 4
- Ice Maker: 8
- Mobile Warming Cabinet: 16
- Exhaust Hoods: 17
- Electric Oven-Steamer: 18
- Induction Stove: 19

Appliances

The large number of commercial kitchen electric appliances creates a large plug load portion of the electric load for the building. Induction stoves actually are ideal for a K-12 instructional kitchen, providing the safest and cleanest equipment for the students and staff. Teaching young people to cook and prepare heated food using induction stoves also promotes the use of zero-carbon appliances among the general population.




CRES COR.
VULCAN
RATIONAL
iCombi Pro
RATIONAL
iCombi Pro

Renewable On-Site Energy Supply

Solar Photovoltaic System

The roof of the Food Literacy Center was designed specifically to optimize the performance of the solar PV panels that were prescribed as part of the project in order to achieve the ZNE goal. The size of the solar PV array was determined by an estimate of the ultimate energy demand of the facility when the program has matured and is fully operational in the future. That demand would essentially depend to a major degree on the number and types of cooking equipment installed in both the commercial kitchen and the demonstration classroom. Because of the limited experience with this type of facility and the likelihood of future changes, the energy demand projections were necessarily wide-ranging. Furthermore, the educational cooking program is expected to grow as the number of schools join the program, even from nearby districts.

Therefore, in order to ensure ZNE performance in the future, the projected size of the installed solar PV array assumed a larger electrical demand than the initial program would require. This enlarged projection required that two canopies be built above the parking area adjacent to the building in addition to the building roof. This substantially sized system consists of 339 solar PV panels[5] and is rated at a total of 135 kW(DC).

On-Site Energy Storage: Batteries

No battery storage was included in the original design, although this could be added in the future for load management and resilience. The project team and SCUSD is currently evaluating the possibility of this additional feature.

[5] JinkoSolar, Module Type JKM410M-72HL-V, 333 watts per panel

(Right) View of the solar PV arrays on the roof of the building (foreground) and the two canopies (beyond) built above the parking areas.
(Photo: HMC Architects)

Design Analysis: Optimizing Zero-Carbon Design

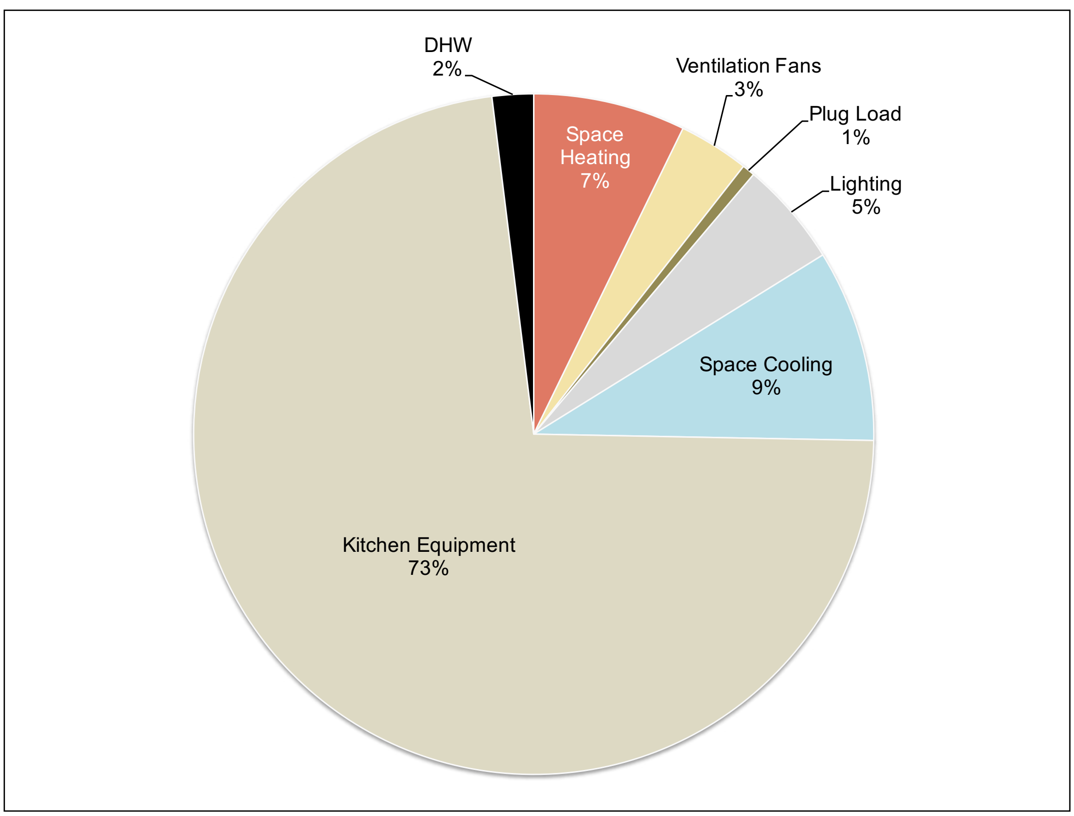
Design Analysis: Embodied Carbon

The embodied carbon content of the project was not calculated as part of the design of the project, but was analyzed after occupancy. Because the structure is primarily wood with a simple concrete slab floor, such an analysis was deemed unnecessary for product or material selection during design. The post-design calculation of embodied carbon[6] was done for various award submittals and used *C.Scale*[7] software, which yielded a value for the embodied carbon of the as-built wood structure of 313 $kgCO_2eq/m^2$. This compares well with conventional wood buildings with values generally if the range of 800-1000 $kgCO_2eq/m^2$.

Design Analysis: Energy Modeling and Operational Carbon

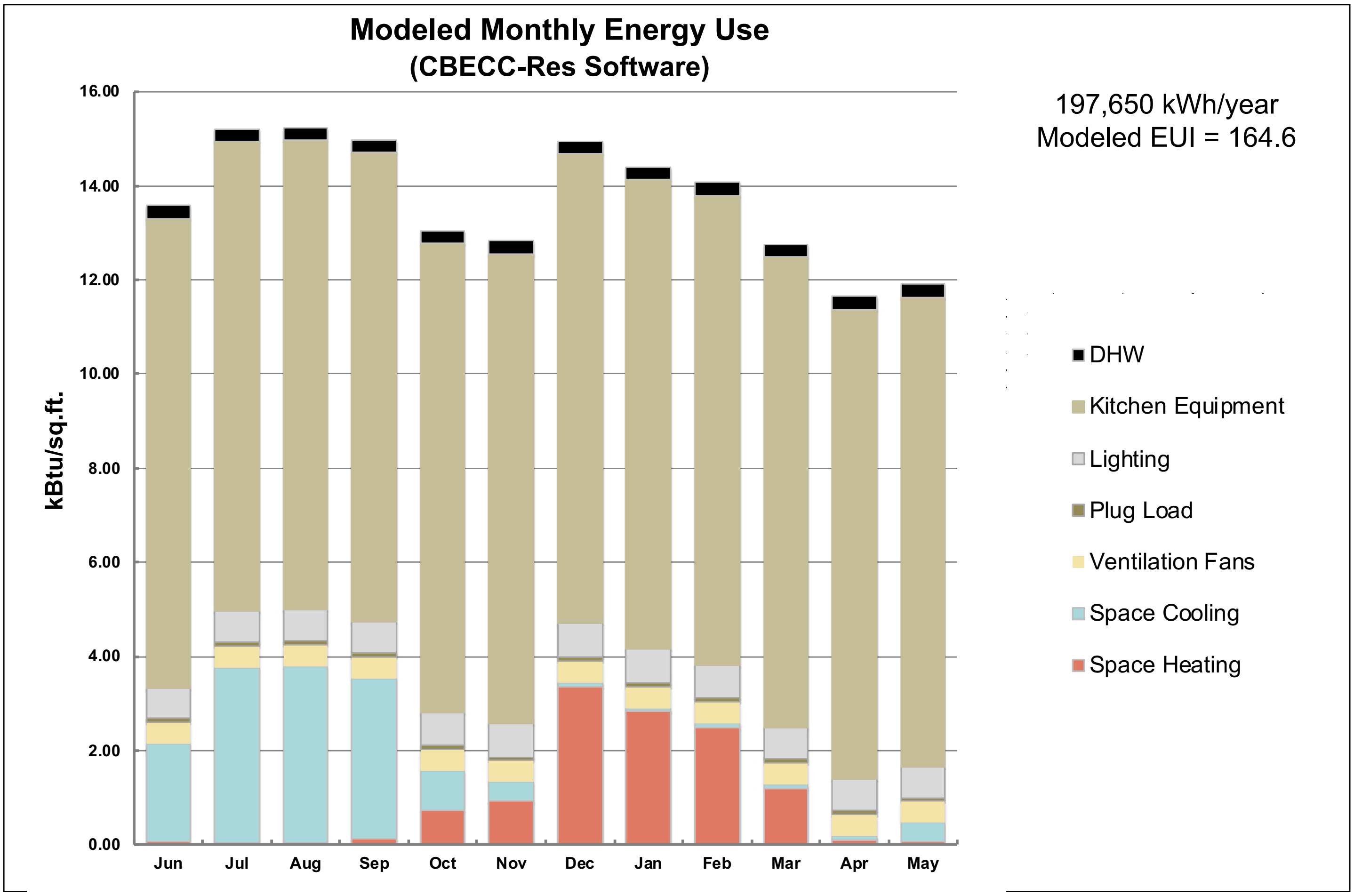
Energy modeling was carried out using the mandated code compliance software in California: *CBECC-Com*, "California Building Energy Code Compliance - Commercial (Non-Residential)". The chart showing the annual modeled energy use of the final design is given below. The chart of the monthly energy consumption for a typical year as categorized by type of use is given on the following page. This monthly energy use chart is displayed in the form of a school year, beginning in June, so that it can be compared with actual data collected for a school year.

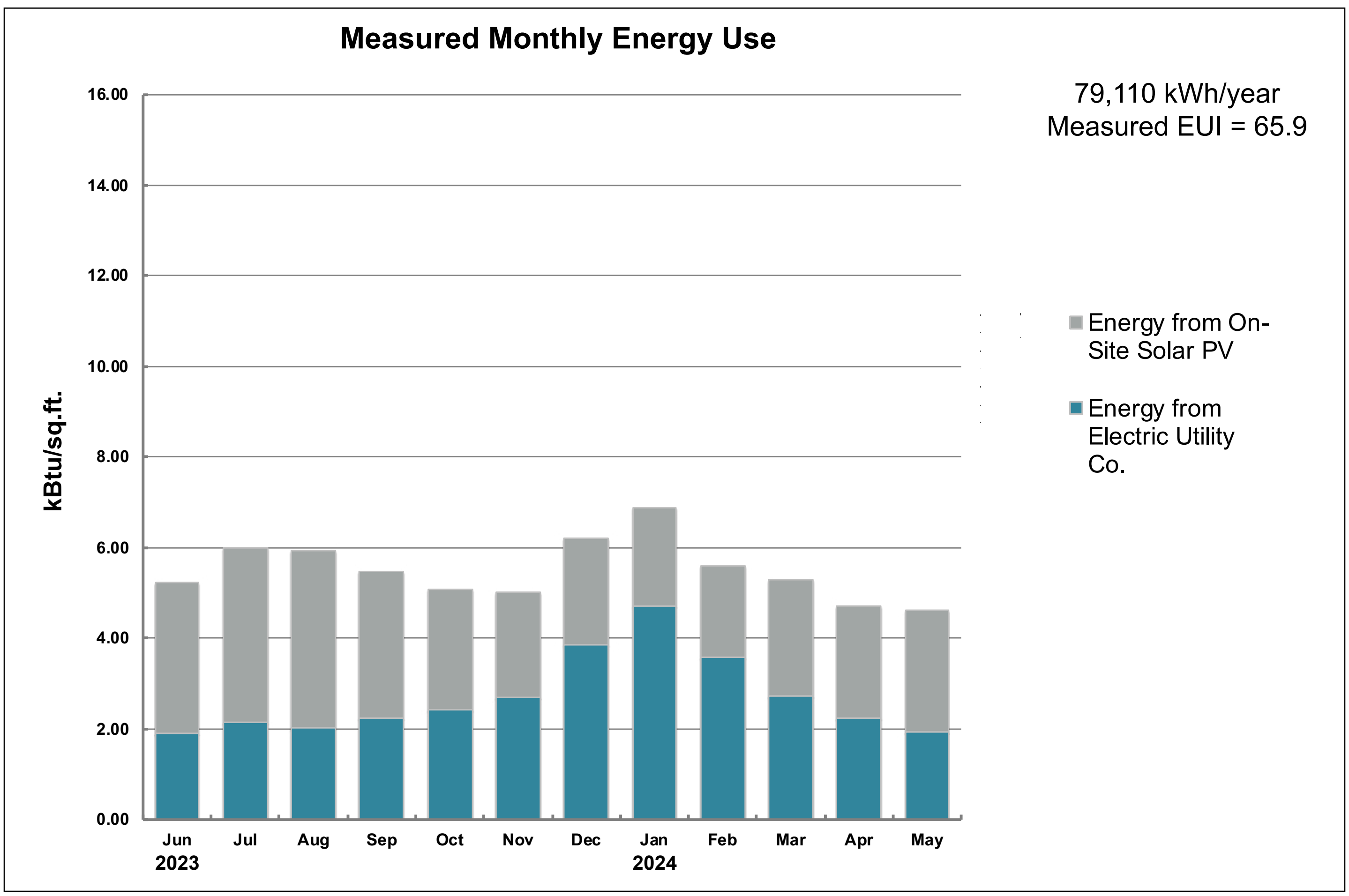
[6] For a thorough discussion of the embodied carbon assessment of new buildings, see *Designing for Zero Carbon, Volume 2*, p.110. For the case of renovation versus new construction, see also *Designing for Zero Carbon, Volume 1*, p.87. For both books, see: https://calbem.ibpsa.us/resources/case-study-books/
[7] See: https://www.cscale.io/. See also: https://epic.ehdd.com/



Modeled Energy Use (Annual) (CBECC-Com Software)

197,650 kWh/year
Modeled EUI = 164.6


Modeled Monthly Energy Use
(CBECC-Res Software)
197,650 kWh/year
Modeled EUI = 164.6
kBtu/sq.ft.
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
DHW
Kitchen Equipment
Lighting
Plug Load
Ventilation Fans
Space Cooling
Space Heating


Measured Monthly Energy Use
79,110 kWh/year
Measured EUI = 65.9
kBtu/sq.ft.
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
Jun
2023
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2024
Feb
Mar
Apr
May
Energy from On-Site Solar PV
Energy from Electric Utility Co.

Energy Performance and Operational Carbon: Post-Occupancy Measurement

Energy Use — Post-Occupancy Measurement

Net energy use data was recorded each month by the Sacramento Municipal Utility District (SMUD) meter at the project site. The energy produced by the large on-site solar PV system was also recorded. As is usually the case, any surplus energy produced by the solar PV system was put into the utility grid and the SCUSD received credit for this on-site generated electric energy at an established rate.

As the chart of the modeled monthly energy use shows (opposite page, top), it is the electric kitchen equipment that creates the largest electrical energy demand of the facility. As discussed earlier, the modeled energy use anticipates the use of the facility by an expanding program of instruction in the coming years with the accompanying growth in energy-intensive activities.

The actual measured energy use in the first year (opposite page, bottom) was significantly less than the modeled amount, primarily because the program was not fully developed in its first year of operation. The total amount of electrical energy consumed in the school year 2023-24 was almost 80,000 kWh and the building's EUI calculated at 65.9 kBtu/sq.ft. per year. (While this EUI is high for educational facilities, it does fall well below the national median EUI of restaurant facilities.)

Comparison with Energy Modeling

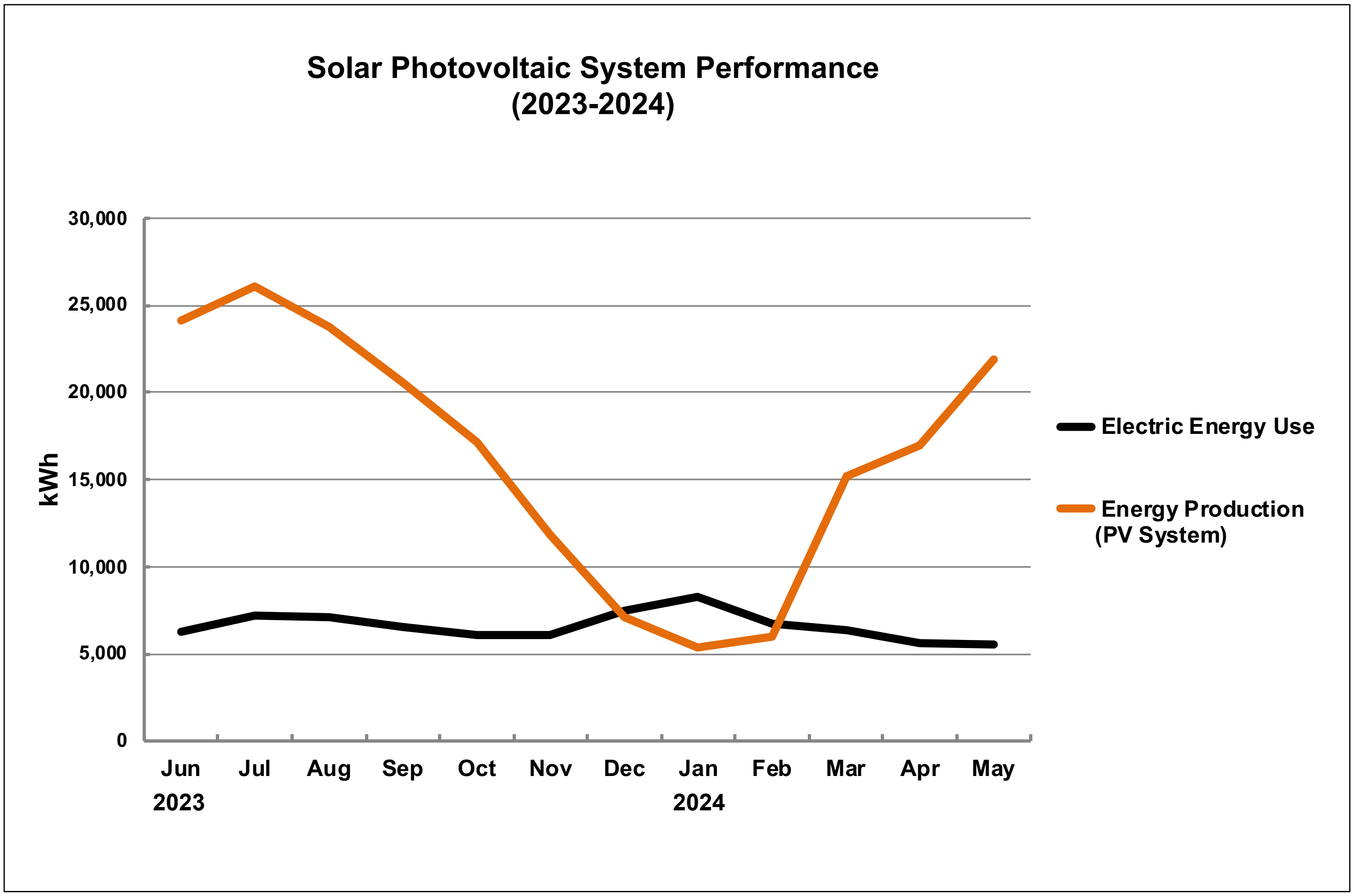
The measured EUI was less than half of the modeled number because of this lower first-year program use. This total energy use is expected to grow in the next few years, although the ultimate energy use total is unlikely to match the modeled amounts. The modeling assumptions were necessarily conservative because of the uniqueness of this facility, the first with this type of scholastic program. Also, achieving the design goal of ZNE performance required this approach.

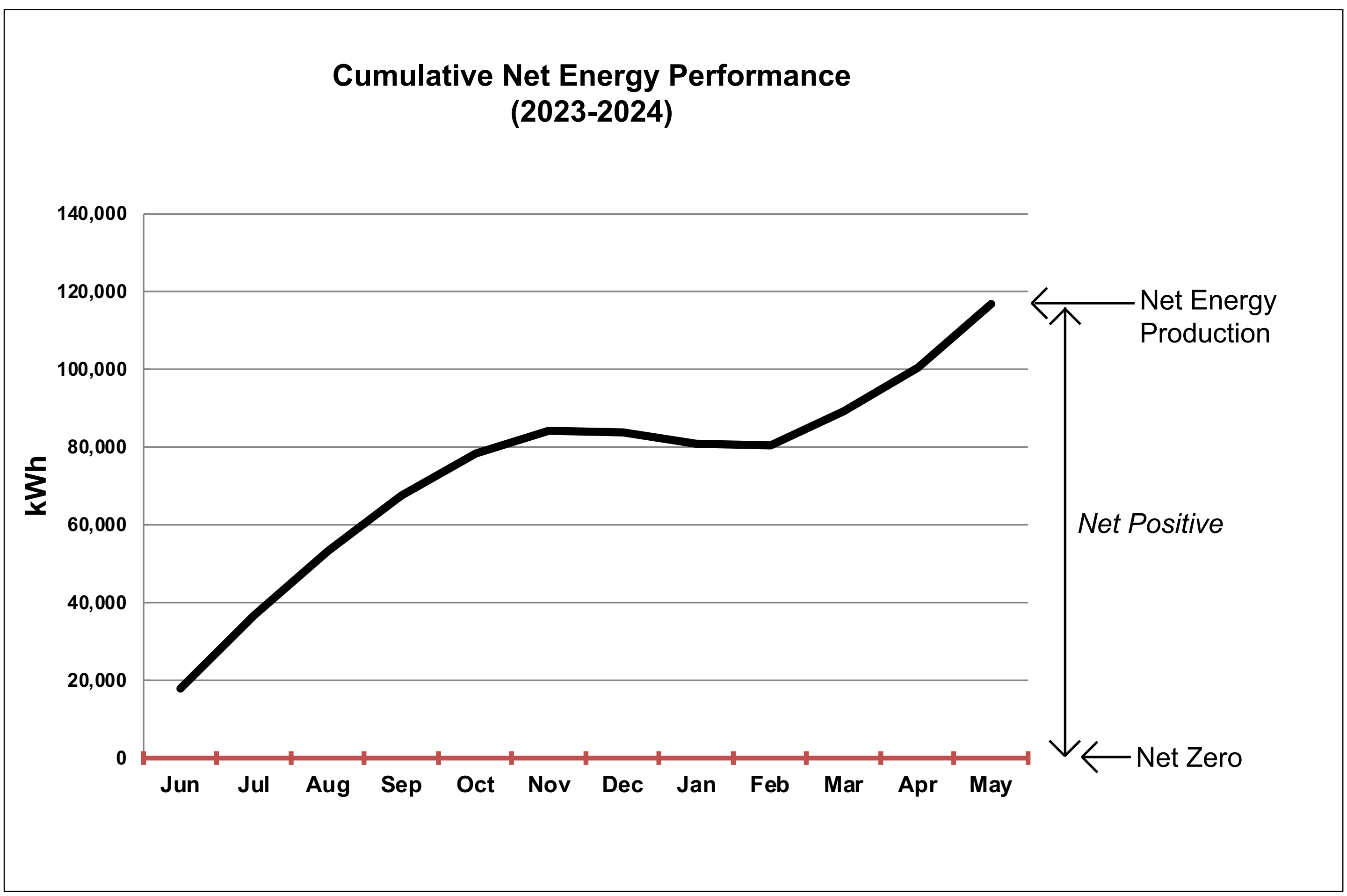
Energy Production versus Energy Use

The interesting revelation of the measured data is the significant portion of the energy used that is obtained from the utility grid. (This is illustrated in the bottom chart on the opposite page.) This is a consequence of some electric kitchen equipment operating twenty-four hours per day. The on-site solar PV system can therefore provide only a fraction of the total energy demand in spite of its large size. Without on-site energy storage (batteries), the large surplus power generated during the day is sent to the utility grid. In turn, the utility grid supplies the energy required during non-solar periods to meet the large continuous demand of the kitchen equipment.

As the instruction program grows in the next few years, the increased electrical energy demand will be largely met by the large on-site solar PV system since this growth will occur primarily during daylight hours. The fraction of the annual total energy use that will be contributed by the public electric utility will decrease, although it will still be significant in the absence of on-site batteries.

The top chart on the following page, *Solar Photovoltaic System Performance*, shows the actual energy produced by the large solar PV system as compared with the actual energy used by the facility. This chart illustrates the large amount of energy generated by the solar PV system in non-winter months, which is delivered to the public utility at those times. The bottom chart on this page, *Cumulative Net Energy Performance*, sums the net energy production each month to that of the month prior, so that the annual total would be exactly zero if the building is achieving ZNE. This data chart displays the large net-positive performance under the building's current program.


Solar Photovoltaic System Performance
(2023-2024)
kWh
30,000
25,000
20,000
15,000
10,000
5,000
0
Jun
2023
Jul
Aug
Sep
Oct
Nov
Dec
Jan
2024
Feb
Mar
Apr
May
Electric Energy Use
Energy Production
(PV System)


Cumulative Net Energy Performance
(2023-2024)
kWh
140,000
120,000
100,000
80,000
60,000
40,000
20,000
0
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Jan
Feb
Mar
Apr
May
Net Energy
Production
Net Positive
Net Zero

(Following Page) Interior of Cooking Classroom, facing east.

Post-Occupancy: Observations and Conclusions

The Food Literacy Center is a unique project with no real precedent, so the design in many aspects was entirely new with no past experience to guide it. Both administrative staff and visiting users from the district schools express great pleasure in the easy connection between the indoor and outdoor spaces, the many openable windows and the ceiling fans for natural cooling. The outdoor space is indeed more frequently used than expected, leading to the staff observation that additional movable glass walls would have been welcomed.

An important post-occupancy observation is the realization that the predominant energy demand from the kitchen equipment actually requires the facility to use a large amount of electric energy from the public utility (SMUD) in spite of the large solar PV system operational at the site. This large solar PV system substantially overproduces during daylight hours (see chart on opposite page), which is then transmitted to SMUD at a low rate. The system would be more balanced and significantly less costly to the school district if an on-site energy storage system (batteries) were added. (The project team and SCUSD is currently evaluating this future addition to the system.)

The embodied carbon analysis was done as part of awards submittal programs, but was not conducted during the design process as a basis for design decisions. The post-occupancy analysis indicated a low embodied carbon number.

(Below) View of north facade of Food Literacy Center from the farm area.


Plant
Parts Salad
BROCCOLI
STATION
Sunflower
Seed Butter &
Seasonal Fruit
Strawberry
Lyric
Tarbit
Arya
Fumiko
Charlotte
Jay'anna
Hope

PHOTO: HMC ARCHITECTS

CASE STUDY NO. 5

Lick-Wilmerding High School

PHOTO: MICHAEL DAVID ROSE

Lick-Wilmerding High School

Case Study No. 5

Data Summary

Project Type: Private
Location: San Francisco, CA
California Climate Zone: 3
Gross Floor Area: 50,488 sq.ft.
Fully Occupied: August 2019

Modeled EUI (Site):
21.5 kBtu/sq.ft. per year
Measured EUI (Site):
27.1 kBtu/sq.ft. per year

On-Site Renewable Energy System Installed:
168.5 kW (DC) Solar PV
On-Site Storage Battery:
None
Measured On-Site Energy Production:
314,575 kWh per year
21.3 kBtu/sq.ft. per year

Client Organization:
Lick-Wilmerding High School

Design Team

Architect:
EHDD Architecture, San Francisco, CA

Structural Engineer:
Forell/Elsesser, San Francisco, CA

Mechanical, Electrical and Plumbing Engineering:
Integral Group (now Introba), Oakland, CA

Energy Modeling:
Integral Group (now Introba), Oakland, CA

Commissioning Consultant:
Guttman & Blaevoet, San Francisco, CA

General Contractor:
Truebeck Construction, San Francisco, CA

Solar Contractor:
Solar Technologies, San Ramon, CA

As noted earlier in this book, private schools in California consist of approximately 10% of the total school enrollment in the state and mirror the public school categories of elementary, middle and high schools. This final case study is an example of a private high school, grades 9-12, which required both modernization and a major renovation at its urban site in response to a planned increase is the size of the student body. The site constraints and existing campus buildings limited the solution options for this secondary school—it is a good example of how *Zero-Net-Energy (ZNE)* and *Zero-Carbon* design can nevertheless be successfully incorporated into such a tightly-constrained project.

Background

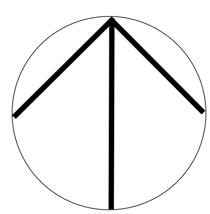
The history of Lick-Wilmerding High School begins, similar to Garfield Elementary School (Case Study No. 3), in pre-earthquake San Francisco. In 1875, the wealthy Gold Rush real estate investor, James Lick, endowed a trust and established the *California School of Mechanical Arts* in the Mission District as a tuition-free private school. Twenty years later, Jellis Wilmerding also bequeathed his Gold Rush investments to help establish another school specializing in building trades education (including architecture), the *Wilmerding School of Industrial Arts*, located in 1900 at the same site in the Mission District. When the 1906 San Francisco earthquake struck, the two adjacent schools were spared from the large fire that engulfed the city (unlike Garfield Elementary School), which destroyed the nearby neighborhood in the Mission District. Then in 1912, the two schools were joined on the site by the *Lux School for Industrial Training for Girls*, which started using the existing facilities of both schools for its sessions and opened its own building on the site in 1913.

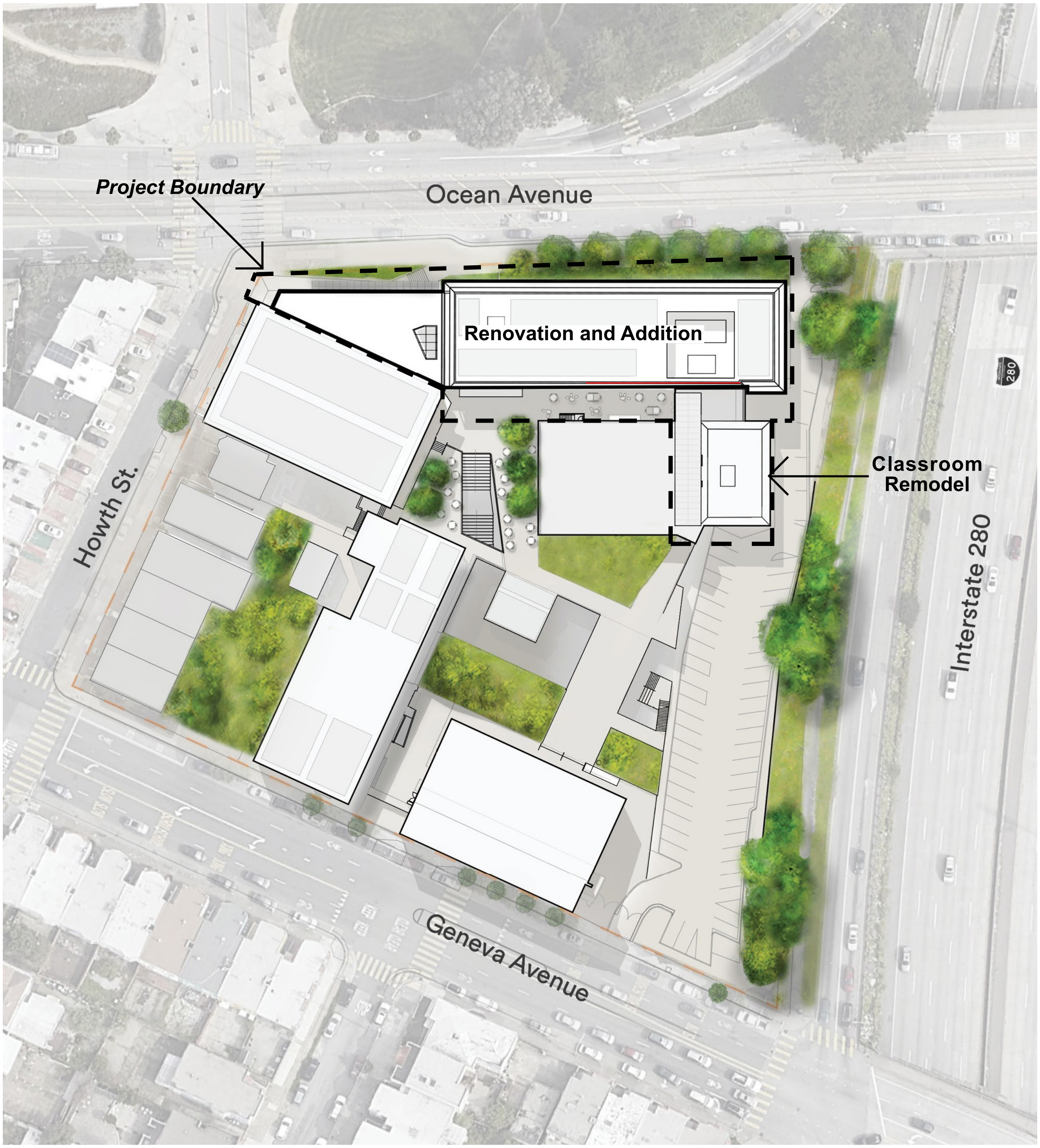
The three trade schools all shared the facilities, though maintained separate programs and administration, until the early 1950s. Then, the original two schools were combined into one educational entity, the *Lick-Wilmerding High School*, still emphasizing vocational education in a variety of fields, but now focusing on a college-preparatory approach to its curriculum. (The Lux School students later joined the Lick-Wilmerding school in 1972.) The Board of Trustees of the newly consolidated high school decided at the same time to move out of the declining neighborhood conditions in the Mission District to another location in the city, to a site that would better accommodate their academic plan. In 1956, Lick-Wilmerding High School was relocated to a new site in the western part of San Francisco, which was relatively undeveloped and could accommodate expansion in the coming decades.

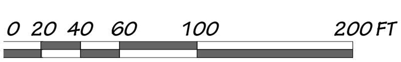
The original facility built at the new location was designed by an early alumnus of the school, architect William G. Merchant, who graduated in 1909 and who founded his own architecture firm in 1946. The two-story mid-century modern design of this original school was the beginning of the development of the entire campus since 1956, which eventually spread to encompass almost the entire large block in western San Francisco. This original building is also the center and focus of the Lick-Wilmerding High School renovation and expansion project that is the subject of this case study.

After almost 60 years at this site, the Board of Trustees decided to expand the number of students at the high school and to accommodate this increase by the renovation and expansion of the now historic classroom/administration building along Ocean Avenue. (See plan of the Lick-Wilmerding High School campus and the project boundary on the following page 92.) A master plan was initially done in 2014, which set the general scope and cost of the project. In 2016, the EHDD Architecture team was selected to develop a detailed program and project approach. The team responded with a design process that fully engaged student and faculty participation and that, in particular, promoted the concept of an all-electric, ZNE design for the facility. All this had to be done with a building that was now a designated historic structure by the State of California.

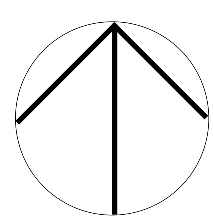
Lick-Wilmerding High School - General Vicinity Plan







LICK-WILMERDING HIGH SCHOOL CAMPUS



(Opposite Page) Campus plan of Lick-Wilmerding High School showing the project boundary of the renovation and expansion project that is the subject of this case study.

(Following Pages) Floor plans and key building sections for the extent of the project scope.

Design Process and Low-Energy, Zero-Carbon Design Strategies

The design team initiated the project with the client by conducting a series of meetings to establish the design goals for the project and prioritize the features of the building program, given the constraints of the site, the existing historic building and the cost. The ZNE goal and the all-electric design aspects were adopted early in this process and became a focus of the development of many of the design features.

These early conversations resulted in the final scope of the project:

1. The rebuilding for the historic 1956 two-story building, preserving only the modernist façade and accommodating the new academic program in flexible, adaptable space;

2. The addition of new space in the form of an architecturally distinct third floor of the rebuilt structure;

3. The separate remodeling of four classrooms in an adjacent two-story building.

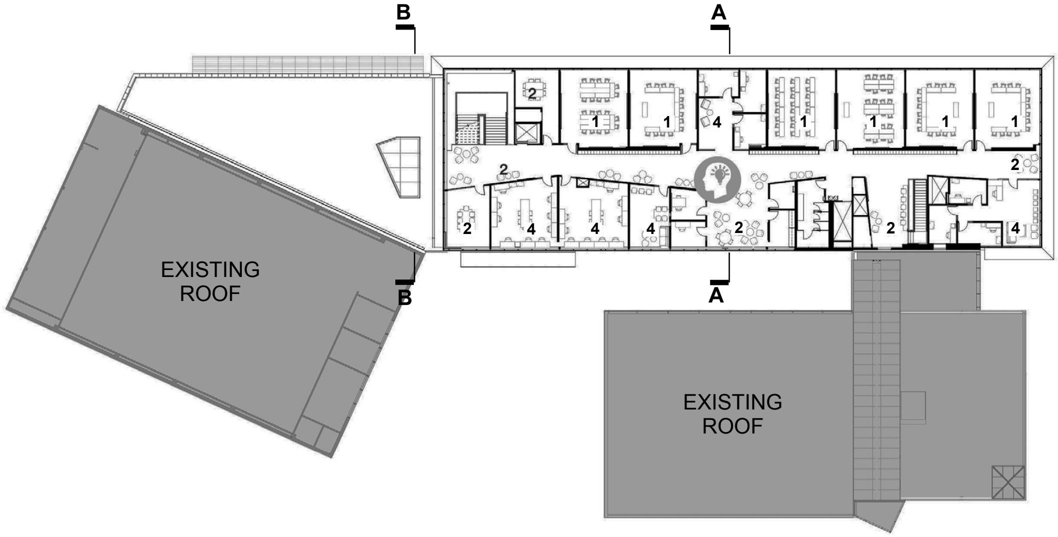
See *Project Boundary* in figure on opposite page for the location of these three parts of the project.

Demolishing the interior floors and walls of the historic building allowed the construction of new flexible and adaptable program spaces as well as energy-efficiency features for daylighting and building envelope design (to be discussed in the following sections of this case study).

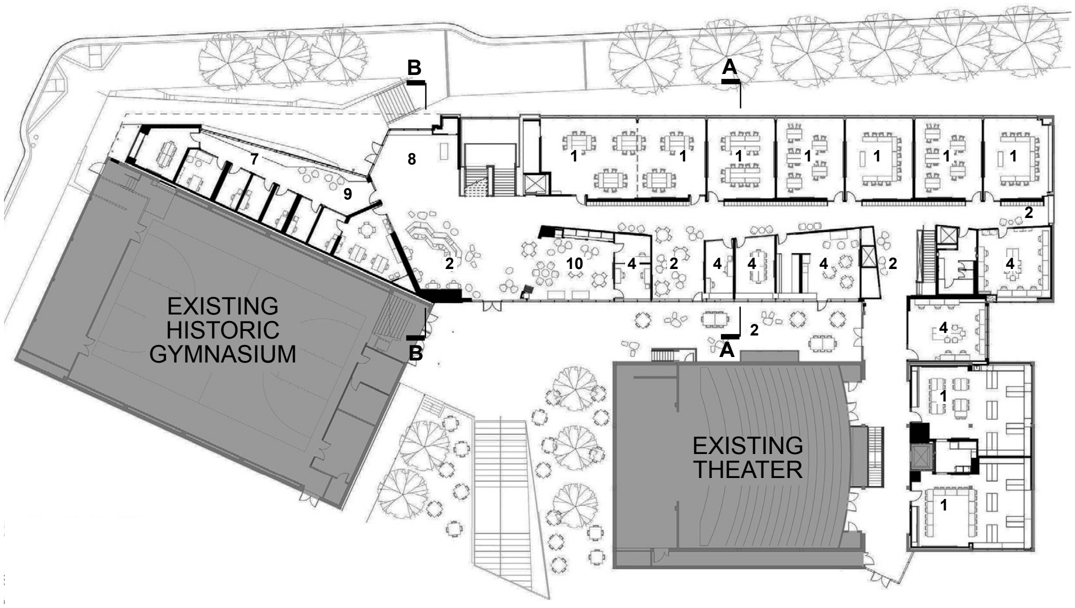
(Below) Construction photo after the demolition of the floors, roof and interior spaces of the original 1956 modernist building. Its historic facade is visible at left, preserved in place. (Photo: EHDD Architecture)

KEY:

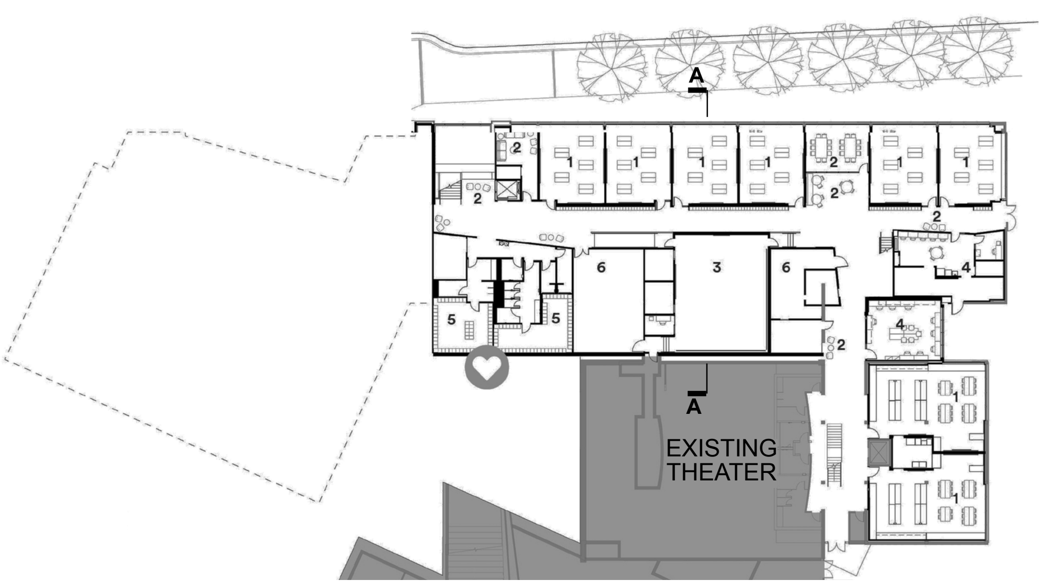
1 Classroom
2 Breakout Area
3 Dance Studio
4 Office
5 Lockers
6 Mechanical/Storage
7 Student Work Display Wall
8 Lobby
9 Dean's Area
10 The Center for Civic Engagement

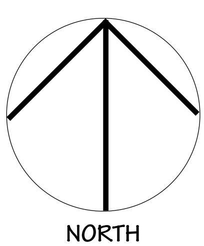


THIRD FLOOR PLAN



SECOND FLOOR PLAN

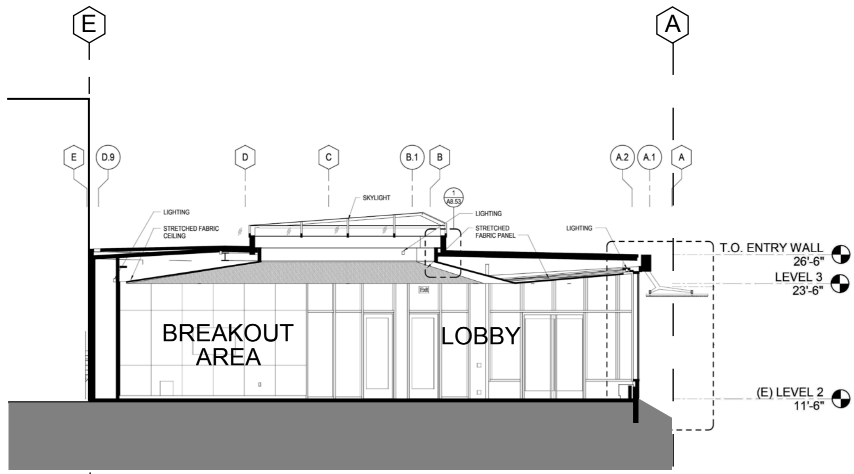




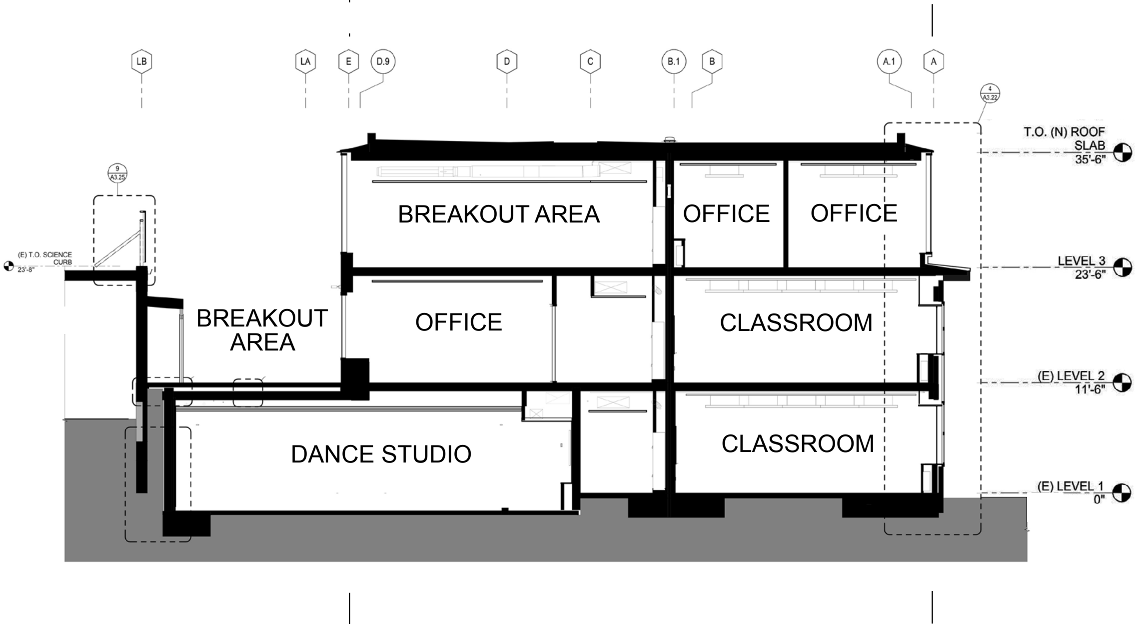
FIRST FLOOR PLAN

0 10 20 30 50 100 FT

LICK-WILMERDING HIGH SCHOOL - FLOOR PLANS



SECTION B - B



SECTION A - A

LICK-WILMERDING HIGH SCHOOL — BUILDING SECTIONS

(Opposite Page, Top) Wall section and partial north elevation of the new building; *(Opposite Page, Bottom)* Photo of the partial north elevation of the completed new building, showing the two-story historic curtainwall facade topped by the new third floor with its distinct all-glass curtainwall.

Building Program

In addition to traditional classrooms and administrative office space, flexible and shared breakout areas were integrated to permit collaborative learning areas and generally adaptable space uses. The latter included space for the new Center for Civic Engagement and a student work display area. Existing science labs were updated in the remodeled classroom areas. The all-electric building design and the goal of a ZNE performance were also mandated in the building program.

Building Envelope – Insulation and Windows

The original building uses a delicate wood and aluminum framed curtain wall system, which was state-of-the-art building technology for its time. This extensive curtain wall of this original building was a large portion of the historic modernist design and the exterior of this façade was required to be maintained in the new/rebuilt structure. Adding to this design issue was the fact that the original window system was single-glazed. To meet the modern energy code, a modified window assembly with better thermal performance had to be designed so that the changes were not visible on the exterior.

The architects developed a solution that added an acrylic pane to the inside of each element of the existing curtain wall to create an insulated glazing system, rendering the details so that this extra layer was not visible. The thin mullions of the existing facade were matched as well so that the exterior appearance was maintained.

A high-performance curtain wall solution was also used on the new third floor addition, although it is detailed to look different than the existing historic curtain wall on the two-story façade below. This satisfied the requirement that any addition appear as a separate distinct element from the historic original. Because there is no shading of the glass curtainwall on the third floor, the glass was specified as a low-e[1] glass. In addition, there is a ceramic frit[2] applied to the east and west sides of this glass-enclosed level, with a different density and pattern for each elevation, providing a reduction in solar gain appropriate to the facade orientation. The frit pattern is gray in color, which reduces its visual presence compared to a typical white frit. This also makes the frit pattern differences barely noticeable at the corners. Lastly, the east facade, which is immediately adjacent to and facing the freeway, incorporates laminated glass to mitigate the freeway noise. This type of glass decreased the measured sound transmission in this location by almost 50%.

The opaque exterior of the original building consisted of uninsulated concrete walls, which had to be designed and detailed with extra insulation to compensate for the large glazing area. This was accomplished by furring out the interior surfaces of these exterior walls with significant insulation installed and by adding two inches of rigid mineral fiber insulation at the inside of the wall furring. (See illustrative drawings on the folowing pages.)

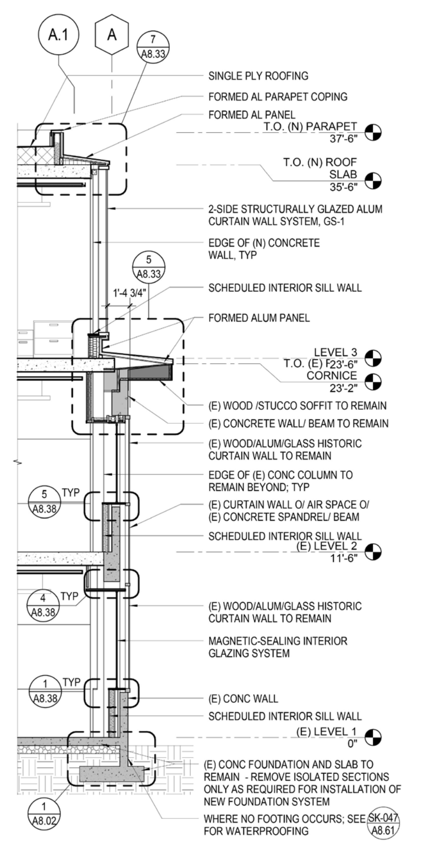
The net result was that the total R-value of the opaque wall systems was brought to an average of R-20. The new roof for the building achieves an average of R-30 using rigid foam insulation above the exposed roof structure.

Building Envelope – Air-Tightness

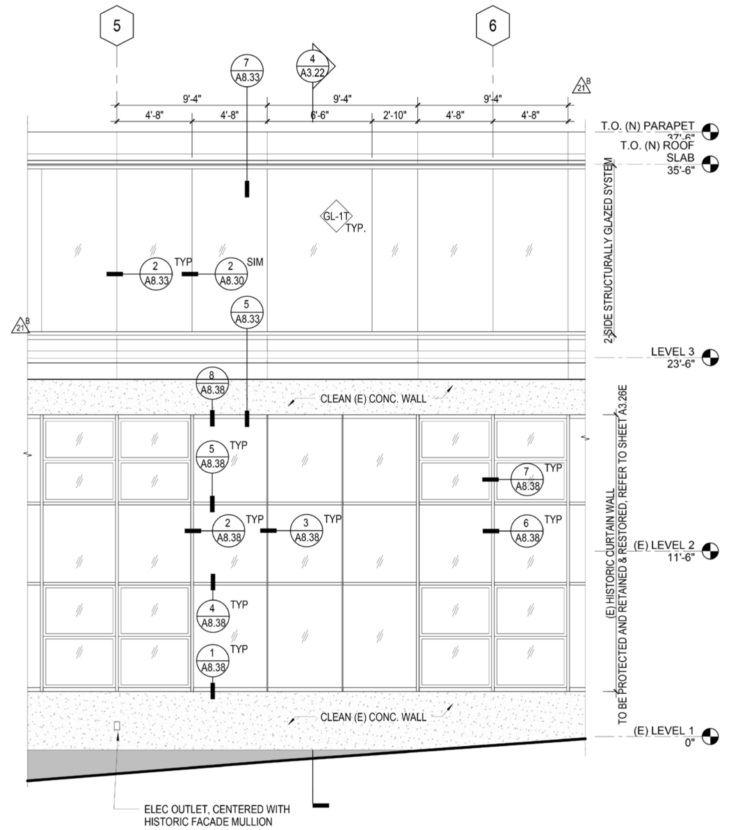
No special air-sealing of the building was designed. Consequently, no air tightness testing was done.

[1] See: https://en.wikipedia.org/wiki/Low_emissivity

[2] See: https://www.hpglazing.com/post/enhancing-construction-a-guide-to-fritted-glass



4 A3.22 NORTH WALL SECTION - HISTORIC CURTAIN WALL
SCALE: 1/4" = 1'-0"



3 A3.22 ENLARGED NORTH ELEVATION - HISTORIC CURTAIN WALL
SCALE: 1/4" = 1'-0"

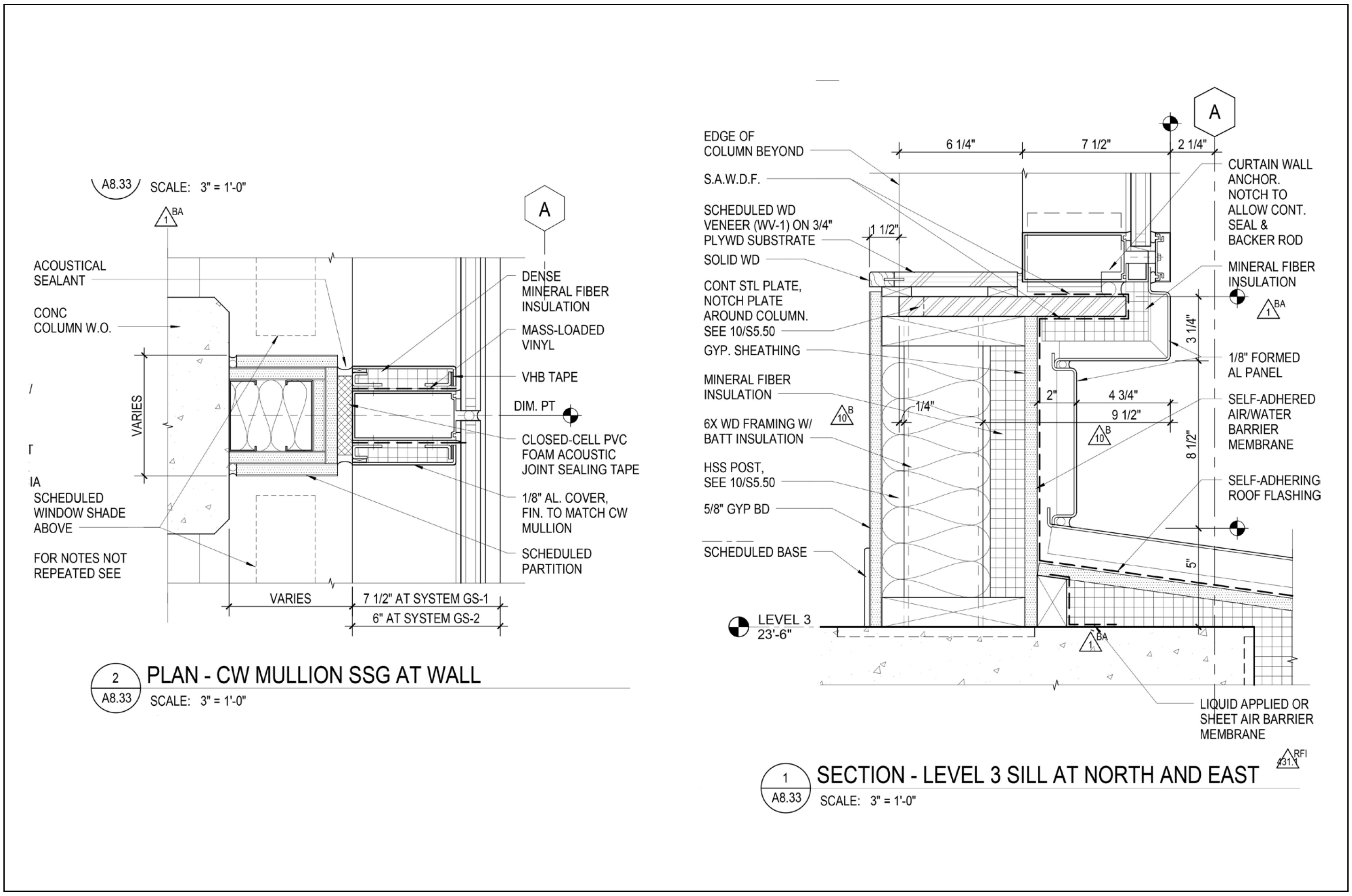

A8.33 SCALE: 3" = 1'-0"
A
ACOUSTICAL SEALANT
CONC COLUMN W.O.
VARIES
SCHEDULED WINDOW SHADE ABOVE
FOR NOTES NOT REPEATED SEE
DENSE MINERAL FIBER INSULATION
MASS-LOADED VINYL
VHB TAPE
DIM. PT
CLOSED-CELL PVC FOAM ACOUSTIC JOINT SEALING TAPE
1/8" AL. COVER, FIN. TO MATCH CW MULLION
SCHEDULED PARTITION
VARIES
7 1/2" AT SYSTEM GS-1
6" AT SYSTEM GS-2
2 A8.33 PLAN - CW MULLION SSG AT WALL
SCALE: 3" = 1'-0"
EDGE OF COLUMN BEYOND
S.A.W.D.F.
SCHEDULED WD VENEER (WV-1) ON 3/4" PLYWD SUBSTRATE
SOLID WD
CONT STL PLATE, NOTCH PLATE AROUND COLUMN. SEE 10/S5.50
GYP. SHEATHING
MINERAL FIBER INSULATION
6X WD FRAMING W/ BATT INSULATION
HSS POST, SEE 10/S5.50
5/8" GYP BD
SCHEDULED BASE
LEVEL 3 23'-6"
6 1/4"
7 1/2"
2 1/4"
1 1/2"
1/4"
2"
4 3/4"
9 1/2"
3 1/4"
8 1/2"
5"
CURTAIN WALL ANCHOR. NOTCH TO ALLOW CONT. SEAL & BACKER ROD
MINERAL FIBER INSULATION
1/8" FORMED AL PANEL
SELF-ADHERED AIR/WATER BARRIER MEMBRANE
SELF-ADHERING ROOF FLASHING
LIQUID APPLIED OR SHEET AIR BARRIER MEMBRANE
1 A8.33 SECTION - LEVEL 3 SILL AT NORTH AND EAST
SCALE: 3" = 1'-0"


PHOTO: MICHAEL DAVID ROSE

(Opposite Page, Top) Third-floor curtainwall details, showing key placement of mineral fiber insulation.
(Opposite Page, Bottom) View of south elevation of the completed new building with the new third-floor curtain wall that wraps around the entire floor.

Heating, Ventilating and Cooling Systems

The all-electric building utilizes a heat pump system for heating and cooling and a separate air-handling system for fresh-air ventilation. This system decouples ventilation air from the delivery of thermal comfort, allowing more efficient space heating and cooling options to be used and avoid recirculating used building air throughout the building. These components of the HVAC system are located on the roof of the third-floor addition.

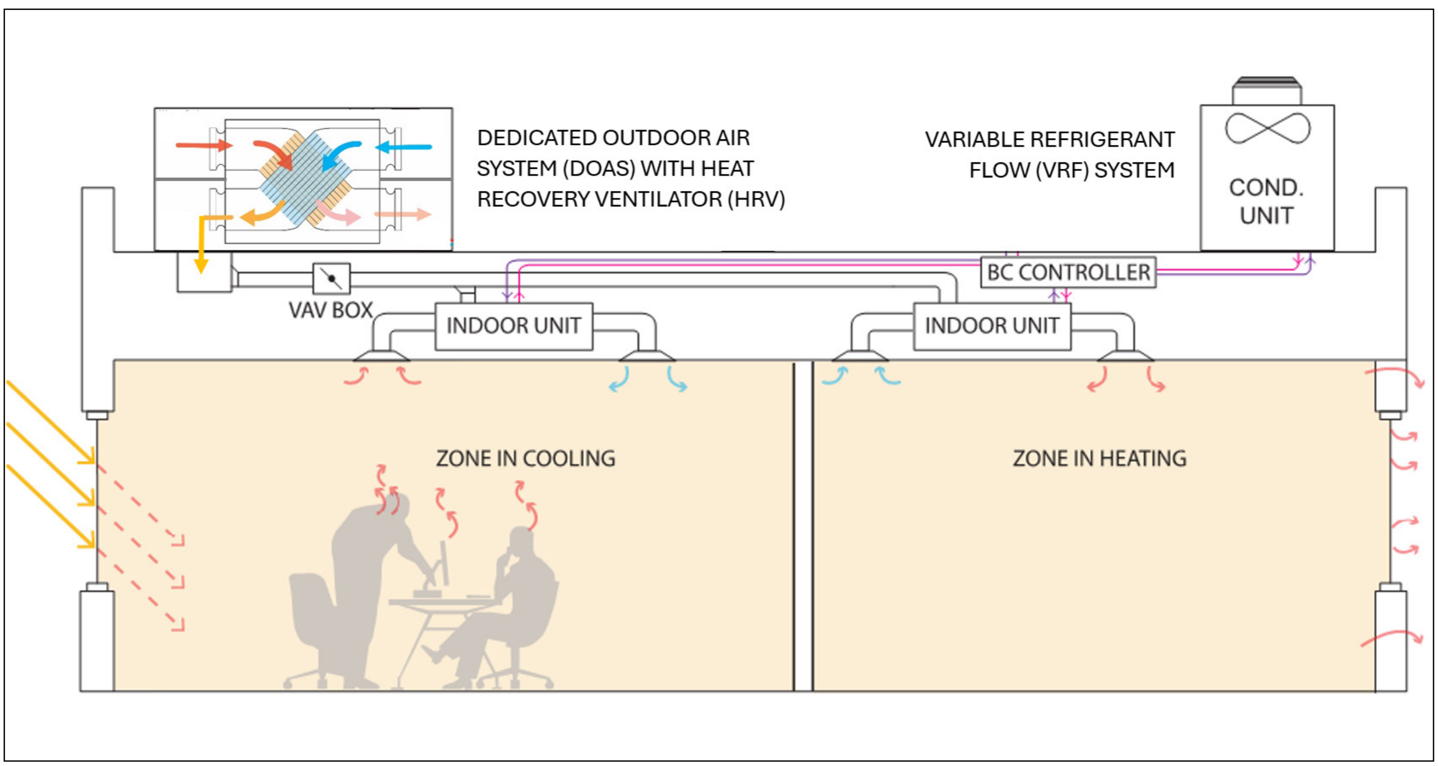
The fresh-air ventilation system, known as a *Dedicated Outdoor Air System (DOAS)*[3], utilizes a heat recovery system to reduce overall energy use and provide pre-conditioning to the incoming outside air. Known as a *Heat Recovery Ventilator (HRV)*[4] and located within the DOAS unit, this component provides indirect heat transfer to the incoming ventilation air by recovering heat from the exhaust air.

The heat pump system, consisting of eight heat pumps for the entire building, utilizes a refrigerant as a heat transfer medium for either heating or cooling. In a process known as *Variable Refrigerant Flow (VRF)*[5], the refrigerant is piped to the individual fan coil units in each zone at the rate needed, providing a high efficiency of heat transfer. The VRF system allows for zone control, efficient heat transfer, and relative ease of installation with corresponding lower first costs.

With the ability to provide simultaneous heating and cooling at different zones, the system can take advantage of heat recovery should various spaces have different loads and conditioning needs, without the direct use of the compressor to heat and cool.

[3] See: https://en.wikipedia.org/wiki/Dedicated_outdoor_air_system
[4] See: https://en.wikipedia.org/wiki/Heat_recovery_ventilation
[5] See: https://en.wikipedia.org/wiki/Variable_refrigerant_flow

(Below) Diagram of the main components of the heating, ventilating and cooling system.



(Opposite Page, Top) Daylit classroom on the new third floor addition.
(Opposite Page, Bottom) Student work and display areas (right) and administrative offices (left).

Domestic Hot Water Systems

The *Domestic Hot Water (DHW)* system for the building is a simple tank-style electric resistance water heater. The use is mainly in the restrooms and cost considerations for such a low-use application made this a practical choice.

Daylighting and Lighting Systems / Control Systems

The building benefits from a large amount of daylighting via the curtainwall facades. In addition, the inclusion of the breakout areas allows daylight penetration to the circulation spaces and reduction of enclosed corridor space. Glass panes are installed above interior doors to allow this daylight to contribute to the enclosed room spaces, providing daylight from both sides.

Efficient light fixtures and light sources were specified, controlled by occupancy sensors and daylight sensors within spaces.

(Below) Daylighting in a breakout area, with The Center for Civic Engagement visible beyond, with its folding glass wall open.


PHOTO: MICHAEL DAVID ROSE

PHOTOS: MICHAEL DAVID ROSE

(Opposite Page) View of Lick-Wilmerding High School campus from the east, with the completed project buildings and their rooftop solar PV systems in the foreground. (Photo: EHDD Architecture)

Renewable On-Site Energy Supply

Solar Photovoltaic System

The school was committed to a zero-net-energy design, which required a sufficiently large solar PV system to offset the calculated loads. The Board of Trustees opted for the installation and maintenance of this system through a *Power Purchase Agreement (PPA)*[6] with a private company, Solar Technologies.[7] The company designed the system using the energy model calculations of the design team and weather data for standard year at this site location. This design required 468 Sunpower panels,[8] for a total rating at full power of 168.5 kW.

The system was installed when the building construction was completed and required the roofs of the project buildings plus the roof of the adjacent gymnasium building. (See photo below.) More than half the solar panels are installed on the gymnasium building and are required to achieve the ZNE performance goal.

A battery storage system was considered to use more of the on-site energy produced, but the system would have required a large dedicated room. Given the spatial constraints of the site, such a room could not be fit into the building without compromising the building program. It also would have been a significant added expense.

(Below) Installed solar PV panels on the roofs of the project buildings (top) and the adjacent gymnasium (left). (Google Earth - 1995)

[6] See: https://www.epa.gov/green-power-markets/solar-power-purchase-agreements
[7] https://solartechnologies.com/?utm_campaign=gmb
[8] Sunpower X22-360-COM panels (360 watts each)

Design Analysis: Optimizing Zero-Carbon Design

Design Analysis: Embodied Carbon

An embodied carbon analysis was not done during the design phase of the project (2018-2019) primarily because the importance of this issue was only just being understood by design professionals, the general database necessary to perform analyses was being assembled and the software analysis tools were being developed.

In fact, EHDD Architecture was in the process of developing its own embodied carbon software tool known as *EPIC (Early-Phase Integrated Carbon Assessment Tool),*[9,10] which later evolved into the commercially available software product called *C-Scale.*[11] The design team consequently applied its collective knowledge and available tools to make informed design choices pertaining to minimizing embodied carbon in the project. Re-use of the existing façade and part of the structure proved to be a major contributor to the reduction achieved.

Years later, the *EPIC* tool was used to evaluate the Lick-Wilmerding High School project for its embodied carbon content at the date of occupancy. This yielded the number 464 $kgCO_2eq/m^2$ as a measurement of the building's embodied carbon content.[12]

Design Analysis: Energy Modeling and Operational Carbon

The new and remodeled buildings within the project boundary were analyzed during the design construction documents phases using a variety of software techniques. The modeled energy use for the 50,488 sq. ft. of project area by category of use over the course of a year is given in the charts on the opposite page.

The results of the modeling show that the project buildings would consume a total of 318 MWh annually (upper chart) with an EUI = 21.5 kBtu/sq.ft. per year. Because of the relatively mild climate and the good daylighting design, the predominant energy demand was predicted to be from the plug load. The lower chart on the opposite page shows the monthly breakdown of the modeled energy use.

The energy modeling assumed low occupancy of the classroom buildings during the summer months, causing the lower energy totals for the months of July and August in the monthly modeled energy chart. (In recent years, this has not been the case, with the buildings maintaining a consistent occupancy throughout the year.)

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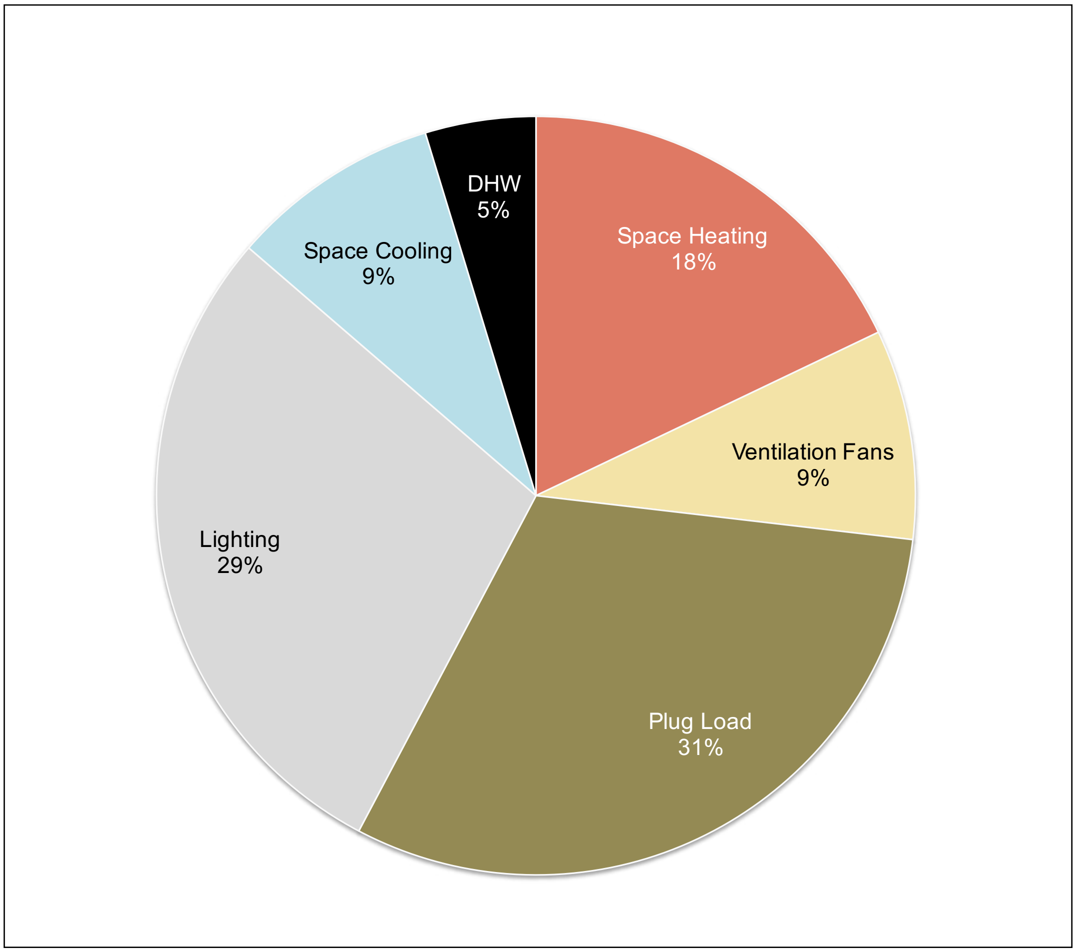
[9] See: https://ehdd.com/philosophy/epic/.

[10] For general introduction and how to use various embodied carbon software tools (EPIC, tallyLCA, EC3), see https://www.youtube.com/watch?v=CzsMeFRfOpQ

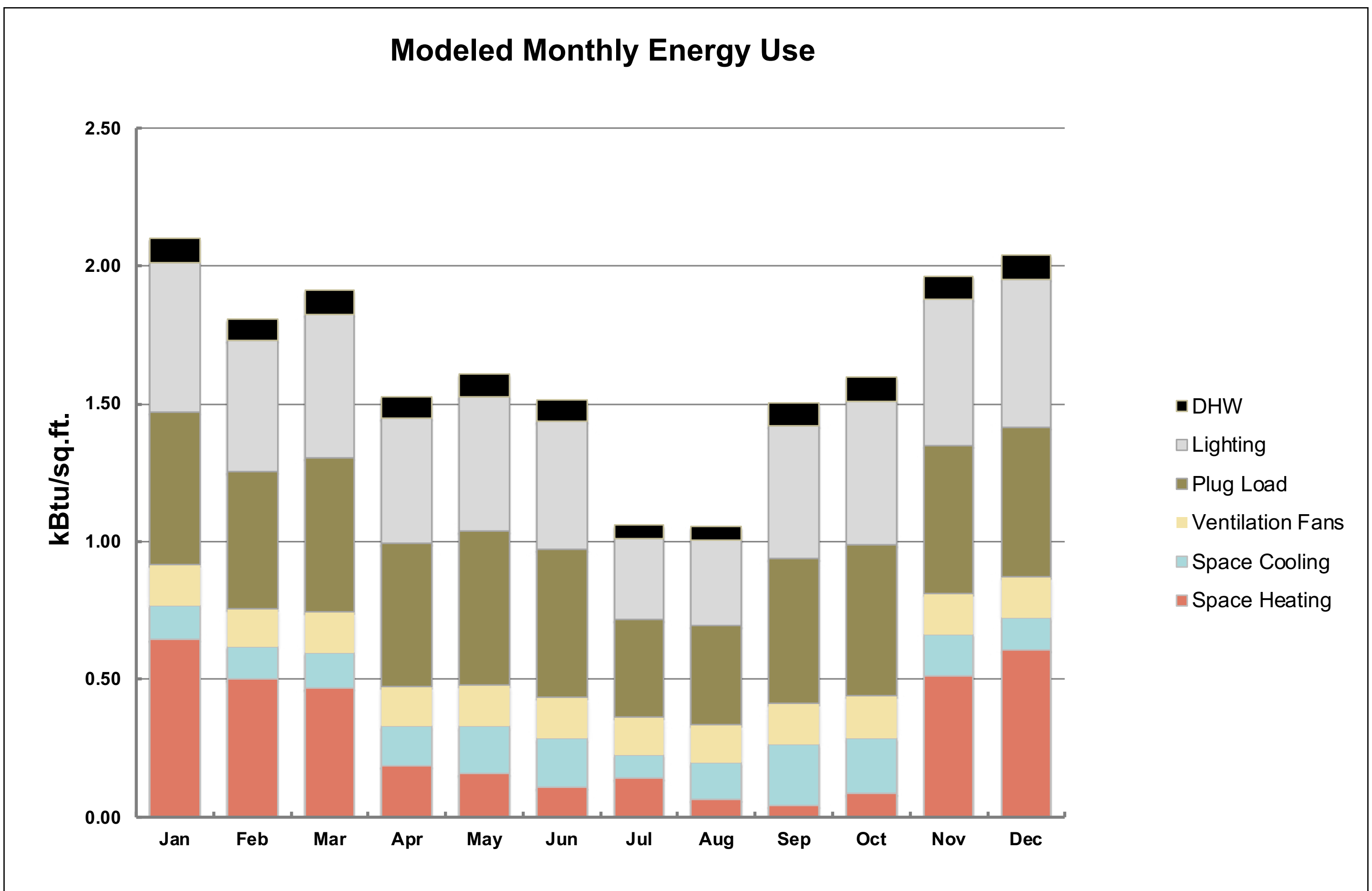
[11] See: https://docs.cscale.io/

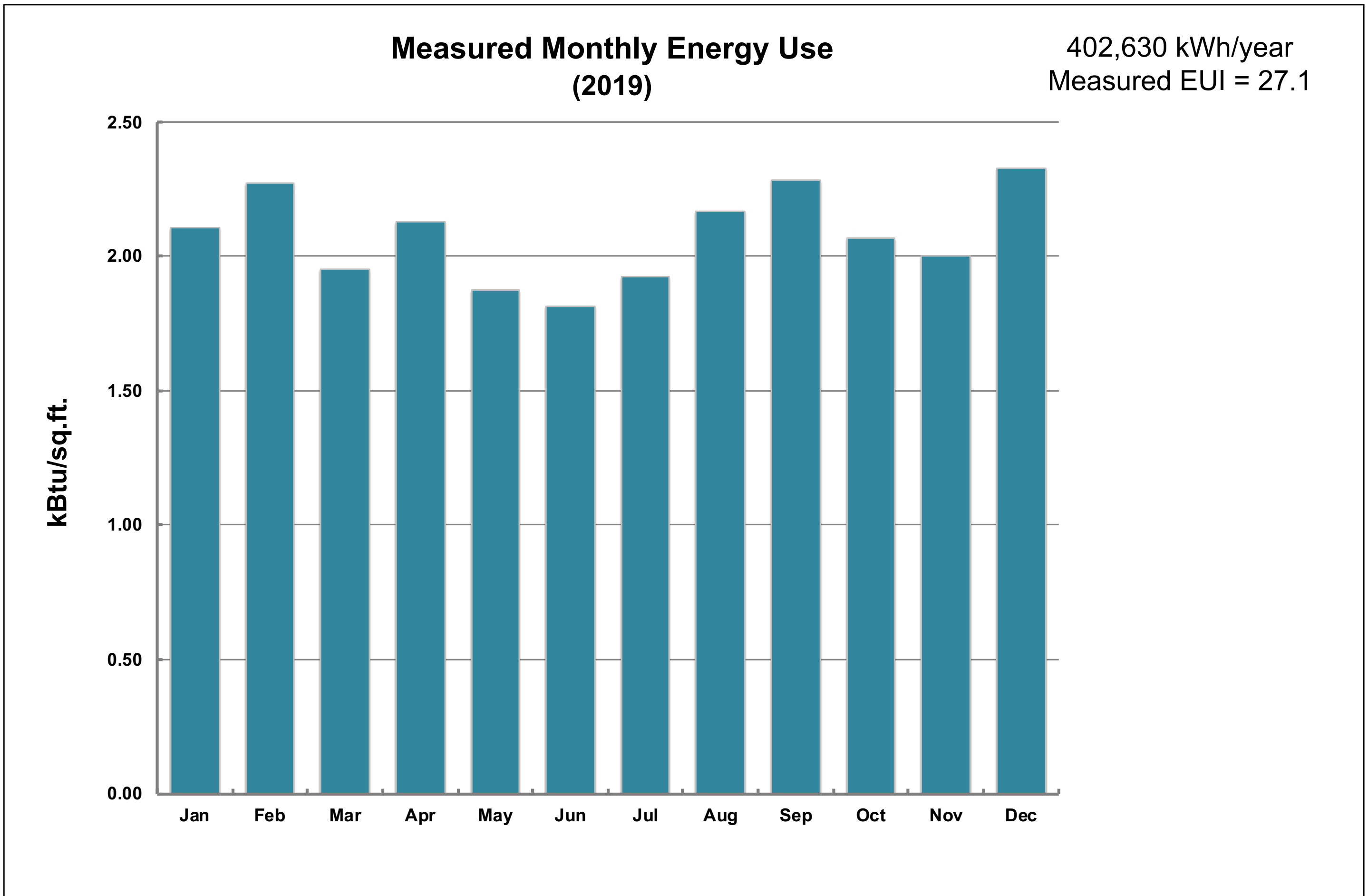
[12] For an introductory discussion of the units of embodied carbon, software tools and the integration of embodied carbon assessment into the design process, see *Designing for Zero Carbon, Volume 2*, p.110. https://calbem.ibpsa.us/resources/case-study-books/

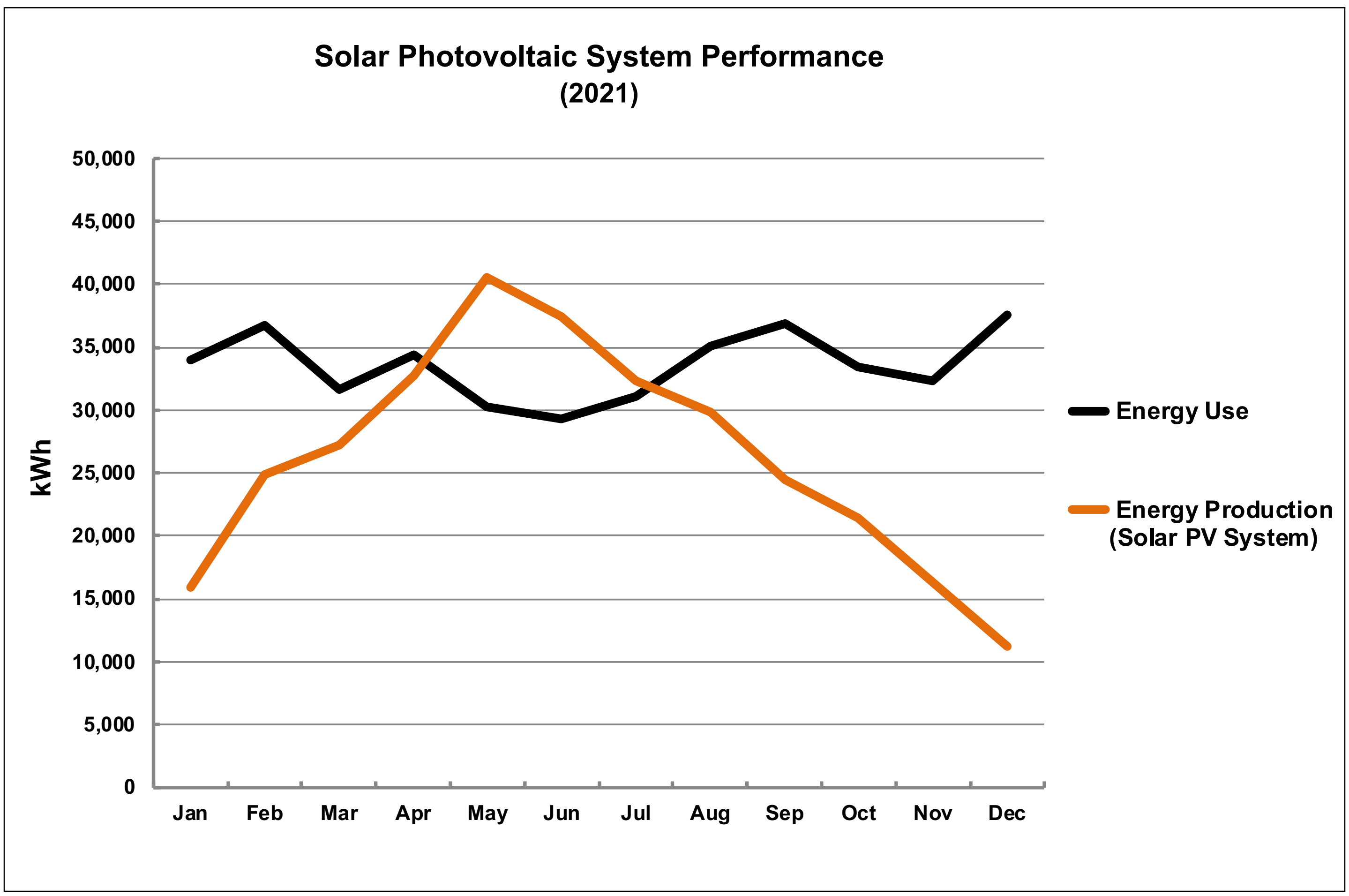


Modeled Energy Use (Annual)

317,980 kWh/year
Modeled EUI = 21.5




Measured Monthly Energy Use
(2019)
402,630 kWh/year
Measured EUI = 27.1
kBtu/sq.ft.
2.50
2.00
1.50
1.00
0.50
0.00
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec


Solar Photovoltaic System Performance
(2021)
kWh
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
0
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Energy Use
Energy Production
(Solar PV System)

Energy Performance and Operational Carbon: Post-Occupancy Measurement

Energy Use — Post-Occupancy Measurement

The public utility meter records the net electric energy drawn from the grid for the entire campus and would not provide the energy use data for only the buildings within the project boundary. However, a special energy meter, called an *eGauge meter,*[13] was installed in order to monitor the energy use of only the project buildings, without accounting for the electricity generated by the on-site solar PV system. The intent was to collect detailed energy use data during a post-occupancy period for commissioning purposes and to assist the client in understanding the optimal operation of systems and controls.

The monthly energy use as measured by the *eGauge* meter for the first year of occupancy (2019) is shown in the chart on the opposite page (top).

Comparison with Energy Modeling

The measured energy use for this first year of occupancy was about 25% higher than the modeled total. This was partly due to some mechanical system issues that were eventually resolved through the commissioning process. In addition, the building experienced higher use than anticipated, especially during the summer months.

Energy Production versus Energy Use

The installed solar PV system produces each year close to the amount of electric energy calculated as necessary to equal the energy used by the project buildings, thereby achieving the goal of ZNE performance. The actual energy used has been slightly higher than modeled for the first few years of occupancy for several reasons, as noted above.

A comparison of the energy produced by the solar PV system to the energy use for the typical school year 2021 is shown on the chart on the opposite page (bottom). The energy produced by the solar PV system in 2021 was 314,575 kWh, which compares well with the modeled energy use total of 317,980 kWh. Actual energy use for these project buildings as measured by the *eGauge* meter, however, is consistently reaching 400,000 kWh.

Post-Occupancy: Observations and Conclusions

The all-electric design objective (i.e., design for zero-carbon operation) was demonstrated to be practical, effective and feasible for this renovation and expansion project. While energy-efficient design of the building envelope, daylighting and natural ventilation is still necessary with its well-understood features and methodologies, the design of electric systems that replace fossil fuel-based systems presents new challenges and opportunities for K-12 school clients and designers.

The design team for this project mentioned some “lessons learned” as they considered the built result and the process that led to it. Principal among these was to design in flexible spaces so that different uses can be accommodated at different times throughout the day or school year. This makes the space not only more optimally used but also more active with student activities.

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[13] An eGauge is a type of energy meter that is also a data logger and web server, designed for detailed monitoring of electrical consumption. It allows users to track energy usage down to the individual circuit level, providing valuable insights into energy consumption patterns and potential savings. See: https://www.egauge.net/.

Additional Noteworthy Projects ▷

Additional Case Study Projects: All-Electric K-12 School Buildings

The case studies detailed in the preceding section are a group of all-electric K-12 school projects with characteristics of energy efficiency and low-carbon effect as documented by operational data and analysis. These case study projects were selected for this publication from a list of similar projects in California. It is worth noting these other projects throughout the state that are exemplary in their design and demonstrate the widespread application of this design approach.

The projects shown on the following pages are other exemplary K-12 school projects that have been recently completed or under construction, both new and renovated structures, that were designed with all-electric energy systems. These additional projects have a particularly unique aspect of their program, building structure or financial constraints that make them especially noteworthy. They are shown in a one-page summary for each, so the reader can seek further information, if desired.

Case Study Projects:
1. Ocean View Elementary School, Albany
2. Blue Oak Middle School, Napa
3. Garfield Elementary School, San Francisco
4. Food Literacy Center at Floyd Farm, West Sacramento
5. Lick-Wilmerding High School, San Francisco

Additional Case Study Projects:
(See the following pages in this section)
6. Ormondale Elementary School, Portola Valley
7. Marin Elementary School, Albany
8. Lynnhaven Elementary School, San Jose
9. Corte Madera Middle School, Portola Valley
10. Bishop O'Dowd High School Environmental Science Center
11. Nueva School Science and Environmental Center, Hillsborough
12. Sacred Heart Arts and Academic Center, Atherton

Ormondale Elementary School, Portola Valley

Public or Private: Public School
*Grades***:** K-3
Gross Floor Area: 8,891 GSF
Fully Occupied: 2023

Heating / Cooling System: Electric heat pump split system with VRF and heat recovery
DHW System: Electric water heater

Project Team

Client:
Portola Valley USD

Architect:
CAW Architects,
Palo Alto, CA

M/P Engineer:
Capital Engineering,
Rancho Cordova, CA

General Contractor:
Beals Martin, Inc.,
Redwood City, CA

Solar Contractor:
Solar Technologies,
San Ramon, CA

Modeled EUI (Site)
19.8 kBtu/sf-year

Modeled Annual Energy Use:
40,478 kWh

Measured EUI (Site)
Not Available

On-Site Renewable Energy System Installed
42.5 kW(DC) Solar PV

Measured On-Site Renewable Energy Production
Not Available

Marin Elementary School, Albany

Public or Private: Public School
Grades: K - 5
Gross Floor Area: 53,366 GSF (New: 24,148 GSF - Renovation: 29,218 GSF)
Fully Occupied: 2023 year

Heating / Cooling System: Electric Heat Pump with VRF system
DHW System: Heat Pump Water Heater

Project Team

Client:
Albany USD

Architect:
LCA Architects,
Oakland, CA

Mechanical Engineer:
Bay City Mechanical,
Richmond, CA

General Contractor:
Alten Construction,
Richmond, CA
(Design-Build)

Solar Contractor:
Northern Electric Inc.,
Santa Rosa, CA

Modeled EUI
(New Buildings Only)
23.9 kBtu/sf-year

Modeled Energy Use:
(New Buildings Only)
162,239 kWh/year

Measured EUI (Site)
Not Available

On-Site Renewable Energy System Installed
Designed but not Installed

Lynhaven Elementary School Administration and Mullti-Use Building, San Jose

Public or Private: Public Charter School
Grades: K - 5
Gross Floor Area: 13,515 GSF
Fully Occupied: 2023

Heating / Cooling System: Electric Heat Pump - Split-System VRF for Administration Building and Rooftop Package Units for Multi-Use Building
DHW System: Heat Pump Water Heater

Project Team

Client:
Campbell Union School District

Architect:
Aedis Architects

Mechanical Engineer:
Capital Engineering Consultants

General Contractor:
Gonsalves & Stronck, San Carlos, CA

Solar Contractor:
None

Modeled EUI (Site)
19.2 kBtu/sf-year

Modeled Annual Energy Use:
81,718 kWh

Measured EUI (Site)
Not available for separate buildings

On-Site Renewable Energy System Installed
None. Existing solar PV system was sufficient

Measured On-Site Renewable Energy Production
Not available for separate buildings

Corte Madera Middle School, Portola Valley

Public or Private: Public School
Grades: 6th - 8th
Gross Floor Area: 20,545 GSF
Fully Occupied: 2023

Heating / Cooling System: Electric heat pump split system with VRF and heat recovery
DHW System: Electric water heater

Project Team

Client:
Portola Valley USD

Architect:
CAW Architects,
Palo Alto, CA

M/P Engineer:
Capital Engineering,
Rancho Cordova, CA

General Contractor:
Beals Martin, Inc.,
Redwood City, CA

Solar Contractor:
Solar Technologies,
San Ramon, CA

Modeled EUI (Site)
22.1 kBtu/sf-year

Modeled Annual Energy Use:
91,425 kWh

Measured EUI (Site)
Not Available

On-Site Renewable Energy System Installed
46.0 kW(DC) Solar PV

Measured On-Site Renewable Energy Production
Not Available

Bishop O'Dowd High School Environmental Science Center, Oakland

Public or Private: Private School
Grades: 9-12
Gross Floor Area: 3,700 GSF
Fully Occupied: 2014

Heating / Cooling System: Electric heat pump
DHW System: Heat Pump water heater

Project Team

Client:
Bishop O'Dowd High School

Architect:
Siegel & Strain Architects, Emeryville, CA

MEP Engineer:
Integral Group (now Introba), Oakland, CA

General Contractor:
Pankow, Oakland, CA

Solar Contractor:
Save a Lot Solar, Oakland, CA

Modeled EUI (Site)
10.1 kBtu/sf-year

Modeled Annual Energy Use:
17,000 kWh

Measured EUI (Site)
10.9 kBtu/sf-year

On-Site Renewable Energy System Installed
11.5 kW(DC) Solar PV

Measured On-Site Renewable Energy Production
17,000 kWh/year

Nueva School Science and Environmental Center, Hillsborough

Public or Private: Private School
Grades: K - 8
Gross Floor Area: 11,600 GSF
Fully Occupied: 2021

Heating / Cooling System: Electric Heat Pump
DHW System: Heat Pump Water Heater

Project Team

Client:
Nueva School

Architect:
Leddy Maytum Stacy Architects, SF, CA

MEP Engineer (Energy Modeling):
Point Energy Innovations, SF, CA

General Contractor:
W.L. Butler, Redwood City, CA

Solar Contractor:
Cupertino Electric, Cupertino, CA

Modeled EUI (Site)
27.3 kBtu/sf-year

Modeled Annual Energy Use:
118,873 kWh

Measured EUI (Site)
34.9 kBtu/sf-year

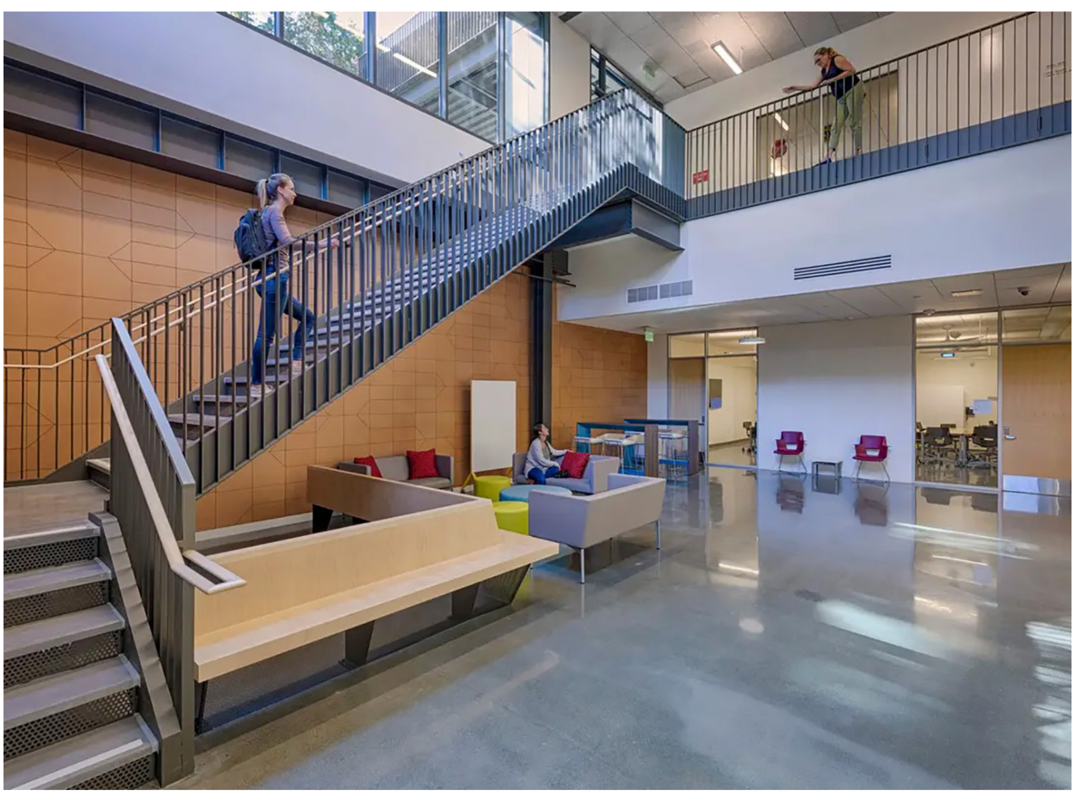
On-Site Renewable Energy System Installed
100 kW(DC) Solar PV

Measured On-Site Renewable Energy Production
1402,276 kWh/year

Sacred Heart Arts and Academic Center, Atherton

Public or Private: Private School
*Grades***:** 9 - 12
Gross Floor Area: 79,000 GSF
Fully Occupied: 2019

Heating / Cooling System: Electric Heat Pump
DHW System: Heat Pump Water Heater



Project Team

Client:
Sacred Heart Schools

Architect:
WRNS Studio, SF, CA

Mechanical Engineer:
Interface Engineerig, Oakland, CA

General Contractor:
XL Construction, Milpitas, CA

Solar Contractor:
InterMountain (Energy Solutions Division), San Carlos, CA

Modeled EUI (Site)
20 kBtu/sf-year

Modeled Annual Energy Use:
453,460 kWh

Measured EUI (Site)
Not Available

On-Site Renewable Energy System Installed
364 kW(DC) Solar PV

Measured On-Site Renewable Energy Production
509,600 kWh/year

Los Angeles USD: Planning for the Zero-Carbon Future

Los Angeles Unified School District (LAUSD) is the largest public school system in California and second-largest in the United States. (Only the New York City public school system has a larger student population.) LAUSD serves over 600,000 students in the K-12 grades, occupying more than 1,300 schools on sites around the entire city of Los Angeles and several adjoining cities. (See map on opposite page.)

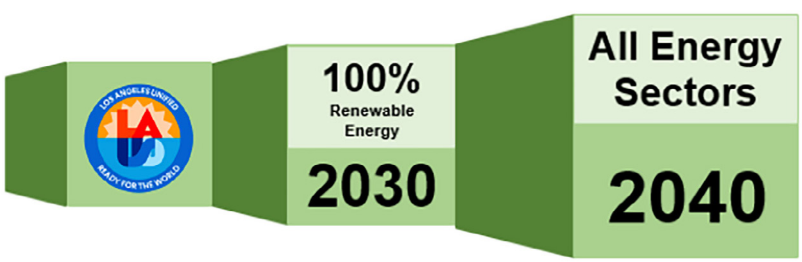
In 2019, the LAUSD Board of Education adopted the Clean Energy Board Resolution, which committed the district to transition to zero-carbon emissions for all of its energy systems by 2040. The resolution also set the intermediate goal of zero-carbon emissions for its electrical systems by 2030. The latter was originally planned to be achieved by having all electricity supplied by renewable energy systems, including on-site solar PV systems. This goal is actually more aggressive than that set by the State of California's 2018 Senate Bill 100 (SB 100), which mandated 2045 for having the entire state electric power grid supplied by zero-carbon resources.

The larger overall goal for LAUSD (zero-carbon emissions for all of its energy systems by 2040) would be realized through the gradual replacement of all gas-fired and propane systems at all of its facilities by the year 2040. Given that the California electric power grid is planned to have zero-carbon emissions just five years after the LAUSD target date to eliminate all fossil-fuels from school facilities, converting school energy systems to all-electric systems will now take priority over installing new solar PV systems.

The focus of modernization projects is now on electrification, prioritizing energy efficiency as a first step. The designs will also install on-site renewables where feasible and use grid interaction technologies to shave peak demand and minmize cost. Pilot studies have been completed in the past five years, with the development of plans for the renovation of some schools intended to accomplish these goals. Three of these pilot projects are highlighted in this special section as an illustration of the type of work being done and the special challenges that can sometimes arise.

The first illustrative project is Lemay Street Elementary School in Van Nuys a single-story "finger-plan" school built in the 1950s. The second pilot project is Maclay Middle School, a similar type of design built in 1958. The third project is the significantly larger facility, Van Nuys High School, a campus of buildings originally built in 1933 and with a correspondingly more complex renovation program for full decarbonization of its required energy systems. (See the map on the opposite page, which shows the location of these three pilot projects.)

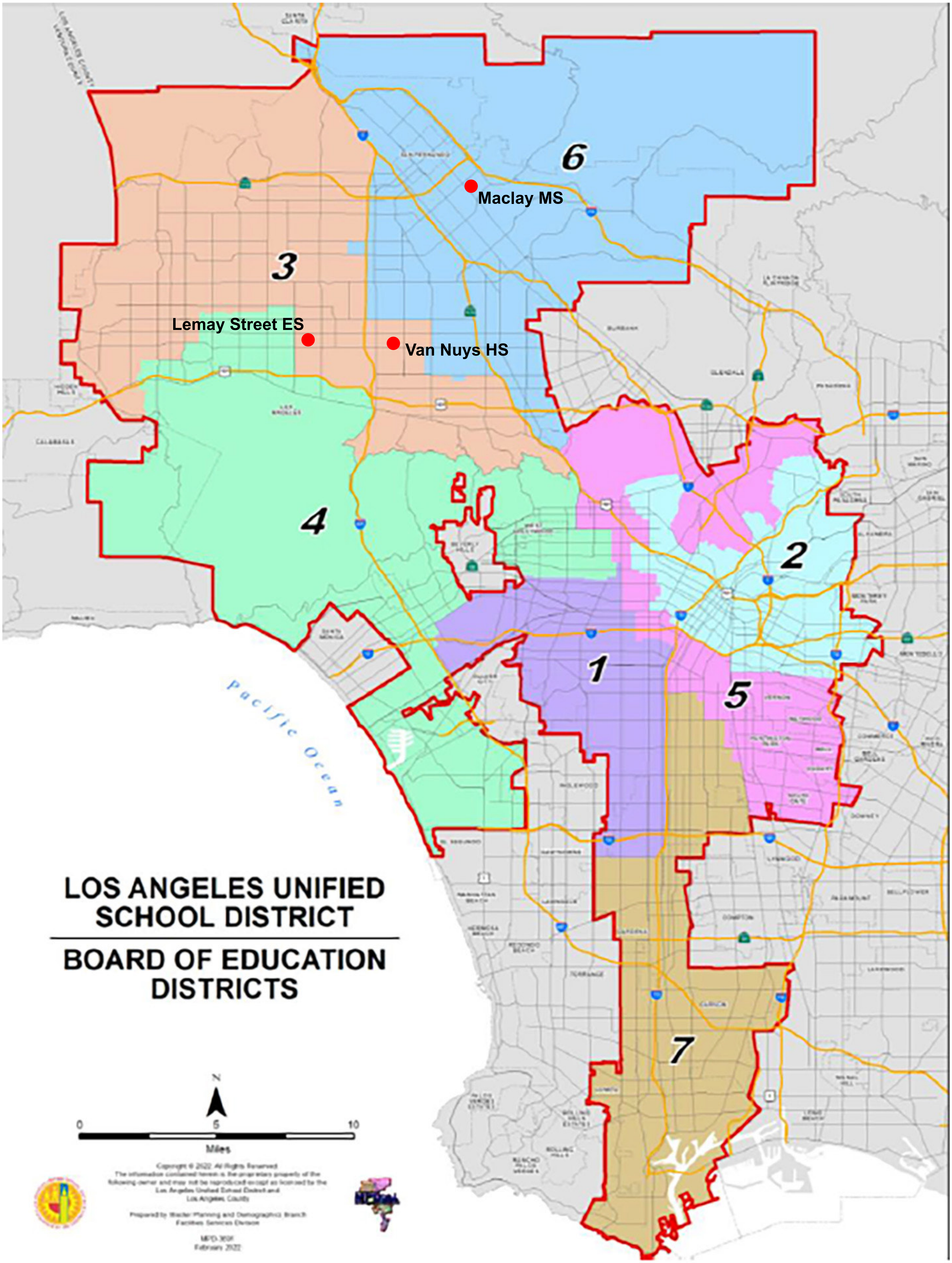
The following pages summarize the electrification scope of work at these three pilot projects.



(Right) Representatiion of the timeline of the 2019 goals of the *LAUSD Clean Energy Board Resolution*. With the passage of California's SB100, mandating a zero-carbon electric utility grid in 2045, the 2030 target of 100% renewable energy has been de-prioritized in favor of electrification.

GHG Emissions in Metric Tons of Carbon Dioxide Equivalent

	2014 Baseline	2024 Target	2030 Target	2040 Target
Electricity	387,135	309,708	0	0
Natural Gas	28,405	22,724	22,724	0
Total	415,540	332,432	22,724	0


LOS ANGELES UNIFIED
SCHOOL DISTRICT
BOARD OF EDUCATION
DISTRICTS
6
Maclay MS
3
Lemay Street ES
Van Nuys HS
4
2
1
5
7
Pacific Ocean
N
0
5
10
Miles

Lemay Street Elementary School, Van Nuys

Los Angeles Unified School District
Grades: Kindergarten - 5th Grade
Gross Floor Area: 38,013 GSF
Date of Construction: 1950-1957
Building types: One-story wood-frame

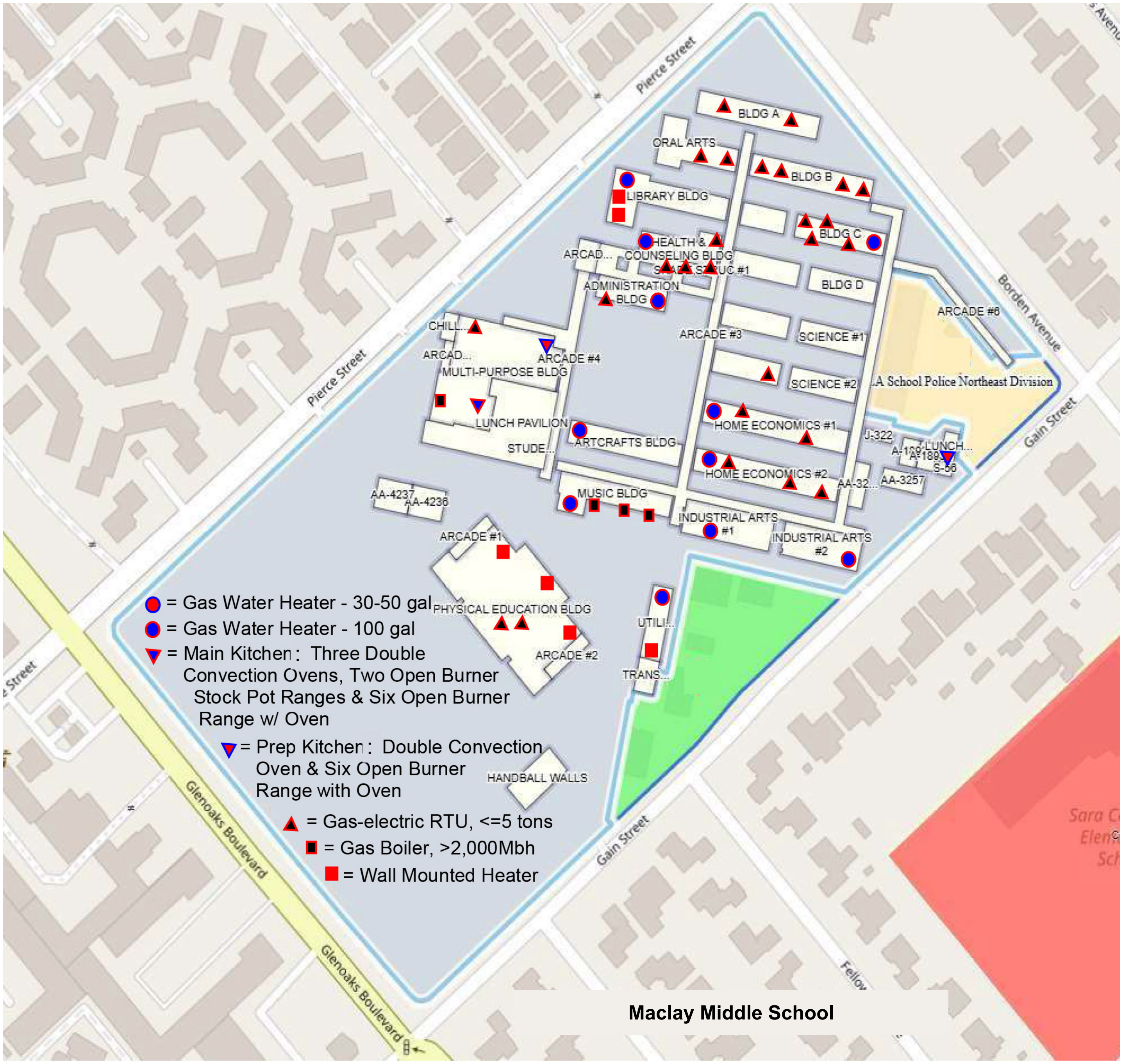
ELECTRIFICATION SCOPE	LEMAY STREET ELEMENTARY SCHOOL
Upgrade and optimize Energy Management System	New EMS + Commissioning
HVAC electrification	Replace 6 gas-electric RTU's and 1 wall heater with 7 roof-top heat pumps < 5 tons
Food service kitchen equipment electrification	Bring additional electrical capacity to building; install 1 combination oven, 1 double convection oven and 2-burner induction cook-top
Water heater electrification	(2) 30 gal water heaters and (1) 100 gal water heater

SITE PLAN - LOCATION OF NATURAL GAS EQUIPMENT

Maclay Middle School, Pacoima

Los Angeles Unified School District
Grades: 6th - 8th Grades
Gross Floor Area: 169,346 GSF
Date of Construction: 1958
Building types: One-story wood-frame

ELECTRIFICATION SCOPE	MACLAY MIDDLE SCHOOL
Upgrade and optimize Energy Management System	Optimize EMS
HVAC electrification	Replace 1 multi-zone package rooftop unit, 2 suspended heaters, 3 wall-mounted heaters and 60 gas-electric RTU s with single-zone package heat pumps; replace 4 chiller/boiler systems and 4 radiators with single-zone package heat pump systems for classrooms and VRF systems for offices
Food service kitchen equipment electrification	Bring additional electrical capacity to building; install 1 combination oven, 1 double convection oven and 2-burner induction cook-top
Water heater electrification	(3) 100 gal water heaters; (1) 50 gal water heaters; (2) 40 gal water heaters; (7) 30 gal water heaters

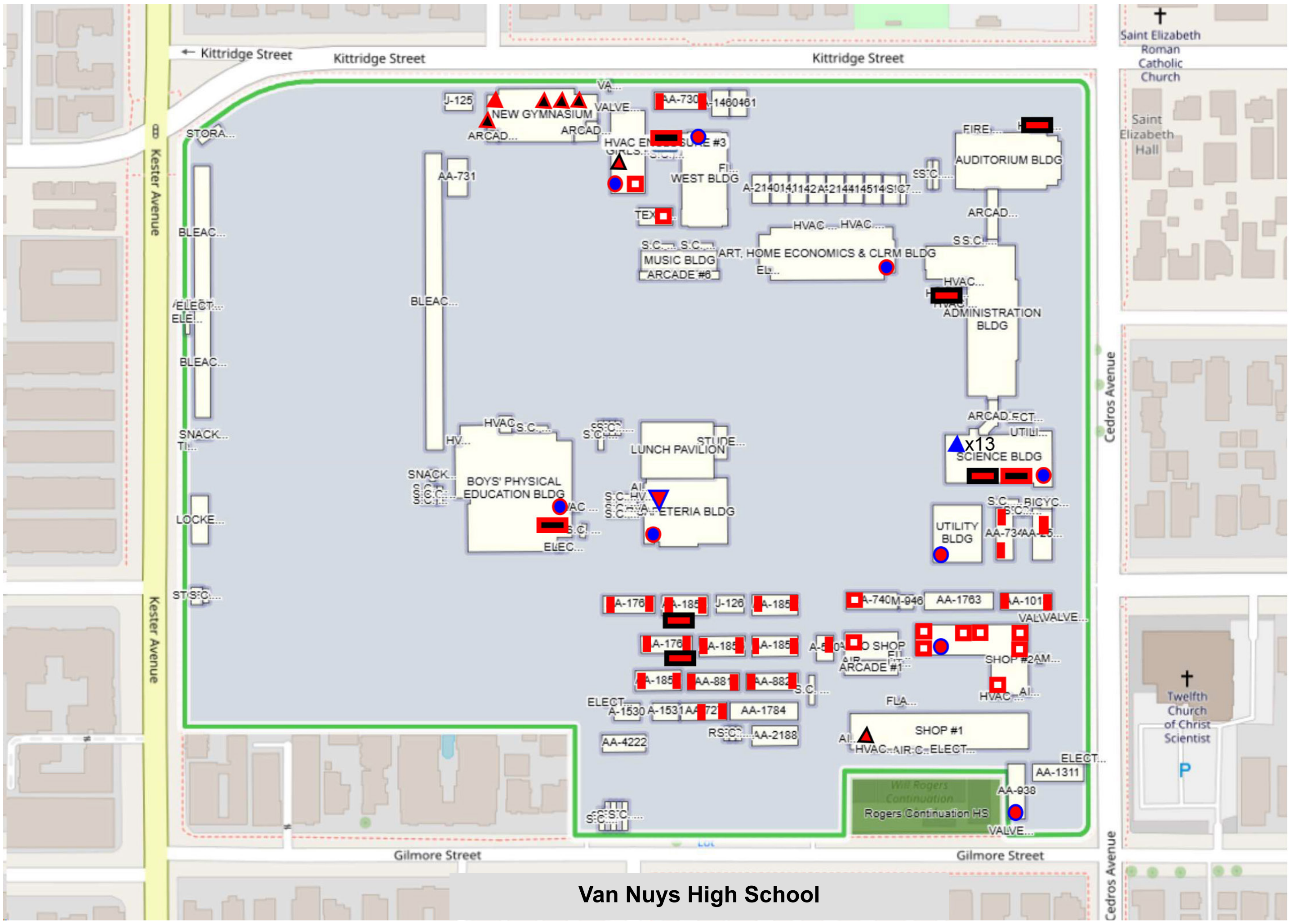


SITE PLAN - LOCATION OF NATURAL GAS EQUIPMENT

Van Nuys High School, Van Nuys

Los Angeles Unified School District
*Grades***:** 9th - 12th Grades
Gross Floor Area: 266,472 GSF
Date of Construction: 1933-1966
Building types: One-story and two-story wood frame and reinforced concrete

ELECTRIFICATION SCOPE	VAN NUYS HIGH SCHOOL
Upgrade and optimize Energy Management System	Replace EMS + Commissioning
HVAC electrification	Replace 11 forced air furnaces, 28 wall-mounted heaters and 7 gas-electric RTU s with single-zone package heat pumps; replace 6 chiller/boiler systems with single-zone package heat pump systems for classrooms and VRF systems for offices
Food service kitchen equipment electrification	Bring additional electrical capacity to building; install 2 new combination ovens, 1 double convection oven, 2-burner induction cook-top and 1 tilt skillet
Water heater electrification	(5) 100 gal water heaters; (2) 30 gal water heaters; (2) 40 gal water heaters



= Kitchen : Three Double Convection Ovens and Six Open Burner Range with Oven

= Gas Water Heater - 30-40 Gallon

= Gas Water Heater - 100 Gallon

= Package Rooftop Unit A/C, Gas-Electric, <=5 tons

= Package Rooftop Unit A/C, Gas-Electric, 6-7 tons

= Package Rooftop Unit A/C, Gas-Electric, 11-15 tons

= Forced Air Heater/Furnace

= Wall Mounted Heater

= Gas Boiler, 1,000 - 2,000 Mbh

= Gas Boiler, >2,000 Mbh

= Gas Jet Lab Stations (will not be replaced)

SITE PLAN - LOCATION OF NATURAL GAS EQUIPMENT

A Peek at the Future: The AIACA 2024 Architecture at Zero Competition

The *Architecture at Zero* architectural design competition was initiated in 2011 in response to the California Public Utilities Commission (CPUC), which had issued a strategic plan for all new buildings in the state to be ZNE by 2030. To assist designers and builders in achieving this goal, this design competition would elicit practical methods and solutions from design teams that demonstrated ZNE performance by focusing each year of the competition on one building-type in a specific location in California. Over the 13 years of this competition event since 2011, the program has included new buildings and renovations, housing, mixed-use and public service buildings.

In 2024, the most recent *Architecture at Zero* competition, the competition subject was a new building for a middle school in the Los Angeles Unified School District (LAUSD). While the competition brief explains that the project uses a real location at an existing school site as a basis for the design competition, the project itself is not currently being planned by the district. It is simply an "ideas" competition, intended to elicit new and creative solutions to traditional design issues for this building type that are both zero-energy and (emphasized in 2024) "decarbonized". In fact, the 2024 competition brief specifically states, "in addition to energy effiiency and renewable generation, designers must design all-electric buildings."

As such, the 2024 competition provided the opportunity for design teams to display innovative approaches that satisfy practical building requirements while delivering optimum energy performance and zero-carbon operation. The competition designs provide an interesting comparison with the already-built all-electric designs of the case studies discussed in detail earlier in this book.

2024 Architecture at Zero Competition – Site and Program

The site for the competition design is in East Los Angeles at the campus of the Griffith Middle School (6th – 8th grades), which is currently housed in temporary portable buildings. (See site plans on opposite page. The competition design is to be located on the portion of the site outlined with a red dashed line.)

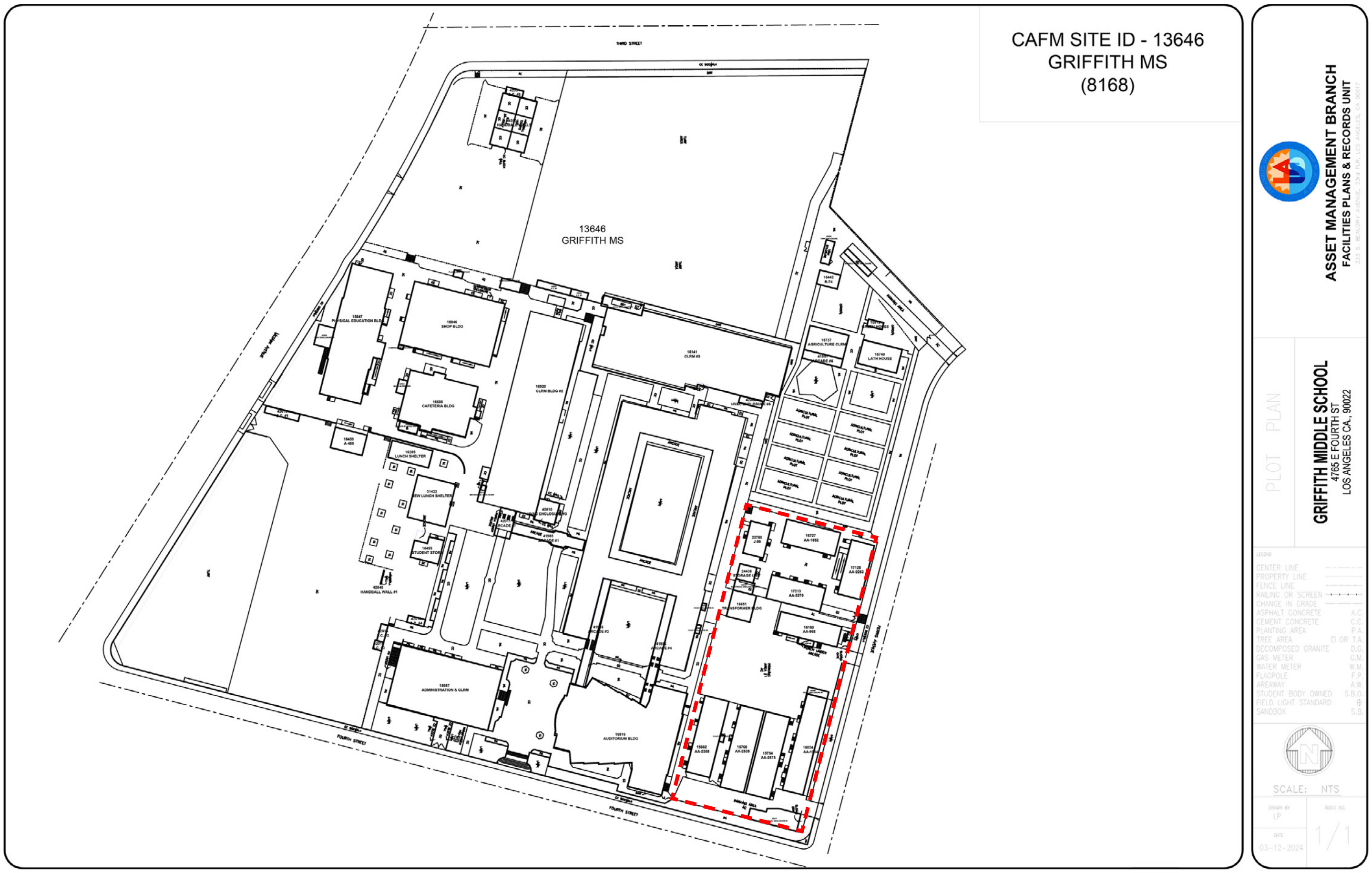
The architectural program for this new facility includes science laboratories, classrooms and "maker space" for education in technology and engineering:

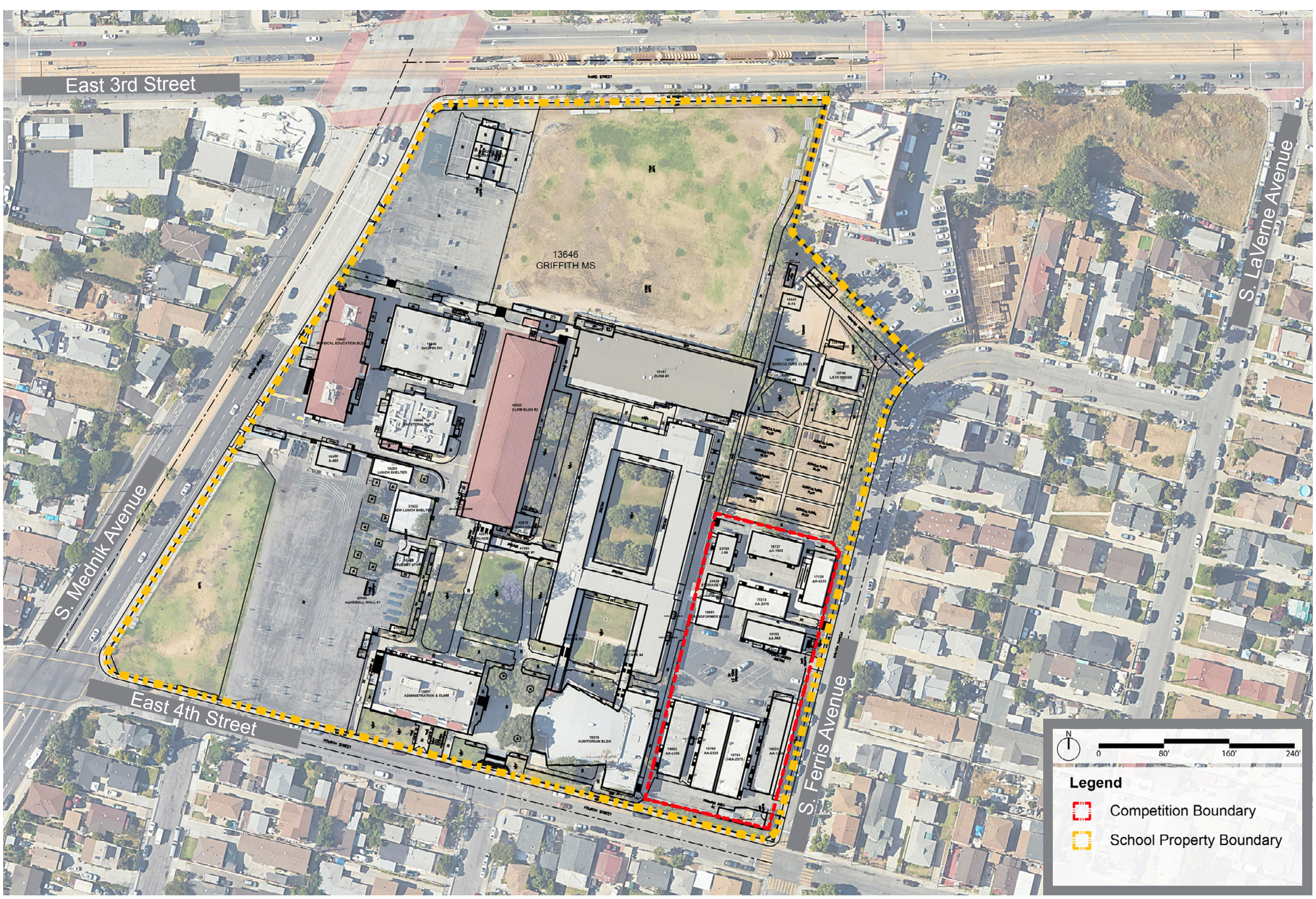
Design must be a two-story building, 12,430 sq. ft. per floor, accommodating the following:

Any floor:		Each floor:	
10 classrooms	10,000 sf	5 restrooms	800 sf
4 science labs	5,200 sf	1 teachers' workroom and storage	750 sf
2 lab workrooms	760 sf	1 collaborationn space	360 sf
1 art class/workroom	1,680 sf		
First floor only:		Adjacent exterior space:	
1 maker space and storage	1,920 sf	1 outdoor maker space	1,000 sf
Battery space	240 sf	1 outdoor classroom	1,000 sf
PV inverter room	120 sf	Staff bicycle storage	100 sf
Mech, elec., storage room	500 sf	20 parking spaces	

2024 Architecture at Zero Competition – Winning Designs

Highlights of the top three winning designs in the *Professional* category, announced in January 2025, are shown in the following pages of this section. For the complete submittals of all categories of the winning entries, see https://www.architectureatzero.com/2024-recipients.


CAFM SITE ID - 13646
GRIFFITH MS
(8168)
13646
GRIFFITH MS
ASSET MANAGEMENT BRANCH
FACILITIES PLANS & RECORDS UNIT
PLOT PLAN
GRIFFITH MIDDLE SCHOOL
4765 E FOURTH ST
LOS ANGELES CA, 90022
SCALE: NTS
1/1


East 3rd Street
13646
GRIFFITH MS
S. LaVerne Avenue
S. Mednik Avenue
East 4th Street
S. Ferris Avenue
N
0
80'
160'
240'
Legend
Competition Boundary
School Property Boundary

AIACA 2024 ARCHITECTURE AT ZERO COMPETITION

HONOR AWARD
Professional Category
(Highest Level of Recogniton)

Title of Design: Agualta STEAM Engine
Designer: *Design Draw Build Inc*, Oakland, CA

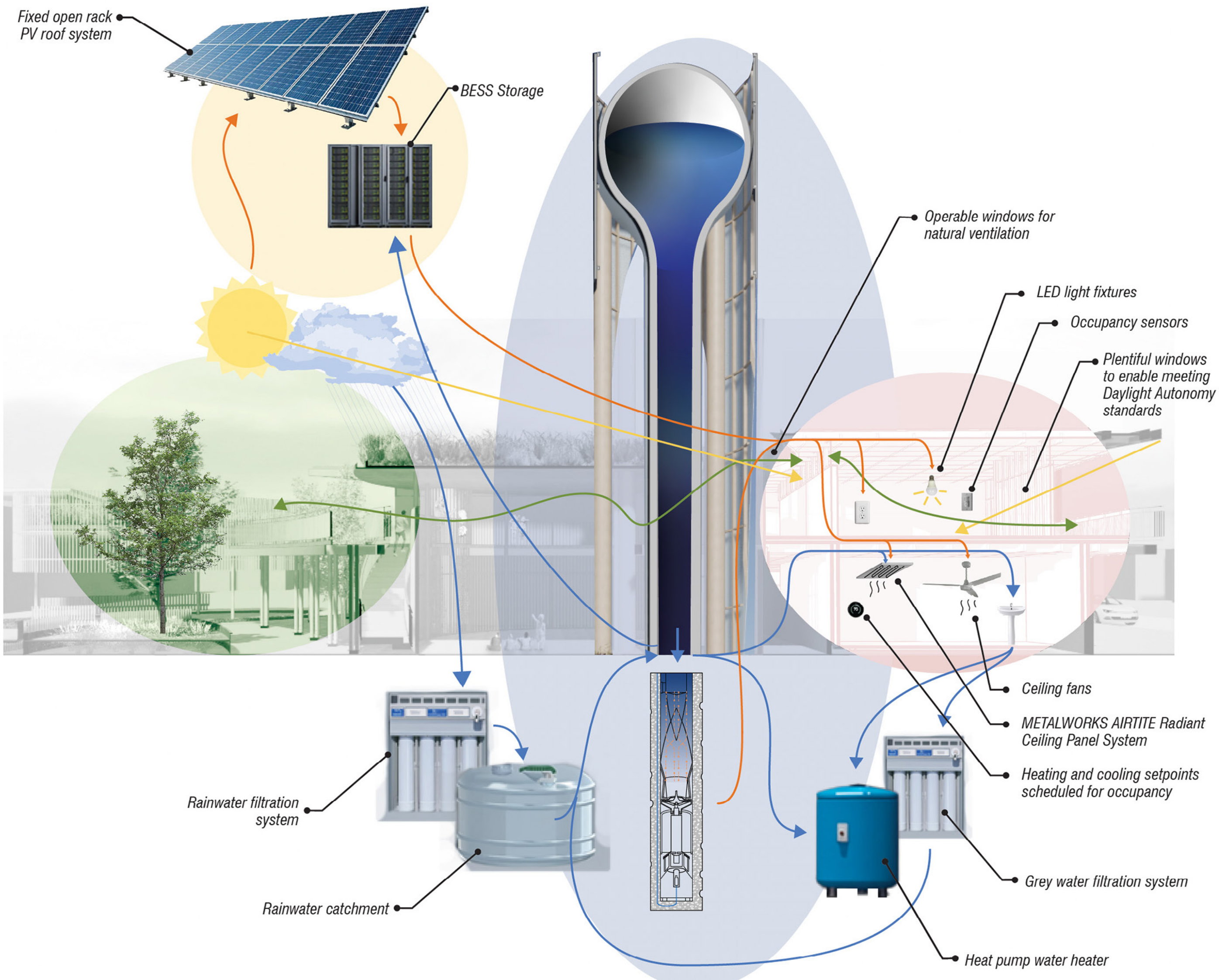
Agualta STEAM Engine

Design Draw Build Inc

Modeled EUI (Site)
24.9 kBtu/sf-year

Modeled Annual Energy Use:
216,900 kWh

Modeled On-Site Renewable Energy Produced
337,964 kWh



Heating System - METALWORKS AIRTITE Radiant Ceiling Panel System, Water Source Heat Pump, Mechanical heat exhaust exchange from Hydroelectric Turbines .

Cooling System - METALWORKS AIRTITE Radiant Ceiling Panel System, Ceiling fans, Natural Ventilation

Ventilation System - Natural Ventilation with cross ventilation and stack effect, Dedicated Outdoor Air System for additional ventilation during periods of bad air quality.

Lighting System - Daylit spaces, many spaces meet 30fc through natural light for up to 80% of occupied hours. Daylight-optimized LED lighting with vacancy control and daylight dimming. Light wells between floor plates, clerestories.

Domestic Hot Water System - 120 Gallon tank Heat pump water heater with additional heating from mechanical heat exhaust exchange.
Rainwater capture and greywater filtration and reuse

Renewable/ Generation System - 214.5 KW rooftop PV array and backup on-site micro hydroelectric generators

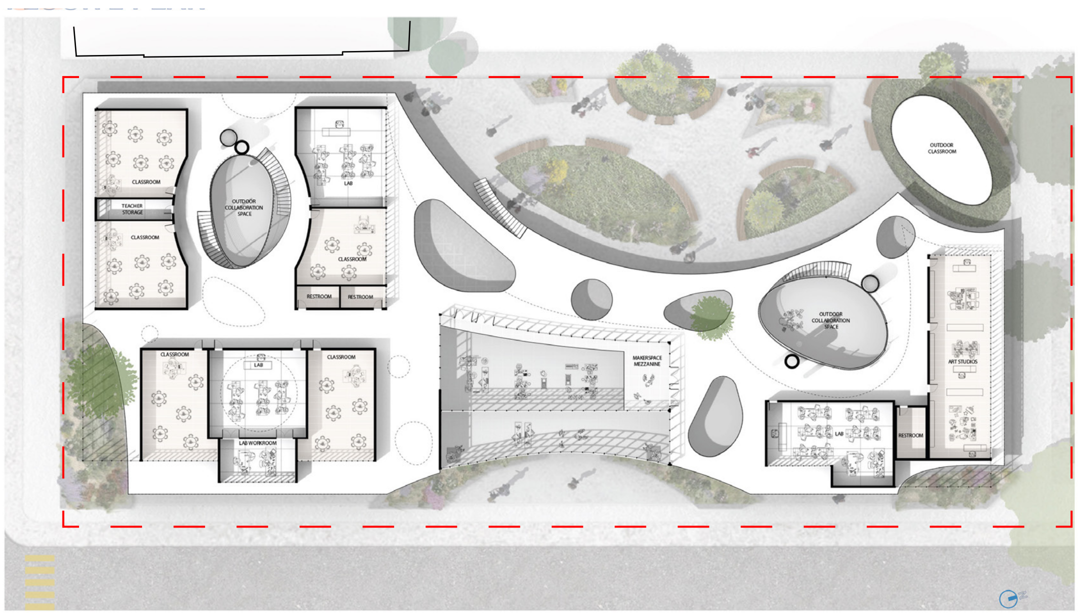
Energy Storage System - 3.2 MWh Battery Electric Storage System with an estimated backup 138 kWh pumped hydroelectric stored as 55,000 gallons in water towers

Water Systems - Rooftop rainwater capture and greywater to subterranean filtration and 40,000 gallon storage tanks to minimize potable water use for non-contact uses, such as hydroelectric generation.

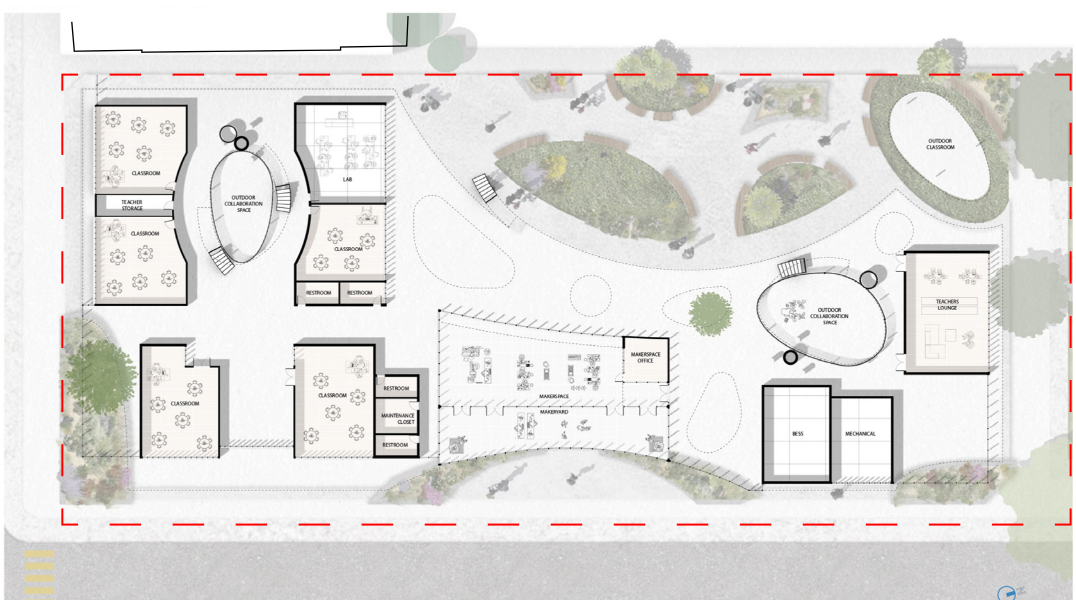
Agualta STEAM Engine

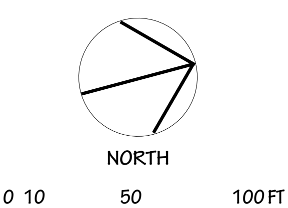
Design Draw Build Inc

ROOF PLAN



SECOND FLOOR PLAN





GROUND FLOOR PLAN

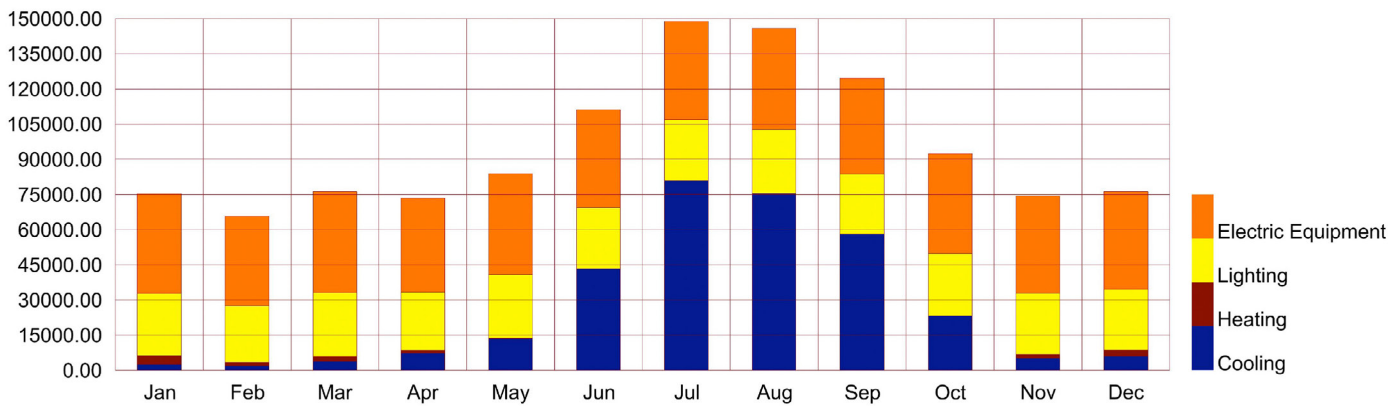
AIACA 2024 ARCHITECTURE AT ZERO COMPETITION

Designer: *McMillan Pazdan Smith Architecture*, Columbia, SC
Title of Design: Link+

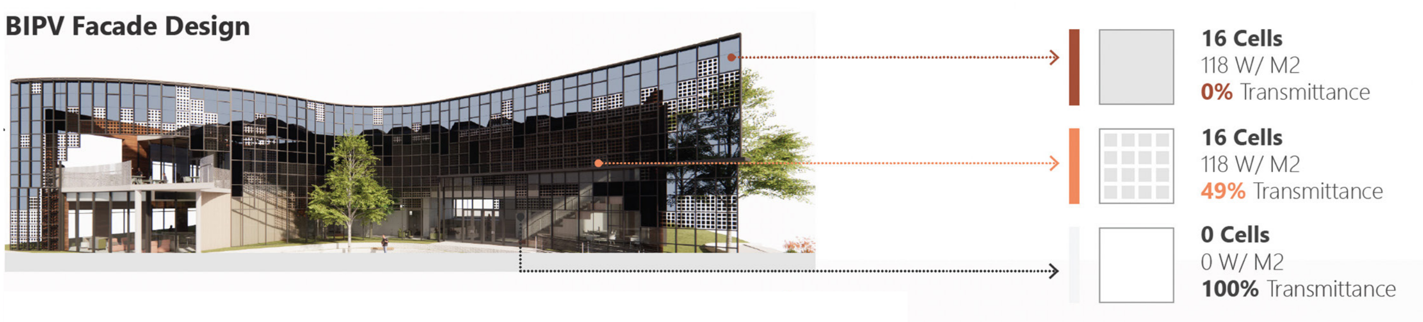
MERIT AWARD
Professional Category
(Distinguished Achievement)

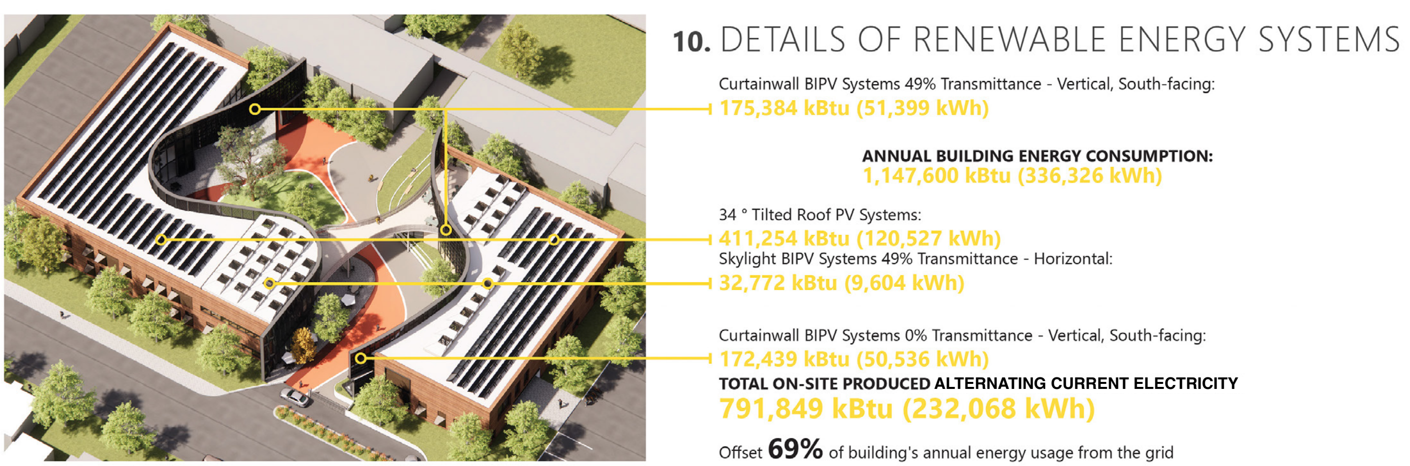
Modeled EUI (Site)
23.3 kBtu/sf-year
Modeled Annual Energy Use:
202,964 kWh
Modeled On-Site Renewable Energy Produced
232,068 kWh

Link +
McMillan Pazdan Smith



Modeled Monthly Energy Use (kBtu)





Link +

McMillan Pazdan Smith

ROOF/SITE PLAN

Legend

1. LOBBY
2. SCIENCE LAB
3. LAB SCIENCE WORKROOM
4. TEACHER WORKROOM
5. STORAGE
6. RECEPTION
7. MECH ROOM
8. ELEC (BATTERY + PV INVERTY)
9. ART CLASS AND WORKROOM
10. MAKER SPACE
11. CLASSROOM
12. OUTDOOR CLASSROOM
13. COLLABORATION SPACE
14. OUTDOOR COLLABORATION
15. GATHERING SPACE
16. INCLUSIVE RESTROOM

SECOND FLOOR PLAN

NORTH

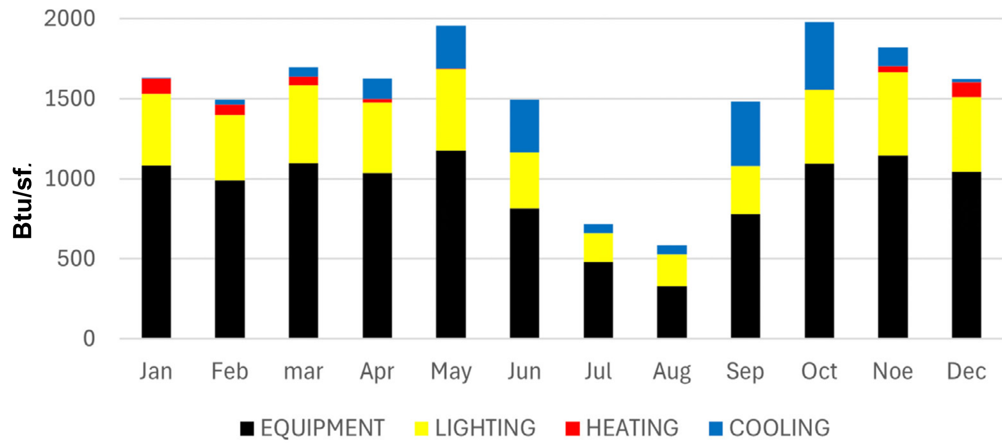
0 10 50 100 FT

GROUND FLOOR PLAN

AIACA 2024 ARCHITECTURE AT ZERO COMPETITION

MERIT AWARD
(Distinguished Achievement)

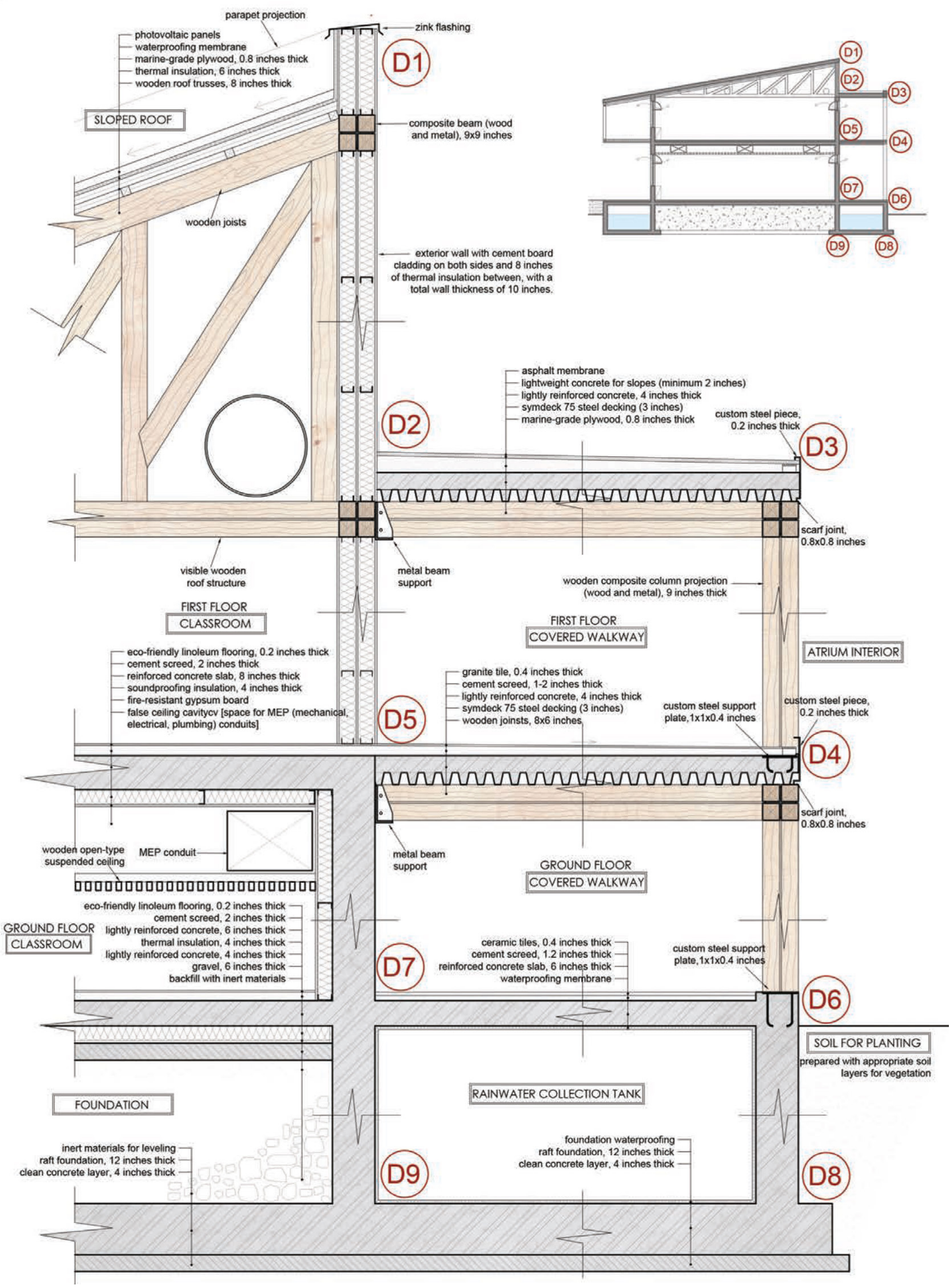
Designer: *Adamakis Architects & Associates*, Volos, Greece
Title of Design: Middle School for Fun Innovation and Technological Sustainability (MISFITS)



Modeled EUI (Site)
18.0 kBtu/sf-year

Modeled Annual Energy Use:
156,796 kWh

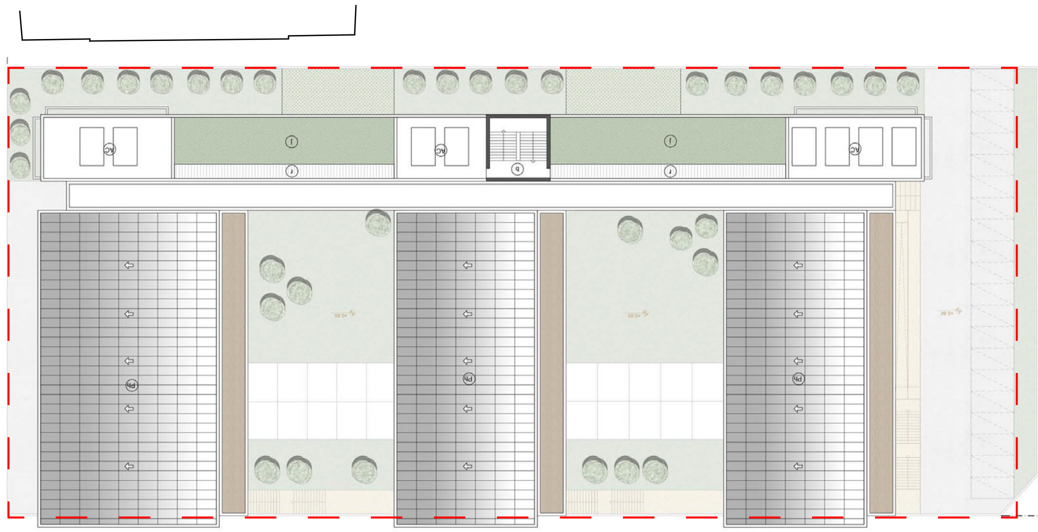
Modeled On-Site Renewable Energy Produced
1,141,127 kWh



(Left) Construction details section

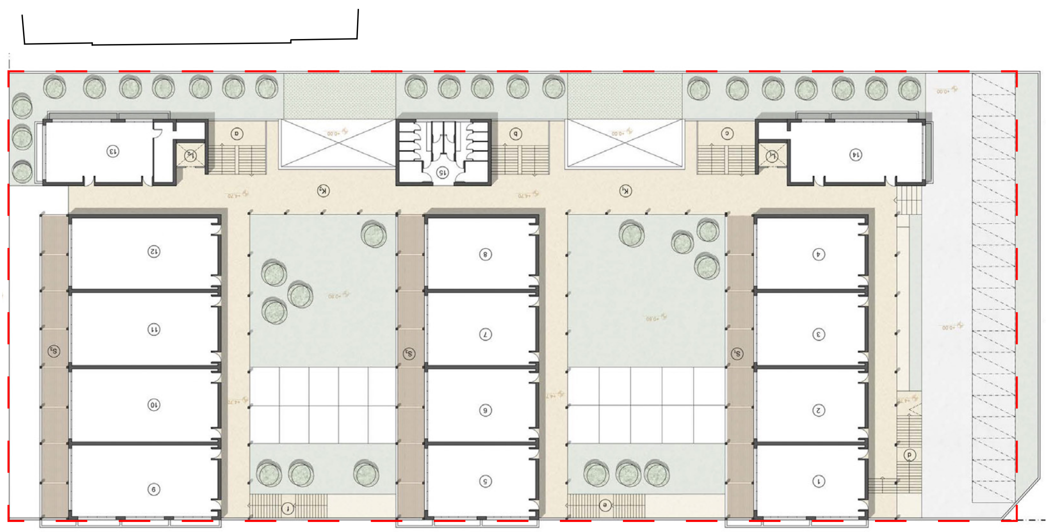
MISFITS

Adamakis Architects & Assoc.

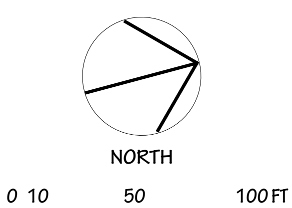


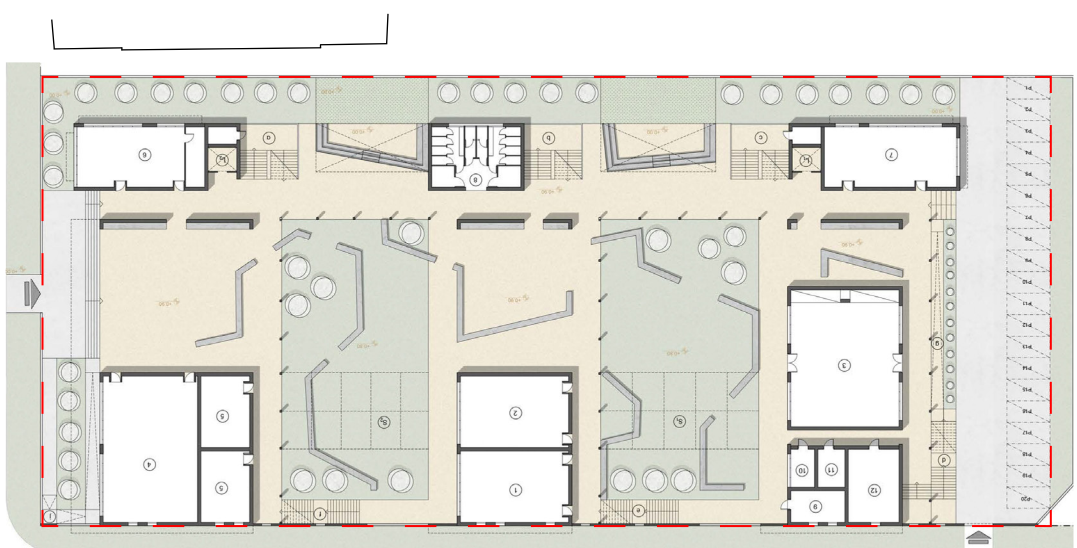
ROOF PLAN

1-2	: Classrooms
3	: Maker space and storage room
4	: Art classroom and workroom
5	: Flexible lab Science workrooms
6	: Teachers Workroom and storage
7	: Collaboration space
8	: Restrooms per floor (1 girls,1 boys, 2 faculty, all gender)
9	: Battery energy storage system (BESS)
10	: Staff bike storage area
11	: Photovoltaic inverter room
12	: Mechanical, electr. room & other storage



SECOND FLOOR PLAN





GROUND FLOOR PLAN

Conclusion ▷

Observations

A Transition Period for K-12 School Projects Also

In the Observations section of the second volume of *Designing for Zero Carbon*, published two years ago, it was noted that building design in general in the State of California has been in a period of transition from an emphasis on ZNE buildings (with a focus on on-site renewable energy systems) to all-electric buildings.

> "The goal to greatly reduce the building-caused greenhouse gas emissions that are contributing to climate change remains the same, but the path to this goal has been altered by recent plans to change the energy infrastructure supplying those buildings, namely to change the electricity grid in California to carbon-free production. Now, projects will be able to operate with zero-carbon emissions after 2045 without necessarily achieving ZNE performance, or to be designed with the size of solar PV system usually required for ZNE. Projects reflecting this change of emphasis have only recently been designed, and the case studies in this book (and the previous Volume 1) demonstrate the design issues that now need to be addressed."

So, the new prioritization of all-electric design has also shifted the priority of building design strategies that involve building mechanical and electrical systems while maintaining the importance of energy-efficiency in general.

Volume 2 presents case studies of all-electric multifamily housing, three of them being affordable housing projects. These case study projects reflected the transition of emphasis underway. Similarly, the K-12 school case studies presented in this Volume 3 indicate the same change in design strategies to reflect the decarbonization mandate of the public utility electric grid in California.

But it turns out that these case studies are not uniformly distributed around California and that K-12 schools have been slow to adopt the change in design strategies seen with other building types. In general, this situation is due to the length of time required from project initiation to project funding to finally approved project design. For public schools, public bond-funding is usually required, lengthening the time required. (See the *Introduction* section to this book for a full discussion of the issues involved in a project initiation and development, particularly for public schools.)

It is expected that the next 20 years, during which time the public utility electric grid is scheduled to be completely decarbonized, all-electric K-12 school projects will be initiated and completed throughout the State of California in ever larger numbers.

So, specifically for the all-electric K-12 school projects studied in this volume, what issues emerged requiring design strategies to produce buildings with the desired low-carbon emission profile?

Some Things Remain the Same (for K-12 School Design)

Even with the programmatic differences and project objectives of the K-12 school category, there is a continuity of design strategies demonstrated by all five case study projects that effectively supports the emphasis on all-electric design solutions that result in zero-carbon emissions when occupied.

it is interesting to note that for schools in particular, unique to other building types, they use energy almost exclusively during daylight hours, when PV is produced, giving them an additional benefit to on-site PV production: schools will have a more direct solar offset to their energy consumption. Which has the potential to improve their payback period.

- Energy Efficiency

  Energy efficiency for the individual project contributes to an overall energy efficiency for the building sector as a whole, putting less strain on the public utility grid and enabling renewable sources to supply the maximum share of the power required at an earlier date. Energy-efficient design is more cost-effective for the building owner as well.

- Importance of Carbon-Free Renewable Energy

  Whether it is sourced from on-site renewable systems at the building site or obtained from the public utility grid, renewable energy supply is clearly beneficial because, once installed, it produces no carbon emissions over the life of the system. For a school administrator, the determination of which source is best will be purely a life-cycle cost evaluation.

  For the case study projects in this book, which will have 20 years of life before the grid is scheduled to be completely decarbonized, the choice of on-site renewable energy systems was a result of cost-effectiveness calculations as well as simply keeping the overall project cost low. In most cases, the school authorities required that the design be able to accommodate a possible future solar PV system, not necessarily large enough to result in a ZNE system. A third-party *Power Purchase Agreement (PPA)* was also a method of providing the solar energy at no initial cost for the system.

  It is interesting to note that for K-12 schools in particular, compared to other building types, energy use occurs almost exclusively during daylight hours when energy can be produced by on-site solar PV systems. This provides additional benefit from the installation of such on-site solar PV systems in school projects, given the current rate structure of California's electric utilites. Energy produced by these systems directly offsets the energy consumption of the school facilities, providing an improved payback period for the solar PV system. There is also less need to invest in relatively expensive battery systems for energy storage for facility operation in non-daylight hours.

- Building Metering and Performance Verification

  Because the transition period to the all-electric building design approach has only recently started, it is essential that the design strategies chosen for these projects be evaluated and their success be confirmed in actual use of the buildings as designed. This can only be done through performance verification after occupancy, typically including actual energy use as metered over one year or more. When building commissioning is carried out, usually by a hired commissioning agent, the performance of all systems can be verified for the post-occupancy period.

  Energy efficiency and optimal solar PV system performance will still be high operational priorities in our decarbonized building future, both for individual K-12 schools and public utility operators. Systematic metering will help ensure this.

What's New and Evolving (for K-12 School Design)

Since the publication of Volume 1 of *Designing for Zero Carbon* in March 2022, there has been continued development of analytical software tools as well as continued improvement in building technologies and their deployment in K-12 school projects.

- An Eye on Embodied Carbon

  When the goal of a decarbonized public utility grid in California is realized in approximately 20 years, every all-electric building will operate with zero-carbon emissions—a promising eventuality. For building designers, there is also an evolving concern with the importance of embodied carbon, since carbon emissions will still result from the manufacture and transport of construction materials of all types.

  There has been a rapidly-developing understanding that this issue can and should be addressed during the design phase of the project. The analytical tools have advanced to the point that they are included in the regular design software and projects can readily be studied for embodied carbon content. (None of the case studies of K-12 school projects in this volume were studied for their embodied carbon content during the design phases.)

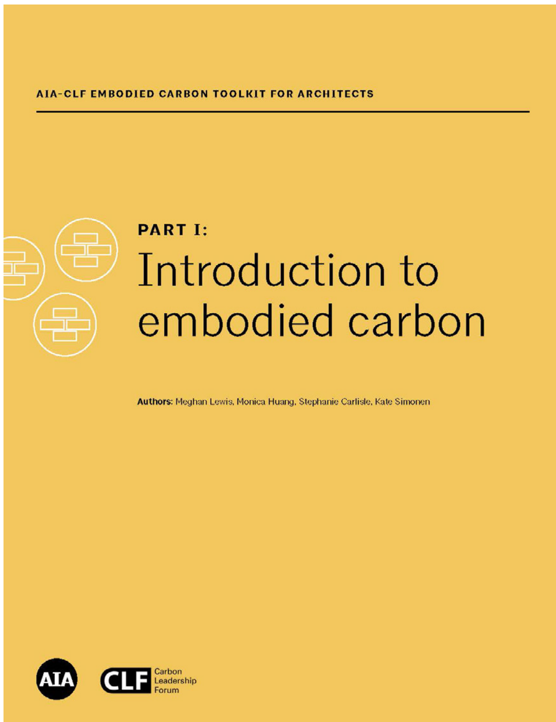
  Materials specified can be identified as “hot spots” of embodied carbon and replaced, minimizing the project’s overall embodied carbon content. Such studies, made feasible only with the recent advances in design software, can make the evaluation of embodied carbon in projects a routine exercise.

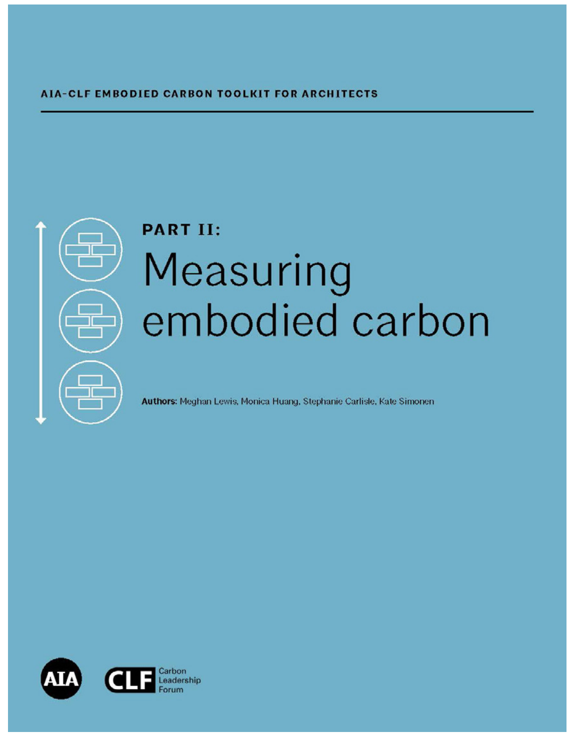
- Batteries

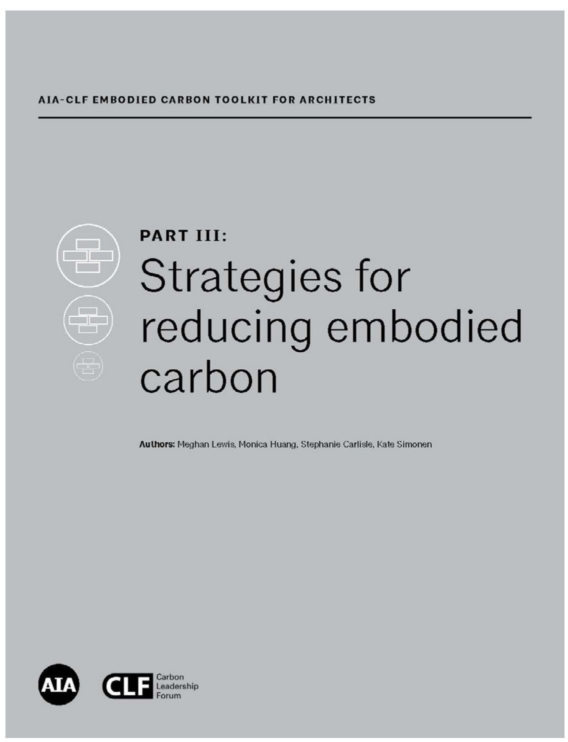
  None of the case study projects in this book use batteries for energy storage due to the first cost investment required. Given that the solar PV system is operating for the most part during traditional school hours, it is not likely that a battery system will be warranted or cost effective.

  There is a possible incentive to provide *resiliency*, ensuring power supply during major shutdowns by the public utility for emergency reasons such as wildfires and flooding. Risk avoidance may be a motivator in the future for school administrators to invest in battery systems for their projects.

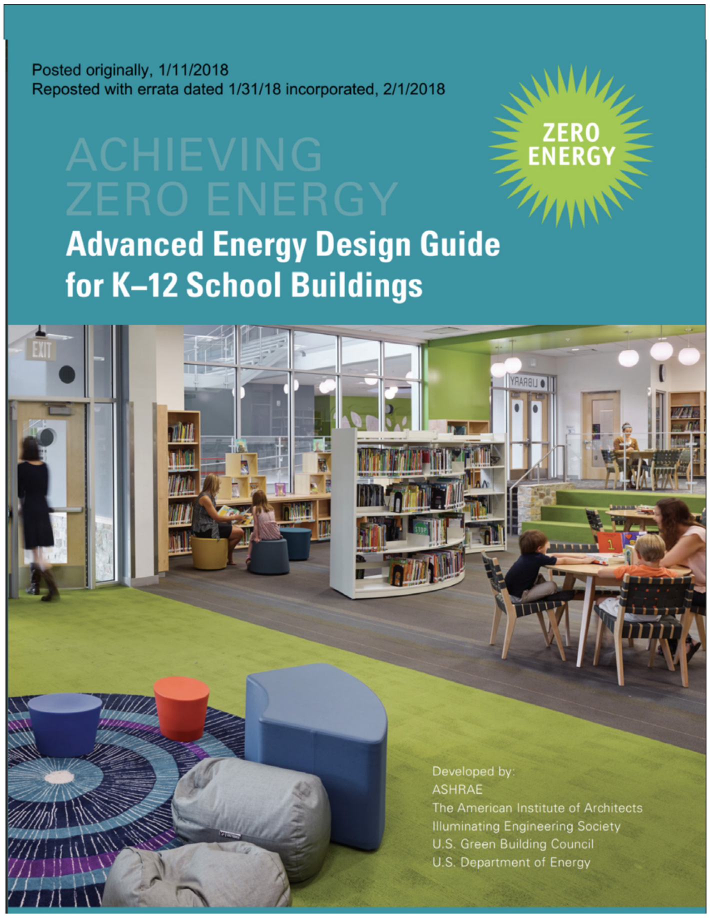
(Below) October 2021 publication, *AIA-CLF Embodied Carbon Toolkit for Architects*.







Additional Resources

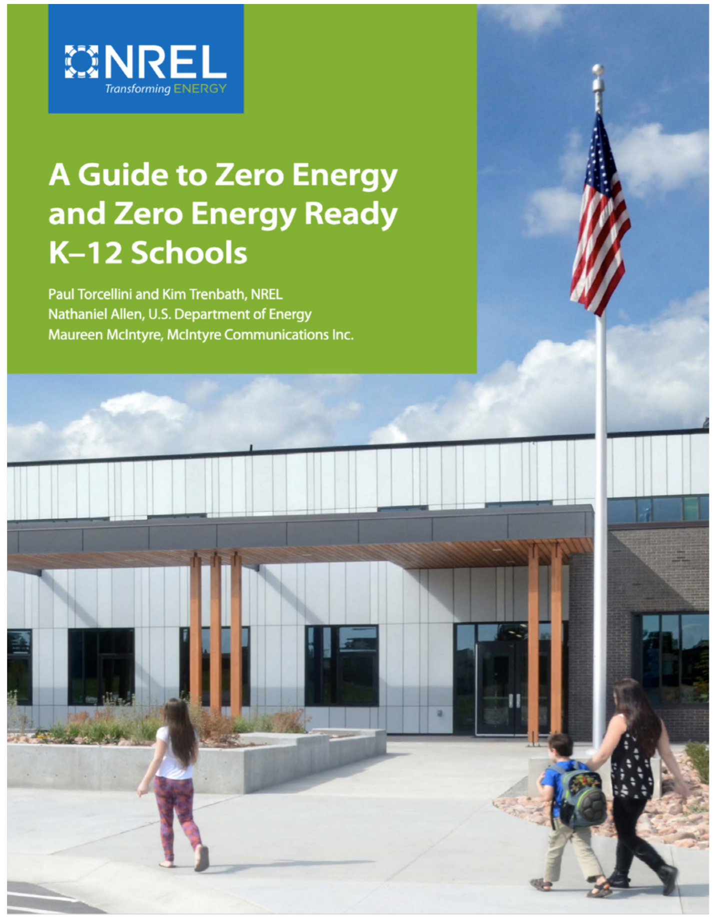


Achieving Zero Energy: Advanced Energy Design Guide for K-12 School Buildings

ASHRAE, AIA, IES, U.S. GBC, U.S. DOE

The Advanced Energy Design Guide—Achieving Zero Energy series provides a cost-effective approach to achieve advanced levels of energy savings. The Guides offer contractors and designers the tools, including recommendations for practical products and off-the-shelf technology, needed for achieving a zero energy building.

https://store.accuristech.com/standards/advanced-energy-design-guide-for-k-12-school-buildings-achieving-zero-energy?product_id=2004569

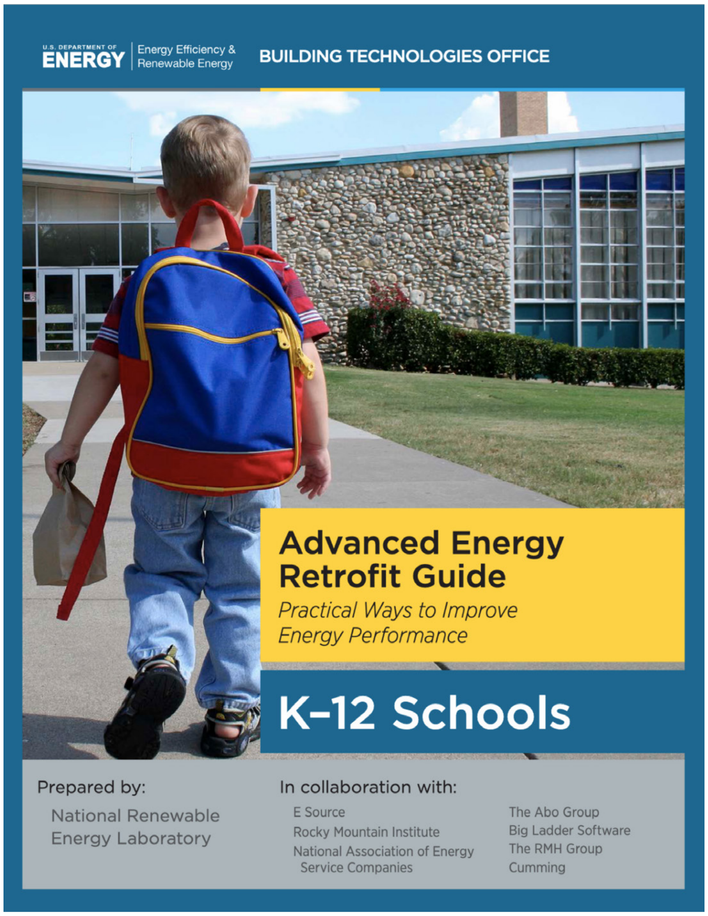


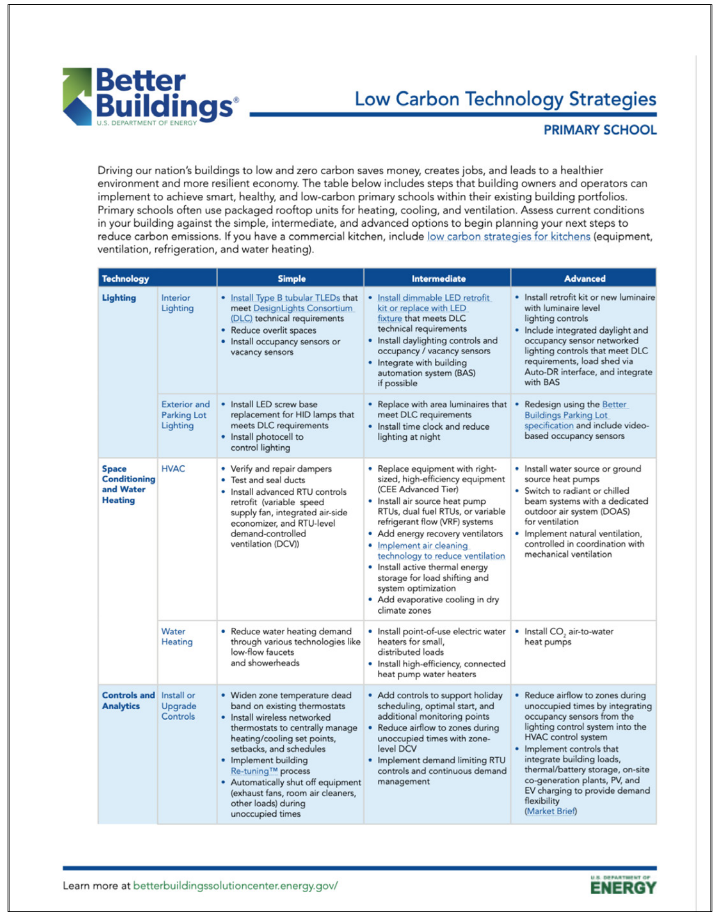
A Guide to Zero Energy and Zero Energy Ready K–12 Schools

NREL, U.S. DOE, McIntyre Communications Inc.

Developed as part of DOE's Zero Energy Schools Accelerator (ZESA), this guide outlines 8 steps to creating a Zero Energy (ZE) school. It is intended to be used in conjunction with Achieving Zero Energy: Advanced Energy Design Guide for K–12 School Buildings

https://www.nrel.gov/docs/fy19osti/72847.pdf





Better Buildings® U.S. DEPARTMENT OF ENERGY

Low Carbon Technology Strategies

PRIMARY SCHOOL

Driving our nation's buildings to low and zero carbon saves money, creates jobs, and leads to a healthier environment and more resilient economy. The table below includes steps that building owners and operators can implement to achieve smart, healthy, and low-carbon primary schools within their existing building portfolios. Primary schools often use packaged rooftop units for heating, cooling, and ventilation. Assess current conditions in your building against the simple, intermediate, and advanced options to begin planning your next steps to reduce carbon emissions. If you have a commercial kitchen, include low carbon strategies for kitchens (equipment, ventilation, refrigeration, and water heating).

Technology		Simple	Intermediate	Advanced
Lighting	Interior Lighting	• Install Type B tubular TLEDs that meet DesignLights Consortium (DLC) technical requirements • Reduce overlit spaces • Install occupancy sensors or vacancy sensors	• Install dimmable LED retrofit kit or replace with LED fixture that meets DLC technical requirements • Install daylighting controls and occupancy / vacancy sensors • Integrate with building automation system (BAS) if possible	• Install retrofit kit or new luminaire with luminaire level lighting controls • Include integrated daylight and occupancy sensor networked lighting controls that meet DLC requirements, load shed via Auto-DR interface, and integrate with BAS
	Exterior and Parking Lot Lighting	• Install LED screw base replacement for HID lamps that meets DLC requirements • Install photocell to control lighting	• Replace with area luminaires that meet DLC requirements • Install time clock and reduce lighting at night	• Redesign using the Better Buildings Parking Lot specification and include video-based occupancy sensors
Space Conditioning and Water Heating	HVAC	• Verify and repair dampers • Test and seal ducts • Install advanced RTU controls retrofit (variable speed supply fan, integrated air-side economizer, and RTU-level demand-controlled ventilation (DCV))	• Replace equipment with right-sized, high-efficiency equipment (CEE Advanced Tier) • Install air source heat pump RTUs, dual fuel RTUs, or variable refrigerant flow (VRF) systems • Add energy recovery ventilators • Implement air cleaning technology to reduce ventilation • Install active thermal energy storage for load shifting and system optimization • Add evaporative cooling in dry climate zones	• Install water source or ground source heat pumps • Switch to radiant or chilled beam systems with a dedicated outdoor air system (DOAS) for ventilation • Implement natural ventilation, controlled in coordination with mechanical ventilation
	Water Heating	• Reduce water heating demand through various technologies like low-flow faucets and showerheads	• Install point-of-use electric water heaters for small, distributed loads • Install high-efficiency, connected heat pump water heaters	• Install CO_2 air-to-water heat pumps
Controls and Analytics	Install or Upgrade Controls	• Widen zone temperature dead band on existing thermostats • Install wireless networked thermostats to centrally manage heating/cooling set points, setbacks, and schedules • Implement building Re-tuning™ process • Automatically shut off equipment (exhaust fans, room air cleaners, other loads) during unoccupied times	• Add controls to support holiday scheduling, optimal start, and additional monitoring points • Reduce airflow to zones during unoccupied times with zone-level DCV • Implement demand limiting RTU controls and continuous demand management	• Reduce airflow to zones during unoccupied times by integrating occupancy sensors from the lighting control system into the HVAC control system • Implement controls that integrate building loads, thermal/battery storage, on-site co-generation plants, PV, and EV charging to provide demand flexibility (Market Brief)

Learn more at betterbuildingssolutioncenter.energy.gov/

U.S. DEPARTMENT OF ENERGY

Advanced Energy Retrofit Guide: K-12 Schools

NREL, E Source, Rocky Mountain Institute, National Association of Energy Service Companies, The Abo Group, Big Ladder Software, The RMH Group, Cumming

The K-12 Schools guide provides convenient and practical guidance for making cost-effective energy efficiency improvements in public, private, and parochial schools.

https://www.nrel.gov/docs/fy14osti/60913.pdf

U.S. DOE Better Buildings - Low Carbon Technology Strategies: Primary School

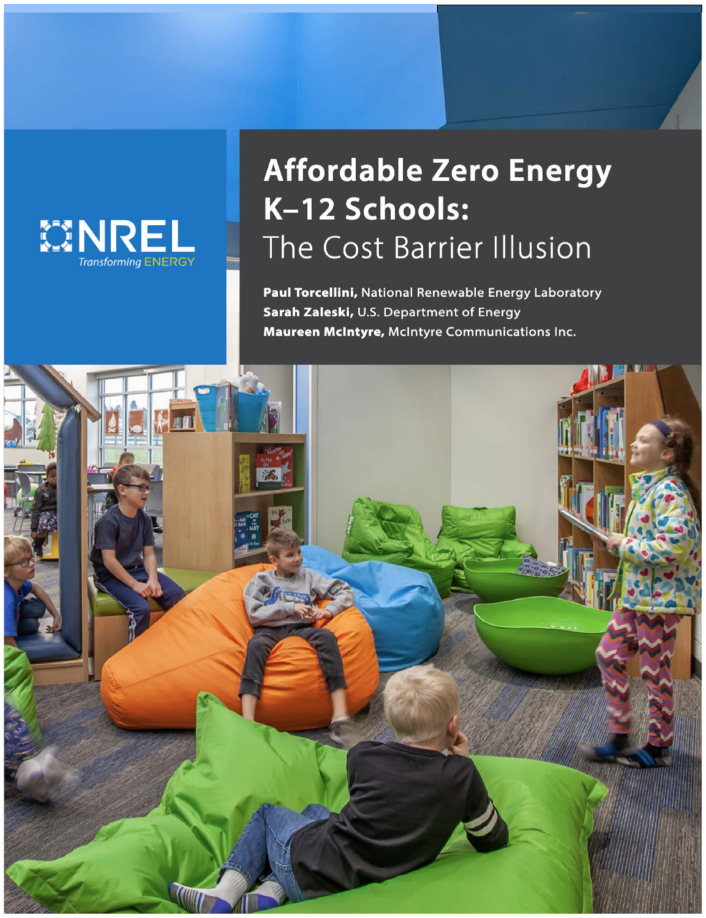
This document includes steps that building owners and operators can implement to achieve healthy, low-carbon primary schools within their existing building portfolios. Primary schools often use rooftop units for heating, cooling and ventilation.

https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Primary_School_BB_Carbon_Strategies.pdf

U.S. DOE Better Buildings -Low Carbon Technology Strategies: Secondary School

This document covers the same topics for secondary schools, includeing complex heating and cooling systems and specialty equipment for gymnasiums, pools, and buses.

https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/Secondary_School_BB_Carbon_Strategies.pdf

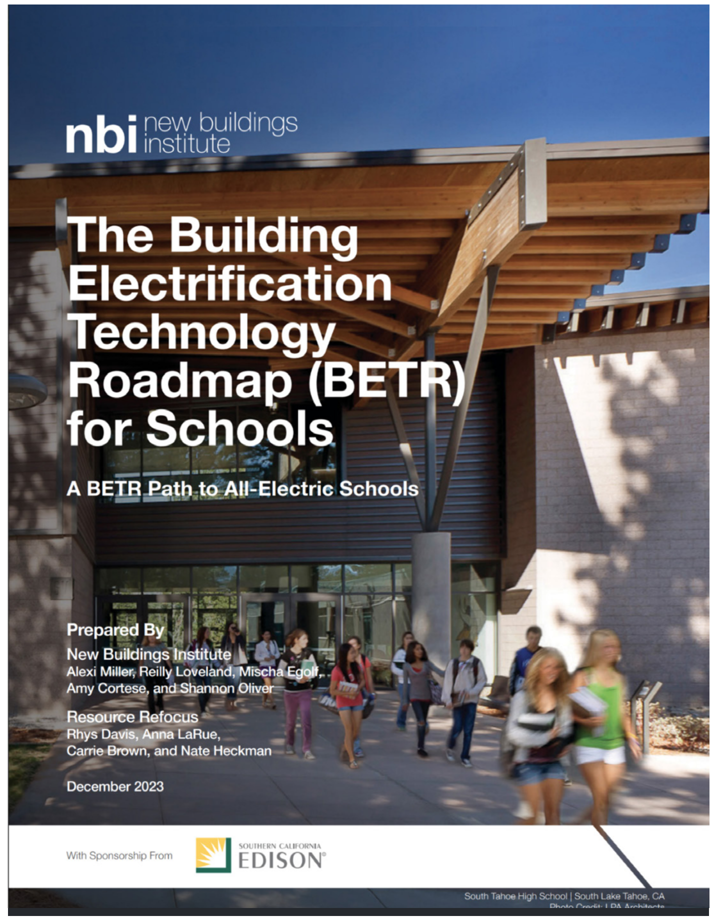


Affordable Zero Energy K–12 Schools: The Cost Barrier Illusion

NREL, U.S. DOE, McIntyre Communications Inc.

The pressures to contain costs in school design and construction can be intense, and—because many stakeholders still cite cost as a major barrier to designing and building a ZE K–12 school—those pressures can thwart efforts to pursue a ZE or zero energy ready (ZER) project. By examining the costs of a subset of existing ZE schools and the strategies used to contain those costs, architects, engineers, owners, and researchers are challenging the notion that cost is a barrier to building ZE schools.

https://betterbuildingssolutioncenter.energy.gov/sites/default/files/attachments/80766.pdf



The Building Electrification Technology Roadmap (BETR) for Schools

NBI, Resource Refocus

Learn strategies tailored for K-12 schools to reduce carbon emissions from water heating, HVAC, buses, and other technologies that power classrooms and operational spaces. This report provides K-12 leaders a roadmap and decision-making tools to electrify their school buildings.

https://newbuildings.org/resource/the-building-electrification-technology-roadmap-for-schools/

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Client Representatives:

Diana Hayton, AIA
Member/ Albany USD Climate Action Plan Committee
Ocean View Elementary School (Albany), Case Study No. 1

Amber Stott, CEO & Chief Food Genius
Food Literacy Center
Food Literacy Center at Floyd Farm (Sacramento), Case Study No. 4

Jeanette Moore, Chief Financial and Operations Officer
Lick-Wilmerding High School
Lick-Wilmerding High School (San Francisco), Case Study No. 5

Design Professionals:

Teresa Jan, Director of Climate Positive Design
Multistudio, San Francisco (formerly Gould-Evans)
Ocean View Elementary School (Albany), Case Study No. 1

Steve Gross, Principal
Interface Engineering, Oakland
Ocean View Elementary School (Albany), Case Study No. 1

Nina Pakanant, Senior Associate
Ratcliff Architects, Emeryville
Blue Oak Middle School (Napa), Case Study No. 2

Pamela Collier, Principal
LDP Architecture, San Francisco
Garfield Elementary School (San Francisco), Case Study No. 3

Kim Zylker, Associate Principal
Engineering 350, San Francisco
Garfield Elementary School (San Francisco), Case Study No. 3

Jennifer Wehling, Director of Sustainability
HMC Architects, Sacramento
Food Literacy Center at Floyd Farm (Sacramento), Case Study No. 4

SiJing Sanchez, Senior Associate
EHDD Architecture, San Francisco
Lick-Wilmerding High School (San Francisco), Case Study No. 5

Eric Solrain, Senior Principal, Design Analytics
Introba, Oakland
Lick-Wilmerding High School (San Francisco), Case Study No. 5

Especially helpful for the Additional Case Study Projects described in the *Additional Noteworthy Projects* section:

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  Marin Elementary School (Albany)

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  Lynhaven Elementary School Administration and Mulltiuse Building (San Jose)

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  HKIT Architects, Oakland
  Jefferson Union HSD Adult Education + District Office Building (Daly City)
  Piedmont High School Performing Arts Center (Piedmont)

- Matt Dohrmann, Principal
  CAW Architects, (Palo Alto)
  Corte Madera Middle School (Portola Valley)
  Ormondale Elementary School (Portola Valley)

- Susi Marzuola, Principal
  Siegel & Strain Architects, Emeryville
  Bishop O'Dowd High School Environmental Science Center (Oakland)

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  WRNS Studio, San Francisco
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- Jasen Bohlander, Senior Associate
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--Edward Dean, FAIA, Bernheim + Dean, Inc.

SOUTHERN CALIFORNIA
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