Project Overview

The [redacted] Library is a 26,750 square-foot public facility located in [redacted]. The community engagement process emphasized sustainability and adaptable outdoor spaces. The final design features a transformative building that seamlessly integrates with the surrounding landscape, including an outdoor amphitheater, public patio, and a universally accessible green roof. The library also features a sound studio, a maker's space for hands-on learning experiences, and an indoor/outdoor workshop. It serves as a community-focused resource for knowledge and engagement while demonstrating sustainable design through performance-driven engineering and high-efficiency systems and is certified as the first public Net Zero Energy building in [redacted].

The project emphasizes long-term environmental and economic resilience through intelligent HVAC system integration, renewable energy generation, and low-impact materials. The design team approached the project with site-specific strategies that maximize energy efficiency and create a timeless sense of place, all within a tightly managed $12.4 million budget. Notably, this budget was set before the decision to pursue Zero Energy Certification. Through energy modeling and thoughtful design, the team demonstrated that net zero energy is achievable on a standard market-rate budget. The result is an energy-efficient, fiscally responsible, multigenerational community space that exemplifies resilience and adaptability, setting a compelling precedent for future public projects.

1. Energy Efficiency

The design of the [redacted] Library was fundamentally shaped by energy modeling used throughout the early concept phase. The building's energy model was developed using eQuest v3.65 (DOE 2.3) in accordance with ASHRAE 90.1 Appendix G. Its form and courtyard placement optimize daylighting, reducing lighting energy use with daylight sensors. Emphasis on envelope performance led to a well-insulated, airtight structure with openings designed for effective daylight use. The building's Energy Use Intensity (EUI) of 32.1 kBtu/sf-yr is 55% better than the national median library energy consumption per the 2024 CBECS database. With a 194.6 kWdc rooftop photovoltaic canopy made up of 512 panels (Figure 1), the building produces 102% of its annual energy needs. This surplus performance not only achieves net-zero energy certification but also offsets minor fluctuations in annual demand. The resulting energy use intensity (EUI) of 32 kBtu per square foot represents a 78% reduction compared to the national average for public libraries, which is 144 kBtu per square foot.

FIGURE 1: Photovoltaic Canopy

FIGURE 2: Monthly Energy Use, Generation and Cost

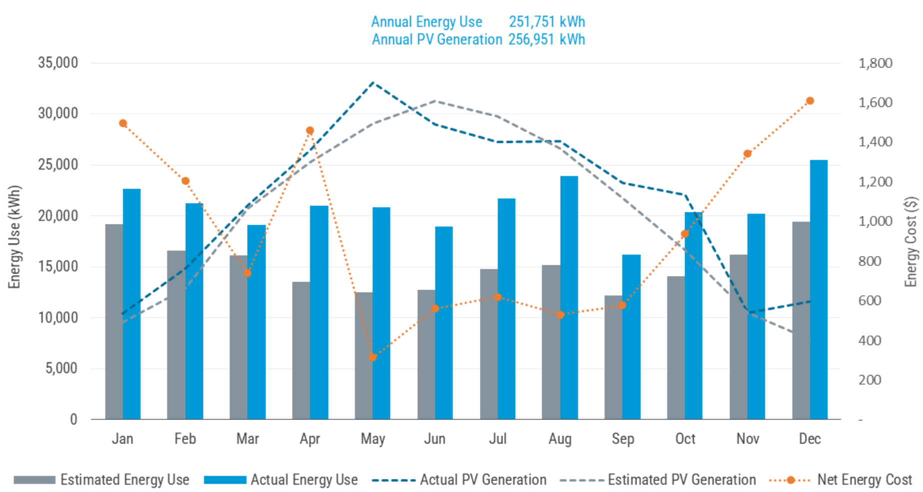


FIGURE 3: Building Energy Use Comparison	
CBECS 2024 National Median Site EUI, kBtu/sf-yr	**71.6**
ENERGY STAR SEDI Median Site EUI, kBtu/sf-yr	**51.0**
Estimated Site EUI, kBtu/sf-yr	**23.3**
Actual Site EUI, kBtu/sf-yr	**32.1**

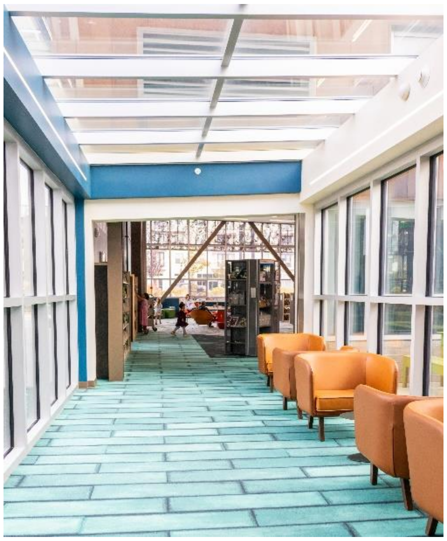


FIGURE 4: Library Windows

The envelope features a window-to-wall ratio of 27%. The opaque wall assembly achieves a U-value of 0.048, and the roof assembly achieves a U-value of 0.022. Storefront glazing systems (SB70XL) achieve an overall U-value of 0.35, SHGC of 0.23, and VT of 0.55, while courtyard glazing assemblies (VRE-54 #2 and VE-85 #4) offer improved thermal performance with a U-value of 0.235, SHGC of 0.21, and VT of 0.35. These values support effective solar control and daylighting without compromising envelope performance.

The building's rectangular shape and optimized window-to-wall ratios were developed by analyzing the impact of shading, daylighting, and glazing properties on energy loads. Twenty tubular skylight devices bring daylight into interior zones with limited perimeter exposure. A vegetated green roof enhances envelope thermal performance, reduces heat island effect, and mitigates stormwater runoff.

FIGURE 5: Tubular Skylights

The ground-coupled mechanical system (Figure 6) was implemented to help achieve net-zero goals. The system consists of a closed-loop vertical bore ground heat exchanger (GHEx) located beneath the parking lot (Figure 7). Each vertical bore is 300 feet deep, and all

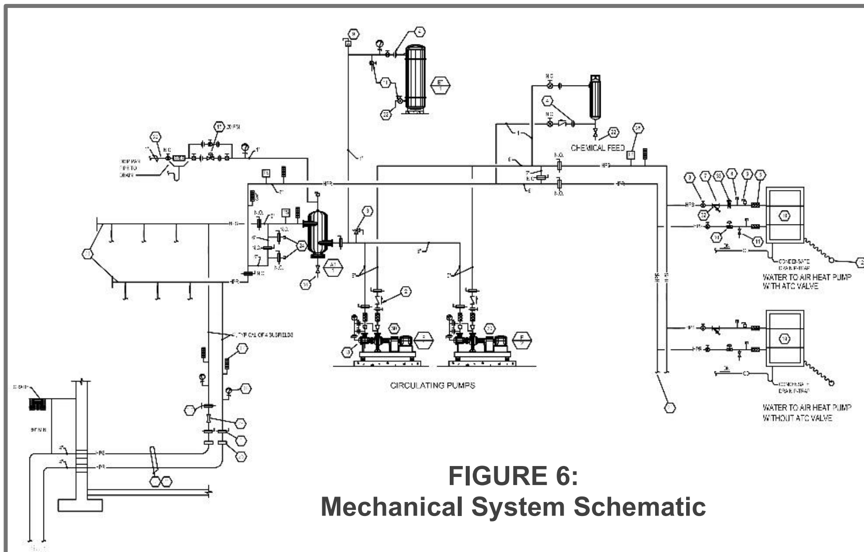


FIGURE 6:
Mechanical System Schematic

bores are fully grouted per National Ground Water Association and IGSHPA 2013 standards. The GHEx loop was designed such that antifreeze was not required, which simplifies maintenance and improves thermal transfer efficiency. Water from the GHEx circulates through a variable primary flow loop, powered by centrifugal pumps controlled by variable frequency drives (VFDs). These pumps are managed by the building automation system (BAS), allowing for reduction of flow based on real-time thermal demand.

FIGURE 7: Ground Heat Exchanger

Each occupied zone is served by a dedicated water-to-air ground source heat pump (GSHP), located in mechanical closets or rooms adjacent to the conditioned space. These units are reverse-cycle type with a minimum coefficient of performance (COP) of 3.7 in heating mode and a minimum energy efficiency ratio (EER) of 17.0 in cooling mode. Performance values for designed equipment were in accordance with ASHRAE/AHRI/ISO 13256-1 GLHP conditions.

Outdoor air is supplied to each zone via dedicated outside air systems (DOAS). These air handlers are heating-only units that pre-treat ventilation air before it is delivered to the space. DOAS units ensure proper ventilation and thermal conditioning under varying load conditions. To keep these systems as efficient as possible and keeping with the net zero design philosophy, the DOAS units are ground coupled water to air heat pumps. All air distribution systems use MERV 13 filtration for both outside air and recirculated return air, enhancing indoor air quality while reducing particulate buildup in system components. The Building Automation System (BAS) allows for precise zone scheduling, enabling HVAC systems to shut down during unoccupied hours. The control platform supports dynamic setpoint resets, equipment sequencing, and full access to 15 months of operational trend data.

2. Indoor Air Quality and Thermal Comfort

Being located in an area designated by the EPA as nonattainment for both fine particulate matter and ozone, it was crucial for the design team to address the challenges with air pollution at the [redacted]

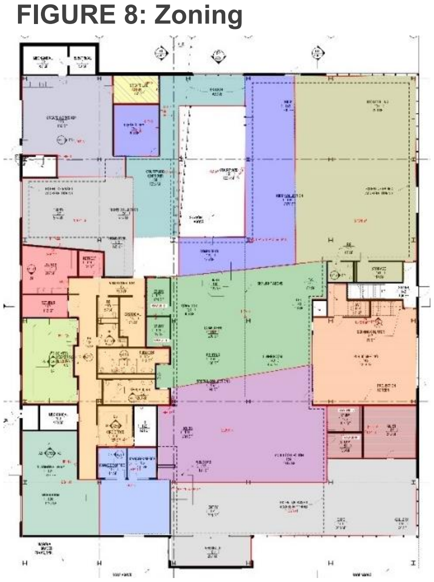
Library. The library's mechanical design goes beyond code minimums to prioritize occupant health and comfort. The HVAC system incorporates high-efficiency filtration (MERV 13A) to address elevated levels of airborne particulates and supports increased ventilation rates. By engineering a safe and healthy indoor environment, the library serves as a model of resilient design and a refuge for the community during frequent winter inversions when outdoor air quality deteriorates rapidly.

The ventilation strategy for [redacted] Library is based on ASHRAE Standard 62.1-2013 and was validated using LEED's Minimum IAQ Performance Calculator (Option 1). Each GSHP zone receives outdoor air through a DOAS unit. Ventilation rates were calculated using zone-specific occupancy profiles, and adjustments were made based on the architect's spatial program to ensure accurate occupant density assumptions.

Zone air distribution effectiveness (Ez) was assigned a value of 0.8, representing worst-case performance during heating mode and complying with ASHRAE Section 6.2.5. The ventilation air is distributed directly to each thermal zone and is monitored by CO2 sensors located in high-occupancy areas.

Thermal comfort is maintained in accordance with ASHRAE Standard 55-2013. Design indoor temperatures for occupied spaces are set between 70 -75 degrees Fahrenheit. Relative humidity targets are 45% during summer and 30% in winter. While the building does not use mechanical humidification or dehumidification, envelope integrity and proper air exchange maintain comfort levels year-round. Weather design conditions used for mechanical sizing were 0.04% for cooling and 99.6% for heating. Simulations show that conditions outside this design range occur for no more than 35 hours per year.

FIGURE 8: Zoning



The thermal zoning strategy (Figure 8) provides individual thermal comfort controls for all group occupancy spaces such as break rooms, meeting rooms and studies, and for 50% of the full-time occupant workspaces. Occupied spaces with exterior exposure were zoned separately from interior zones to further improve local thermal comfort. To evaluate occupant perception of indoor air quality, a post-occupancy survey was conducted. Among respondents, 33.3% reported feeling very satisfied with the air quality, 50% were satisfied, and 16.67% felt neutral. Half of the respondents indicated they had spent more than an hour in the library, while the other half had remained for several hours.

3. Innovation

The [redacted] Library sets a strong precedent for integrating geothermal and solar energy systems in civic architecture. Certified in 2024 as [redacted]'s first Net Zero Energy public building under the ILFI Zero Energy program, the project also achieved LEED v4 New Construction Gold certification in 2022. The use of closed-loop geothermal heating and cooling, combined with an on-site photovoltaic array, results in a completely electric facility that uses no fossil fuels for mechanical or domestic water heating.

The design team also prioritized cost-effective innovation. The geothermal system does not require backup boilers due to its optimized loop sizing and seasonal balance. By installing mechanical equipment within conditioned mechanical closets and eliminating rooftop units, the design avoids additional weatherproofing, structural loading, and long-term roofing penetrations.

The library integrates a control system that supports open-protocol communication and direct digital control (DDC). The system allows for full remote access and integration with [redacted]'s broader building management system. The same platform also controls the domestic hot water system, which was originally planned to operate through a heat pump tied into the GHEx. While this strategy was modified during construction, it reflects the team's intent to maximize thermal integration and system synergy.

4. Operation and Maintenance

All HVAC equipment is located in accessible mechanical spaces to simplify maintenance procedures. By using a standardized line of GSHP units throughout the facility, the operations staff can maintain a limited spare parts inventory. All units are specified from a single manufacturer and are

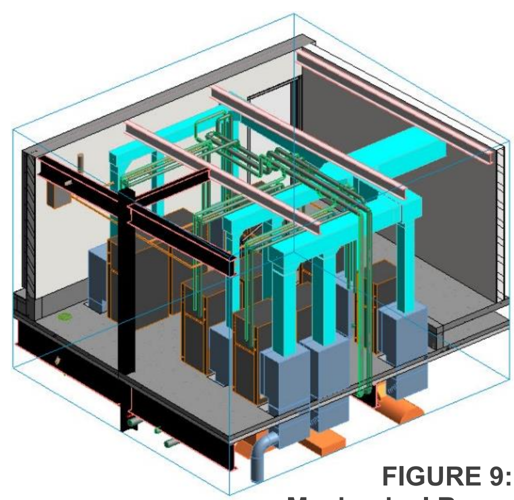


FIGURE 9: Mechanical Room

installed in a way that supports fast service, including front-facing filter access and built-in condensate protection. The geothermal loop is sealed and does not require antifreeze or chemical maintenance. System flow and temperatures are continuously monitored by the BAS. The system provides trend data, alarm notifications, and real-time feedback on equipment run-time hours and filter pressure drops.

One change that was made late in the design was the method of heating culinary water. The original design intent was to utilize a dedicated water to domestic water heat pump tied to the ground heat exchanger. At the last minute, literally as construction documents were being issued for bid, we found that the basis of design equipment was not able to reliably perform the role, and we switched to electric water heaters. While not as efficient as the ground source unit, it was still more efficient than gas-fired equipment, and also kept the project on track for our net-zero design goal.

Meters were installed on the building and on various electrical and water systems to allow tracking of specific energy end-uses. Building level end uses include domestic water heating, domestic water use, lighting and receptacle loads. Energy systems included heating/cooling systems, HVAC fans, and circulation pumps. Data from the meters is recorded and stored by the BMS. BMS data reports for energy meters are formatted for hourly, daily, monthly and annual totals for use by [redacted] in tracking energy use within the facility. Utility bills from rocky mountain power, the utility service provider in the region, were also used to track monthly energy use and energy costs. In addition to energy use monitoring, on-site PV generation was monitored using the solar edge platform.

The combined commissioning and training efforts helped close the gap between design and actual building performance, enabling [redacted] Library to operate as a high-performance, adaptable community resource.

- **Commissioning Process:** The commissioning plan for the [redacted] Library focused on ensuring all mechanical, electrical, and plumbing (MEP) systems were installed and operated according to design intent. This included thorough functional testing, system verification, and tuning post-occupancy to optimize performance. Special attention was given to complex systems such as the innovative ground source HVAC and photovoltaic arrays, requiring detailed startup procedures and continuous monitoring to achieve net zero energy goals.

- **Staff Training:** Library operations staff received targeted training on building systems to support efficient operation and maintenance. This included hands-on instruction on HVAC controls, lighting systems, and energy management tools, emphasizing how to monitor and adjust setpoints and schedules to match real-world occupancy patterns. Training also covered routine maintenance tasks and troubleshooting to ensure sustained system performance.
- **Integration of Training and Commissioning:** The commissioning team worked closely with library staff to transfer knowledge, providing documentation, walkthroughs, and follow-up support. This collaboration enabled staff to understand system capabilities and limitations, empowering them to maintain occupant comfort while maximizing energy efficiency.

Five key lessons learned during first year of operation

- **Continuous Commissioning and System Tuning**: Post-occupancy adjustments to HVAC schedules and setpoints, daylight sensors, exterior lighting schedule, were needed to align with actual occupancy and use, as initial settings didn't fully match real operations.
  - Daylight sensor low thresholds were set too high and had to be re-set at 20% of max output.
  - HVAC schedule was initially set at 6am to 10pm which was changed to 6am to 8pm based on feedback from library staff allowing setback operation sooner.
  - Heating Occupied/Unoccupied temperatures were set at 70F/64F which was changed to 69F/64F
  - Cooling Occupied/Unoccupied were set at 76F/82F which was changed to 76F/85F
- **Maintenance and Verification Are Crucial**: Regular checks and comparison of anticipated and actual PV generation revealed discrepancies. Monitoring the Solar Edge interface enabled identification of a non-functional inverter on a PV array. Site visit revealed that a few PV panels blew away in a strong rare windstorm which were replaced. These events highlighting the importance of field verification and maintenance, especially for complex systems on site.

- **Adapting to Real-World Use**: Actual occupancy and programming differed from design assumptions, requiring flexible operations and scheduling to support community needs.
- **Value of Post-Occupancy Evaluation**: Third-party certification efforts drove active monitoring and issue identification, helping close the gap between design intent and real performance.
- **Community Engagement and Flexibility**: Library staff engagement led to well-used, adaptable spaces that respond effectively to evolving community demands.

5. Cost Effectiveness

The annual energy costs for this building based on data from year 2023-2024 are about $11,390. This is a 70% lower operational energy cost as compared to a CBECS national median library, saving the client about $27,153 annually.

FIGURE 10: [redacted] Power Net Billing Schedule 137 - Summary

	Energy Charges (cents/kWh)	Demand Charges ($/kW)	Export Credit (cents/kWh)
Oct-May (winter)	3.445	11.74	4.745
Jun-Sept (summer)	3.888	13.27	6.739

The team was unable to fully investigate the difference between the modeled and actual measured Energy Use Intensity (EUI) because the building does not have end-use energy monitoring in place. Despite this limitation, the team reviewed commonly undercounted end-uses, such as pumps and miscellaneous equipment. Specific miscellaneous loads—including the book sorting machine, maker space equipment, and computers—were evaluated to determine if their actual consumption significantly deviated from the modeled plug

FIGURE 11: Energy and Cost for an Entire Year
**See Figure 2 for graph of this data*

Billing Cycle		Estimated Energy Use	Actual Energy Use	Estimated PV Generation	Actual PV Generation	Net Energy Cost	credit $	$
01/08/24-02/06/24	Jan	19,206	22,640	9,566	10,400	1,496	178.41	1,674
02/06/24-03/06/24	Feb	16,597	21,250	12,881	14,850	1,204	373.9	1,578
03/06/24-04/04/24	Mar	16,111	19,148	20,741	21,068	738	836.01	1,574
04/05/23-05/04/23	Apr	13,562	21,030	25,288	26,470	1,460	326.46	1,787
05/04/23-06/08/23	May	12,533	20,870	29,076	33,110	313	811.03	1,124
06/08/23-07/06/23	Jun	12,739	18,933	31,254	29,013	562	847.42	1,409
07/06/23-08/04/23	Jul	14,821	21,690	29,739	27,290	619	959.6	1,578
08/04/23-09/07/23	Aug	15,171	23,920	26,614	27,360	530	967.76	1,497
09/07/23-10/05/23	Sep	12,164	16,230	21,783	23,270	577	766.77	1,344
10/05/23-11/07/23	Oct	14,059	20,360	16,669	22,040	938	603.56	1,542
11/07/23-12/06/23	Nov	16,210	20,200	10,513	10,520	1,343	220.17	1,563
12/06/23-01/08/24	Dec	19,427	25,480	7,861	11,560	1,610	201.19	1,811
Total kWh		182,600	251,751	241,984	256,951	**11,390**	7,092	18,483
Total kBtu		623,031	858,974	825,650	876,717			
EUI		23.3	32.1	30.9	32.8			

and miscellaneous load assumptions. It was determined that these loads did not account for the observed discrepancy between modeled and actual EUI. Additionally, the team noted that the energy modeling software used, eQuest, has significant limitations when modeling ground source heat pump (GSHP) systems. These limitations may contribute to variations between the modeled and actual EUI. However, due to the lack of HVAC end-use energy data, the team was unable to confirm whether the GSHP modeling limitations were a primary source of the discrepancy.

6. Environmental Impact

The [redacted] Library community wanted “wild space” with a return to natural plantings surrounding the library which are drought tolerant and nurture local wildlife. The wish list also included lots of walking paths and bike trails and resulted in a 25-foot-wide pathway sweeping up to a green roof (Figure 12). Light tunnels from the roof to the first floor further add natural lighting and energy efficiency.

FIGURE 12: Green Roof

ILFI Zero Energy program prohibited use of fossil fuel and required no combustion onsite. The operational carbon footprint of this building is at 69 MT-CO2e, avoiding 64 MT-CO2e as compared to the national median per CBECS 2024. Although the actual water use has been monitored and compared with estimated like energy, it was anticipated that landscape would use 60% less water than typical baseline (EPA Water Budget) and indoor fixtures would use 32% less water than typical baseline (LEEDv4), saving about 480,000 gallons of water every year.

[redacted] branch manager, [redacted], said she enjoys taking visitors on a tour of the building and seeing the awe on their faces when they realize how the library is sustainable and environmentally friendly.

FIGURE 13: Library Interior