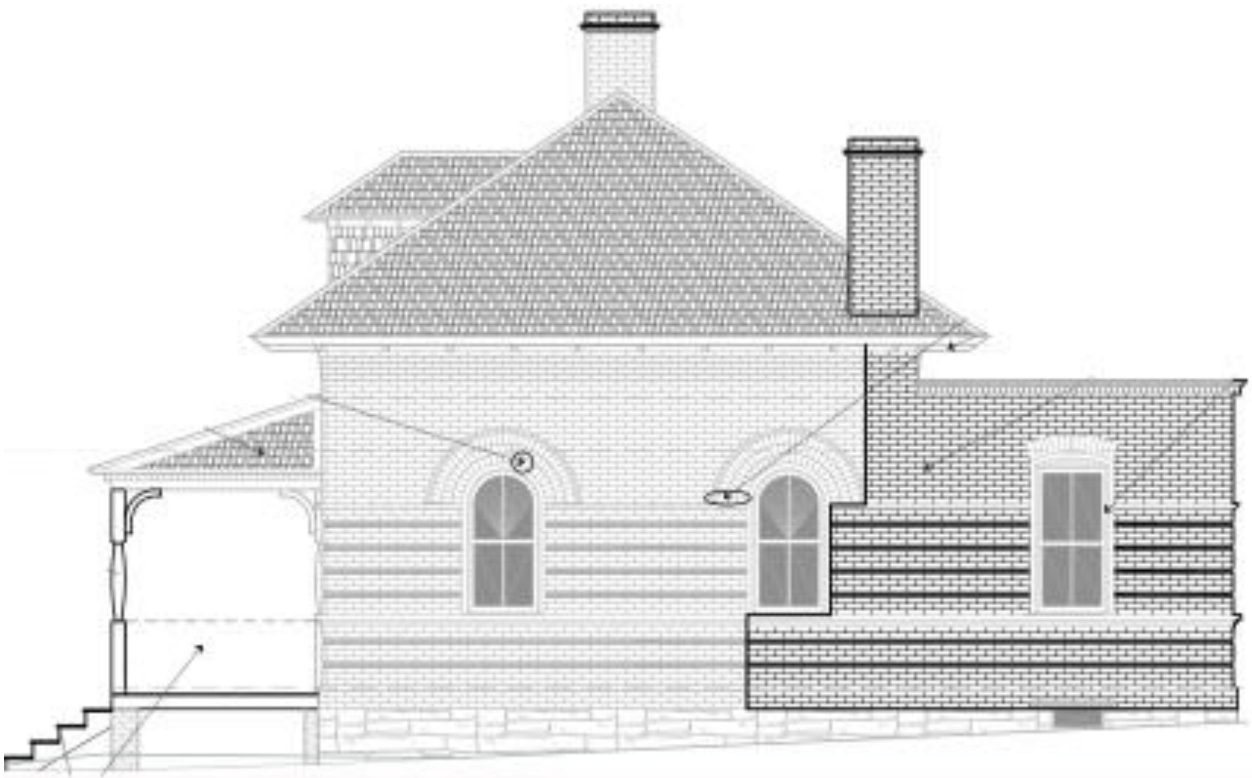
Intermediate Design Report



March 5th, 2020

S.S. Brickhouse

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Project Overview

Brickyard House Background

The Brickyard House was built in the early 20th century to serve as a showcase of the ornate brick types produced by Golden Pressed & Fire Brickworks while it was operating [1]. Since its initial construction, the Brickyard House has served many purposes that range from a family home, to an office building, to a house for night watchmen, and even as a shelter for horses [1]. Golden Landmarks Association (GLA) has completed Phase 1 of the project's restoration and has restored the exterior to its original condition. Phase 1 was funded using grants from the City of Golden (CoG) and the Colorado State Historical Fund [2]. Currently, the property is designated as a historic landmark by the CoG, and it is GLA's goal to list the property on the State and National Registers of historic places following the restoration completion.

The Brickyard House is also of importance to the CoG and its Sustainability Initiatives because there is potential for a ground mount solar array on an open, south facing slope on the property. The Brickyard House property could be used to contribute to the CoG's goal to achieve 100% renewable energy for electricity by 2030 by providing solar energy to the community. In addition, the Brickyard House can become an example to the community showing sustainable upgrades to an older/historic building.

The goals and vision of GLA and the CoG have shaped our project scope. Our project entails designing a ground-mount solar photovoltaic (PV) system capable of meeting or exceeding all potential energy needs of the Brickyard House. This includes designing a smaller solar array to meet the energy needs of the Brickyard House and a larger solar array that maximizes the potential of the available land on the property to create a community solar garden.

Problem Statement

The goal of our project is to maximize sustainable development while maintaining the historical integrity of the Brickyard House.

Project Deliverables

1. "Brickyard House" array specifically sized to support the electricity needs for the Brickyard House alone.
2. "Community Solar Garden" design which is sized to produce as much solar energy as possible with the land available.
3. Final Design Report
4. Site Plan
5. Cost Estimation
6. Material Specifications

Pre-Design Specifications

Regulations

General Photovoltaic Regulations

- Xcel energy requires that any residential PV system will not exceed 120% of the annual customer usage [3]. The Brickyard House is currently unoccupied and does not use much energy. Therefore, the annual usage is calculated based on the assumption that the future use of the building will be an office building.
- Jefferson County requires photovoltaic electrical plans, a building permit submission, an electrical permit submission, an underground electrical inspection, a final electrical inspection, and a final structural inspection before construction can begin [4].

Community Solar Garden Specific Regulations

- The CoG municipal code requires at least a five-foot minimum front setback for a solar garden that is less than 100 kW [5]. The available space for the solar array limits the solar garden to less than 100 kW.
- The solar panels cannot be placed within utility or drainage easements without written permission from the easement holder [5].
- The system must offset at least 10 percent of the overall energy use of the site regardless of size [5].
- The Brickyard House is in the PUD district, so special approval will be required [6].

Xcel Energy Regulations

- The nameplate capacity of a community solar garden must be 2 MW or less [7].
- The community solar garden is required to have at least 10 subscribers with no single subscriber acquiring more than 40% of the total garden allocation [7].
- The minimum subscriber allocation is 1 kW [7].
- The solar energy allocated to each subscriber cannot exceed 120% of the subscriber's annual energy usage [7].

Historical Building Considerations

- The solar array design cannot make any visible or hidden changes to the building that deviate from its original design.
- The solar panels and equipment cannot not be visible from anywhere in the building or its south-facing porch.

City of Golden Building Code

- Panels must withstand a snow load of 43 psf (pounds per square foot)[8].
- Must withstand a wind speed of 150 mph [8].

Design Analysis

Site Analysis

The first step in the design process was to analyze the topography of our site. Topographic data provided by Denver Regional Council of Government's (DRCOG) Regional Data Catalog for the CoG was compiled into AutoCAD Civil 3D software to map the physical contours of the site [9]. As shown in Figure 1 below, the site includes a retention pond with a south-facing slope. South-facing solar panels are optimal for energy production in the northern hemisphere. While the area of this south-facing slope is large, it is limited by three very important constraints.

Major Design Constraints

- High-water mark of the retention pond constrains the design to the South.
- Visibility from the porch of the Brickyard House constrains the design to the North.
- Approximately 30% slope along the entire area (18°).

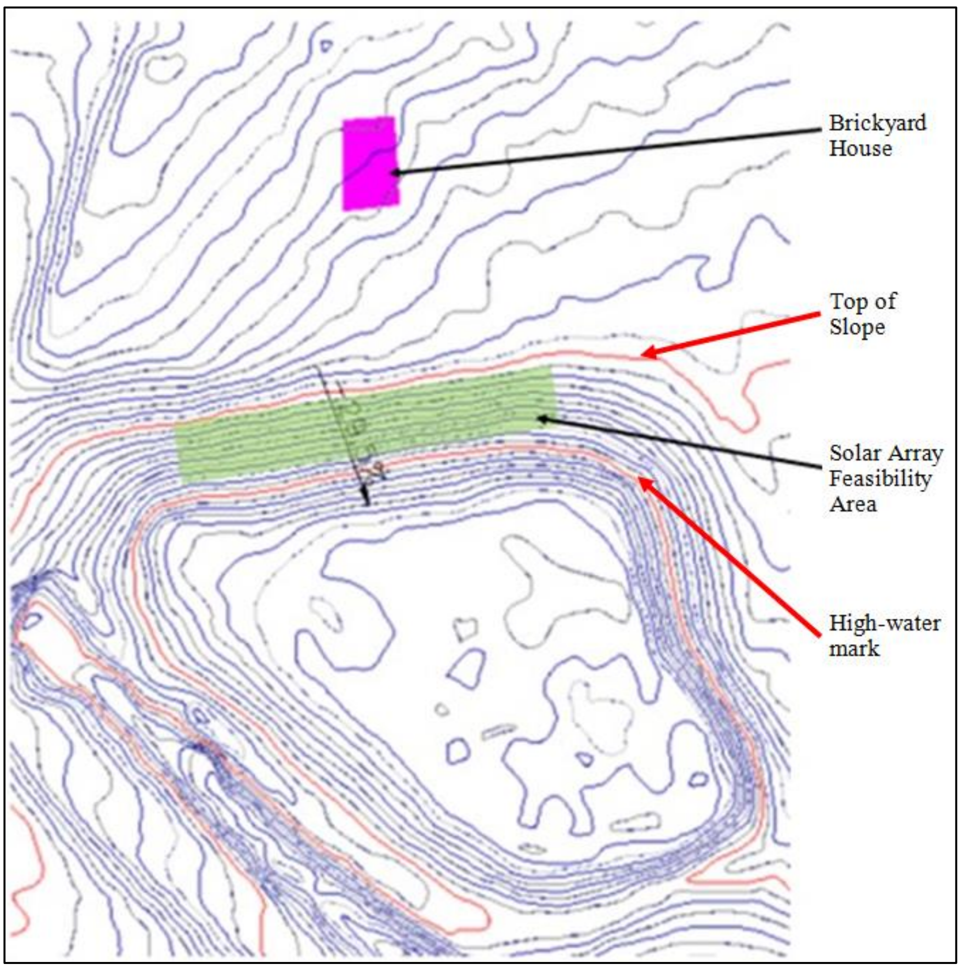


Figure 1: Feasible Area for Panels and Retention Pond Slope

The location and size of the array are constrained by the top of the slope and the high-water mark. The solar array must be located on the slope such that it is not visible from the Brickyard House porch. The height of the solar array must be minimized in order to eliminate visibility. The array must not be located below the high-water mark of the retention pond because the pond is designed to fill with water and that would compromise the system. The steep slope limits solar racking options the team could choose from. As seen in Figure 1, the grade of the feasible area is approximately 29.5%. The team researched a variety of different mounting options that could handle this slope; however, *most* mounting systems are only able to mount panels on hillsides with a maximum grade of 20% [10]. In addition to the slope, the soil must be capable of supporting a solar array without collapsing. A soil analysis of the site indicated that the area suitable for panels is located on critchell gravelly sandy loam. This type of soil has a high infiltration rate, which is generally favorable for construction since is minimally expansive overtime [11].

Energy Estimate

Brickyard House Design

For this project, the team has been tasked with two different design focuses. The first design focuses on providing a solar powered system that is designed to fulfill the anticipated energy needs of the Brickyard House. For the purposes of this design, it was assumed that the Brickyard House would be converted to an office setting. In addition to the normal electricity needs (lights, computers, appliances, etc.), the energy estimate for the Brickyard House includes the use of an electric heating system. The heater is estimated to run for 4 hours a day for six to eight months out of the year, using 7,500 W [12]. A typical house's water heater runs for 3 hours a day, and since there will be little need for hot water in an office setting, the water heater will be assumed to run for only 1 hour per day, using 4,000 W [13]. As a result, the estimated annual energy use of the Brickyard House is estimated to be between 19.2 and 27.5 MWh [14]. Since Xcel limits solar arrays to 120% of the annual electricity usage for the property, the Brickyard House design will be for 33 MWh (based on the upper estimate of 27.5 MWh).

Community Solar Garden Design

The second design focuses on maximizing the solar power generation with the available area in order to provide a solar array that is large enough to support a community solar garden. This community solar garden must comply with Xcel Energy regulations, CoG regulations, and historical site restrictions relevant to the site while also proving to be a worthwhile investment for the CoG. The limiting factor for the solar garden will be the land available for the solar array, with the energy generated being dependent on the solar panel layout and selection. The main reason for a community solar garden is to help the CoG achieve its goal for all electricity to be generated by renewable energy by 2030.

Solar Panel Selection

There is a wide variety of solar panels to choose from as the industry continues to grow and advance. Any solar installation is a long-term investment, so multiple factors were used to determine which solar panels will be used in the designs.

Solar Panel Selection Factors:

- Panel Efficiency
- Panel Wattage
- Power Output
- Performance Ratio
- Physical Size
- Compatibility with Racking Solution
- Cost
- Local Distribution Availability
- Manufacturing Location/Sustainability
- Warranty Options
- Lifetime Reliability

The solar panel selection process was fluid throughout the design process. As changes were made to the location, tilt, size, inverter, and racking solution, the solar panel selection was reevaluated. The performance ratio for each design was calculated using Helioscope solar modeling software. This software utilized the exact site location data, panel efficiency, inverter compatibility, tilt, and orientation of each design to produce energy output and performance ratio values. Figure 2 below shows part of a Helioscope report that displays the energy output and sources of loss in a solar array that reduce the performance ratio. Each controllable source of loss was minimized. Sources of loss that could not be controlled depended on weather and location such as soiling, iridescence, reflection, and temperature.

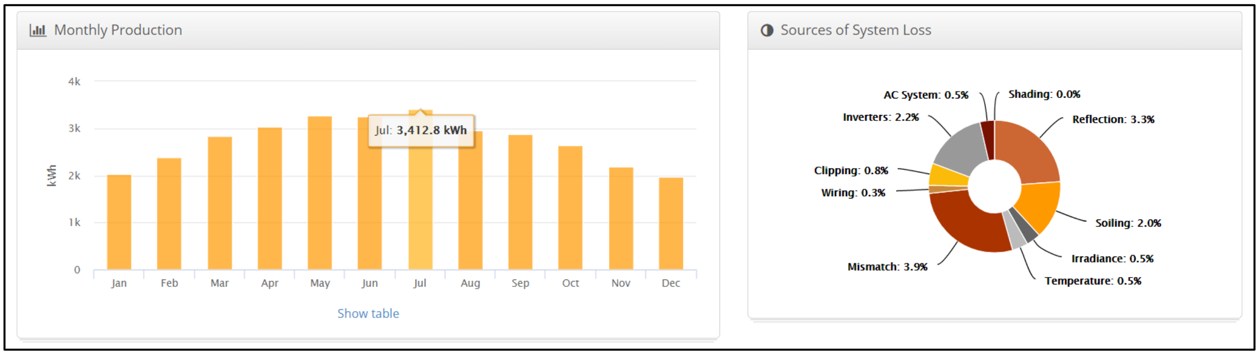


Figure 2: Helioscope Report Segment Showing Energy Output (kWh) and Sources of Loss

Inverter Selection

Inverters are needed for solar arrays because they convert the energy produced by the solar panels (DC) to energy that can be used by the grid or in a household (AC). The inverters used for a solar array is a crucial electrical component because a single inverter can be responsible for converting the power for the entire solar array (depending on the size). Microinverters are a different type of inverter that converts the DC power output from each individual panel into AC at the source (1 microinverter per panel). This type of inverter is most efficient and practical in very large solar arrays. Microinverters distribute the risk of inverter failure from a few inverters to one per panel. Microinverters are typically more expensive. The costs and benefits were weighed when determining the type of inverter to use.

Inverter Selection Factors:

- Efficiency
- Power/Wattage
- Compatibility with Array Size (DC/AC Ratio)
- Compatibility with Solar Panel Selection
- Type of Inverter (Traditional vs. Microinverter)
- Losses
- Cost
- Manufacturing Location
- Local Distribution Availability
- Warranty Options
- Lifetime Reliability

The power output of the selected inverter must be optimized for the size of the solar array. As the power output of the solar array changed based on restraint factors and solar panel wattage, the inverter selection was critiqued and optimized. A DC/AC ratio of 1.15 was found to be optimal for solar arrays. This ratio is a comparison between the power output of the solar array (DC) and the power that the inverter can convert into usable energy (AC). The Helioscope solar modeling software was used to calculate clipping and inverter losses for the solar array designs. These types of losses can be controlled by inverter selection and were minimized in design.

Racking Solution Selection

The racking solution for the solar panel array was a critical design selection because of the need to limit visibility from the Brickyard House and the steep slope of the site. In addition, the wind and snow load for Golden, CO is much higher than most of the United States. The wind load that the racking solution must withstand is 140 mph and the snow load is 40 psf according to the CoG building code. Most solar racking solutions are not designed to withstand high wind and snow loads or be placed on a slope. With the limitations depicted in Figure 1, our design needed to be short and wide to optimize the space on the slope.

Racking Solution Selection Factors

- Compatibility with Solar Panel Selection
- Ability to Withstand Wind and Snow Loads
- Compatibility with 30% Slope
- Ease of Installation
- Panel Orientation and Size
- Cost
- Manufacturing Location
- Local Distribution Availability
- Warranty Options
- Lifetime Reliability

All factors listed above were optimized to provide the best racking solution for the project. The Community Solar Garden design requires a much larger solar array than the Brickyard House design. The frame size of the solar array had to be compatible with the racking solution. The height of the solar racking system was minimized by refining the racking solution design.

Site Grading and Location Design Considerations

The Brickyard House team's overall goal is to maximize sustainable development while maintaining the historical integrity of the Brickyard House. Sustainable development includes both maximizing renewable energy sources and minimizing disturbances to the existing vegetation/ecosystem. Our team aimed to reduce the grading and site disturbance required for our designs as much as possible. These location considerations had to be kept within the area on the slope that was not visible from the porch of the Brickyard House.

Solar Array Location Factors

- Proximity to High-Water Mark
- Proximity to Top of Slope (Visibility Limitation)
- Cut-Fill Grading Ratio
- Lot Lines
- Size of Array Design
- Racking Height

The area that the solar array would be placed on was first determined by the size of the solar array needed for the design. Then, the selected area size was modeled in AutoCAD Civil3D. The location of the array was first compared to the high-water mark constraint shown in Figure 1. The north side of the solar array was compared to the maximum visibility elevation that could be seen from the Brickyard House porch which is at 5996 ft. This elevation was determined using Graphical Information System (GIS) points collected by the CoG's GIS Analyst. These points were overlayed onto the topographic site data in AutoCAD Civil3D. The max visibility elevation was calculated using the relationship between the location and elevation data. The north side of the solar array was located such that the height of the solar array did not exceed 5996 ft. The exact location of the solar array was reiterated with every design change to minimize the need for grading and minimize visibility from the Brickyard House porch.

Solar Array Orientation Design Considerations

The tilt of the solar panels and orientation were determined using site geography and an advanced solar design software called Helioscope. As mentioned above, our designs were focused on limiting both the height of the solar array and the need for grading on the site.

Solar Array Orientation Factors

- Tilt
- Orientation
- Site Geography
- Resulting Array Height
- Solar Performance Ratio

The optimal tilt for solar panels in Golden, CO is 35^{o} and the optimal orientation for solar panels is 180^{o}, or is true South [15,16]. Using these perfect case scenario values, the solar array would look similar to the Helioscope rendering in Figure 3 below.

Figure 3: "Optimal" Tilt and Orientation

With this orientation, the height of the solar array would be about 6 ft on the north end. The north end is the end closest to the Brickyard House. At this height, the solar array shown farthest from the Brickyard House would be visible by about 3 ft. The closer solar arrays would be even more visible. The tilt of 35^o creates this height. The orientation of 180^o causes the staggering of the solar array because the area between the red lines is not perfectly aligned due south (180^o). Although the 'optimal' tilt and orientation seem the right way to design, the tilt and orientation values were refined to maximize the number of solar panels that could be placed on the site while eliminating visibility from the Brickyard House.

Final Designs

Solar Panel, Inverter, and Racking Solution

Although the size and energy production of each design is different, the solar panel, inverter, and racking solution is consistent across both designs. The REC365 AA solar panel was chosen for both designs because it has the highest efficiency rates, performance ratio, and return on investment compared to all other panels. Other panels may have shown better values for one of those categories, but the REC365 AA panel excelled overall. The REC solar panels are readily available from local distributors and offer one of the best warranties for any solar panel on the market [17]. The REC solar panels are ethically manufactured in Singapore and come with a take-back program for end-of-life recycling that is free to the purchaser. The specifications for the REC365 AA panel and warranty information are included for our client in addition to this report.

The Fronius USA Symo 17.5 inverter was selected for both designs because of its compatibility with array sizes, lifetime durability, and market availability. The inverters are manufactured in the USA and are one of the most efficient inverters on the market [18]. The power input/output ratio is optimal for each solar design because the number of inverters used for each design is different. The Fronius USA Symo 17.5 inverter specifications and warranty information is included for our client in addition to this report.

The racking solution used for each design is provided by IronRidge. The IronRidge racking solution is specifically designed to withstand the wind and snow loads for Golden, CO. The racking system is also designed to be constructed on the existing slope of the site. The racking system is flexible because it can be designed in a 3-up, 4-up, or 5-up landscape orientation depending on the needs of a project. The Brickyard House design is smaller and used the 3-up design while the Community Solar Garden design maximized capacity with the 5-up design. The IronRidge racking solution was designed to minimize the height of the solar array and reduce visibility from the Brickyard House. This racking solution requires no heavy machinery to construct making it quick to install. The racking solution can be sourced locally from WESCO Distribution along with the REC365 AA panels. The specifications, warranty information, installation guide, and specific design information for the IronRidge racking system is included for our client in addition to this report [19].

Solar Array Tilt and Orientation

The tilt and orientation of the Brickyard House and Community Solar Garden design is different than what is stated as ‘optimal’ in the design analysis section. The tilt for the solar array has been reduced from 35^{o} to 20^{o}. The main reason for the angle reduction is the impact that the tilt angle has on the solar array height. When the angle is larger, the north clearance is taller making the array more visible from the Brickyard House. Figures 4a and 4b show the reduction in north clearance due to the change in tilt angle.

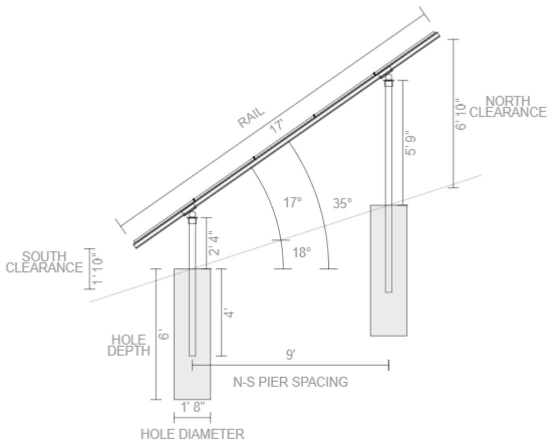


Figure 4a: 35^{o} Tilt

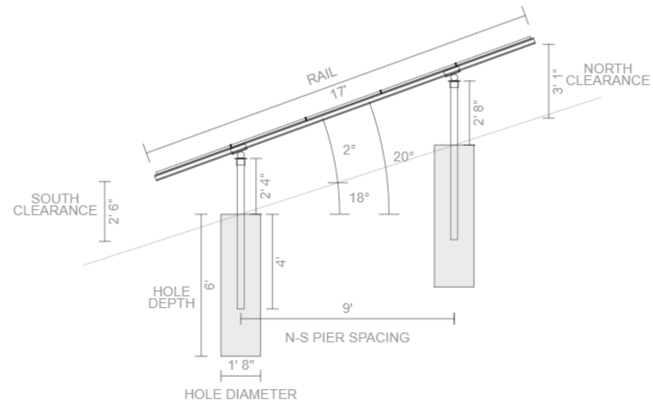


Figure 4b: 20^{o} Tilt

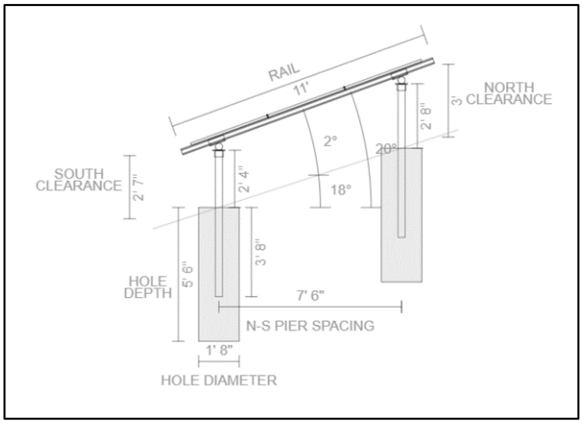
The use of a 20^{o} tilt aligns the solar array best with the slope of the existing topography and reduces the array height dramatically.

The true south orientation depicted in Figure 3 is 'optimal' based on the location of the sun in the norther hemisphere, but it was not optimal for maximizing the space available for our solar designs. The orientation of the existing slope is about 171^{o} as opposed to a true south orientation of 180^{o}. The Brickyard House and Community Solar Garden designs employ a 171^{o} orientation that almost perfectly matches the orientation of the existing slope. This orientation change both reduces grading needs and increases the solar capacity of the site.

Adjusting the solar tilt and array orientation from 'optimal' values resulted in a minor loss of energy output. This loss of energy output only affected the Community Solar Garden design as it was designed to maximize energy output. The Community Solar Garden design loses 5,600 MWh annually from a *change in tilt* which is only a decrease in the performance ratio of 0.2%. The annual energy loss is less than 5% of the total energy output of the Community Solar Garden array. This energy loss was considered negligible compared to the increase in solar capacity that the change in orientation provided for the design. The solar array shown in Figure 3 has 156 solar panels while the finalized Community Solar Garden design has 200 solar panels. This increases the energy output of the array by 22%. In addition, the solar panel arrays in Figure 3 are all visible from the Brickyard House while they are almost completely invisible with the 'non-optimal' design changes.

Visibility from Brickyard House Calculations

The height of the north clearance of the solar array was compared to the maximum visible elevation (5996 ft) to determine the visible height of the solar array. The exact north clearance of the solar array for each design is provided by the default IronRidge engineering drawings. The IronRidge racking design shows the highest that the design could be to be structurally sound. The default height is optimal for our design because of the high snow load present in Golden, CO. If the designs were lowered, snow would not slide off the array. This would greatly inhibit the energy production of the solar array. Figures 5a and 5b show the IronRidge racking designs for the Brickyard House design and the Community Solar Garden design, respectively.



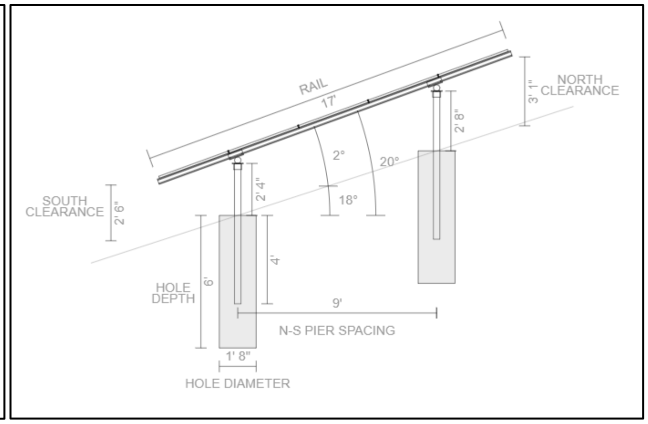


Figure 5a: Brickyard House Design Height **Figure 5b: Community Solar Garden Design Height**

The visibility from the Brickyard House porch was calculated using the north clearance (shown in Figures 5a and 5b) and the exact location of the solar array modeled in AutoCAD Civil3D. The area of the solar array was provided by IronRidge. The solar array was not visible from the Brickyard House if Equation 1 below is true.

$$5996\ ft\ \geq Elevation\ at\ north\ side\ of\ area + north\ clearance \qquad \text{[Eq. 1]}$$

The height of the array was crucial to each design and was minimized as much as possible to limit visibility from the Brickyard House.

Brickyard House Design

The solar array design for the Brickyard House focused on satisfying 120% of the maximum projected energy use of the Brickyard House alone. The energy production estimate is 33,000 kWh per year which is the maximum amount of solar energy production allowed for the Brickyard House according to Xcel Energy. Our team focused on designing as close to this energy production goal as possible without exceeding it and violating Xcel Energy regulations. A visual representation of the Brickyard House design is shown in Figure 6 below.

Figure 6: Helioscope Visual of Brickyard House Design

By integrating all design factors listed in the last section, our team designed a solar array that satisfies 98% of the maximum energy production goal for the Brickyard House and is not visible at all from the Brickyard House porch. All selection factors listed and explained in the Design Analysis section were considered for this design. An organized overview of the Brickyard House design is shown in Table 1 below.

Annual Energy Production	32,300 kWh
Number of Solar Panels	54
Number of Inverters	1
Performance Ratio	0.871
Visibility from Brickyard House	0 in
Estimated Cost	$63,700
Payback Period	16.6 years

Table 1: Overview of Brickyard House Design

The Brickyard House design does not reach exactly 100% of the energy production goal because racking solution for this design is oriented in 3-up landscape. When solar panels were added or subtracted from the design, it was done in groups of three. So, to reach 100%, three more panels would have to be added and this would cause the solar array to exceed the maximum allowable energy production for the solar array according to Xcel Energy's regulations. It is possible to add a single solar panel onto the array and reach 99% of the energy production goal but this would require the racking system to provide space for three additional solar panels. This miniscule addition is not beneficial from a cost perspective or an energy perspective for the client and is not recommended. As mentioned before, the maximum energy production goal for the Brickyard House design is 120% of the maximum energy use estimate for the Brickyard House. There would almost never be a time when the Brickyard House requires 120% of its energy use. For most of the year, the Brickyard House solar design would be overproducing energy for the Brickyard House and selling the excess back to the grid. The estimated cost and payback period will be discussed later in this report.

Community Solar Garden Design

The Community Solar Garden design focused on maximizing the solar capacity on the south facing slope of the retention pond while staying within the design constraints discussed earlier. An additional design consideration of the Community Solar Garden design was to find its capacity to cover the energy use demands of the other historic buildings in Golden, CO. Historic buildings possess more obstacles for placing renewable energy sources on site because of historic building regulations. Typically, placing solar panels on the roof of a historic building is prohibited. The proposed ground-mount community solar garden on the Brickyard House site is a great opportunity to allocate renewable energy sources for historic buildings without interfering with the historic integrity of the building. Figure 7 below shows a visual representation of the Community Solar Garden design.

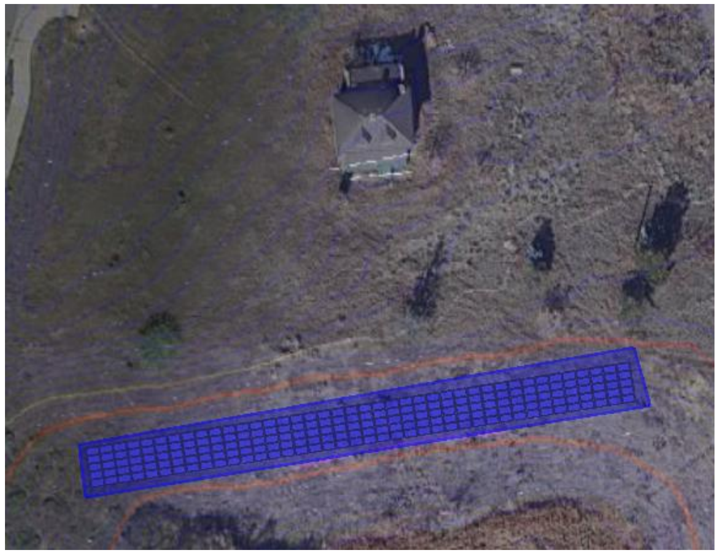


Figure 7: Helioscope Visual of Community Solar Garden Design

The space available was maximized to produce the most energy while limiting visibility from the Brickyard House and limiting disturbance to the existing topography. The Community Solar Garden array satisfies 135% of the historic building energy load in the CoG. The historic buildings included in the energy estimate were discussed earlier in the report. Overall, the Community Solar Garden design covers Golden's historic building energy load and produces an extra 31,000 kWh annually. This extra solar energy can be used to include more historic buildings or any subscribers that the CoG chooses. The average annual energy use for an American household is 10,000 kWh [20]. The Community Solar Garden design has the potential to supply energy for all historic buildings in Golden and three residential houses. Table 2 below shows an organized overview of the Community Solar Garden design.

Annual Energy Production	120,500 kWh
Number of Solar Panels	200
Number of Inverters	4
Performance Ratio	0.877
Visibility from Brickyard House	11 in
Estimated Cost	$199,700
Payback Period	10.2 years

Table 2: Overview of Community Solar Garden Design

The Community Solar Garden design has maximized the available space on the south facing slope of the site, but; 11 inches of the array is visible from the Brickyard House porch (according to our topographic and GIS data). Our design team chose to select this design rather than reducing the racking height from 5-up to 4-up landscape because we have a solution to limit visibility. Our solution is to use native foliage that grows to a maximum of 1.5 ft in height along the north side of the solar array. Two recommended native shrub options are *rabbitbrush* and *sagebrush*. These two shrubs are already present on the Brickyard House site and the surrounding foothills. These species are native and non-invasive. Figures 8a and 8b below show images of these two shrubs which are easily recognizable in Golden already.

Figure 8a: Rabbitbrush **Figure 8b: Sagebrush**

This foliage would be lower than knee height and bring the view from the Brickyard House back to one that looks completely natural. The shrubs would not inhibit the energy production of the solar array at all because they are on the north side of the array and the sun is always located to the south in the northern hemisphere. The massive solar array sitting on the south slope of the retention pond will be completely invisible within a year of construction. As a team, we believed that this a wonderful compromise for introducing a renewable energy source for the CoG that would also benefit the Brickyard House. The estimated cost and payback period will be discussed later in this report.

Cost Estimation

Racking Costs

The Racking Costs include the IronRidge racking materials and the cost of concrete for the racking foundation. The cost for the IronRidge racking materials was quoted by WESCO Distribution for the Brickyard House and Solar Garden Designs, respectively. The cost for the concrete was estimated using local Denver area concrete suppliers.

Solar Panels and Electrical Equipment Costs

The Solar Panels and Electrical Equipment costs include all electrical equipment needed for the solar arrays to function. This includes the REC365 AA solar panels, the Fronius Symo 17.5 inverters, and surge protectors. The cost of the copper wire to connect the panels to each other, to connect to the grid, and to supply electricity to the Brickyard House onsite was also included. The cost for the solar panels were quoted from the Denver office of WESCO Distribution at $287.69 each.

Civil and Installation Costs

The civil and installation costs were found by comparing the estimated racking costs and the solar/electrical costs to the Photon Brothers' estimate. Photon Brothers is a local REC certified solar installer which means that the solar panels would receive an extra 5 years of warranty. A REC certified installer ensures that the REC panels are installed correctly and safely so that they can reach their highest performance. These costs include all the labor and machinery needed to install and connect the solar arrays to the grid and to the Brickyard House.

Total Costs

The total cost estimation for each design is shown in Table 1 below.

Design	Racking Costs	Electrical Equipment Costs	Civil/Installation Costs	**Total Upfront Cost**
Brickyard House	$8,700.00	$20,500.00	$34,600.00	**$63,800.00**
Community Solar Garden	$26,100.00	$76,400.00	$97,100.00	**$199,600.00**

Table 1: Total Cost Estimation

Payback Period

The payback period for the Brickyard House design is 16.5 years. The payback period for the Community Solar Garden design is just over 10 years. Both payback period calculations begin with the upfront cost. Then, Xcel Energy's Solar*Rewards program and annual electricity bill savings are incorporated as positive cash flow. The Brickyard House design (19.7 kW) qualifies for Xcel Energy's 'small' solar energy system because it is between 0.5 kW and 25 kW. This will provide the Brickyard House design with $0.005/kWh annually for 20 years after installation. The Community Solar Garden design (73.0 kW) qualifies for Xcel Energy's 'medium' solar energy system. The Community Solar Garden design will earn $0.0375/kWh annually for 20 years after installation. The Solar*Rewards savings were estimated assuming that the energy production of the solar panels depreciate by about 0.3% each year. The electric bill savings were calculated annually assuming the energy production depreciation and assuming the cost of electricity will rise over time. After 15 years, operation and maintenance costs are included yearly as estimated by Photon Brothers. A detailed 30-year cost estimate is shown in the included Excel spreadsheet. A year-by-year breakdown of the payback period was provided in a quote from the Photon

Brothers. Table 2 shows an overview of the upfront cost, payback period, 30-year electricity bill savings, and Solar*Rewards savings for each design.

Design	Payback Period (yrs)	Upfront Cost	20-year Total Solar*Reward Payback	30-Year Electricity Bill Savings
Brickyard House	16.6	$63,800.00	$2,810.00	$147,300.00
Community Solar Garden	10.2	$199,600.00	$108,300.00	$635,700.00

Table 2: Payback Period, Upfront Costs, Solar*Rewards, and Electricity Bill Saving for Each Design

Risk Analysis

This project had many risks to consider. Of these risks, there were 2 high-risk factors (20-50% probability), 3 medium risk factors (5-20%), and 9 low risk factors (0-5%).

High-Risk Factors

Array Installation: Since the array is on a 18°, there is a high risk of injuries to the construction workers as well as damage to equipment during the construction process. To combat this, we recommend using an experienced and certified local installer such as the Photon Brothers.

Cost Estimation: There is a high risk that the cost of the project is underestimated due to minimal experience and expertise in our team. To prevent this, we have spoken with suppliers and experts in the field, and we will also be estimating the cost at 110% of our calculated price to allow for a comfortable margin of error.

Medium-Risk Factors

Visibility of Solar Panels: The risk that the solar array visibility from the Brickyard House porch is underestimated stems from surveying error and miscalculation. To minimize the error in our calculations, we used GIS location data in addition to an in-person visual assessment to determine the design constraints. We also recommend conducting a more accurate and in-depth survey of the area for added accuracy in the design.

Proximity to High Water Mark: Similar to the solar panel visibility, this risk also stems from surveying error. The surveying error is estimated to be 4 inches, so the array has been placed one foot above the high-water mark. To confirm this, a more accurate and in-depth survey should be taken of the area before construction begins.

Soil Degradation and Water Sedimentation: This risk is a result of the construction process in which the land is disturbed, creating the potential for erosion and uncontrolled storm water runoff, leading to clogged stormwater pipes. This can be easily prevented through a construction plan that considers runoff and erosion as well as re-seeding the disturbed land after construction is complete.

Low-Risk Factors

Soil Failure: Soil failure could cause damage to the solar panels and racking system. To prevent this, a soil report from the USGS was used, and the racking system was designed for the worst-case scenario soil.

Chemical Leaching, Panel & Racking Failure, and Installation Risks: If the solar panels are installed incorrectly, there is a higher chance that the panels will be damaged, producing chemical leaching and bad panel performance. Incorrect installation also leads to increased risk of injury. To prevent and minimize these risks, an REC certified installer should be used, since they are trained specifically in the installation of REC panels. In addition, when installed by an REC certified company, there is a 25-year warranty for the panels. Further preventative measures include routine maintenance and inspection on each section of the array.

Vegetation and Wildlife Interruption: Since the site being developed is the slope of a drainage pond, there is little wildlife and vegetation in the area. This makes the risk easy to avoid by simply reseeding the area disrupted during construction with native grass and plants.

Maintenance Risks: These risks include injury from slipping and electrocution, in addition to damaging the panels. To prevent this, all maintenance should be done by an experienced maintenance worker.

Inverter Failure: Inverter failure can occur from lightning strikes, power surges, and normal wear and tear. These risks can be mitigated by using surge protectors and scheduling regular maintenance and inspections [21].

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