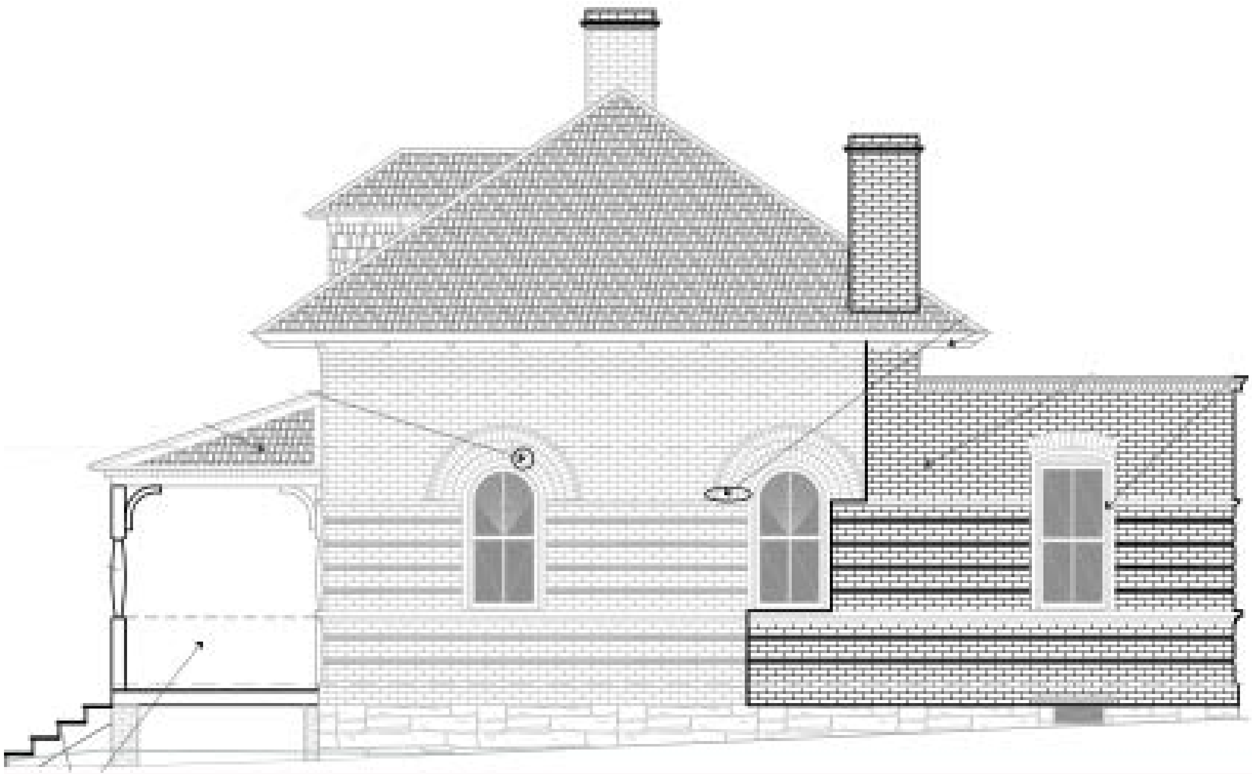
Preliminary Design Report



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S.S. Brickyard House

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Background, Boundaries, and Characteristics

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 more than a century ago [1]. Since its initial construction, the Brickyard House has served many purposes, ranging from a family home, an office building, house for night watchmen, and even as a shelter for horses [1]. Golden Landmarks Association (GLA) has completed the Phase I of the project's restoration, and has renovated the exterior to the original condition, funded by a $50,000 grant from the city of Golden, as well as a $140,000 grant from the State Historical Fund [2]. Currently, the property is designated as a historic landmark by the city of Golden, and it is GLA's goal to list the property on the State and National Registers of historic places following completion of the restoration.

In addition to the goal to fully restore the property and showcase the property as a significant historical site, the City of Golden also aims to decrease the environmental footprint of the building, with the goal of the overall property being Net Zero. This goal of making the property Net Zero defines the objective for our team. Our project entails designing a PV system capable of meeting or exceeding all potential energy needs of the building. Although the scope of our project is only limited to the Brickyard House, it is the city's hope that this property can serve as an example to the larger community on how it is possible to renovate historic properties to reduce their environmental impact, while still maintaining the historic integrity, as Golden has one of the largest numbers of historic buildings from the early 1900s in the state of Colorado.

There are additional constraints on alterations to the Brickyard House because the project has previously received a large amount of funding from the state historic fund. These constraints define that our team cannot make any visible or hidden changes to the building that deviate from its original design. The constraints also limit the design of the panels and equipment, as they cannot not be visible from anywhere in the building or its porch. Although these limitations place additional challenges on the design of the project, the panels can be visible from other places on the property, and the large lot size and natural south facing slope make the site a relatively optimal location for placing ground mounted photovoltaic panels.

Design Specifications

General Photovoltaic Regulations

Any property that desires to have a solar energy system will need to abide by regulations from the utility supplier (Xcel Energy) and the City of Golden.

Xcel energy requires that any residential PV system will not exceed 120 % of the annual customer usage [3]. Since the Brickyard house does not currently use much energy, the annual usage is calculated based on the assumption that the future use of the building will be an office building.

Before construction of the project can begin, 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 if necessary [9].

Community Solar Garden Specific Regulations

According to the City of Golden's municipal code, if a garden is less than 100 kW, then there must be at least a five-foot minimum front setback [4]. Also, the solar panels can't be placed within utility or drainage easements without written permission from the easement holder [4]. If the garden is larger than 100 kW, the same regulations apply; however, there are a few more regulations that need to be addressed [4]. A planning commission must find that there is no significant adverse impact on the natural or manmade characteristics of the area, and they must find that the proposal minimizes the glare on nearby roads [4]. Also, the site cannot exceed 500 kW unless the property is within the R3, C1, C2, M1, or M2 districts without authorization from the planning commission [4]. The Brickyard House is in the PUD district, so special approval would be required [5]. The system must also offset at least 10 percent of the overall energy of the site regardless of size [4].

In addition to regulations required by the City of Golden, Xcel Energy has regulations governing a community solar garden. As the community solar garden will be tied into Xcel Energy's grid, this project must also take these regulations into consideration. Xcel Energy limits the nameplate capacity of a community solar garden to 2 MW or less [27]. The community solar garden is also required to have at least 10 subscribers with no single subscriber acquiring more than 40% of the total garden allocation [27]. The minimum subscriber allocation is 1 kW and the solar energy allocated to each subscriber cannot exceed 120% of the subscriber's annual energy usage [27].

Site Analysis

The area in which the solar panel design would be located was determined using topographic data provided by Denver Regional Council of Governments (DRCOG) Regional Data Catalog for the City of Golden [28]. This data was compiled into AutoCAD Civil 3D software to project the topography of the site. As shown in Figure 1 below, the project site includes a retention pond with a south-facing slope, which is optimal for the effectiveness of photovoltaic panels. The area of this south-facing slope is large; however, it is limited by two vertical constraints. The first of these constraints is the high-water mark of the retention pond. The second of these constraints comes from historic regulations mentioned earlier that state the panels cannot be visible from the porch of the house. After reviewing the topography of the site, the team was able to establish a general boundary area where the solar panels could feasibly be placed.

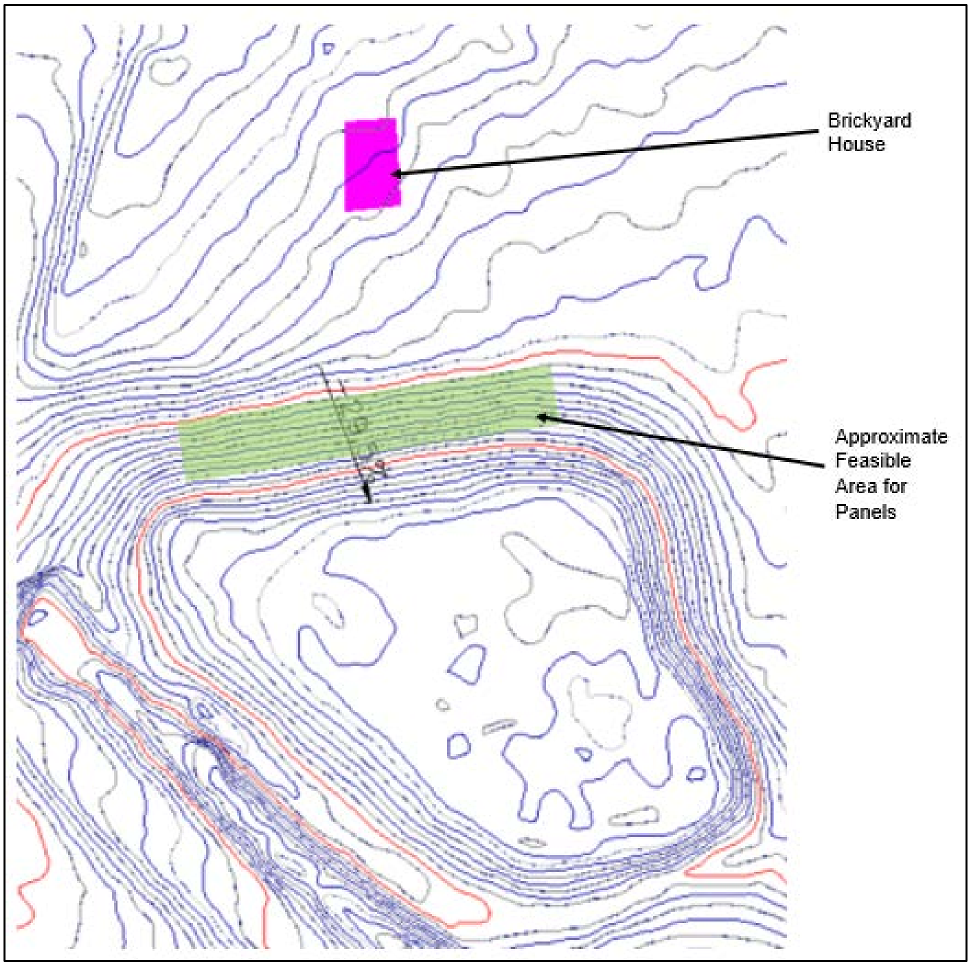

Figure 1: Feasible Area for Panels and Retention Pond Slope

One challenge that the analysis of the site revealed was the limited options for mounting panels. As seen in Figure 1, the slope 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 slope of about 20% [6]. At this point, the team has found one manufacturer that builds mounting systems capable of supporting panels on slopes as steep as 36% with any quality of soil [7]. We are currently researching this option to find more specifics on the pricing and capabilities of this mounting system with our selected panels. Grading the site to reduce the steepness of the slope is another option that the team will analyze for feasibility. Civil costs associated with grading tend to be much higher than premiums associated with more advanced mounting systems. So, we are focusing our research on more alternatives which avoid having to do earthwork. A soil analysis of the site indicated that the area suitable for panels is composed on critchell gravelly sandy loam [8]. This type of soil has a high infiltration rate, which is generally very favorable for construction, as it is much less expansive overtime [8]. Although more expensive, the good soil would be beneficial if grading is required because better soil would likely not need to be brought in from offsite.

Concept Exploration

Sizing Rationalization

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 connected to the utility grid 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 and thus would use similar energy requirements.

Typical office buildings use between 13.2-16.9 kWh/ft^2 [10]. Generally, office buildings will use natural gas for their heating needs; however, it is the goal of the city to move away from natural gas by converting the heating elements to electric systems. This adds significant energy usage to the building. A heater for a home runs for about 4 hours a day for six to eight months out of the year [11]. A typical water heater works for 3 hours a day [12]. For an office such as this, there will be little need for a shower, bathtub or other appliances that use large amounts of hot water. As a result, the water heater was assumed to be in use for 1 hour a day. The water heater was assumed to be 4,000 W and the house heater was assumed to be 7,500 W [11, 12]. As a result, the total energy of the Brickyard House is estimated to be between 19,200 and 27,500 kWh over the course of a year. The design of the system was based on 120 % of the high end of the usage of the building (approximately 33,000 kWh).

The second design focuses on maximizing the feasible area on the south facing slope of the retention pond to provide a solar array that is large enough to support a community solar garden. This community solar garden had to comply with the Xcel Energy regulations, City of Golden regulations, and historical restrictions relevant to the site while providing enough energy to be a worthwhile investment for the City of Golden. One of the main drivers behind the idea of a community solar garden is to help the City of Golden achieve 100% renewable energy by 2030.

Recommended Materials

Several options for solar panels were explored and the best panels for this project were selected to be used in solar modeling for each design focus. These panels have differences in specifications based on efficiency, power, etc. Power output influences how much energy the solar panels will be able to produce. The efficiency influences how much of the power that is available to the system is converted to electricity. The Average Power Temperature Coefficient determines how much the efficiency decreases as the temperature increases above 25 degrees C [13]. The efficiency increases as the temperature decreases below 25 degrees C as well [14]. The recommended solar panels are shown in Table 1.

Table 1: Recommended Solar Panels and Relevant Specifications

Solar Panel	Power Output (W)	Efficiency (%)	Average Power Temperature Coefficient %/C°
SunPower SPR-E20-345-COM-VC [15]	Nominal: 435 Average: 439	20.3	-0.38
REC Group REC Alpha (measured at STC) [16]	360-380	20.6-21.7	-0.26
REC Group REC Alpha 72 (measured at STC) [17]	430-450	20.3-21.3	-0.26
Solaria PowerXT-360R-PD [18]	Max: 360	19.9	-0.39

There were also several inverters selected for this project. These inverters vary based on voltage, power, and several other factors. The voltage influences whether it can be tied directly into the house and the output power determines how many inverters are needed to support the system (higher output power reduces the number of inverters). The recommended inverters are shown in Table 2. Since the residential connection is 120 V, the Sunny Tripower Core1 inverter is large enough that it may need a transformer to connect to the Brickyard House [19]. This module is best for the solar garden design.

Table 2: Recommended Inverters and Relevant Specifications

Inverter	AC Voltage (V)	Output Power
Sunny Tripower Core1 33kW [20]	480 V/277 V WYE	33.3 kW
Fronius Symo 15.0-3 208 [21]	208 V	15000 VA
15 kW Fronius String Inverter Primo 15.0 TL [22]	208/240 V	208 V: 13750 W 240 V: 15000 W

There are a few micro-inverters that might be reasonable for the solar panels. Micro-inverters are inverters tied to only one solar panel [23]. These are good for increasing efficiency of the system overall and improving the reliability of the system. However, micro-inverters do tend to have a higher up-front cost [23]. The recommended micro-inverters are shown in Table 3. Note that the micro inverters are built into the first two SunPower AC modules.

Table 3: Recommended Micro-inverters and Relevant Specifications

Micro-Inverter	Voltage	Max Power
SunPower E20-327-C-AC 17 [24]	208/240 V	320 W
SunPower X22-360-C-AC 17 [25]	208/240 V	320 W
SunPower SPWR-A4 [26]	240 V	349 W
Solaria IQ7X-96-2-US (240) [26]	240 V	315 W

Preliminary Concept Designs

Site Analysis and Overlays

The topographic data shown in Figure 1 above was overlaid into the solar modeling software Helioscope. Figure 2 shows the overlay of the topographic data into the solar modeling software at the location of the Brickyard House site. In Figure 2, the two topographic lines highlighted in red represent the beginning on the slope (top) and the high-water mark (bottom) on the detention pond. The solar array designs for both the Brickyard House and the community solar garden were limited to the area between the two red lines shown in Figure 2.

Figure 2: Topographic Overlay in Helioscope Solar Modeling Software

Brickyard House Only Design

The design for the Brickyard House focused on designing enough solar capacity to satisfy 120% of the maximum projected energy use of the building which is approximately 33,000 kWh per year. The Helioscope modeling software was used to model 26 different combinations of solar panels and inverters that were plausible for the site. These combinations were created using the solar panels and inverters provided in Tables 1-3. The tilt angle of the solar panels chosen for this design was 35° because a tilt between 30 and 40 degrees was found to be optimal for the Denver, CO area [29]. The tilt degree was chosen as a rough estimate to use while evaluating the different solar panel and inverter combinations. The exact tilt degree will be refined further once the design is narrowed down and the racking system is chosen. The orientation of the solar panels was chosen to be landscape to produce the shortest configurations in consideration of the historical restriction that the panels could not be seen from the front porch. The maximum frame size of the solar arrays modeled did not exceed 4x6 because that is the largest array allowed when using the solar racking system mentioned previously that could accommodate steep slopes [7]. Figure 3 below shows an example of one of the designs formulated for the Brickyard House.

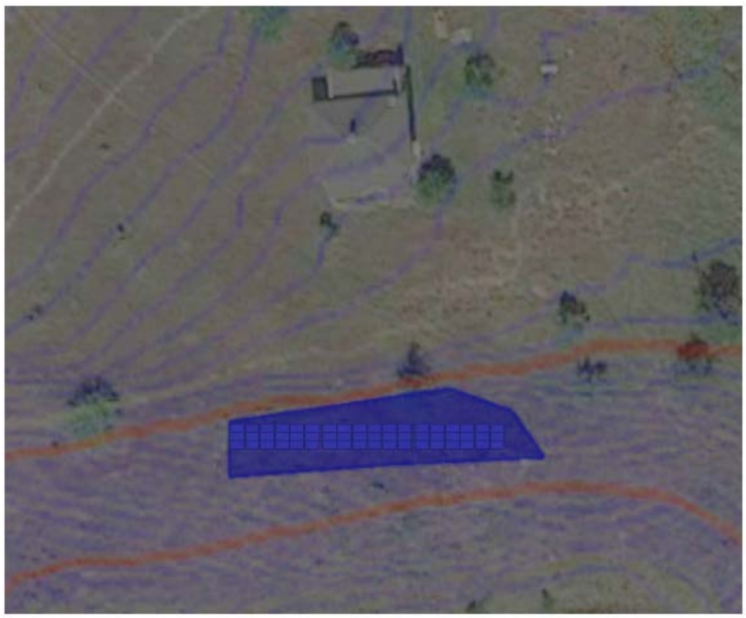

Figure 3: Brickyard House Only Design Example

The size and capacity of the solar panels used in each design varied the frame size and number of solar panels needed to satisfy the energy needs of the Brickyard House. Figure 3 shows one example of a solar design with a frame size of 3x6 and 54 solar panels. The size of the feasible area for the solar array on the slope of the retention pond is much larger than needed for the Brickyard House only design.

Community Solar Garden Design

The design for the community solar garden focused on maximizing the solar capacity as much as possible on the south facing slope of the retention pond. The east and west facing slopes on either side of the retention pond were disregarded for this preliminary design because they are the least optimal when designing a solar array. The Helioscope modeling software was used to model 26 different combinations of solar panels and inverters that were plausible for the site. These combinations were the same as the combinations used in the previous Brickyard House only design. The frame size maximum was kept to 4x6 and the tilt of the array is 35° facing due south. Figure 4 below shows an example community solar design projection.

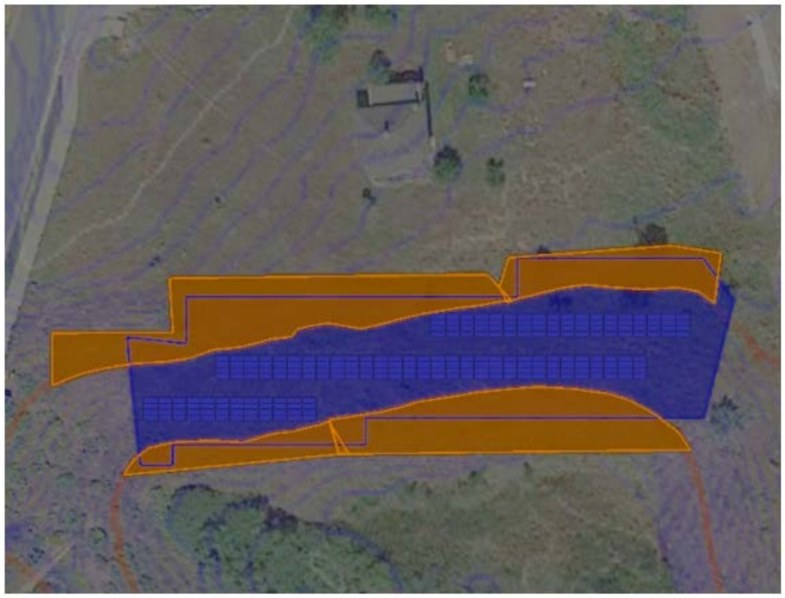

Figure 4: Community Solar Garden Design Example

Figure 4 shows one example of a community solar garden design with a frame size of 4x6 and 240 panels. The steepness of the south facing slope and the average height of the solar array was considered to determine spacing between the modules shown in Figure 4. The distance between the modules was chosen to be 8.7 feet in order to eliminate shading of the modules and provide ample maintenance access. Figure 5 is a technical drawing which justifies the spacing of the solar arrays.

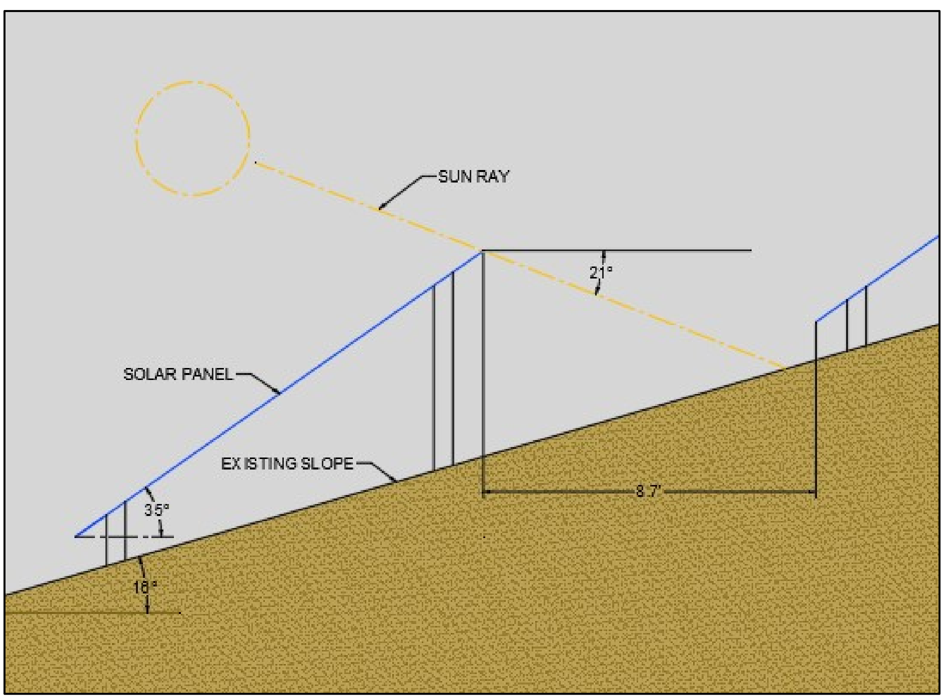

Figure 5: Solar Array Spacing

In Figure 5, the tile of the solar panels is 35° and the spacing between the panels is 8.7 feet horizontally. The angle of the sun is 21° because that is the lowest that the sun will be in Golden, CO on the winter solstice at 10:00am [30]. This sun angle is used to determine if the solar panel array will experience any shading loss due to spacing distance. As shown in the diagram above, the height of the solar panels will not block any sunlight to the next panel even when the sun is at its lowest during the year.

Concept Selection

There were 26 designs for each of the design concepts. These design concepts were narrowed down to 3 choices each based on performance ratio and energy to grid (kWh) statistics generated through the Helioscope modeling software. The performance ratio was one of the biggest factors in selecting a design because it determines how efficiently the solar panel and inverter combination works together. The energy to grid factor was also key because for the Brickyard House design, the annual energy production could not exceed 120% of the projected energy use. So, the designs were made to get as close to that number as possible. For the community solar garden, the maximum annual energy production was desired so designs with higher kWh statistics were favorable. In addition, the designs were chosen that minimized losses for the system. Figure 5 below is an example of the losses that a system could experience.

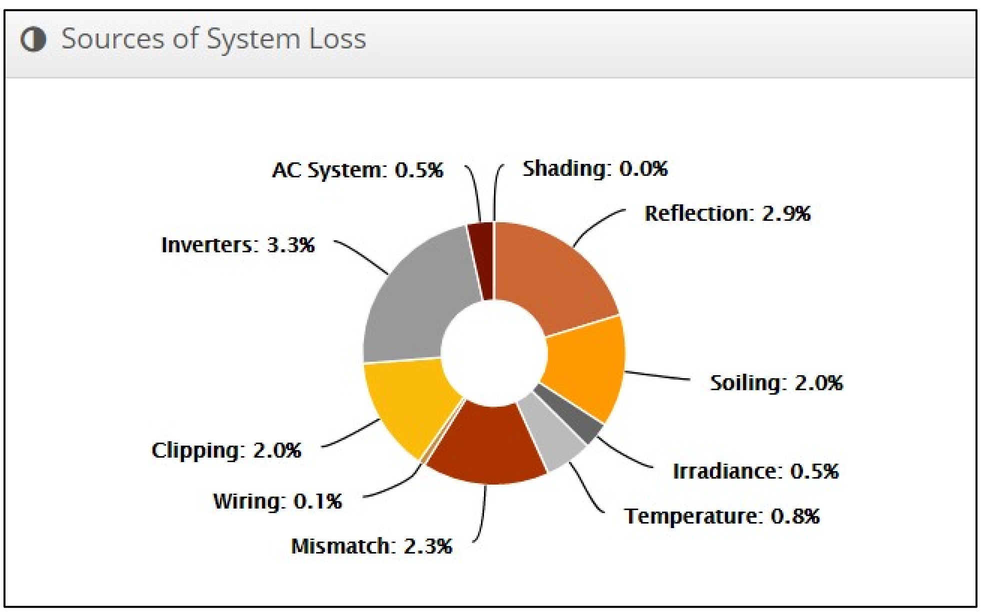

Figure 5: Example Sources of System Losses (from design 1B)

The losses that our team had the most control over were losses due to shading, clipping, and inverters. These sources of losses were minimized when choosing optimal designs.

For each design concept, two DC systems (conventional) and one AC system (micro-inverters) were chosen. Overall, it was observed that higher wattage panels produced more energy per panel. However, higher wattage panels are larger and more expensive. Table 4 below shows the three design concepts chosen for the design that includes power generation for only the Brickyard House.

Table 4: Brickyard House Design Concepts

#	# of Panels	Module	Inverter	Energy to Grid	Perf. Ratio
1	54	SunPower 330W	Fronius Symo Adv. 15.0	30,138 kWh	0.87
2	40	REC 450W	Fronius Symo Adv. 15.0	30,033 kWh	0.85
3	48	Solaria PowerXT 355W	Enphase IQ7X-96-2	29,368 kWh	0.88

Table 5 below shows the three design concepts shown for the community solar garden design.

Table 5: Community Solar Garden Design Concepts

#	# of Panels	Module	Inverter	Energy to Grid	Perf. Ratio
1	312	REC 360W	Sunny Tripower 33V	180,748 kWh	0.82
2	312	REC 380W	Fronius Symo Adv. 15.0	189,505 kWh	0.82
3	312	Solaria PowerXT 355W	Enphase IQ7X-96-2	178,866 kWh	0.83

Initial Concept Validation and Project Progress

Stakeholder Engagement

Throughout the design process the team has reached out to several key stakeholders to receive feedback and advice on the progress of the report. Most notably the team has had bi-weekly meetings with Theresa Worsham and Marissa Major to continuously narrow down and better define the scope of the project. The team also walked the site with the President of Golden Landmarks Association (GLA) to validate that our plans for the project aligned with GLA's vision for the future of the site. The team has also reached out to industry experts and collaborated with the McKinstry senior design team at Colorado School of Mines to receive advice and guidance on what panel manufacturers and models are best.

Scholarly Research

The earlier portion of our design project was focused on understanding what information needed to be researched for this project and acquiring that information. Our team had some initial knowledge of solar panels but needed to research more in depth information in order to best serve our client. Our team members with expertise in electrical and mechanical engineering were tasked with researching information about the best solar panels and inverters to use for this project. In addition, those team members researched information regarding the energy use of office buildings to produce the best energy use estimate for the Brickyard House. Our team members with expertise in civil engineering researched applicable codes that would govern the actual installation of the solar panel arrays. Soil reports and topographic data were also acquired to aid in the civil design portion of this project.

Analysis

Multiple site specific designs were analyzed based on the research and stakeholder input gathered for this project. The energy use estimate and civil design restrictions were incorporated into the Helioscope modeling software to produce the most accurate design options. The Helioscope modeling software produced comprehensive reports that analyzed the solar array options designed for the site. Helioscope automatically factors in electrical data provided by the solar panel and inverter producers, tilt angle, array size and local weather information to determine produce reports for each design option. These reports provide critical information such as the performance ratio, system losses, and energy production for each design option. These reports were analyzed thoroughly, and design options were chosen to best reflect the needs of the project.

Concept Critique

This senior design project is part of the Sustainable Environment Design Studio at Colorado School of Mines. Therefore, our team has had a focus of incorporating sustainable design into our design process. Our team has chosen to utilize the sustainability guidelines laid out by the LEED Building Design and Construction: New Construction checklist [31]. Although the Brickyard House project doesn't encompass an entire new building, there are some LEED credits that are very applicable to our project. The limitations of the LEED checklist for our particular project are the lack of specific instructions for solar panel array design. Therefore, the team must use these guidelines as a way to look at the entire project as a whole and not just design specifics.

Under the Sustainable Sites category, the Site Development credit directly applies to our project. This credit requires that at least 40% of the greenfield area of the site is preserved and protected from all development and construction. The team's solar panel and utility connection design inherently protects most of the greenfield areas of the site because historic regulations require that the view from the porch is preserved. The team is furthering this idea of preservation by looking into design options that require the least disruption to the existing site.

Under the Energy & Atmosphere category, the Renewable Energy Production credit also directly applies to our project. This credit aims to reduce the environmental economic harms associated with fossil fuel energy by increasing self-supply of renewable energy. The team is designing for 100% energy use to be renewable and onsite for the Brickyard House design. On top of this, the Brickyard House design incorporates heating and cooling equipment that uses only renewable energy and no natural gas. With the solar garden design, renewable energy access to Golden residents is increased and more homes/businesses could subscribe and meet their goals of using more renewable energy. So, the designs in this project are both beneficial to the Brickyard House but also the entire City of Golden.

The two credits mentioned above pertain to the project. However, there are many other credits that could aid the future design considerations of the Brickyard House project. Our team has looked into ways to optimize the energy efficiency of the Brickyard House while staying within the historical building regulations. Although this is slightly out of the scope of the project, the team hope to incorporate energy efficiency recommendations into the final design for the project. Energy efficiency optimization is directly related to the Optimize Energy Performance and Advanced Energy Metering credits in the LEED BD + C New Construction checklist. As the interior of the Brickyard House will be redone in the future, the team recommends the use of the LEED Operations & Maintenance: Existing Buildings checklist [32]. Following this checklist will optimize the sustainability of the Brickyard House and set an example for the rest of the city. Using this checklist will provide a framework for incorporating water efficient, energy efficient, and environmentally friendly designs into the interior of the Brickyard House.

Next Steps

At this point our major next step is to make sure all designs will still be able to meet the requirement of not being visible from the building porch and modify accordingly. After surveying the site with Melissa Crocker, the GIS Analyst for the city of Golden, the team identified that the maximum height of panels previously determined may be too high, as the team underestimated the height of the porch. In order to not be visible from the porch, the designs would need to go much further down into the side of the retention pond, which would impede upon the lower vertical restriction mentioned earlier. To minimize costs associated with the issue, the team will develop multiple options included adding vegetation that would block the panels as well as grading down a step to lower max height but keep the panels an acceptable distance above the high-water line of the retention pond.

In addition, an overall cost analysis for each design will be completed based on panel, inverter, and installation costs. This cost analysis will also include the mounting and racking cost for the solar panels. While extensive research into this is yet to be complete, one of the more promising options is from TerraSmart. This is a promising option due to the racking system's high wind and snow load tolerance [7]. This cost analysis with be used to guide us in refining which design options are best based on best value, most efficient, least expensive, etc. Finally, the Site design will be refined and completed enabling a complete and comprehensive presentation of the designs to our client.

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