CU Solar Architecture

Consulting Report

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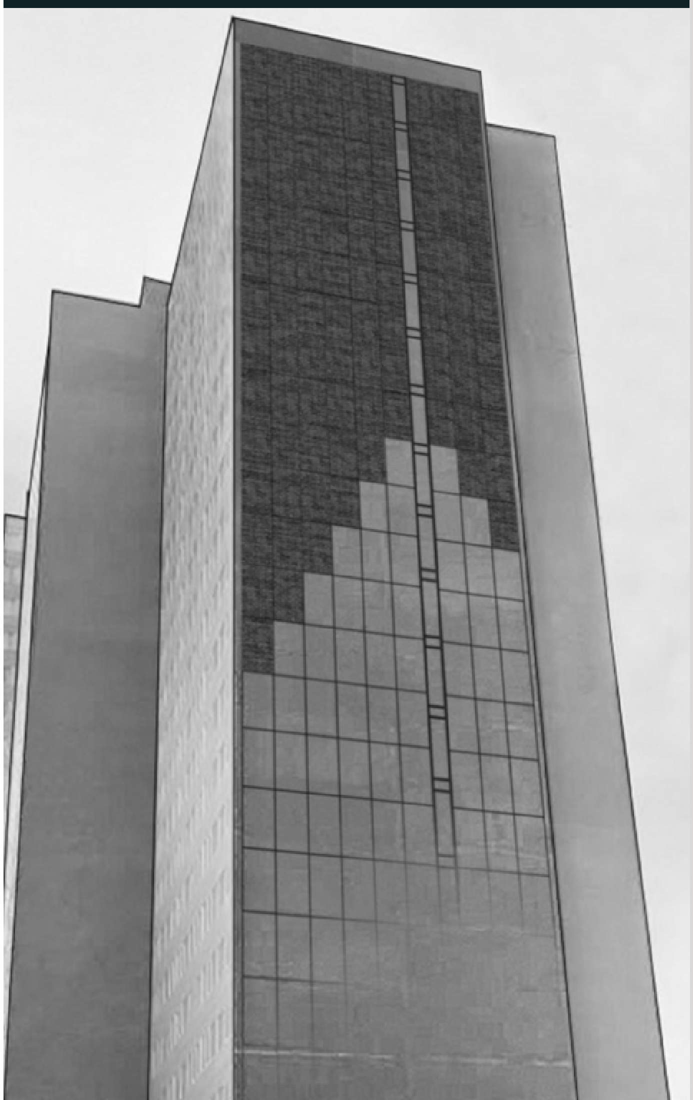


Sections

Executive Summary

CU Boulder aims to become carbon neutral by 2050, cutting down the university's emissions by 80%. Despite Boulder's 300 days of sun a year, the university generates less than 1% of its energy from solar. This is in part due to aesthetic requirements to maintain the Tuscan architecture style on most campus buildings, preventing installation of visible solar panels on roofing.

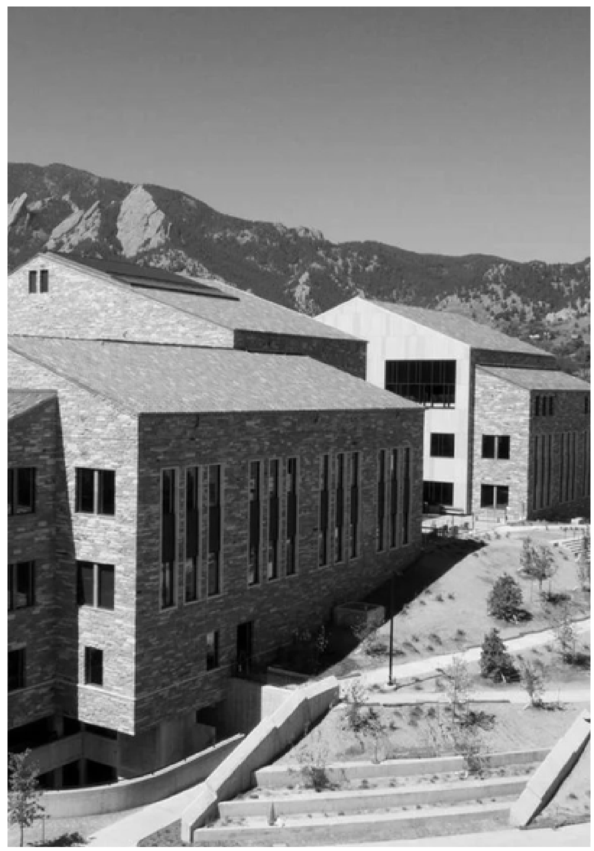
This report provides less-visible solar solutions in order to help CU reach its mission. The team, consisting of a group of passionate students and one of CU's senior planners, analyzes the application of "invisible" solar facades from Mitrex, the world's largest BIPV manufacturer, on several existing and future locations around campus. Power and cost analyses were done on the Engineering center, due to the large percentage of unoccupied wall areas, along with two new installations on campus, the chemistry building, being planned for Main campus, and the back of the soon to be renovated stadium scoreboard.

Based on these analyses, an ROI was determined, which for each project, was longer than the lifespan of the facades. Due to CU's sustainability goals, these proposals are still recommended with an emphasis on the potential branding opportunities these facades provide towards CU's sustainability mission. For the stadium scoreboard, the façade backing is less than 5% of the total scoreboard project cost and can easily be integrated into the current design. For the chemistry building, the south-facing wall is the most cost efficient and should be a starting point for any solar façade projects. For the engineering center, the ROI for the project as a whole was far longer than the life of the panels, though facades can be installed as sidings fail to reduce cost. Based on student input, obtained through a survey, a prototype is proposed for a wall near the business field which can serve as a branding opportunity for CU's sustainability mission and garner support for future solar projects.

Potential future projects include solar windows and solar film, which are both in the pre-production stage, and photovoltaic roof tiles which mimic the Tuscan architectural style.

Introduction

According to CU Boulder's Energy Master Plan, the university has a "goal to reach carbon neutrality by 2050" and has "reduction targets of 20 percent, 50 percent, and 80 percent reduction in GHG emissions by 2020, 2030, and 2050, respectively". With these goals in mind, solar power is a tempting solution due to the over 300 days of sunlight Boulder receives but restrictive building codes centered around the Tuscan architecture style prevent large-scale on campus installation of solar panels.



The beautiful mountains and Tuscan architecture on campus is a large draw for prospective students, causing the university to value maintaining this aesthetic, even when it can conflict with their sustainability goals. With guidance from Wayne Northcutt, Senior Planner at CU, "invisible" solar solutions are explored to maintain campus aesthetic while making headway towards CU's sustainability goals.

Our Team

We are a student lead team with support from CU's Architect and Senior Planner Wayne Northcutt. Each of us comes from different branches of engineering so while we all have been taught to be innovative we each have different specialties when it comes to ideation and project execution. While having Wayne's support is critical, our student initiatives is invaluable to the perspective of this issue and project.

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CTD ENGINEERING

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AEROSPACE ENGINEERING

Wayne Northcutt

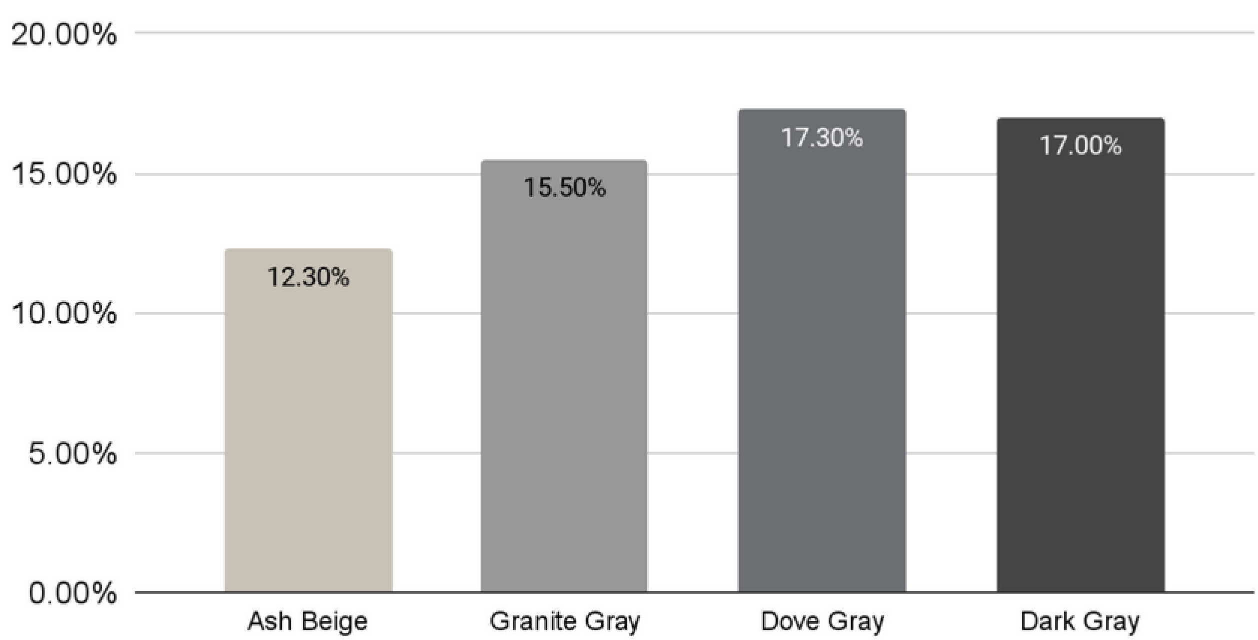
ARCHITECT/SENIOR PLANNER

Background Research

A viable solution to circumvent the building codes on campus is Mitrex Integrated Solar Technologies, the world's largest BIPV manufacturer based out of Canada. They develop intriguing solar and non-solar façades that can look like brick, concrete, tile, or any number of custom designs; however, the caveat with such freedom is the efficiency at which the panels operate given different color schemes. The plot below gives a few efficiency ratings for solid colors available at Mitrex. Efficiency generally trends upwards as the color darkens, peaking at around 17.3%.

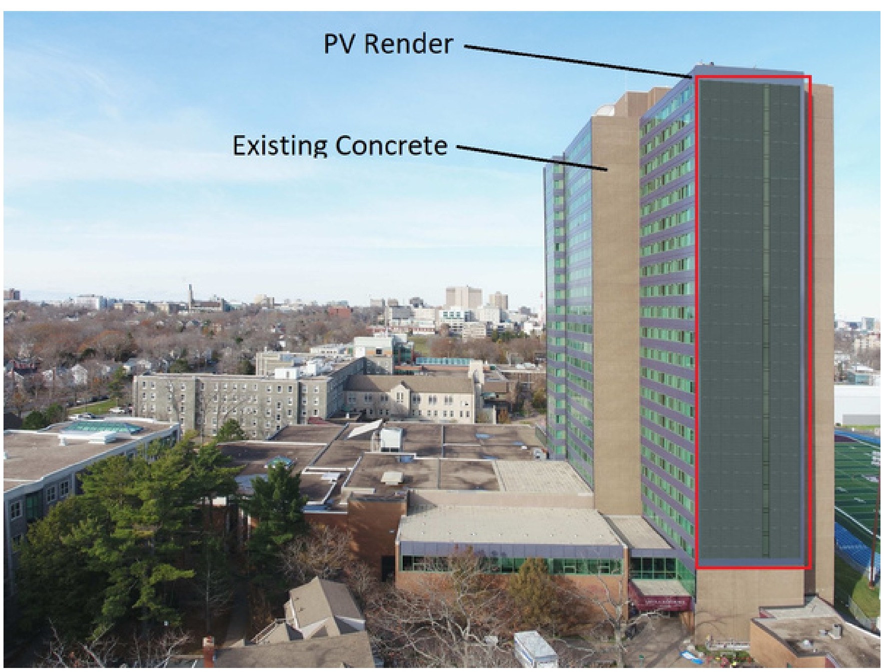
This number is slightly lower than a high-efficiency unit, around 20-21%, but still well within the current PV efficiency range (15-21%). With that being said, Mitrex guarantees at least 80% performance by the 25-year mark with all its installations, which is also in line with other traditional solar panel arrays. The creative freedom given with the panels is lower because of this but tradeoffs of efficiency in favor of design can still be analyzed in future sections when exploring marketing opportunities.

Color and Efficiency



Comparative Research

A current Mitrex project at the University of Saint Mary's, Halifax, set to finish in the summer of 2023, shows the technology's flexibility and gives insight into how other universities approach sustainability initiatives. The Loyola residence was in dire need of resurfacing due to the existing concrete facades beginning to fail, and the school chose Mitrex to do the job. While most sections would be covered in a standard non-PV Mitrex façade, a 6,000-square-foot PV installation is planned to be added on the east side of the building. Dennis Gillis, a senior director of facilities management at the University, made it clear that St. Mary's foremost concern when approaching renovation is making it as sustainable as possible. With the flexibility that Mitrex's facades provide, planners could evaluate adding solar to just the south wall and found that it would only marginally increase the overall cost, providing a realistic return on investment for the already required renovation. Given that St Mary's shares a similar goal for carbon neutrality by 2050, CU could benefit from the same approach to their own renovation projects. St. Mary's also uses these types of installations to raise awareness about sustainability and brand their institution as a renewables-first school. The branding opportunities that come with initiatives such as this cannot be overlooked, and CU could leverage this to promote student sustainability and attract new sponsors for future projects. With the insight of the planners at St Mary's and the versatility advertised by Mitrex, no better option is currently available, and its range of applications provides a multitude of possible projects on Boulder's sprawling campus.



Render of Loyola residence at St. Mary's Halifax. While all existing concrete will be covered by a new façade, only the part with integrated PV is rendered in the photo

Design Research and Planning

When it comes to the design of solar facades, both aesthetics and efficiency play a role in the final design concept; however, ROI and efficiency supersede looks. Thus having a darker color and placing panels in the most well-lit areas are most important. These areas tend to be west and south facing as they receive the most amount of sunlight. This section will be broken into three different project proposals: the Stadium score board, the new Chemistry Building and the Engineering Center.

Score Board

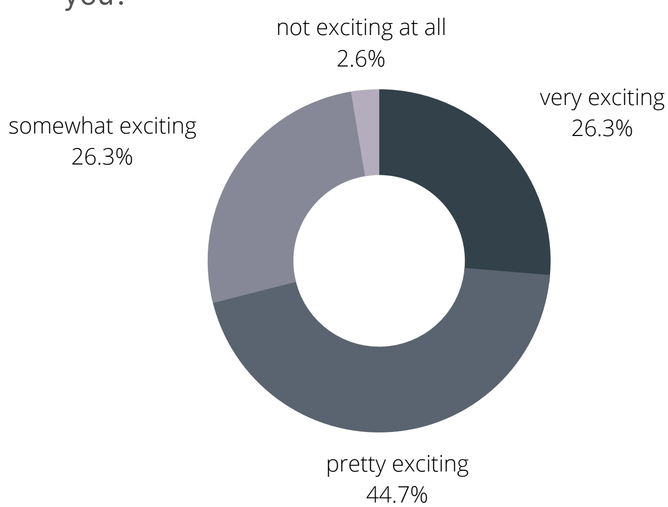
CU has a 20 million dollar plan to replace and upgrade the stadium score board by football season 2024 (UCB000816 - CU Scope Development Form). We propose they include solar facades on the back of the score board while performing this retrofit. This area is south facing, without obstruction, which would provide approximately 3100 hours of sunlight a year. Having a black background with a CU buffalo would provide the highest façade efficiency while also providing a branding opportunity. The buffalo will represent the football team and showcase our mascot to be seen across campus. Additionally, prospective student tours stop at the stadium to discuss Raphie and the football team. Having solar facades on the score board would be a great opportunity to market CU Boulder as an environmentally conscious campus with this façade being a central symbol of their sustainability commitments right in the heart of the univsersity.

Chemistry Building

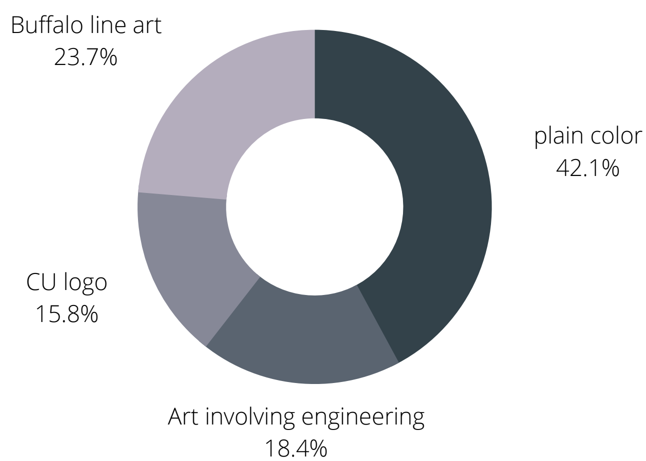
The second proposal involves the construction of a new 150,000 sqft chemistry building planned to be placed on Main Campus. The introduction of solar facades in new installations is promising as it can be implemented in the initial design rather than retrofitting an existing construction. As the floorplan was not confirmed, a high level assumption was made, based on input from CU's Senior Planner, that the floorplan would be square, giving a south-facing wall area of 13,800 sqft with 20% of that area being covered by windows. This proposal would be the first solar façade project on a new installation and can hopefully expand to newer installations while maintaining the campus aesthetic.

Engineering Center Survey (n = 39)

Q: How exciting does this project sound to you?



Q: Which design idea looks the best to you?



Engineering Center

The concrete façade of the engineering center lacks uniformity with the Tuscan style architecture and thus is a prime candidate to be refaced. Student insight can be invaluable when dealing such large changes that can alter the look of the campus, so we conducted a survey that focused on the potential façade colors and graphic designs for the engineering center. Areas considered were the south, east, and west faces of the building (see appendix A7 for photos).

In order to diversify our sample group for the survey, we reached out to students from multiple university programs and included those who live on and off campus. This data is a result of 39 participants.

As the survey results to the left suggest, this project has overwhelming support from students, a promising sign that students will continue to be involved in this project and others in the future

Although this survey serves as a good guide, due to the small sample size our recommendations weren't solely based on the results. A combination of background research and discussion with our stakeholder led us to recommend the second most voted plain color (dark grey) for the panels rather than the first (tan), although given the considerable support for a logo or art piece, we also suggest incorporating this idea somewhere in the design while not jeopardizing the efficiency of the entire array

Power Analysis

Engineering Center

The Engineering Center Walls were tallied and its areas were calculated using a CAD rendering. Due to substantial window coverage and obstruction, the ITLL and DLC were not included in these calculations. Using Google Earth, these areas were reduced to account for windows and possible obstructions. Full tables can be found in the appendix (A1 - A3). As can be seen below, there are slight differences between the CAD model and the current Engineering Center layout (as shown on Google Earth). These differences appear to be minor and the CAD model is sufficient for an approximation of available wall areas for solar facades. Using these wall area calculations along with wall orientation, potential power output was calculated using PVWatts, a US DOE solar power calculator which CU Boulder also uses for it's renewable energy projects. Below are the area and resulting power calculations for the South, West and East sides of the Engineering Center using a 350W Dove Grey Siding, the most efficient panel Mitrex offers. The wall areas of the North side was not gathered due to the lower power outputs due its orientation. An example power output is provided showing the significant reduction in power generated. Additional Power Calculations found in the appendix (A5).

Engineering Center - CAD Model

Engineering Center - Google Earth

PVWatts	Area (ft^2)	Area (m^2)	DC System Size (kW)	Output (kWh/Year)
South Side	44209.34605	4107.148462	710.536684	707600
West Side	45364.96325	4214.50792	729.1098701	448083
East Side	35477.0876	3295.901858	570.1910214	410767
North Side (Example)			650 (Example Value)	160145

Stadium Scoreboard

The Folsom Field scoreboard is being upgraded and solar façade backings were also explored. This wall location is ideal due to its south facing orientation, large unobstructed area and possibility for a logo, which the facades can be colored to display. The CU buffalo, as shown in the proposal image, can be replicated on Mitrex solar facades, creating a branding opportunity towards CU's sustainability commitment.

Render - Stadium Scoreboard
CU Scope Development Form (UCB000816-STAD-Replace South Scoreboard in Folsom Field)

The dimensions of the scoreboard were determined through use of the proposal images, and references to Google Earth and the CAD model (for overall stadium dimensions). These calculations can be found in the appendix (A4). Based on those dimensions, the power output was calculated in PVWatts.

Stadium - Google Earth

PVWatts	Area (ft^2)	Area (m^2)	DC System Size (kW)	Output (kWh/Year)
Stadium	8886.3214	825.5594017	142.8217765	142786

Chemistry Building - South Wall

Chemistry Building Location at Business Field on Main Campus (Google Maps)

A new Chemistry Building is planned to be built on Main Campus. The dimensions of the building were not yet specified so assumptions were made towards the layout of the building based on input from CU's senior planner. The building was assumed to be 4 floors, 30,000 sqft per floor, and each floor being 20ft high. The floorplan was assumed to be a square, giving a south facing wall area of 13,800 sqft. A reduction in wall area was assumed due to window coverage and estimated to be 20% as that is in line with the window coverage of the Engineering Center. The power calculation focused on the southern wall, as it received the most sunlight and the orientation was assumed to be aligned with true south. Based on these dimensions and assumptions, the power output was calculated using PVWatts. Although these numbers represent a very high level assumption of the final design, the building can be designed with them in mind since development is still in its infancy, an advantage to incorporating solar into new builds that should be taken advantage of.

PVWatts	Area (ft^2)	Area (m^2)	DC System Size (kW)	Output (kWh/Year)
Chemistry Building	11,085	1029.833256	178.1611533	177976

Cost Analysis

The cost of these systems were calculated based of the pricing of Mitrex's most efficient panel, the 350W Dove Grey façade, being at just over $20/sqft. Based on input from CU's senior planner, the labor costs were assumed to be equivalent to the $25/sqft for the Engineering Center and Chemistry Building, and $500,000 for the Stadium. Additional costs of 20% of total project were for electrical work (power distribution, meters, sub-panels) and an additional 10% project cost for project contingency, for a total 30% additional project cost. Further cost information can be found in the appendix (A6).

These costs were totaled and the ROI in years was determined at an electricity cost of $0.0824/kWh. These times, as shown below, are far longer than the 25-year efficiency guarantee of the panels. However, given CU's commitment to sustainability, this report recommends pursuing some of these projects regardless. The Stadium Scoreboard's solar façade, would cost less than $1 Million, compared to a scoreboard budget of $20 Mil, a less than 5% total project cost. Specific south-facing walls on the engineering center also have far better ROI's and can be done in sections for a lower project cost.

Grants/Subsidies/Discounts

The calculate costs and ROI's do not include any grants or subsidies as funding towards CU is not guarantied. The Inflation Reduction Act (IRA), a sustainability measure passed by congress, may potentially fund up to 30% of the project cost. Mitrex also provides discounts on panel costs for buying in bulk, though exact values would need more solidified project specifications for a proper quote.

Location	Cost	ROI
Stadium	$903,000	77 years
EC-Total	$7.5 Million	58 years
EC-South	$2.6 Million	46 years
EC-West	$2.7 Million	74 years
EC-East	$2.1 Million	63 years
Chemistry Building	$668,000	46 years

Prototype

The south-facing walls of the Engineering Center receive the most sunlight and can be done wall-by-wall, reducing upfront project cost while progressing towards CU's sustainability goals.

A small scale implementation of the solar facades would be in the form of a prototype. Pictured to the right is the suggested design. The buffalo art was the highest voted selection from the student survey. The location chosen is on the south side of the engineering center and it is facing the business field.

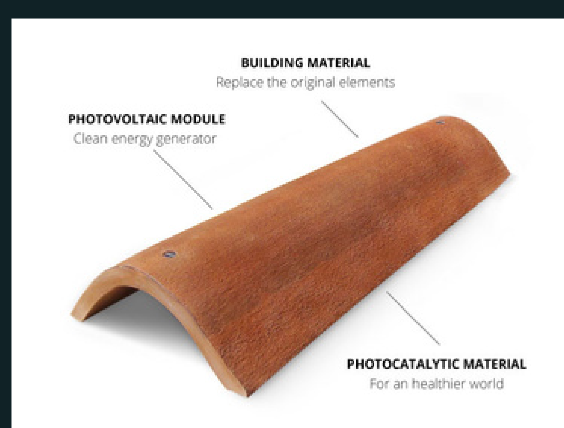
This prototype's estimated cost is $91,000 dollars, far less than the other projects proposed, creating a suitable starting point for "invisible" solar solutions on campus. This small scale prototype can also confirm panel performance and give improved ROI estimates.

Beyond testing, this prototype provides an excellent branding opportunity for CU's Engineering School, Business School or CU Campus as a whole. The facades would be highly visible and will show prospective students CU's commitment to environmentalism.

Future Promising Projects

There are three other PV technologies that have not yet made it to commercial use but may prove to be useful in future projects. Two such products are solar film and solar windows. Both would involve a retrofit of existing windows on campus to provide solar energy while also tinting high-exposure surfaces to improve temperature regulation inside. Manufacturing of both are still several years in the future, but when they become available, their low profile and versatility will be a major selling factor as an unobtrusive way to make older buildings more environmentally friendly.

The final product attempts to tackle the dilemma surrounding CU's stunning terracotta roofing, a staple of the campus aesthetic. The school's mandate of using mixed clay tiles on any sloped roof on campus essentially eliminates the possibility of having traditional solar roof installations, but CU can take advantage of photo-voltaic roof tiles to maintain the same look while increasing solar capability. PV tiles currently sold by Dyaqa, a company based out of Italy, mimic terracotta roofing but their durability is questionable in an environment like Colorado's given their sparse certification and their intention for use in Italian heritage sights. Other more accessible companies may develop similar technology in the near future such as Tesla, who currently sell clay-styled PV panels but not with the Tuscan aesthetic CU requires.



Conclusion

CU's opportune location, receiving 300 days of sun a year, make solar power an attractive option to reach their sustainability goals, but aesthetic requirements limit solar installation on campus. "Invisible" solar solutions were explored, with the best commercial option being Mitrex's solar facades. Three projects were examined, the stadium, chemistry building and engineering center, but based on poor ROI's only the stadium backing and chemistry building are recommended. The engineering center can be done wall-by-wall, reducing the upfront cost and a prototype is proposed across the business field to create a branding opportunity for CU's sustainability initiatives.

In general, projects like this will never be in the best interest of cost. They are instead an investment into a more sustainable future for CU Boulder. Any change that can help CU towards its 2050 goal should be weighed, and sacrifices will have to be made. We believe our suggestions on these projects can provide a proper direction for their implementation and lead to a greener mindset for everyone at CU

Appendix

A1. EC South Side Wall Area

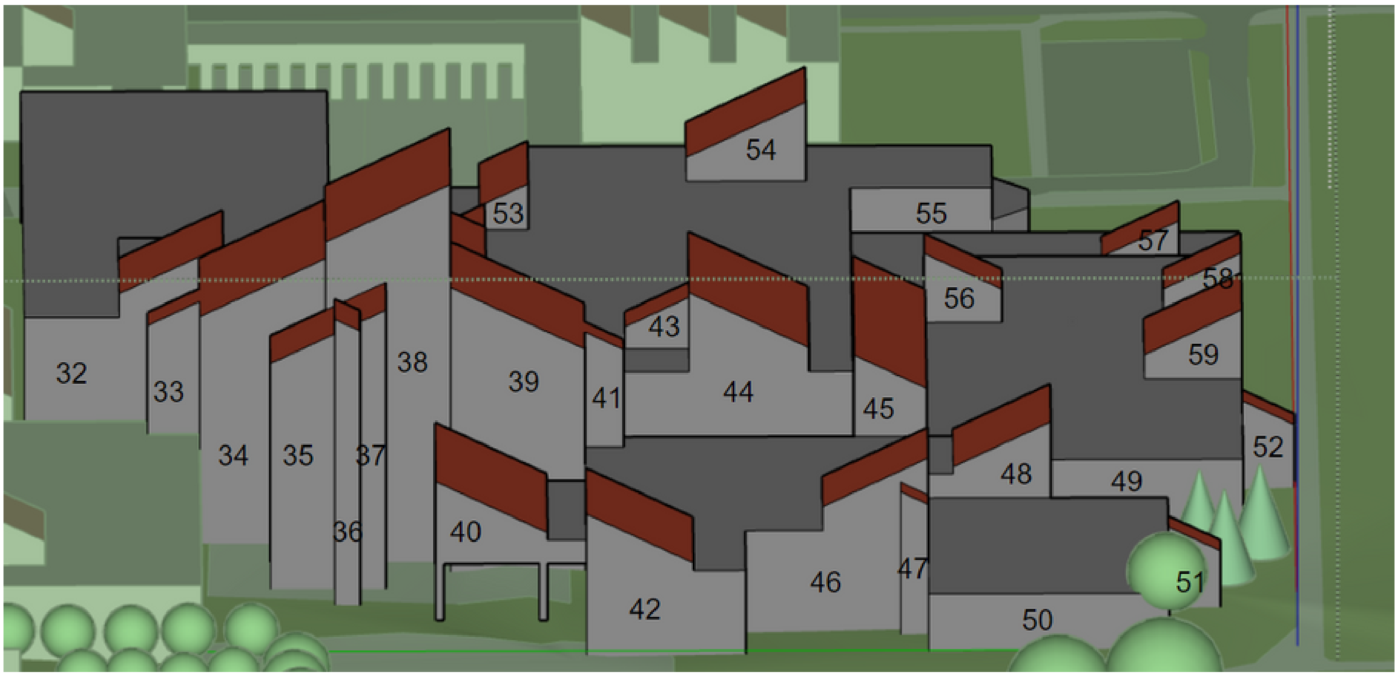
	South Side			
#	Theoretical Area (ft^2)	% free after windows	% Not blocked	Reduced Area (ft^2)
1	2874.33	1	1	2874.33
2	3879.78	0.8	0.7	2172.6768
3	817.89	1	1	817.89
4	404.69	0.4	1	161.876
5	2183.65	1	1	2183.65
6	3830.7	0.7	1	2681.49
7	3013.79	1	0.2	602.758
8	12322.53	0.4	1	4929.012
9	399.83	1	1	399.83
10	1240.02	1	1	1240.02
11	9273.91	0.2	1	1854.782
12	2274.66	1	1	2274.66
13	810.37	1	1	810.37
14	2724.04	1	1	2724.04
15	1685.52	1	0.5	842.76
16	1246.73	1	0	0
17	2914.08	0.95	1	2768.376
18	599.29	1	0.7	419.503
19	2684.88	1	0	0
20	275.39	1	1	275.39
21	1149.93	1	1	1149.93
22	2494.28	0.7	1	1745.996
23	642.51	1	1	642.51
24	2529.77	1	0.5	1264.885
25	2176.28	1	0	0
26	2027.95	0.95	0.5	963.27625
27	642.51	0.3	1	192.753
28	13239.98	0.5	1	6619.99
29	338.94	1	1	338.94
30	557.99	0.8	1	446.392
31	811.26	1	1	811.26
Total	82067.48		**Reduced Total**	44209.34605

South Side Wall Labels

A2. EC West Side Wall Area

	West Side			
#	Theoretical Area (ft^2)	% free after windows	% Not blocked	Reduced Area (ft^2)
32	9638.63	0.6	0.5	2891.589
33	2290.65	1	1	2290.65
34	6366.64	0.5	0.5	1591.66
35	3094.21	1	1	3094.21
36	1424.25	0.2	1	284.85
37	1404.09	1	1	1404.09
38	5056.43	0.5	0.95	2401.80425
39	6771.44	0.5	0.7	2370.004
40	1303.31	1	0.85	1107.8135
41	662.83	1	1	662.83
42	4828.74	1	1	4828.74
43	375.9	0.5	1	187.95
44	9501.37	0.5	0.6	2850.411
45	745.2	1	1	745.2
46	4822.11	0.3	1	1446.633
47	931.92	1	1	931.92
48	939.78	1	1	939.78
49	5797.87	0.5	0.6	1739.361
50	5563	0.9	1	5006.7
51	1304.79	1	1	1304.79
52	1304.79	1	1	1304.79
53	273.43	1	1	273.43
54	988.94	1	1	988.94
55	3284.27	1	0.7	2298.989
56	636.28	1	1	636.28
57	285.2	1	1	285.2
58	636.28	0.9	1	572.652
59	728.2	1	1	728.2
Total	80960.55		**Reduced Total**	45169.46675

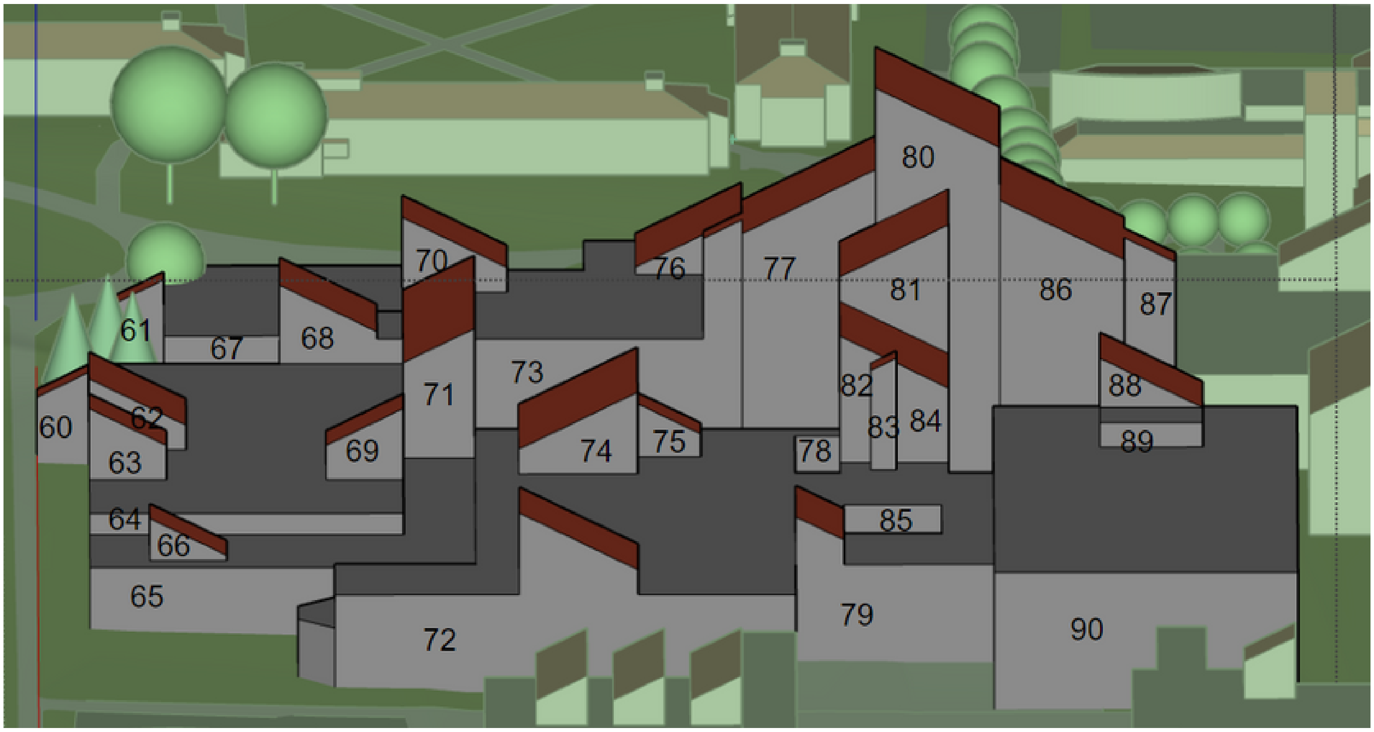
West Side Wall Labels



A3. EC East Side Wall Area

	East Side			
#	Theoretical Area (ft^2)	% free after windows	% Not blocked	Reduced Area (ft^2)
60	1304.79	1	1	1304.79
61	1304.79	1	0.1	130.479
62	782.2	1	0.5	391.1
63	636.28	1	0.3	190.884
64	1050.21	0.5	0.9	472.5945
65	7706.77	0.8	0.4	2466.1664
66	282.2	0.5	1	141.1
67	4035.11	0	0	0
68	939.78	0.8	1	751.824
69	1261.08	1	1	1261.08
70	814.02	0.7	0.9	512.8326
71	1261.08	0.8	0.8	807.0912
72	11738.38	0.8	0.8	7512.5632
73	7938.35	0.8	0.8	5080.544
74	988.94	0.9	1	890.046
75	375.9	1	1	375.9
76	545.53	1	1	545.53
77	5934.19	0.5	0.5	1483.5475
78	1047.26	0	0	0
79	4893.02	0.3	0.5	733.953
80	4416.99	0.5	1	2208.495
81	1302.12	1	1	1302.12
82	579.97	1	1	579.97
83	424.63	0.5	1	212.315
84	710.96	1	1	710.96
85	6366.74	0.5	0.9	2865.033
86	2290.65	1	0.5	1145.325
87	396.81	1	1	396.81
88	396.81	0	0	0
89	8845.01	0.8	0.4	2830.4032
90	2282.24	0	0	0
Total	79461.03		**Reduced Total**	35477.0876

East Side Wall Labels



A4. Stadium Scoreboard Backing Area

Stadium Dimensions				
Height (ft)	Width - Main (ft)	Width - Left (ft)	Width - Right (ft)	Total Area (ft^2)
57.58	104.83	24.75	24.75	8886.3214
Assumption: Height is same as distance from bottom to ground				
Assumption: Orientation is South Facing				

A5. EC and Stadium Power Outputs

EC -South

RESULTS

Print Results

707,600 kWh/Year*

System output may range from 657,290 to 728,474 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	4.48	82,204
February	4.72	78,066
March	4.25	75,189
April	2.96	48,169
May	2.25	34,883
June	2.05	29,140
July	2.17	32,001
August	2.71	41,787
September	3.62	57,160
October	4.24	73,841
November	4.53	79,083
December	4.12	76,076
Annual	3.51	707,599

EC - West

RESULTS

Print Results

448,083 kWh/Year*

System output may range from 416,225 to 461,302 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	1.57	28,472
February	2.04	33,673
March	2.58	46,289
April	2.65	45,523
May	2.73	46,347
June	2.77	44,686
July	2.44	39,663
August	2.46	40,603
September	2.41	39,238
October	1.83	31,647
November	1.65	28,510
December	1.30	23,433
Annual	2.20	448,084

EC - East

RESULTS

Print Results

410,767 kWh/Year*

System output may range from 381,567 to 422,885 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	1.56	22,280
February	2.27	29,714
March	2.72	38,689
April	2.82	38,278
May	2.97	39,921
June	3.80	48,865
July	3.46	45,189
August	3.28	43,024
September	2.78	35,759
October	2.09	28,660
November	1.60	21,616
December	1.32	18,772
Annual	2.56	410,767

Stadium

RESULTS

Print Results

142,786 kWh/Year*

System output may range from 132,634 to 146,999 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation (kWh / m^2 / day)	AC Energy (kWh)
January	4.50	16,588
February	4.75	15,793
March	4.28	15,199
April	2.97	9,712
May	2.26	7,044
June	2.06	5,894
July	2.18	6,466
August	2.72	8,429
September	3.63	11,518
October	4.25	14,862
November	4.55	15,949
December	4.14	15,334
Annual	3.52	142,788

Chemistry

RESULTS

Print Results

177,976 kWh/Year*

System output may range from 165,321 to 183,226 kWh per year near this location.
Click HERE for more information.

Month	Solar Radiation ($kWh / m^2 / day$)	AC Energy (kWh)
January	4.49	20,676
February	4.75	19,675
March	4.27	18,938
April	2.97	12,108
May	2.26	8,778
June	2.06	7,343
July	2.18	8,057
August	2.72	10,508
September	3.62	14,361
October	4.25	18,534
November	4.54	19,882
December	4.13	19,117
Annual	3.52	177,977

A6. EC and Stadium Cost Calculations

	Area (ft^2)	Cost per sqft	Cost of Panels	Labor ($/sqft)	New Equipment Cost	Electrical	Contingency	**Total Cost ($)**
South Side	44209.34605	20.591	910314.64	25	1105233.651	1.2	1.1025	**2666570.395**
West Side	45364.96325	20.591	934109.96	25	1134124.081	1.2	1.1025	**2736273.634**
East Side	35477.0876	20.591	730508.71	25	886927.19	1.2	1.1025	**2139867.697**
Stadium	8886.3214	20.591	182978.24		500000	1.2	1.1025	**903580.2167**
Chemistry	11,085	20.591	228253.81	25	277128.1292	1.2	1.1025	**668620.3087**

	Output (kWh/Year)	Total Cost ($)	Cost of Electricity ($/kWh)	Savings per Year ($)	Years to Pay Off
South Side	707600	2666570.395	0.0824	58306.24	45.73
West Side	448083	2736273.634	0.0824	36922.0392	74.11
East Side	410767	2139867.697	0.0824	33847.2008	63.22
Stadium	142786	903580.2167	0.0824	11765.5664	76.80
Chemistry	177976	1308201.029	0.0824	14665.2224	45.59

A7. EC Surfaces to Cover

Engineering Center - East facing

Engineering Center - South facing