Krannert Center for the Performing Arts

Solar Project Feasibility Study

University of Illinois at Urbana-Champaign

Project Number: U12239

Phase 1

March 1, 2013

Table of Contents

Appendices

Appendix A – Site Plan
Appendix B – Payback Analyses and Opinion of Probable Construction Cost for Roof Top Construction Activities
Appendix C – Schematic Roof Plan – Great Hall
Appendix D – Shadow Studies
Appendix E – Renderings – Line Type for Great Hall at 34° and 10° inclination of Solar Panels and Overall Ground Level Photo Renderings
Appendix F – Conceptual Crane Placement
Appendix G – Generic Wiring Diagram, Example of Micro-inverter and Product Data Sheet for Typical Photovoltaic Panel
Appendix H – Product Brochure for Photovoltaic Glass Unit
Appendix I – Reserved for: UIUC Review Comments

Executive Summary

The purpose of the study is to examine the feasibility of installing a solar photovoltaic (PV) system on one or more of the roofs at Krannert Center for the Performing Arts (KCPA). The study also addresses the potential for the use of photovoltaic glass units (PVGU) on the west curtain wall of the Great Hall.

Phase 1 of the study, presented herein, examines the visual impact on the facility and presents to the University an opinion of probable construction cost (OPCC), general considerations of construction phasing and associated general construction, and a simple payback analysis for the PV array. As part of Phase 1, the space requirements for the PV system's inverters have been identified along with potential installation location(s) within the KCPA facility.

If after considering the findings of Phase 1 of this study the University elects to further evaluate the feasibility of installing a PV array atop one or more of the roofs of the KCPA facilities, this study will continue with a second phase (Phase 2). This second phase will include an evaluation of the structural load the PV system would impose on the facility (gravity and wind), and an assessment of the general condition of the existing roofing material to identify the anticipated remaining useful life of the roofs. A noise and vibration analysis will also be included in Phase 2 to identify the acoustic impact the PV system installation may be expected to have on the performance spaces within the facility.

A five hundred eighty-five thousand dollar ($585,000) construction budget, excluding contingencies, has been established for this project. Based on the assessments that have been completed during Phase 1, approximately four hundred fifty-seven thousand dollars ($457,000) would be directed toward the purchase and installation of solar panels and electrical work, with the remaining, one hundred twenty-eight thousand dollars ($128,000), being directed toward the costs of the associated general construction and construction access. This results in a net effective installed cost of between seven dollars and twenty-five cents and seven dollars and fifty cents ($7.25 and $7.50) per Watt. For general consideration, using an offset in consumption of 105,120 Watts / year, and a utility cost of twelve cents ($0.12) / Watt, the estimated payback period is substantially longer than 25 years.

1. Description, Options, Objectives, Program and Special Conditions

1.1 Project Description

This project would construct PV cells atop one or more of the roofs at Krannert Center for the Performing Arts (KCPA) and or install electrochromic glazing on the west curtain wall of KCPA. Refer to Appendix A for an overall Site Plan.

1.2 Master Plan Impact and Options

This project does not add to or subtract from the campus inventory of facilities or spaces, nor does it have any appreciable impact on current space use. Its goals and objectives are described below. In consideration of those goals, it may be appropriate to consider installing PV cells at another facility on or adjacent to campus should it be concluded that the installation of PV cells at KCPA is not feasible or desirable. For general comparison purposes, payback analyses for the roof-mounted PV array at Krannert and a ground-mounted array (assumed to be locatable on a generally open, level site) are included in Appendix B.

1.3 Major Project Objectives, and Design Requirements

This project has been proposed to Facilities and Services by the Student Sustainability Committee (SSC). The understood objectives of the project would be to partially offset the power demand of the KCPA facility with sustainable (solar) power and to provide an example of how such energy sources can be used in facilities such as KCPA. These PV sources would be either PV cells positioned atop one or more of the roofs of KCPA, PVGU on the west curtain wall of the Great Hall, or a combination of these. Several decision criteria are to be evaluated in this assessment. The primary considerations are:

A. The cost / benefit ratio of the PV installation. Payback analyses are included in the first phase of the study.

B. The visual impact to the facility needs to be considered. This is included in this first phase of the study.

C. The acoustic impact to the facility needs to be considered. This will be deferred to Phase 2 of the study.

D. The installation will need to be executed in a manner that minimizes disruption to the regularly scheduled performances, recordings and other uses of KCPA. Accordingly, the premium cost of labor during non-standard working hours needs to be included in the assessment of costs.

E. The maintainability of the PV system and the roof(s) on which the PV array is / are placed needs to be considered. The impact the addition of PV cells will have on the integrity and maintainability of the roof system.

1.4 Program Summary

The intended program seeks to derive the benefit of solar energy to offset the building's power consumption within an overall construction budget of $585,000, excluding bid and construction contingencies. This budget is to be directed toward the PV installation, and does not include the cost of replacement of any other building features, such as roofing, that should otherwise be included as part of the building's regular maintenance.

1.5 Special Conditions

Architectural

Layout of the PV cells should maximize exposure to the sun, limit visual impact on the facility and, within the foregoing constraints, facilitate maintenance of the building and the new equipment as much as reasonably practicable. Also, the layout must not obstruct roof access with respect to existing openings. Given these objectives, the roofs of the Great Hall, Drama Theater and Music Theater were initially considered as probable locations for PV arrays. However, the focus of the study was ultimately directed to the roof of the Great Hall. This decision was reached in consideration of maximizing sun exposure (the backstage housing projections at the Drama Theater and Music Theater block the afternoon sun to a much greater extent than the backstage housing projection of the Great Hall blocks the morning sun), and the higher elevation of the Great Hall roof mitigates the visual impact the PV array has on the building. Refer to Appendix C for a "Schematic Roof Plan" of the Great Hall that depicts the PV array. Refer to Appendix C for Shadow Studies. The optimal angle of inclination of the solar panels for the latitude of Champaign, Illinois is considered to be approximately 34°. Line-type renderings showing the projection of the panels at 34 degrees inclination and 10 degrees inclination are included in this report for general comparison of visual impact. Ground level photo renderings are included for the 34° inclination of the PV array. Refer to Appendix E.

PV cells generate Direct Current (DC) that needs to be converted to Alternating Current (AC) for efficient distribution and compatibility with building power. The DC current from the panels could be routed to a centralized inverter, located somewhere within the facility, or alternatively, micro-inverters can be included with each of the PV panels, eliminating the interior space need for the central inverter. For purposes of this study, it appears that a central inverter could be located in one of the booths at the rear of the Great Hall if the central inverter configuration is chosen.

Roofing

Roofs at the Great Hall and theaters are fully adhered EPDM.

Facilities and Services has reviewed their records for the roofing of the Great Hall and reported that the roofing of the Great Hall was replaced by King Lar in 1995, and was covered by a 15 year (Firestone) warranty. Roofs of the Drama Theater and Music Theater were replaced in 1998 by Advanced Roofing. These roofs were also reportedly covered by 15 year Firestone warranties.

Facilities and Services has reported that there have been a number of leak calls on the roof of the Great Hall, reportedly due to the perimeter flashing details.

Given the age of the roofs, Facilities and Services has recommended that they be replaced prior to the installation of any rooftop PV array.

Configuration of the PV array and the chassis that supports it must provide a working vertical clearance between the roofing and the nearest components of the PV array. For purposes of the aesthetic assessment, this minimum clearance is taken as 12 in. between the top of the roofing and the supporting frame. Because of the 1:12 roof slope, this clearance increases linearly to approximately 33 in. at the east end of each panel frame assembly.

Lightning Protection

Currently the roof of the Great Hall is divided into an upper and lower area. The upper area of the roof currently has a lightning protection system install. The lower area where the solar panels will be installed is not protected by a lightning protection system. With the installation of the new photo-voltaic panels it would be prudent to consider adding a lightning protection system to the roof to help protect the electronics from being damaged by surges from lightning strikes.

Structure

An assessment of the structural system is deferred to Phase 2 of this study. For purposes of cost assessment, a preliminary structural review of the roof structure was conducted. Based on this review, the framing system for the PV array has been conceptualized to deliver its load to the primary roof framing components (trusses), and not the secondary components (6 in. concrete roof deck and rolled steel beams). This general decision was reached in anticipation of limited capacities of the secondary components, and to minimize points of attachment for the structural frame.

Further structural evaluation, deferred to Phase 2, will assess the effects the PV panels will have on the total roof snow load due to snow drifting, and the structure's capability to sustain the weight of the panels, the support frames, and the additional snow load.

Noise and Vibration Analysis

An assessment of the acoustic impact the PV array may have on the facility is deferred until Phase 2 of the study. Preliminary considerations are that acoustics may be affected by transmission of vibration from wind and rain noise / vibration through the anchorage of the PV array to the building's primary structural system. Concerns for wind and rain noise transmission are not, at least at this point in the study, considered to be a factor for the installation of PVGU on the west curtain wall of the Great Hall.

2. Codes and Permits

2.1 Applicable Codes and Standards

- University of Illinois Facilities and Services Standards for Design and Construction.
- ASCE 7-05 "Minimum Design Loads for Buildings and Other Structures."
- Structural Loadings (gravity and wind) will need to be assessed per the International Building Code, 2009.
- Electrical design shall conform to the National Electrical Code (NEC) 2011.
- Code of Federal Regulations 29 CFR 1910 (pertaining to servicing of equipment near roof edges).
- 2012 International Fire Code (pertaining to maintenance of access to existing roof openings).

2.2 Applicable Permits

Should this project proceed to subsequent phases of investigation and design, configuration of the disconnect will need to be confirmed with the Electric Utility so that in cases of power outages the distribution network would not be back-fed by the PV array, thus energizing lines that would otherwise be thought to be de-energized. An additional protection to the manual disconnect switch is the inverter monitor's normal power, and if it is lost, the inverter automatically disengages the system's ability to back-feed power.

3. Site Requirements

Construction access for work on the Great Hall is expected to be gained via the east (Gregory Place) side of the facility. Laydown space and routing for deliveries is, at this time, thought to be achievable via the use of the plinth level immediately east of the Great Hall. At times, deliveries of equipment and materials may necessitate limitations on parking and pedestrian access from the Gregory Place side. Such limits (or shutdowns) would need to be coordinated around the scheduled activities at KCPA.

It is likely that a crane will be required to hoist components for the frame that will be constructed atop the roof to support the PV array. None of these components is expected to be extremely heavy (maybe on the order of 700 pounds for an individual steel beam, if it is concluded that the frame will indeed be steel-framed), but due to the required reach of the crane, a 165 ton all terrain crane is expected to be necessary for material hoisting. Refer to Appendix F for "Conceptual Crane Placement."

Regular construction phase access for workmen and lighter material components and personnel to the roof of the Great Hall might be accomplished via a temporary construction stairway that could be installed somewhere along the east façade of the Great Hall. The benefits to the project of installing such a stairway are reduced travel time for the workmen to the roof, and a reduction of interruptions to the occupants of the facility.

This project is not expected to require any demolition, abandonments or relocations of utilities.

It is thought that the impacts of construction noise (crane engines, hammer drilling, concrete coring) on the functionality of the facility can be satisfactorily addressed by minimizing (or even prohibiting) such activities during performances and recordings. To achieve this objective, the contractor and KCPA administrators will need to agree to a work schedule, the general constraints of which should be defined in the bidding documents. For purposes of this study, some work activities are considered as being required to take place during non-standard working hours, and a 50 percent labor rate premium is included.

4. Maintenance Budget & Energy Budget for Sustainability

The PV array should require only minimal maintenance, and should have a service life of 20 to 25 years. This project should not result in an increase in the overall campus energy budget. On the contrary, this project should result in a reduction in the energy budget, as described within this report.

5. Design Concepts

Roof-mounted PV Array

A field investigation was conducted on Friday February 15, 2013. The focus of the investigation was to determine a suitable location for the electronics and panel-boards required for a new PV system and to observe the main electrical service room serving the Great Hall.

The current focus is to limit the location of new PV panels to the roof of the Great Hall only. Several factors went in to making this decision. From the perspective of electrical efficiency, a significant consideration is limiting, to the extent practicable, the number of three phase AC feeders that will need to be routed from the roof level of the building down to the lower level and connected into the main AC distribution system for the building. Currently the building's electrical power is served from four different locations. The existing service consists of primary metering and primary cabling routed underneath the building to four separate unit substations. Focusing on the Great Hall is considered to provide the maximum amount of solar generation, within the project budget, while minimizing dollars on other associated construction, such as running additional conduits and wiring.

Consideration has been given to the many types of inverter technologies for solar systems including; central inverter systems, string inverters and micro-inverters. Based on the limited amount of physical space near the roof level of the building and the difficulty in getting larger equipment to the upper level of the Great Hall, micro-inverters are recommended as a reasonable approach to this particular installation. A micro-inverter would be located at each photo-voltaic panel and the voltage is converted to AC right at the panel. The AC power will then be connected to a new power distribution panel in the upper level of the Krannert facility. The panel will then be tied back into the building main distribution system allowing power from the photo-voltaic array to be utilized to offset the building's electricity consumption.

Based on the project budget and preliminary evaluation, it has been preliminarily conceptualized that an 80 KW photo-voltaic system should be constructible on the facility. This is expected to consist of 320, 250-watt photo-voltaic panels. It is expected that the panels would fit on the lower portion of the roof of the Great Hall as can be seen in the "Schematic Roof Plan – Great Hall" (Appendix C). A new 208Y/120VAC three phase 400A panel will need to be installed on the upper level of the Krannert facility in one of the existing rooms. A new feeder will then be routed down to the lower level of the building and tie into an existing main distribution panelboard. It is thought that the chase located near the southwest corner of the Great Hall can be used for cable rating.

A network communications cable will need to be installed to the location of the new panel at the upper level of the facility. A communications gateway then can be installed to monitor the specific energy generation of the system. This information can then be transported over the facility's IP network and be displayed at a computer or Kiosk for convenient monitoring.

A basic non-project specific wiring diagram, example of a micro-inverter and a product data sheet for a typical solar panel are included in Appendix G.

<u>West Elevation Great Hall Photovoltaic Glass Unit (PVGU) Window Replacement</u>

Through research into the PVGU system it was found that there are several products in development that could be available in the near future. One company was also identified that currently has a product on the market. This company is Pythagoras Solar, and they offer a direct window replacement for curtain wall applications that employs a mono crystalline type solar cell sandwiched between two layers of 1/4 in. thick glass. The outer layer of glass is designed to bend the solar radiation to the horizontally mounted solar cell as the light hits the window at different angles thereby concentrating the light onto the PV cells. This allows the PV system to operate at up to 12 percent efficiency for power generation. The window is also designed to act as a high performance shading device. These windows can provide a maximum power density of 11.15 Watts / Square Foot. It is estimated that there is approximately 3,000 sq. ft of glass surface on the west elevation of the facility. In optimal conditions, a system of this type might be expected to generate around 30-33KW of electrical energy.

It should also be noted that a system of this type cannot use a micro-inverter as would be recommended for the Roof Mounted PV system (described above) so a Central type inverter system would be necessary that would require physical space at or near the Window wall. The space for this needs to be further studied.

Pythagoras Solar may be the only company in the marketplace with this type of direct window replacement system. Information about the Krannert facility has been submitted to them and Hanson is currently waiting on a response from them to determine if this is a feasible project for their system. Once Hanson receives a response from Pythagoras we will be better informed to determine the initial cost of the system and potential payback.

A product brochure and technical specification for the PVGU system can be found in Appendix H.

<u>Roof Access for Maintenance of the PV Array</u>

Periodic access (every six to nine months) for maintenance of the PV array should be expected. This access would be facilitated if ladder and scuttle layout that accesses the west end of the roof of the

Great Hall were reconfigured to allow a single ladder run from the Booth floor level to the roof. In its current configuration, personnel who access the roof of the Great Hall from the Booth level first pass through an opening in the ceiling. From just above the ceiling, they must then pass through a portal type opening to another floor from which a second ladder leads to the roof. This passageway is cumbersome and consideration should be given to improving it. It appears that shifting the roof hatch 3 to 4 ft to the south would provide for this direct access. This alternate location is shown on the conceptual roof plan layout of the PV array. The cost for this improvement is not included in the evaluation for this project, as it may be more appropriate to include this work with the separate roofing replacement project that would precede the PV installation

6. Opinion of Probable Construction Cost

The opinion of probable construction cost for the roof-mounted PV system, considering the difficulty level of the installation, is between seven dollars and twenty-five cents and seven dollars and fifty cents ($7.25-$7.50) per Watt. For an 80 KW (or 80,000 Watt) system the opinion of installed cost for the photo-voltaic system is summarized as follows:

Roofing Replacement	NOT IN PROJECT
Access and General Construction	$128,000
Roof Scuttle improvements	NOT IN PROJECT
Electrical conduit / routing	$117,000
PV cells and Micro-inverters	$326,000
Electrical Power Distribution Equipment	$10,000
Kiosk	$4,000
TOTAL (excluding contingencies)	$585,000

An allowance for shifting the roof scuttle to allow a single ladder run from the Booth level to the roof is not included in the Opinion of Probable Construction Cost (OPCC), but it is recommended that such an improvement be made to facilitate access to the roof.

It is recommended that the project be bid with alternates. For example the Base Bid could include a 60 KW system and there could be an alternate additive per unit bid for additional 10KW blocks.

Grants may be available to partially offset construction cost; however, identifying such grants is not within the scope of this study.

7 Payback Analysis

The payback analysis is included in Appendix B of this report. The analysis shows an estimated annual payback of around twelve thousand six hundred dollars ($12,600) from energy savings on the five hundred eighty-five thousand dollar ($585,000) initial investment for the roof-mounted PV array. No attempt has been made to assign a dollar value to the benefits of environmental stewardship. For comparison purposes, a ground-mounted PV array may be expected to have an annual payback of nineteen thousand dollars ($19,000) on the same five hundred eighty-five thousand dollar ($585,000) initial investment.

8. Project Schedule

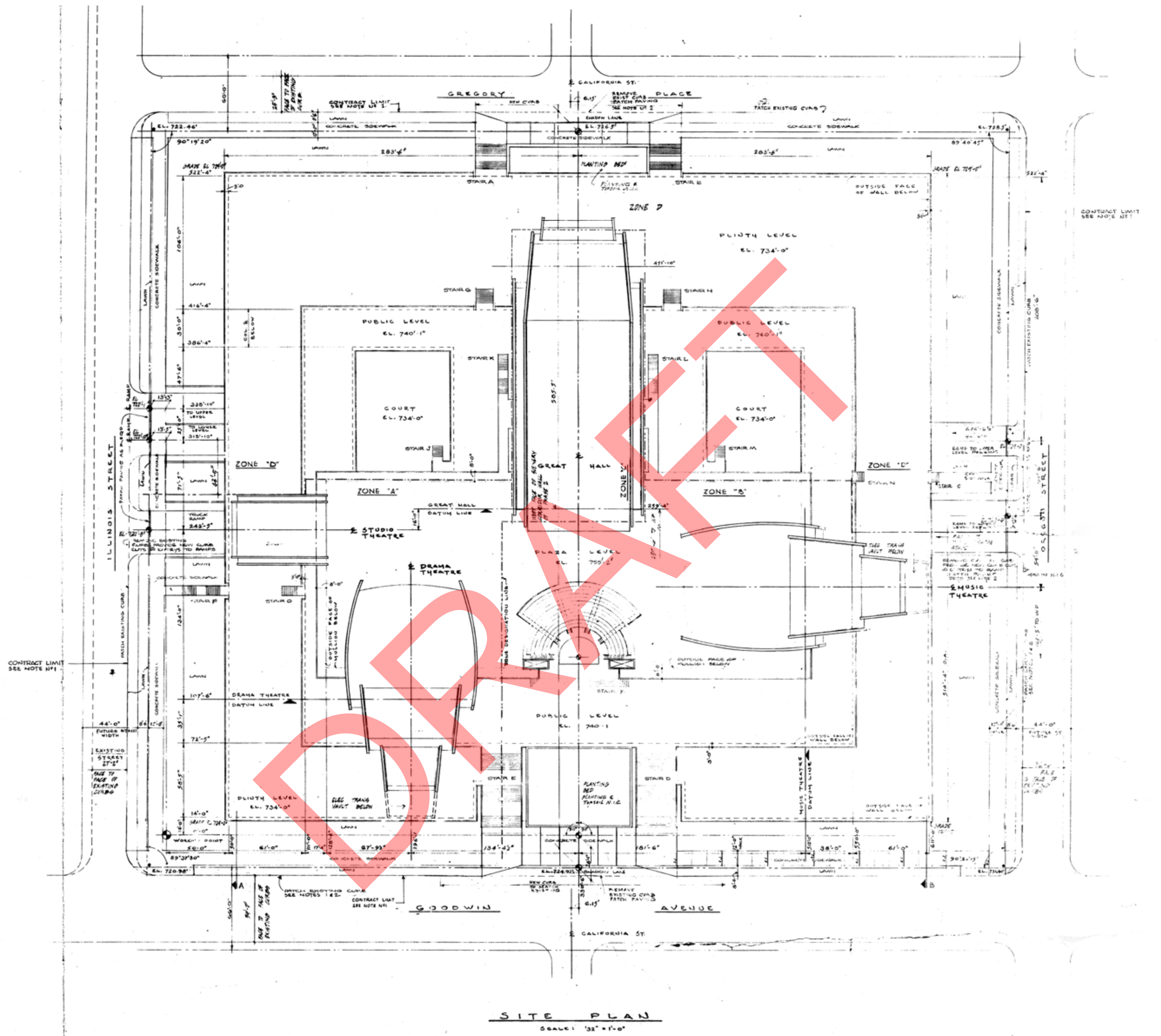
A tentative project schedule will be identified during Phase 2 of the study. At this time, it is thought that on-site construction duration would be no more than eight weeks, assuming a construction schedule that would allow a 40 hour work week, of reasonable blocks of time. It is recognized that such working blocks of time may be limited to early morning, or night-time hours.

9. UIUC Review Comments

Refer to Appendix I (Reserved).

Appendix A

Site Plan



SITE PLAN

1

NO SCALE:

HANSON Hanson Professional Services Inc.	SITE PLAN
	UIUC PROJECT NUMBER: U12239 KRANNERT CENTER FOR THE PERFORMING ARTS SOLAR PROJECT FEASIBILITY STUDY
	11G0002I — A.1

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Appendix B

Payback Analyses and
Opinion of Probable Construction Cost
for Roof Top Construction Activity

PAYBACK ANALYSES

AND

OPINION OF PROBABLE CONSTRUCTION COST

The Payback Analyses and Opinion of Probable Construction Cost (OPCC) prepared by Hanson Professional Services Inc. (Hanson) represent our best judgment as design professionals familiar with the construction industry. It should be recognized, however, that Hanson has no control over the cost of labor, materials or equipment, over the Contractor's methods of determining bid prices, over competitive bidding or market conditions, or over escalation in costs subsequent from the date of preparing these analyses and opinions of cost. Accordingly, Hanson cannot and does not guarantee that bids and actual payback will not vary from the opinions expressed herein.

The OPCC is based on Means 2013, first quarter for the Champaign-Urban area.

Payback Analysis
for a
Roof-Mounted Grid-Tied PV System in Illinois
With No Incentives

INITIAL COSTS AND BENEFITS	Quantity	Unit Cost	Total
INITIAL SYSTEM COST			
250 Watt Solar Panel (EA)	320	$600	$192,000
Structural Support System Installed with Labor (LS)	1	$128,000	$128,000
Micro Inverters and Connecting Wires (EA)	320	$300	$96,000
Disc. and Power Panels and Branch Circuits Installed with Labor (LS)	1	$10,000	$10,000
Monitoring System with Cat 6 Cabling Set Up and Programming (LS)	1	$4,000	$4,000
400 Amp Feeder: Conduit Wire and Boxes Installed with Labor (LF)	600	$175	$105,000
Grounding wire Installed with Labor (LF)	600	$20	$12,000
Labor Solar Install 1.5 Hours per Panel (Hourly + OH&P)	475	$80	$38,000
Initial System Cost Total			**$585,000**
System Cost after Basic Credits			**$585,000**
Total			**$585,000**

ANNUAL PRODUCTION	
Number of Panels	320
STC Rating in Watts Per Panel	250
Total watts per hour assuming optimum conditions	80,000
Performance under typical solar conditions	80%
Adjusted watts per hour assuming real conditions	64,000
Average hours of sunlight per day	4.5
Estimated Watt Hours per day output	288,000
Estimated kilowatt hours per year	105,120
Illinois Electricity Rate	$0.12
Estimated Income (Year 1)	$12,614
Electrical Rate Annual Inflation Assumption	1.0%

REVENUES AND EXPENSES

	2013 Year 0	2014 Year 1	2015 Year 2	2016 Year 3	2017 Year 4	2018 Year 5	2019 Year 6	2020 Year 7	2021 Year 8	2022 Year 9	2023 Year 10	2024 Year 11	2025 Year 12
Initial System Cost & Salvage Value	($585,000)												
Electricity Sales		$12,614	$12,741	$12,868	$12,997	$13,127	$13,258	$13,390	$13,524	$13,660	$13,796	$13,934	$14,073
Cumulative Electricity Sales		$12,614	$25,355	$38,223	$51,220	$64,346	$77,604	$90,994	$104,519	$118,178	$131,975	$145,909	$159,982
Simple Payback (Personal) {Year cash flow turns positive}:		($572,386)	($559,645)	($546,777)	($533,780)	($520,654)	($507,396)	($494,006)	($480,481)	($466,822)	($453,025)	($439,091)	($425,018)

	2026 Year 13	2027 Year 14	2028 Year 15	2029 Year 16	2030 Year 17	2031 Year 18	2032 Year 19	2033 Year 20	2034 Year 21	2035 Year 22	2036 Year 23	2037 Year 24
Initial System Cost & Salvage Value												$0
Electricity Sales	$14,214	$14,356	$14,500	$14,645	$14,791	$14,939	$15,089	$15,240	$15,392	$15,546	$15,701	$15,858
Cumulative Electricity Sales	$174,196	$188,553	$203,053	$217,698	$232,489	$247,428	$262,517	$277,757	$293,148	$308,694	$324,396	$340,254
Simple Payback	($410,804)	($396,447)	($381,947)	($367,302)	($352,511)	($337,572)	($322,483)	($307,243)	($291,852)	($276,306)	($260,604)	($244,746)

OPINION OF PROBABLE COST

PROJECT	Krannert PV Study	SUBMITTAL NO.	
LOCATION	Urbana, IL	TRADE	Gen_Struct
ARCHITECT	Hanson Professional Services Inc.		
ENGINEER	Hanson Professional Services Inc.	DATE	2/28/2013
PREPARED BY	R. Fiorito	PRICES BY	2013 RS Means
CHECKED BY	G. Clack		

Division Reference	Div. #	Description	QTY	UNIT	UNIT MAT'L	EXT. MAT'L	UNIT LABOR	EXT. LABOR	UNIT TOTAL INCL O&P	EXT. TOTAL INCL O&P
15419500600	15	**Crane**								
		Mobilization	1	LS					3000.00	3000.00
		Crane Time for PV Installation (OT)	16	Hr					505.00	8080.00
		Demobilization	1	LS					3000.00	3000.00
		Access Scaffolding Rent							277.00	
015423702250	01	Scaffolding	20	Ea	32.00	640.00			35.20	704.00
015423702900	01	Stair	10	Ea	40.00	400.00			44.00	440.00
Custom	01	Setup	8	Hr			180.00	1440.00	277.00	2216.00
15433403500	15	**Light Plant**	2	M					1724.80	3449.60
		Pipe Columns								
50519101430	05	Anchors	192	Ea	8.90	1708.80	24.00	4608.00	52.00	9984.00
		OT Installation	113	Hr			12.00	1356.00	16.83	1901.79
51223650450	05	Pipe Base Plate	33.12	SF	40.00	1324.80			44.00	1457.28
221113441400	22	Pipe Columns (Galvanized)	96	LF	41.00	3936.00			51.00	4896.00
51223171750		Erection	48	Ea			47.50	2280.00	59.07	2835.36
		OT Erection	48	Ea			23.75	1140.00	29.54	1417.92
		Wide Flange Dunnage								
51223751300	05	Wide Flange Framing	926	LF	55.13	51050.38	4.68	4333.68	70.71	65477.46
51223171100	05	Galvanizing	20372	LB	0.25	5093.00			0.28	5704.16
		OT Erection	926	LF			2.34	2166.84	2.69	2490.94
		Roofing Repairs								
Custom	07	EPDM Boot	48	Ea	15.00	720.00			20.00	960.00
	07	Insulation Repair	48	Ea	10.92	524.16			12.53	601.44
76523108200	07	Roof Repair	48	Ea	20.00	960.00	38.20	1833.60	84.35	4048.80
Custom		**Asbestos Abatement**	1	Ea					5000.00	5000.00
					MAT'L TOTAL	**66357.14**	**LAB'R TOTAL**	**19158.12**	**TRADE TOTAL**	**127664.75**

Payback Analysis

for a

Ground-Mounted Grid-Tied PV System in Illinois

With No Incentives

INITIAL COSTS AND BENEFITS	**Quantity**	**Unit Cost**	**Total**
INITIAL SYSTEM COST			
250 Watt Solar Panel (EA)	485	$600	$291,000
Structural Support System Installed with Labor (LS)	1	$89,000	$89,000
Micro Inverters and Connecting Wires (EA)	485	$300	$145,500
Disc. and Power Panels and Branch Circuits Installed with Labor (LS)	1	$10,400	$10,400
Monitoring System with Cat 6 Cabling Set Up and Programming (LS)	1	$4,000	$4,000
800 Amp Feeder: Conduit Wire and Boxes Installed with Labor (LF)	50	$300	$15,000
Grounding wire Installed with Labor (LF)	50	$20	$1,000
Labor Solar Install .75 Hours per Panel (Hourly + OH&P)	364	$80	$29,100
Initial System Cost Total			**$585,000**
System Cost after Basic Credits			**$585,000**
Total			**$585,000**

ANNUAL PRODUCTION	
Number of Panels	485
STC Rating in Watts Per Panel	250
Total watts per hour assuming optimum conditions	121,250
Performance under typical solar conditions	80%
Adjusted watts per hour assuming real conditions	97,000
Average hours of sunlight per day	4.5
Estimated Watt Hours per day output	436,500
Estimated kilowatt hours per year	159,323
Illinois Electricity Rate	$0.12
Estimated Income (Year 1)	$19,119
Electrical Rate Annual Inflation Assumption	1.0%

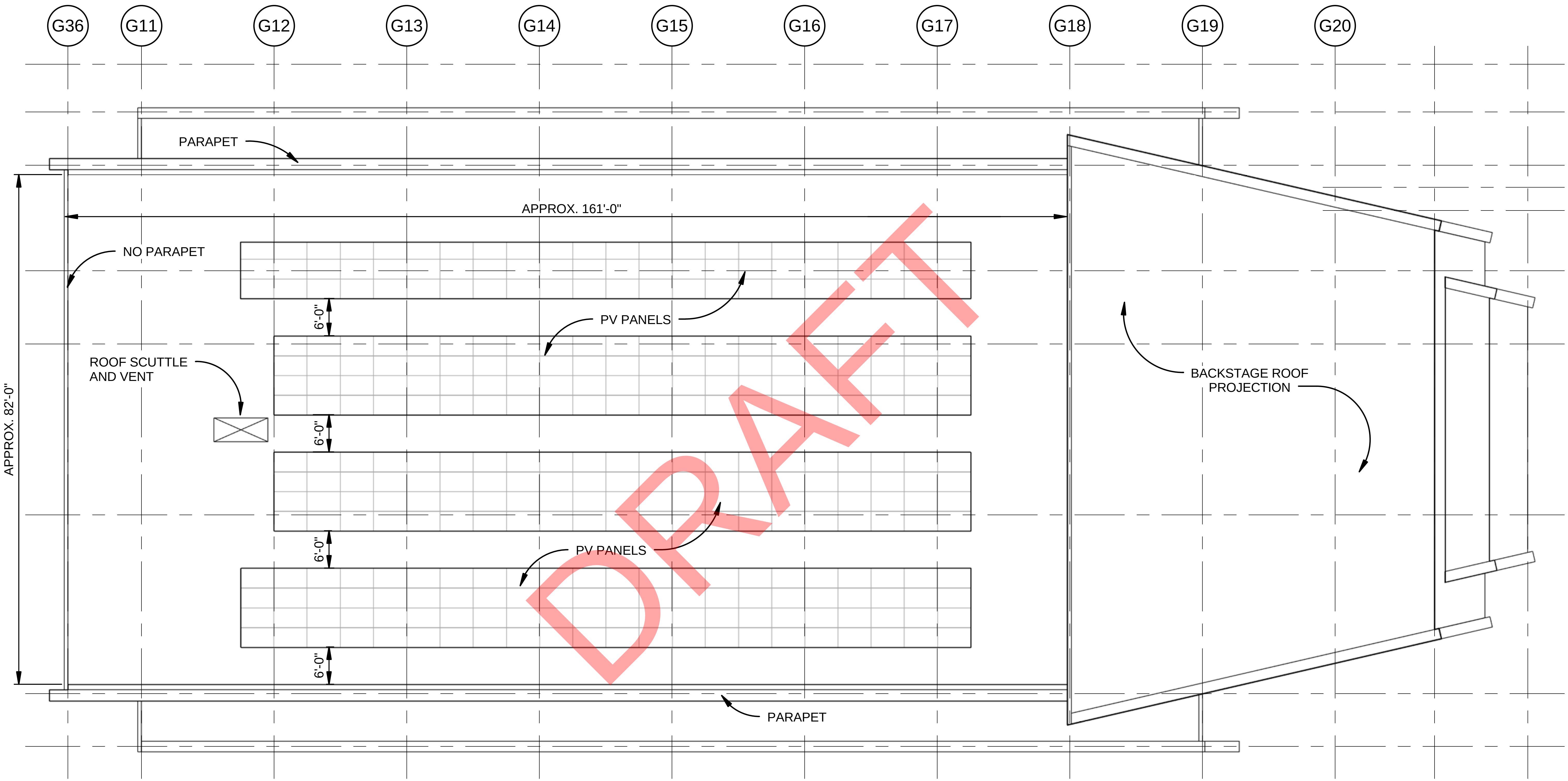
REVENUES AND EXPENSES

	2013 Year 0	**2014 Year 1**	**2015 Year 2**	**2016 Year 3**	**2017 Year 4**	**2018 Year 5**	**2019 Year 6**	**2020 Year 7**	**2021 Year 8**	**2022 Year 9**	**2023 Year 10**	**2024 Year 11**	**2025 Year 12**
Initial System Cost & Salvage Value	($585,000)												
Electricity Sales		$19,119	$19,310	$19,503	$19,698	$19,895	$20,094	$20,295	$20,498	$20,703	$20,910	$21,119	$21,330
Cumulative Electricity Sales		$19,119	$38,429	$57,932	$77,630	$97,525	$117,619	$137,913	$158,411	$179,114	$200,024	$221,143	$242,473
Simple Payback (Personal) {Year cash flow turns positive}:		**($565,881)**	**($546,571)**	**($527,068)**	**($507,370)**	**($487,475)**	**($467,381)**	**($447,087)**	**($426,589)**	**($405,886)**	**($384,976)**	**($363,857)**	**($342,527)**

	2026 Year 13	**2027 Year 14**	**2028 Year 15**	**2029 Year 16**	**2030 Year 17**	**2031 Year 18**	**2032 Year 19**	**2033 Year 20**	**2034 Year 21**	**2035 Year 22**	**2036 Year 23**	**2037 Year 24**
												$0
	$21,543	$21,759	$21,976	$22,196	$22,418	$22,642	$22,869	$23,097	$23,328	$23,562	$23,797	$24,035
	$264,016	$285,775	$307,752	$329,948	$352,366	$375,008	$397,877	$420,975	$444,303	$467,865	$491,662	$515,698
	($320,984)	**($299,225)**	**($277,248)**	**($255,052)**	**($232,634)**	**($209,992)**	**($187,123)**	**($164,025)**	**($140,697)**	**($117,135)**	**($93,338)**	**($69,302)**

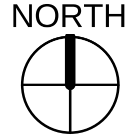
Appendix C

Schematic Roof Plan – Great Hall



1 ROOF PLAN

SCALE: 1/16" = 1'-0"



HANSON Hanson Professional Services Inc.	SCHEMATIC ROOF PLAN - GREAT HALL
	UIUC PROJECT NUMBER: U12239 KRANNERT CENTER FOR THE PERFORMING ARTS SOLAR PROJECT FEASIBILITY STUDY
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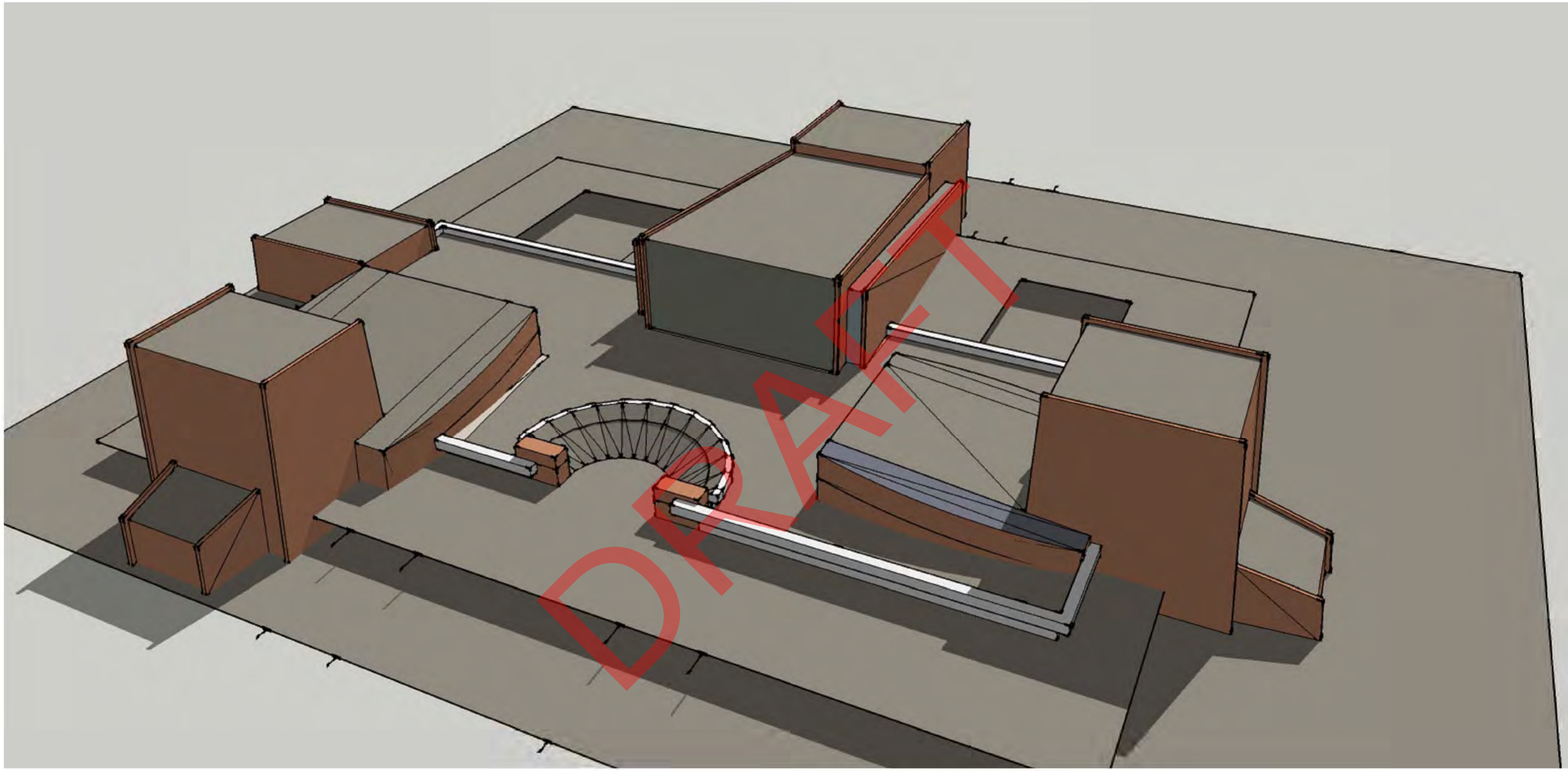
Appendix D

Shadow Studies



1 SHADOW STUDY - JUNE 21, 2013; 10:00 AM

PERSPECTIVE VIEW

SHADOW STUDY - JUNE 21, 10 AM

HANSON
Hanson Professional Services Inc.

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
SOLAR PROJECT FEASIBILITY STUDY

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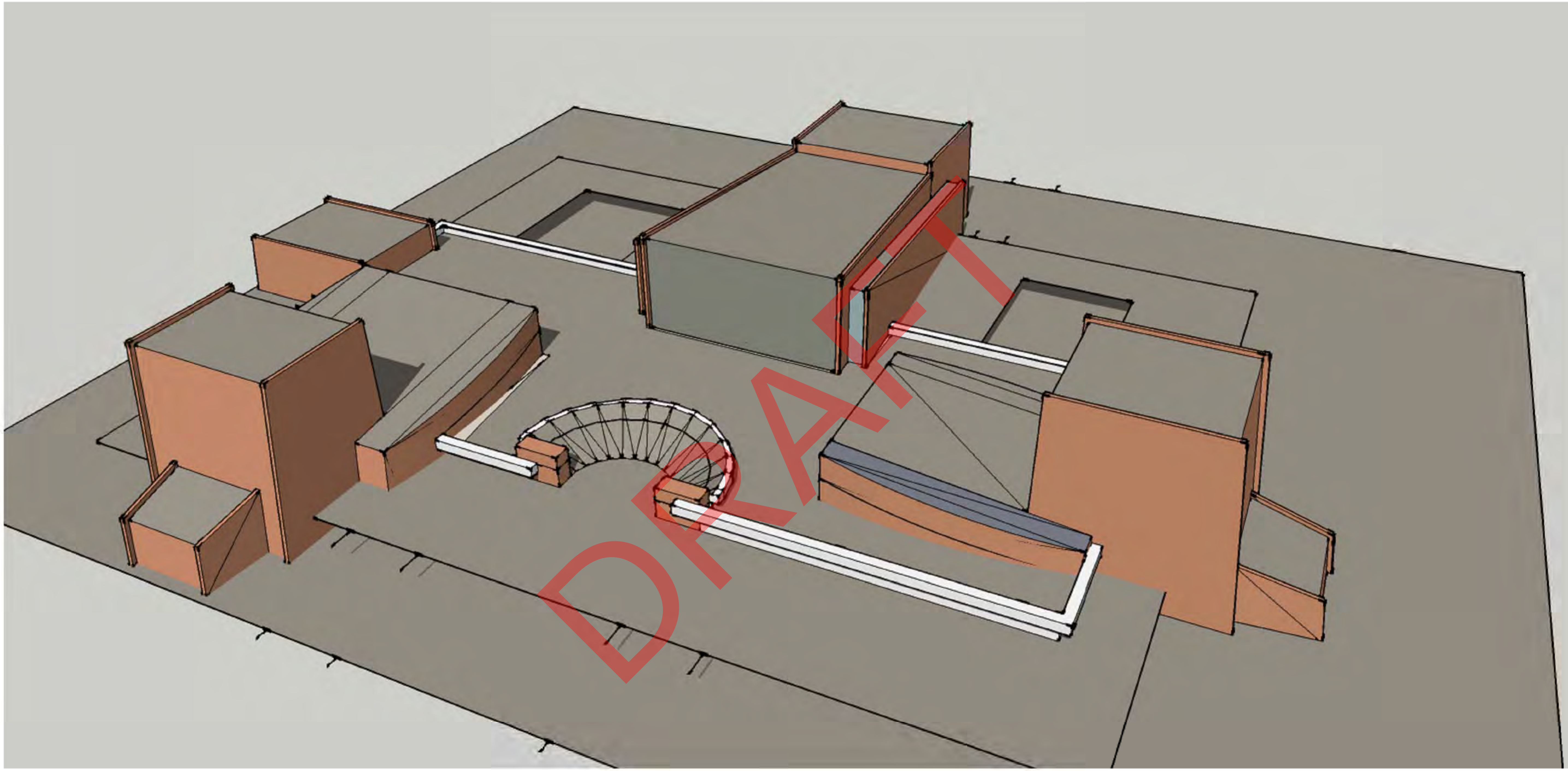

SHADOW STUDY - JUNE 21, 2013; 4:00 PM

1 PERSPECTIVE VIEW

SHADOW STUDY - JUNE 21, 4 PM

Hanson Professional Services Inc.

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
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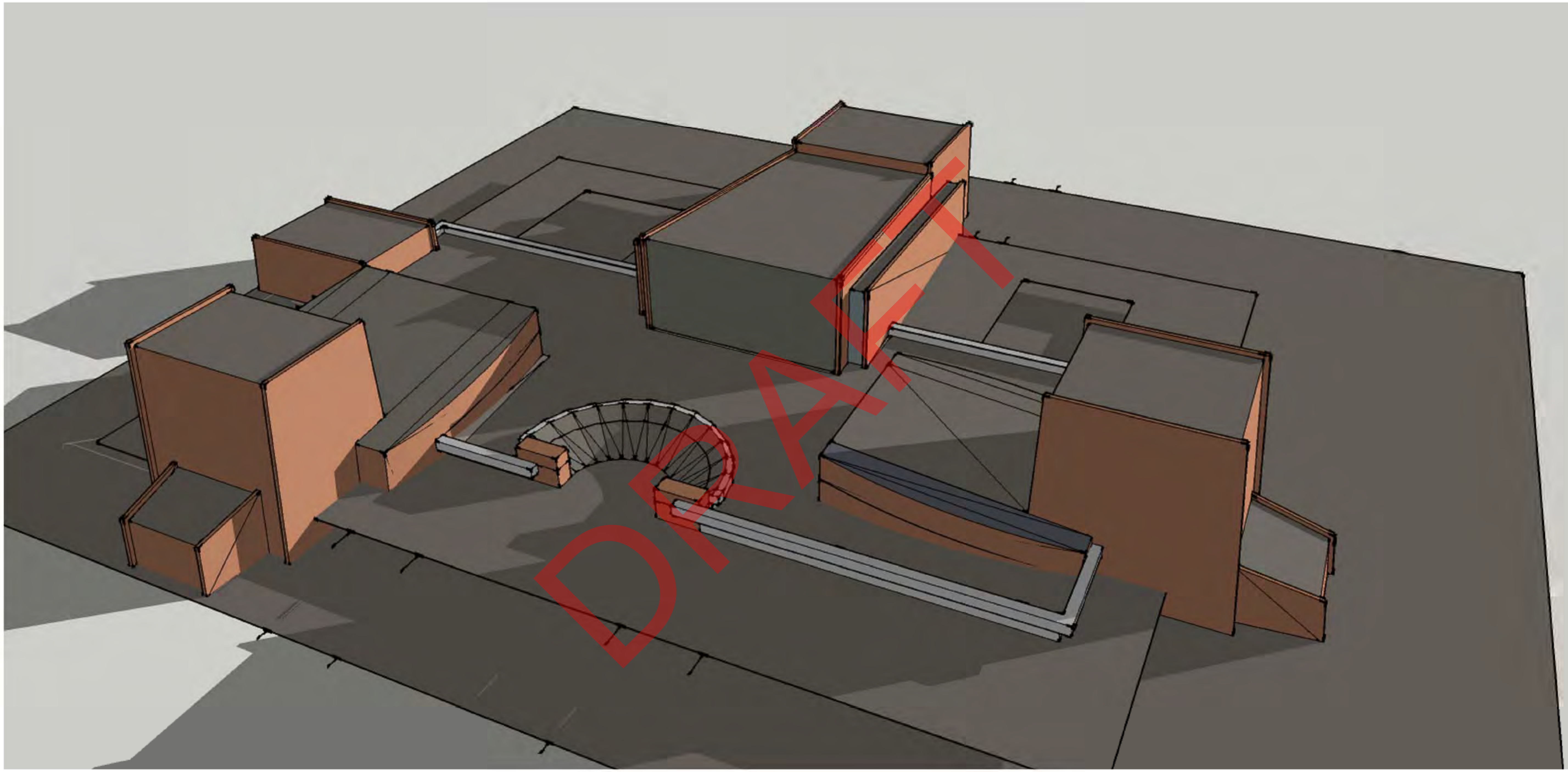

SHADOW STUDY - DECEMBER 21, 2013; 10:00 AM

1 PERSPECTIVE VIEW

SHADOW STUDY - DECEMBER 21, 10 AM

HANSON
Hanson Professional Services Inc.

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
SOLAR PROJECT FEASIBILITY STUDY

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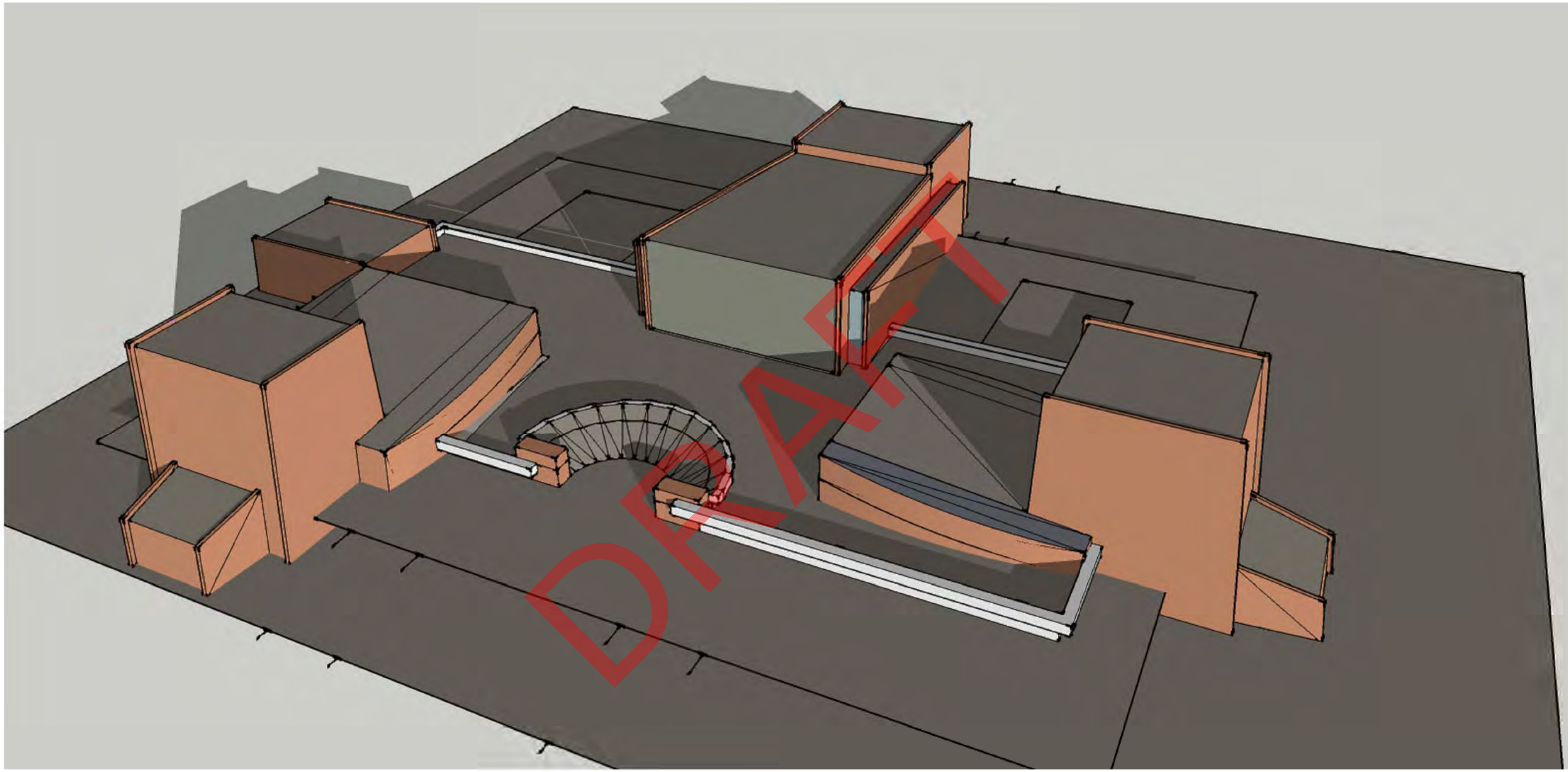

① **SHADOW STUDY - DECEMBER 21, 2013; 4:00 PM**

PERSPECTIVE VIEW

HANSON Hanson Professional Services Inc.	SHADOW STUDY - DECEMBER 21, 4 PM
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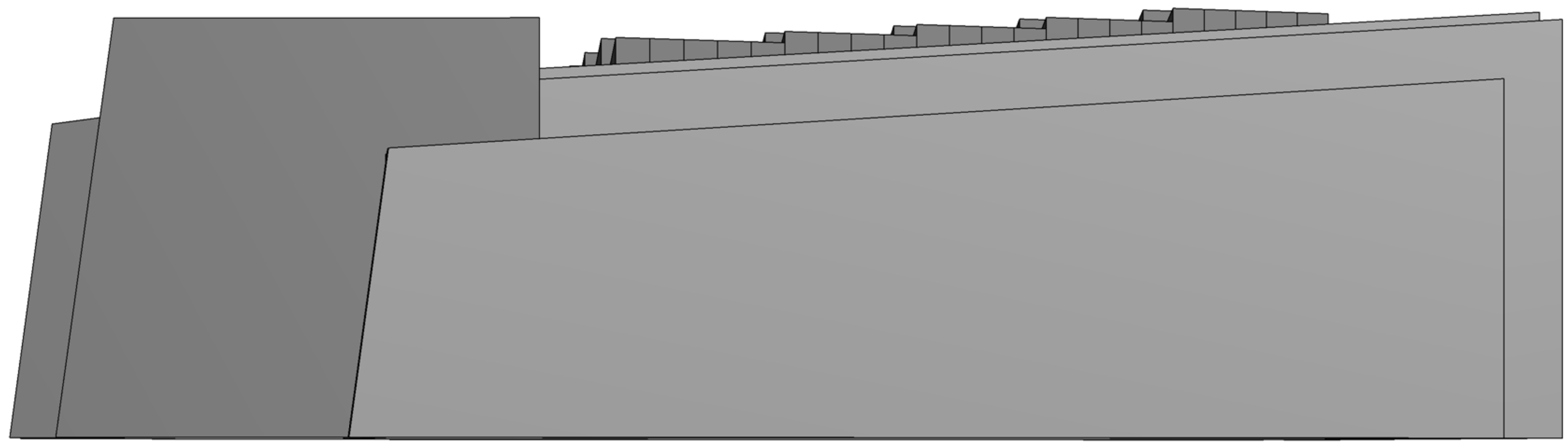
Appendix E

Renderings – Line Type for Great Hall at
34° and 10° Inclination of Solar Panels and
Overall Ground Level Photo Renderings



1 **NORTH CAMERA - 34º INCLINATION OF SOLAR PANELS**

PERSPECTIVE VIEW - GREAT HALL ONLY FROM ILLINOIS STREET, LOOKING SOUTH

HANSON Hanson Professional Services Inc.	PERSPECTIVE FROM NORTH - 34º INCLINATION
	UIUC PROJECT NUMBER: U12239 KRANNERT CENTER FOR THE PERFORMING ARTS SOLAR PROJECT FEASIBILITY STUDY
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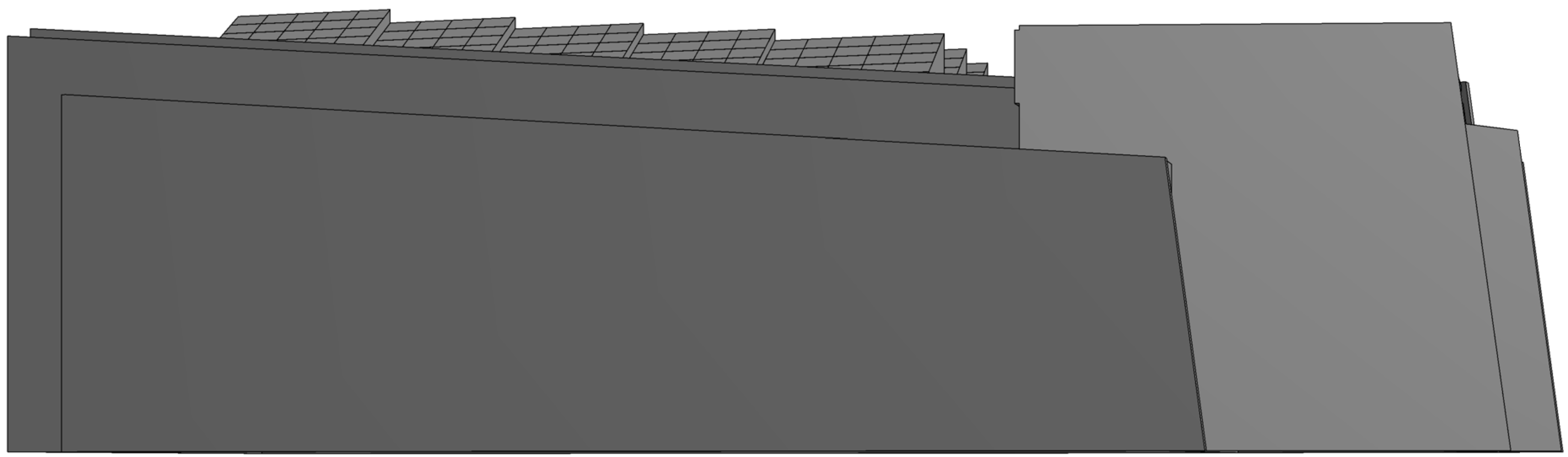

1 SOUTH CAMERA -34º INCLINATION OF SOLAR PANELS

PERSPECTIVE VIEW - GREAT HALL ONLY FROM OREGON STREET, LOOKING NORTH

PERSPECTIVE FROM SOUTH - 34º INCLINATION

HANSON
Hanson Professional Services Inc.

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
SOLAR PROJECT FEASIBILITY STUDY

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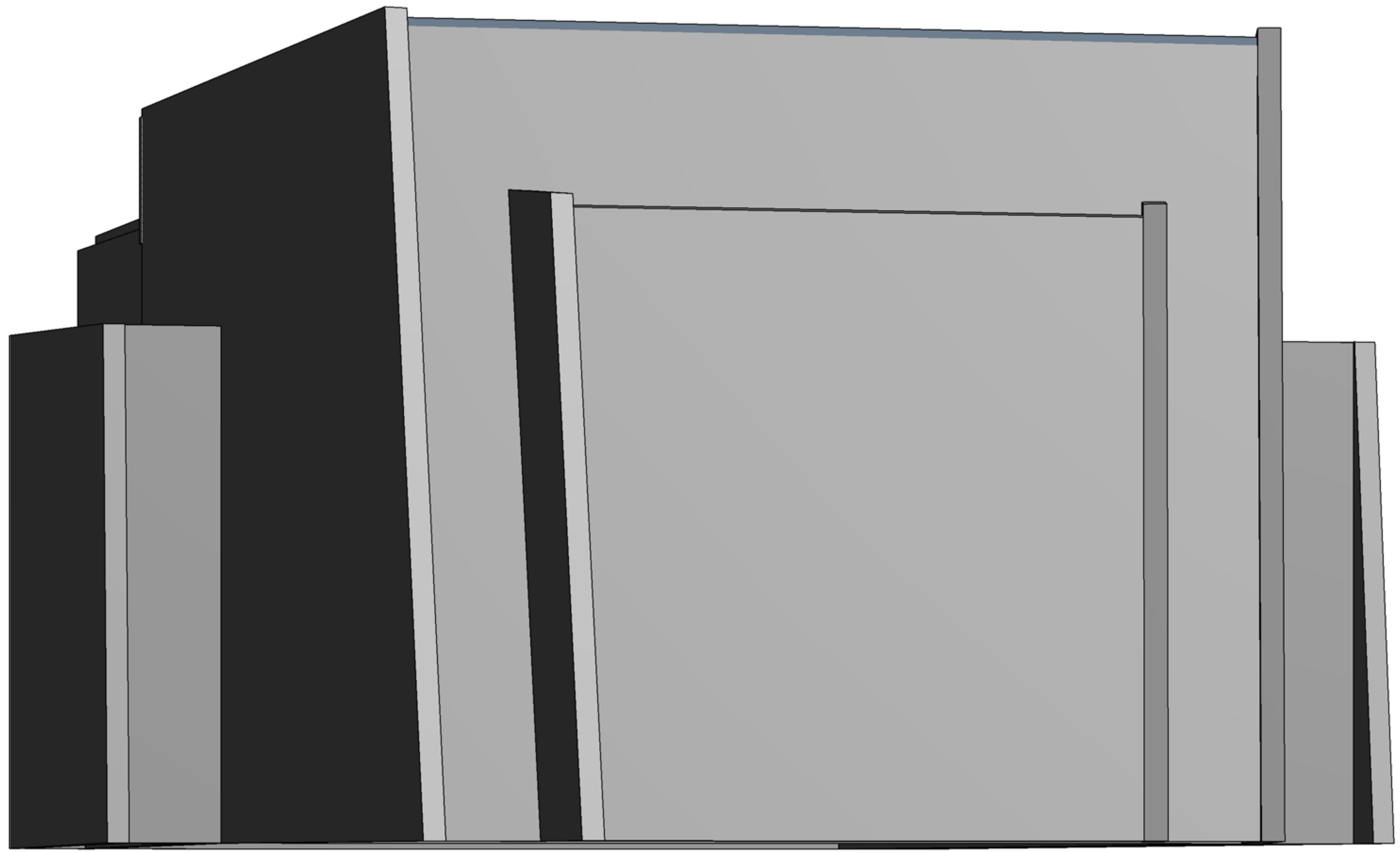

1 EAST CAMERA - 34º INCLINATION OF SOLAR PANELS

PERSPECTIVE VIEW - GREAT HALL ONLY FROM 400 FT EAST OF GREGORY PLACE, LOOKING WEST

Hanson Professional Services Inc.

PERSPECTIVE FROM WEST - 34º INCLINATION

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
SOLAR PROJECT FEASIBILITY STUDY

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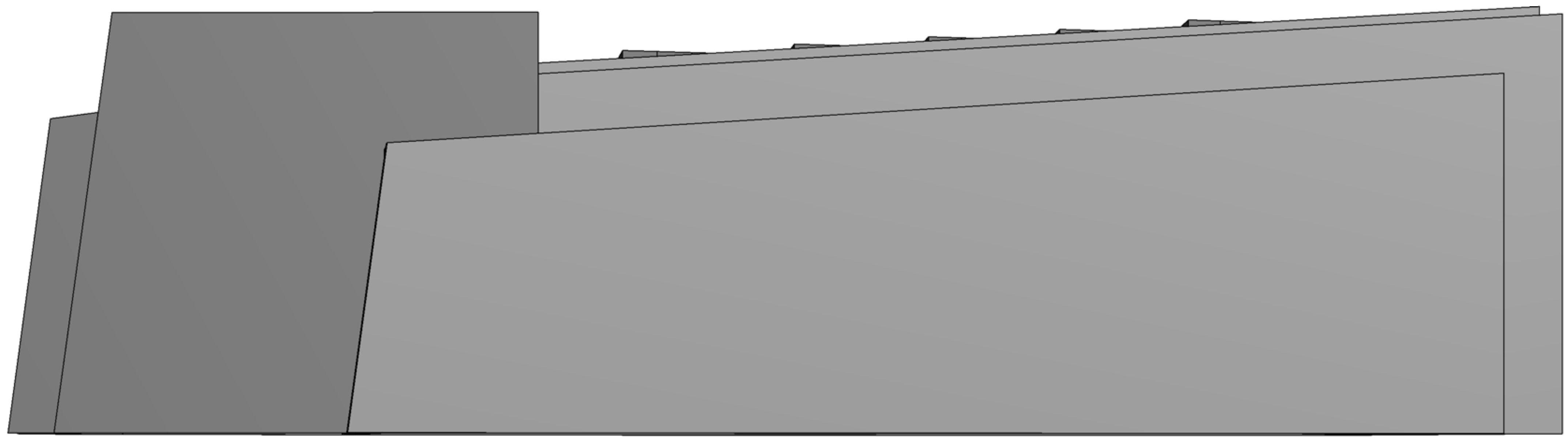

1 NORTH CAMERA - 10º INCLINATION OF SOLAR PANELS

PERSPECTIVE VIEW - GREAT HALL ONLY FROM ILLINOIS STREET, LOOKING SOUTH

Hanson Professional Services Inc.

PERSPECTIVE FROM NORTH - 10º INCLINATION

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
SOLAR PROJECT FEASIBILITY STUDY

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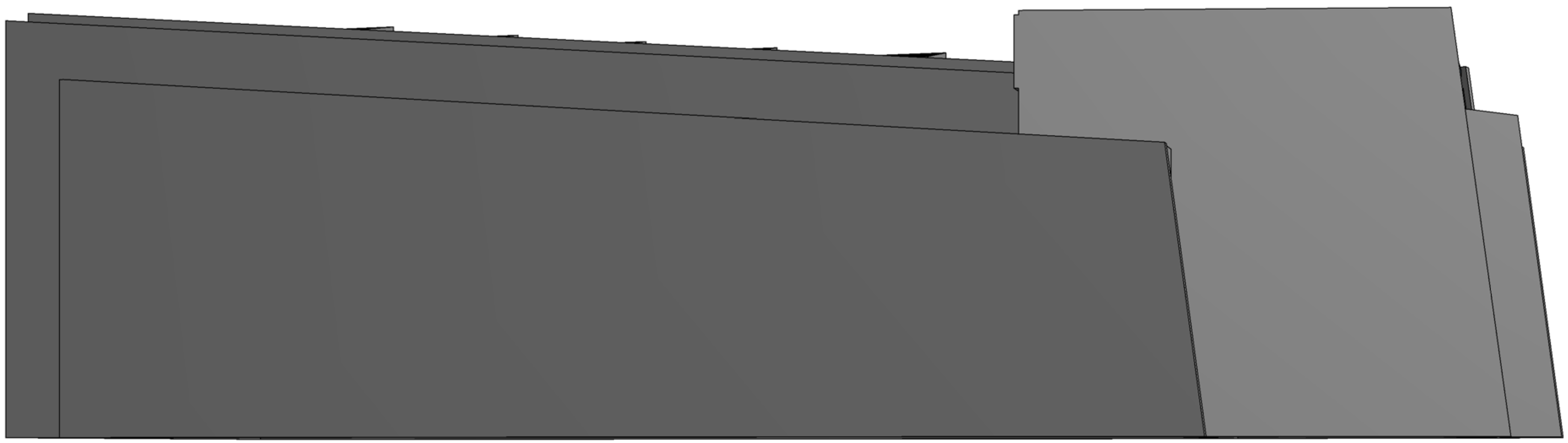

SOUTH CAMERA -10º INCLINATION OF SOLAR PANELS

1 PERSPECTIVE VIEW - GREAT HALL ONLY FROM OREGON STREET, LOOKING NORTH

HANSON
Hanson Professional Services Inc.

PERSPECTIVE FROM SOUTH - 10º INCLINATION

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
SOLAR PROJECT FEASIBILITY STUDY

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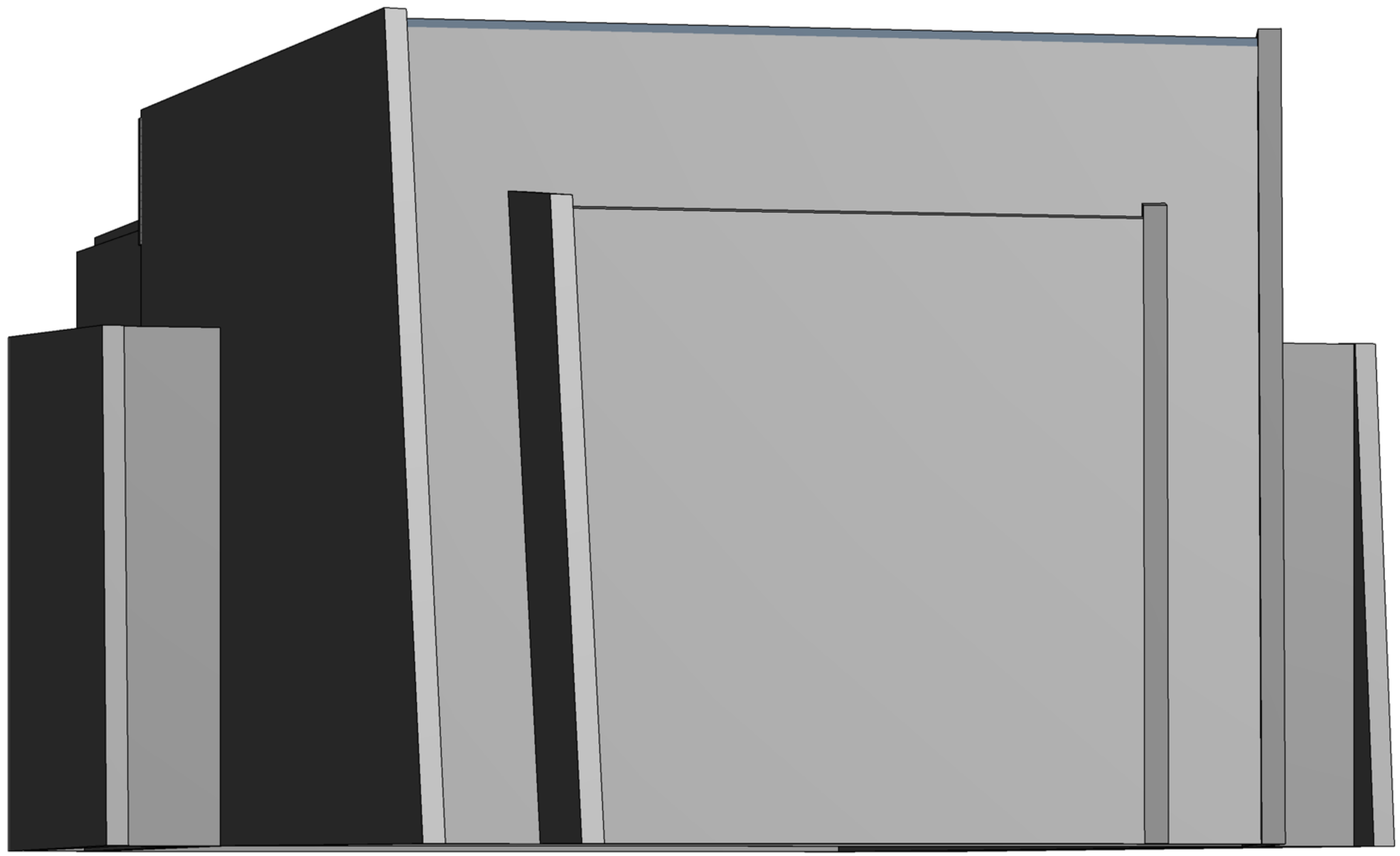

1 EAST CAMERA - 10º INCLINATION OF SOLAR PANELS

PERSPECTIVE VIEW - GREAT HALL ONLY FROM 400 FT EAST OF GREGORY PLACE, LOOKING WEST

HANSON Hanson Professional Services Inc.	PERSPECTIVE FROM WEST- 10º INCLINATION
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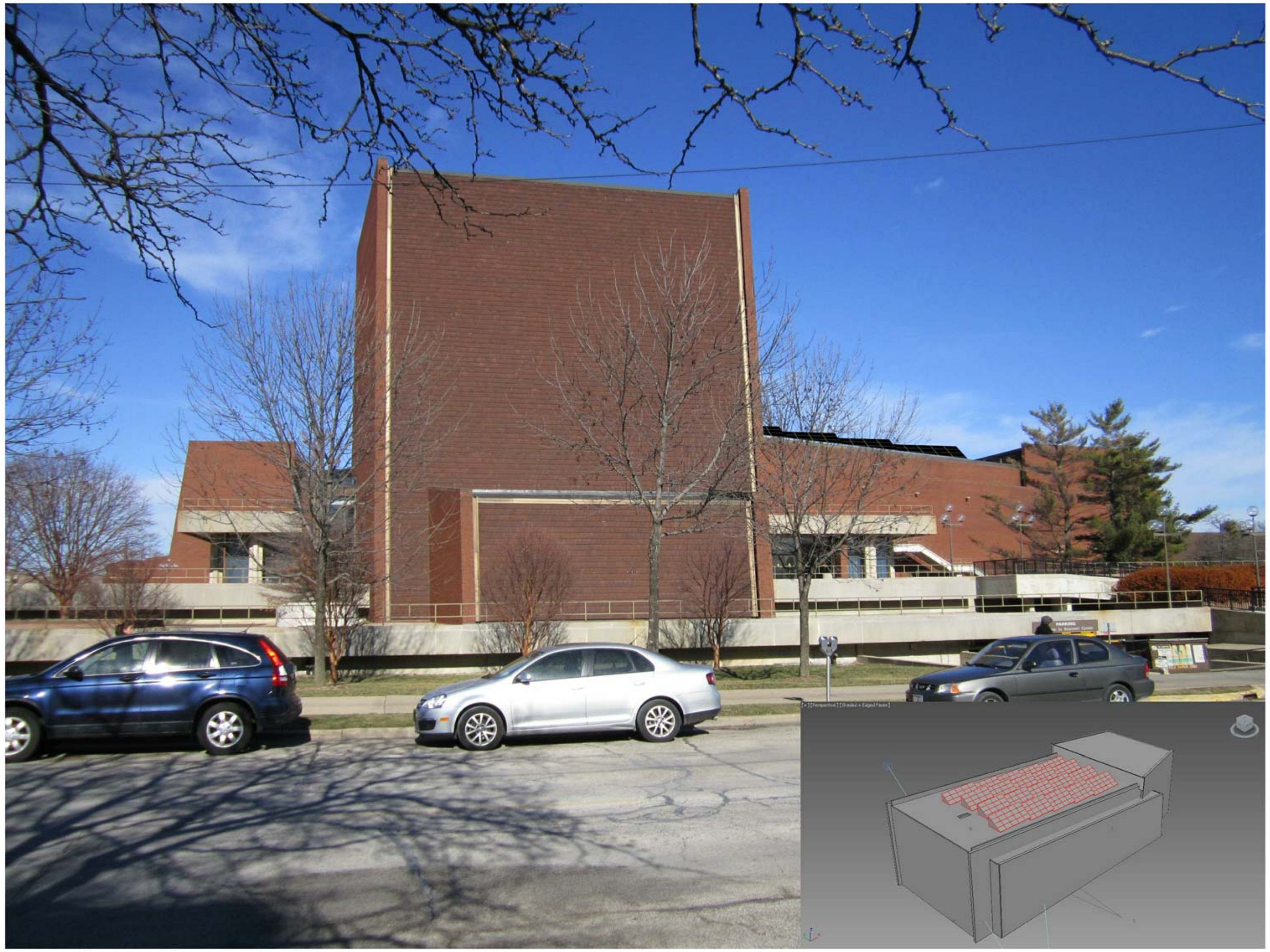

1 **SOUTH RENDERING 34º INCLINATION OF SOLAR PANELS**

NO SCALE:

HANSON Hanson Professional Services Inc.	RENDERING FROM SOUTH - 34º INCLINATION
	UIUC PROJECT NUMBER: U12239 KRANNERT CENTER FOR THE PERFORMING ARTS SOLAR PROJECT FEASIBILITY STUDY
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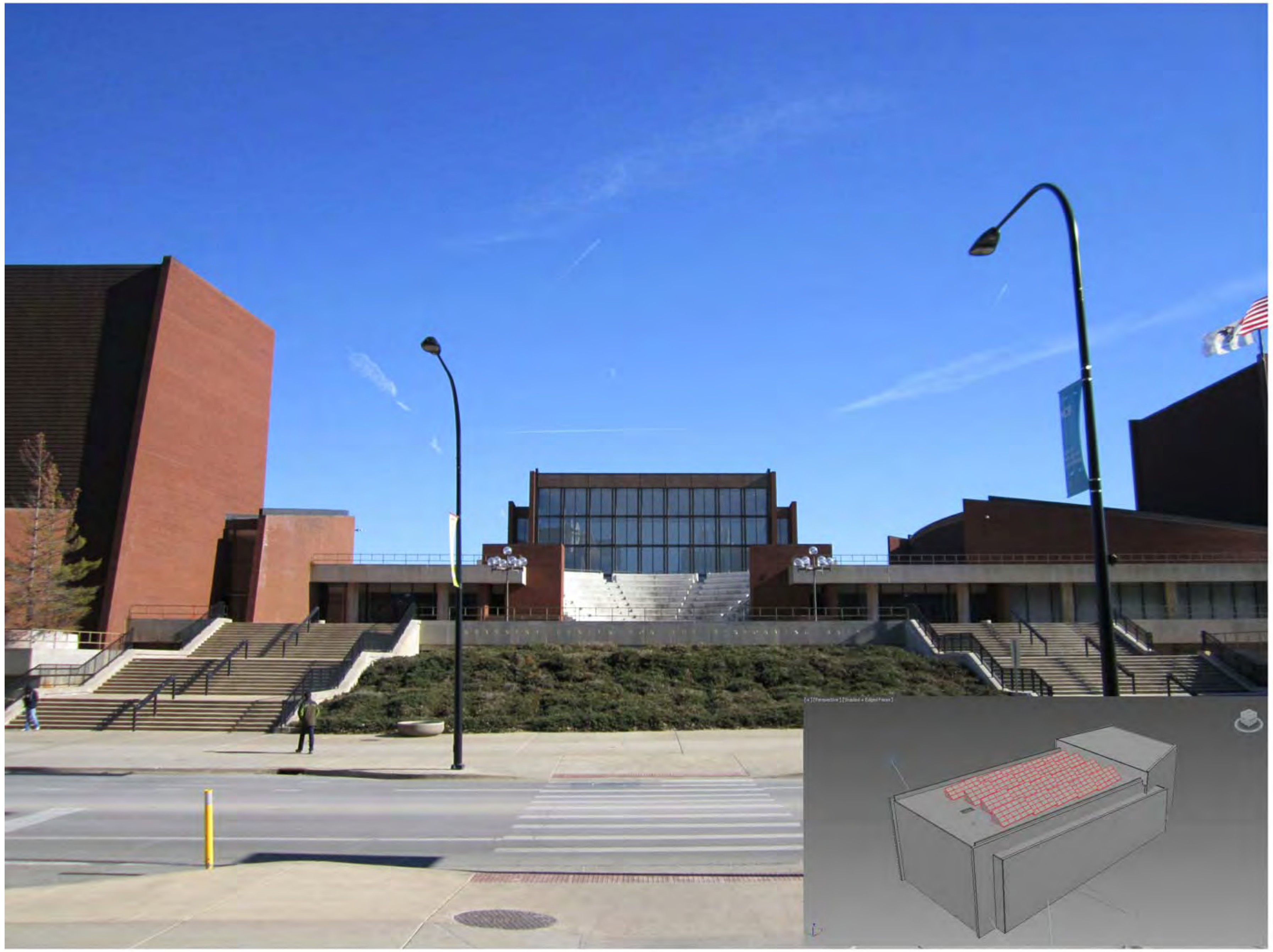

1 WEST RENDERING 34º INCLINATION OF SOLAR PANELS

NO SCALE:

Hanson Professional Services Inc.

RENDERING FROM WEST - 34º INCLINATION

UIUC PROJECT NUMBER: U12239
KRANNERT CENTER FOR THE PERFORMING ARTS
SOLAR PROJECT FEASIBILITY STUDY

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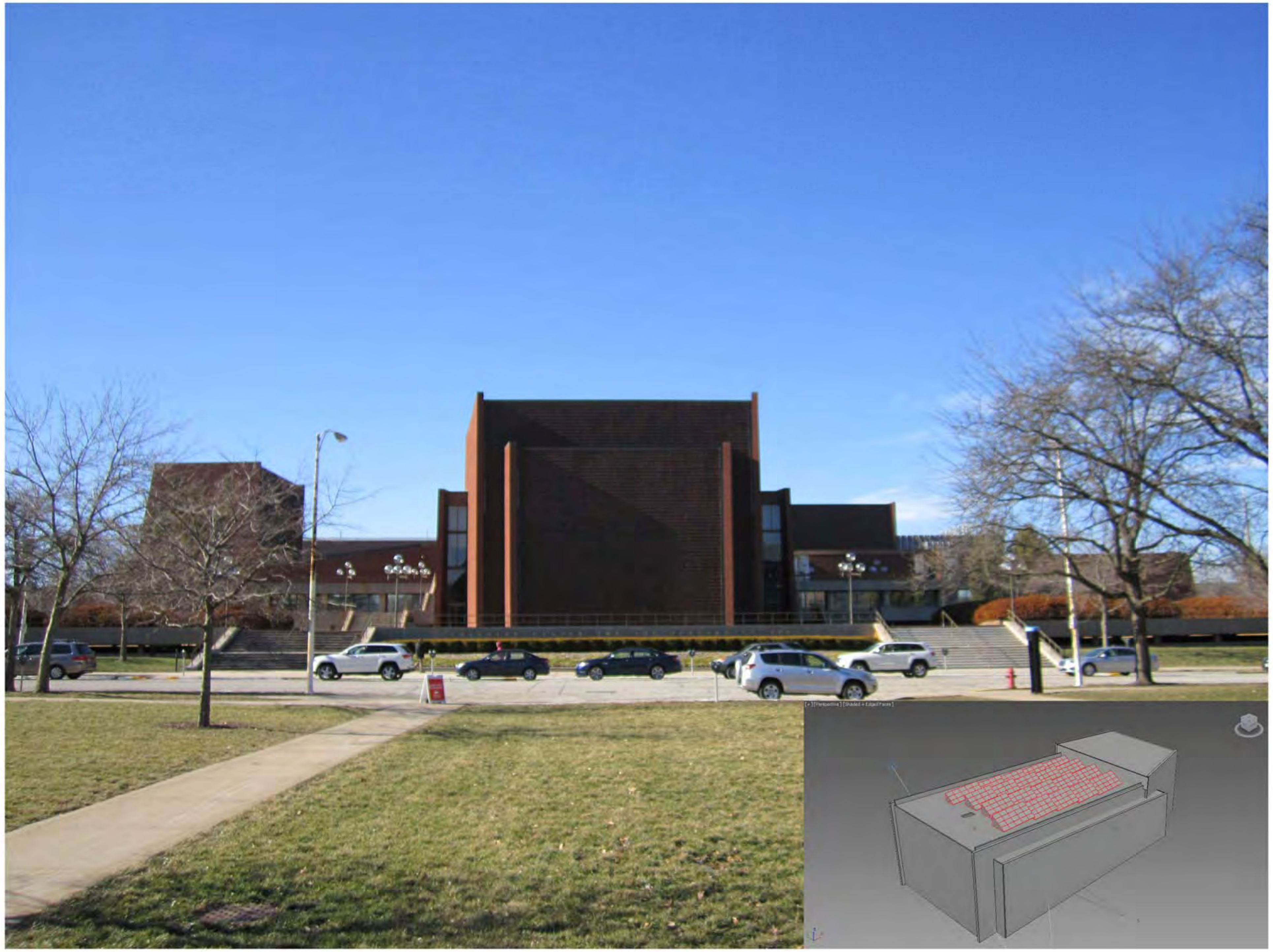

1 EAST RENDERING 34º INCLINATION OF SOLAR PANELS

NO SCALE:

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Appendix F

Conceptual Crane Placement

1 CRANE PLACEMENT
PERSPECTIVE VIEW

HANSON Hanson Professional Services Inc.	CONCEPTUAL CRANE PLACEMENT
	UIUC PROJECT NUMBER: U12239 KRANNERT CENTER FOR THE PERFORMING ARTS SOLAR PROJECT FEASIBILITY STUDY
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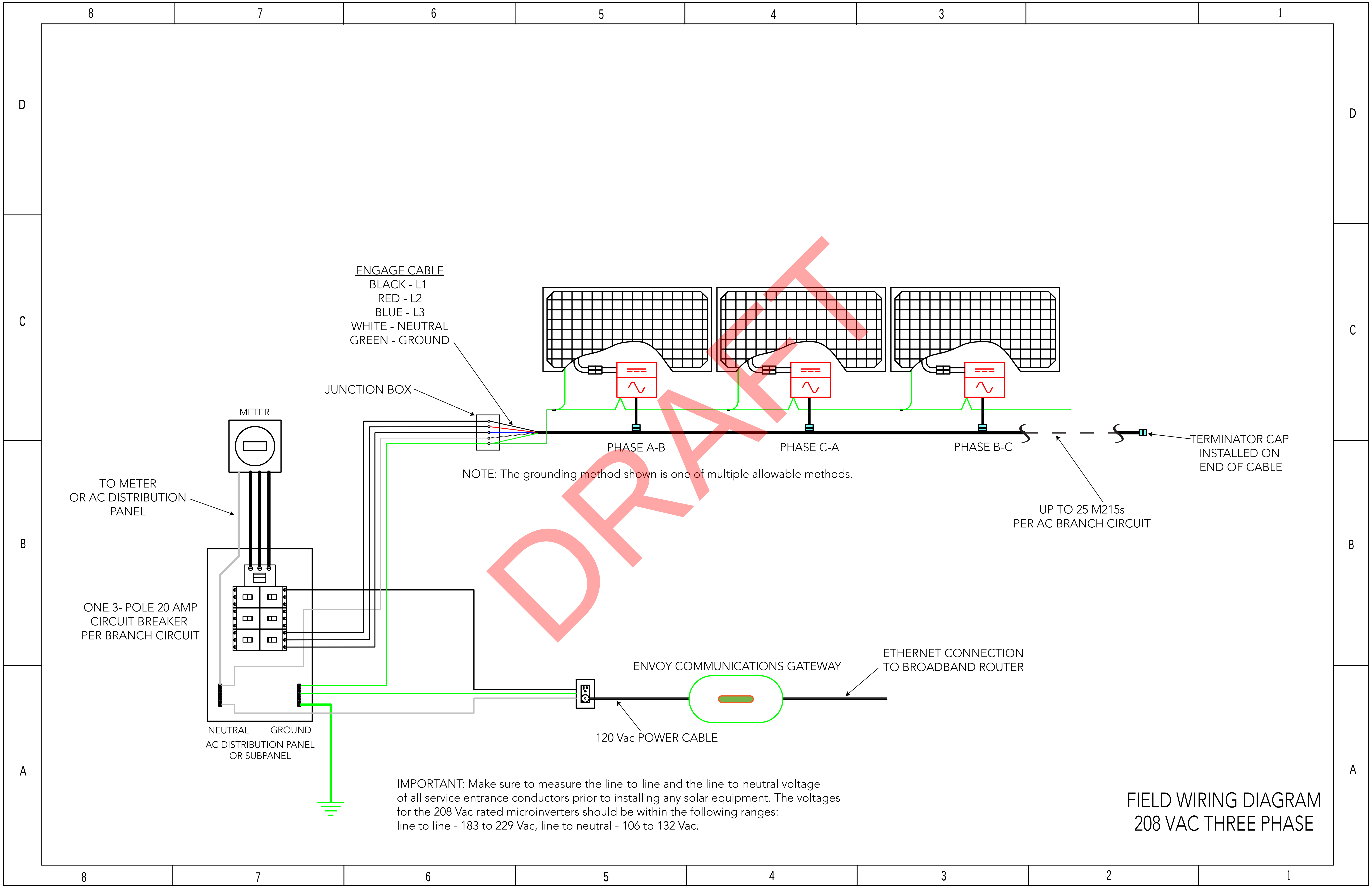
Appendix G

Generic Wiring Diagram, Example of
Micro-inverter and Product Data Sheet
for Typical Photovoltaic Panel


ENGAGE CABLE
BLACK - L1
RED - L2
BLUE - L3
WHITE - NEUTRAL
GREEN - GROUND
JUNCTION BOX
METER
TO METER
OR AC DISTRIBUTION
PANEL
PHASE A-B
PHASE C-A
PHASE B-C
TERMINATOR CAP
INSTALLED ON
END OF CABLE
NOTE: The grounding method shown is one of multiple allowable methods.
UP TO 25 M215s
PER AC BRANCH CIRCUIT
ONE 3- POLE 20 AMP
CIRCUIT BREAKER
PER BRANCH CIRCUIT
ENVOY COMMUNICATIONS GATEWAY
ETHERNET CONNECTION
TO BROADBAND ROUTER
120 Vac POWER CABLE
NEUTRAL
GROUND
AC DISTRIBUTION PANEL
OR SUBPANEL
IMPORTANT: Make sure to measure the line-to-line and the line-to-neutral voltage
of all service entrance conductors prior to installing any solar equipment. The voltages
for the 208 Vac rated microinverters should be within the following ranges:
line to line - 183 to 229 Vac, line to neutral - 106 to 132 Vac.
FIELD WIRING DIAGRAM
208 VAC THREE PHASE
DRAFT

G.1

M215™ MICROINVERTER

enphase® ENERGY

The Enphase Energy Microinverter System improves energy harvest, increases reliability, and dramatically simplifies design, installation and management of solar power systems.

The Enphase System includes the microinverter, the Envoy Communications Gateway™, and Enlighten®, Enphase's monitoring and analysis software.

PRODUCTIVE

- Maximum energy production
- Resilient to dust, debris and shading
- Performance monitoring per module

RELIABLE

- System availability greater than 99.8%
- No single point of system failure

SMART

- Quick and simple design, installation and management
- 24/7 monitoring and analysis

SAFE

- Low voltage DC
- Reduced fire risk

C US

M215 — MICROINVERTER TECHNICAL DATA

Input Data (DC)	M215-60-2LL-S22/S23/S24 and M215-60-2LL-S22-NA/S23-NA (Ontario)
Recommended input power (STC)	190 - 270W
Maximum input DC voltage	45V
Peak power tracking voltage	22V - 36V
Operating range	16V - 36V
Min./Max. start voltage	22V/45V
Max. DC short circuit current	15A
Max. input current	10.5A

Output Data (AC)	@208 Vac	@240 Vac
Maximum output power	215W	215W
Nominal output current	1.0A (arms at nominal duration)	0.9A (arms at nominal duration)
Nominal voltage/range	208V/183-229V	240V/211-264V
Extended voltage/range	208V/179-232V	240V/206-269V
Nominal frequency/range	60.0/59.3-60.5 Hz	60.0/59.3-60.5 Hz
Extended frequency range	60.0/59.2-60.6 Hz	60.0/59.2-60.6 Hz
Power Factor	>0.95	>0.95
Maximum units per 20A branch circuit	25 (three phase)	17 (single phase)
Maximum output fault current	1.05 Arms, over 3 cycles; 25.2 Apeak, 1.74ms duration	

Efficiency	
CEC weighted efficiency	96.0%
Peak inverter efficiency	96.3%
Static MPPT efficiency (weighted, reference EN50530)	99.6%
Dynamic MPPT efficiency (fast irradiation changes, reference EN50530)	99.3%
Night time power consumption	46mW

Mechanical Data	
Ambient temperature range	-40°C to + 65°C
Operating temperature range (internal)	-40°C to + 85°C
Dimensions (WxHxD)	17.3 cm x 16.4 cm x 2.5 cm (6.8" x 6.45" x 1.0")*
Weight	1.6 kg (3.5 lbs)
Cooling	Natural convection - No fans
Enclosure environmental rating	Outdoor - NEMA 6

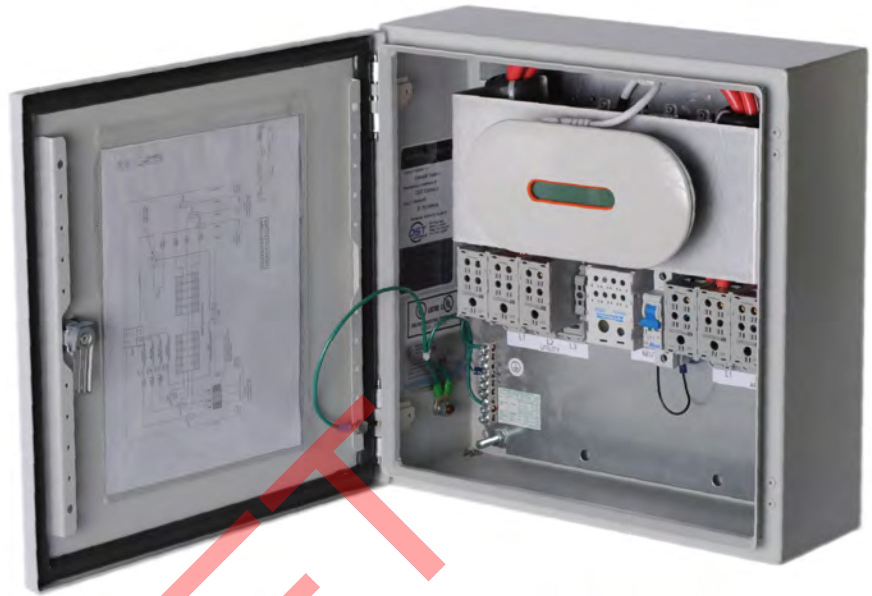
* without mounting bracket

Features	
Compatibility	Pairs with most 60-cell PV modules
Communication	Power line
Warranty	25-year limited warranty
Monitoring	Free lifetime monitoring via Enlighten software
Compliance	UL1741/IEEE1547, FCC Part 15 Class B CAN/CSA-C22.2 NO. 0-M91, 0.4-04, and 107.1-01

Enphase Energy, Inc.
1420 N. McDowell Boulevard
Petaluma, CA 94954
P: 877-797-4743
info@enphaseenergy.com
http://www.enphase.com

142-00010, Rev 04b

Installing the Enphase Line Communications Filter (LCF)



LCFs are required at large installations that require more than one Envoy Communications Gateway™. Each Enphase LCF contains an Envoy and terminations for phase conductor lines in and out. By running phase conductors through the LCF, it filters power line communications and eliminates any potential inter-Envoy crosstalk in multi-Envoy installations.

Installation Considerations

1. The LCF services a maximum number of Enphase Microinverters per the following table, at a total continuous current of 100 Amps per phase.

208 VAC three-phase, approx 36 kW AC	Microinverters supported
M215-60	166
M190-72	189
M210-84	171
240 VAC single-phase, approx 24 kW AC	
M215-60	111
M190-72	126
M210-84	114

2. See the unit rating label for the compatible AC voltage requirements.
3. Use NEMA 4-rated, water-tight cable glands and hubs for all conduit entry. These must not compromise the integrity of the LCF's NEMA enclosure rating.
4. When determining the installation location for the LCF, account for conduit/cable entry for the bottom or side of the LCF enclosure.
5. Select wire size based on ampacity. At a minimum, you will need:
   - #2-#2/0 copper wire for L1, L2, L3 and neutrals
   - #8 AWG minimum for line grounding wire
   - CAT5E or equivalent for Ethernet
6. The LCF terminal blocks have AC fasteners that require compression to a specific torque value during installation. These terminal blocks connect the circuit conductors from PV load center and the grid load center. The terminal block screws must be set to the recommended torque values as specified by the terminal block manufacturer to securely fasten the conductors. See the following sections for wiring steps and for torque values. **Over-torqueing the set screws can compromise the performance of the LCF**.
7. If you are using aluminum wire, use the specified procedure to install this wire. Refer to the terminal blocks for compatible gauge and wiring type.

DANGER: Risk of electrical shock. Adhere to all warnings and notes.

WARNING: Installation of the LCF must be done by a qualified electrician.

WARNING: Make sure that power is turned off from the utility and from the solar array before connecting the LCF.

WARNING: Ensure that all connnections are torqued to values listed on the terminal block.

NOTE: Perform all wiring in accordance with the National Electric Code and ANSI/NFPA 70.

NOTE: Improper installation and/or maintenance of an LCF could result in reduced product reliability and/or damage to the product.

NOTE: The LCF must be installed between the utility-side circuit and the array-side circuit protection.

NOTE: Any changes or modifications to Enphase equipment not expressly approved by Enphase Energy could void the user's authority to operate this equipment.

1 Mount the LCF

1. Use the mounting holes on the back of the LCF enclosure for installation.
2. Remove all four hole seals and hang the LCF using 8mm mounting hardware with sealing washers.

2 Wire the LCF

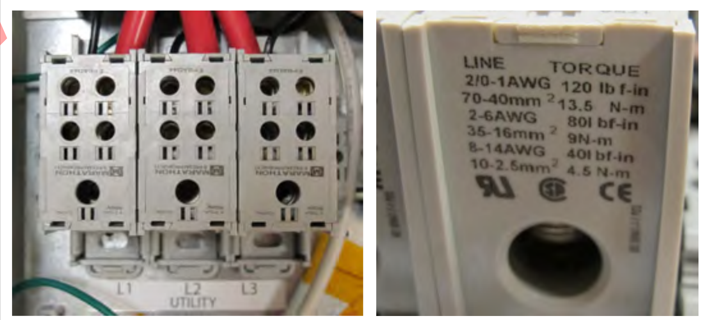
1. De-energize all circuits before wiring the LCF.
2. Use antioxidant joint compound on all field termination connection points.
3. On the utility side, use cable ties to hold L1, L2 and L3 together. Allow offset for cable bending.
4. Remove the ferrite core from the assembly bag and slip it over the utility-side wire bundle.
5. Use a torque wrench and the specified hex bit to make the terminations in steps 6, 7 and 8. **Tighten the terminals to the torque values specified on the terminal blocks, according to conductor gauge and material**. See table.
6. Terminate the utility-side lines to the terminal block labeled "**Utility**".
   - For black terminal blocks, use a 3/16 wrench that is at least 1.25 inches long.
   - For grey terminal blocks, use both a 5mm wrench (at least 1.5 inches long) and a 6mm wrench (at least 1.25 long).
7. Terminate the neutral lines to the block labeled "**Neutral**" using an 8mm wrench that is at least 1 and 1/8 inches long.
8. Terminate the array-side lines to the terminal block labeled "**Array**".
   - For black terminal blocks, use a 3/16 wrench that is at least 1.25 inches long.
   - For grey terminal blocks, use both a 5mm wrench (at least 1.5 inches long) and a 6mm wrench (at least 1.25 long).
9. Route the ground wires through the LCF so that they make contact with all hubs and connect them to the ground bus using an approved grounding connection method.

Conductor gauge	Terminal block type and torque specifications		
	Marathon Black (Line)	Ferraz Shawmut (Neutral)	Marathon Grey (Line)
#2/0 - #6	120 lbf-in	---	---
#2/0 - #1	---	100 lbf-in	120 lbf-in
#2 - #6	---	80 lbf-in	80 lbf-in
#8	40 lbf-in	60 lbf-in	40 lbf-in

10. Use a 1/2 inch knockout set to create a conduit knockout on the left side of the enclosure, and pass the CAT5E through the knockout.
11. If needed, to allow the CAT5E to pass through the strain relief, cut and reterminate the CAT5E.
12. Connect the one end of the CAT5E to the Envoy, and connect the other end to the broadband router.
13. After 30 minutes, retighten all terminations to the appropriate torque value. **Do not over-torque.**

Terminal Block Types & Torque Specifications

Marathon Black (Line)



Marathon Grey (Line)

Ferraz Shawmut (Neutral)

3 Turn Up the LCF

All system diagnostics are performed using a Internet-connected computer or laptop and the Envoy. Prior to turn up, ensure that all AC wiring is complete and that the Ethernet connection is complete to the Envoy.

Refer to the *Envoy Communications Gateway Installation and Operation Manual* for more information on the Envoy.

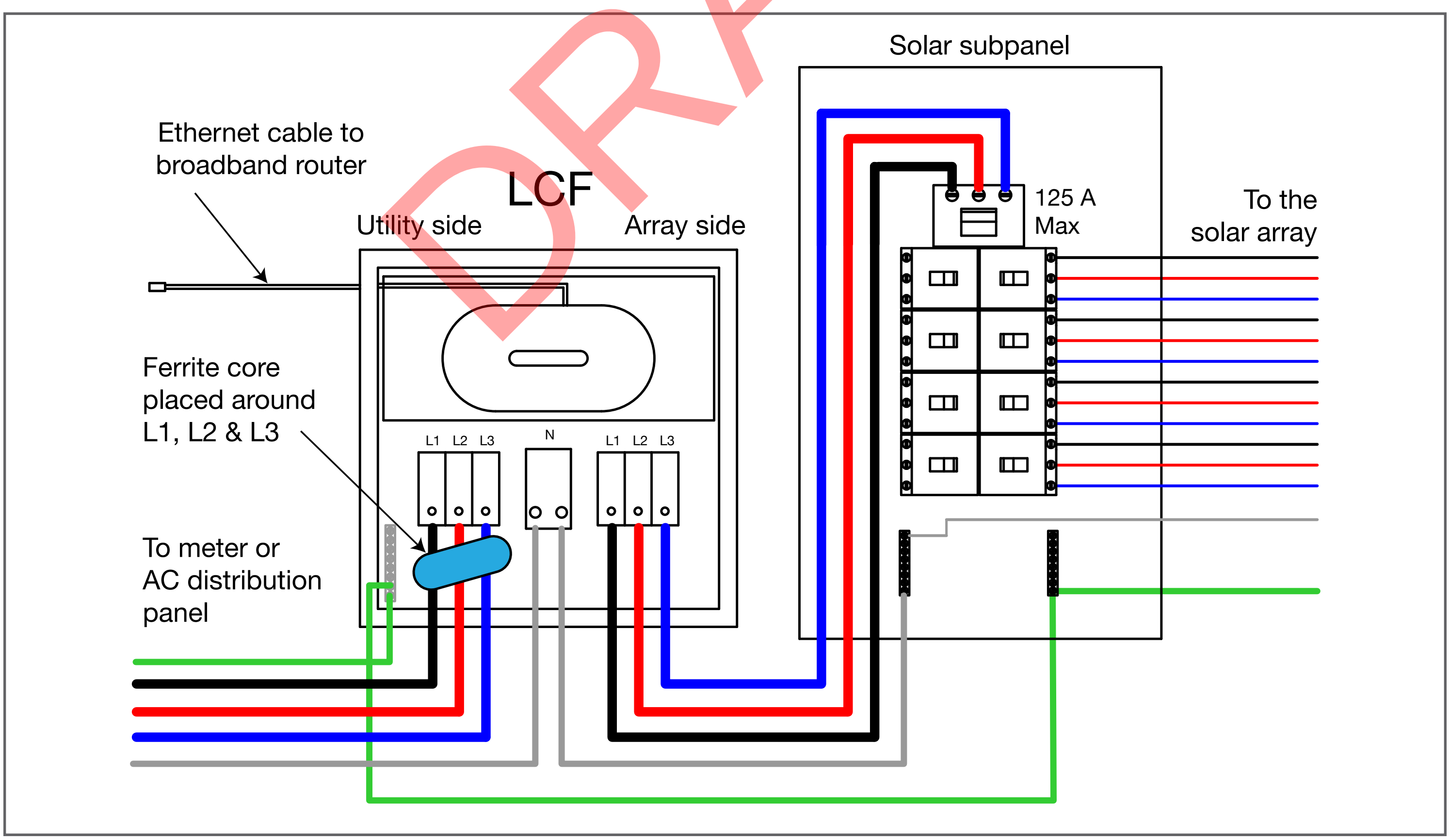
1. Energize the system at the utility side.
2. Energize all the array-side circuit breakers.
3. Flip the blue switch on (to the right of the neutral block) inside the LCF. This breaker protects the Envoy.
4. Ensure the Envoy starts up. The LCD screen will be active.

Periodic Maintenance

During regular scheduled maintenance of the PV system, do the following:

1. De-energize or disconnect all circuits before working with the LCF.
2. Check the terminal blocks for proper torque. The torque values of each terminal block should be checked for compliance with the torque requirements listed on the terminal block.
3. Periodically check that the integrity of the enclosure and all internal connections are not compromised.

LCF Wiring Diagram



MAGE SOLAR

MAGE POWERTEC® PLUS

250 / 6 MH PHOTOVOLTAIC MODULE

Three Full Decades of Power - Guaranteed

- With our 30-Year, 80% Power Guarantee, you can be assured top-production for 3 decades
- Industry leading 12 Year, 90% Power Guarantee

High Efficiency Modules when Value Matters Most

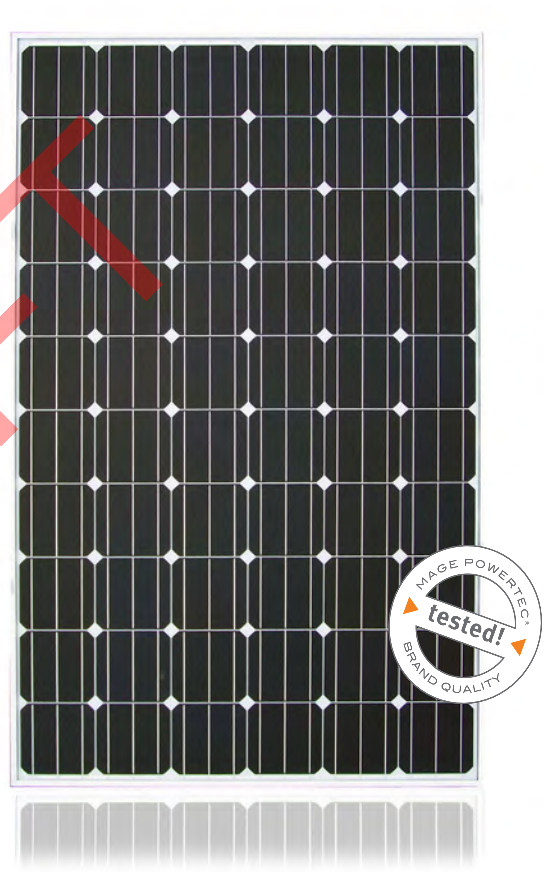
- Only positive tolerances of up to +5 watts ensure maximum power without compromise
- Simple compatibility with any of our inverter partner products to achieve maximum system output

Quality Tested, Service Assured

- Certified by the most rigorous US and International standards
- 10-Year Product Warranty
- Built to withstand even the most harsh conditions

Flexible Design

- Ideal for all rooftops and ground mount installations
- Easily connected to the grid or used in off-grid scenarios
- Suitable for use on ungrounded PV arrays
- Allows for string size up to 1000 V, which can reduce cost



Number of Cells: 60
Solar Cell Type: monocrystalline
Power class: 250 Wp

DRAFT

30 YEAR 80% POWER GUARANTEE

12 YEAR 90% POWER GUARANTEE

10 YEAR PRODUCT WARRANTY

+5 WATTS POSITIVE TOLERANCES

THE SUN ON YOUR SIDE

MAGE SOLAR

MAGE POWERTEC® PLUS

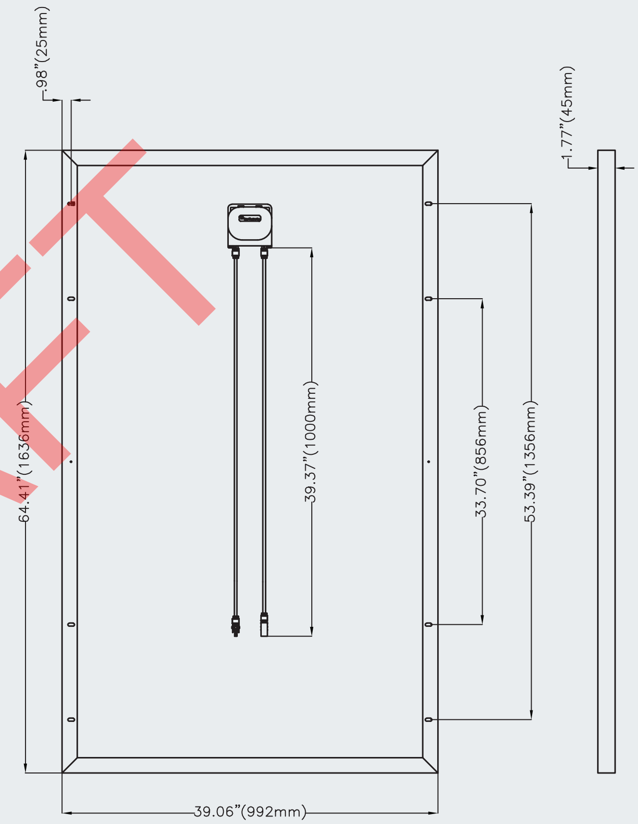
250 / 6 MH PHOTOVOLTAIC MODULE

ELECTRICAL CHARACTERISTICS*		
Maximum Power Rating	P_{mp} (W)	250
Tolerance of P_{mp}	(W)	-0/+5
Maximum Power Voltage of P_{mp}	V_{mp} (V)	30.40
Maximum Power Current P_{mp}	I_{mp} (A)	8.22
Open Circuit Voltage	V_{OC} (V)	37.51
Short Circuit Current	I_{SC} (A)	8.88
Maximum System Voltage	(V)	1000
Maximum Series Fuse	(A)	15

* STC @ 25° C, 1000 W/m², AM 1.5

TECHNICAL FACTS	
Number of Cells (Matrix)	60 (6 x 10)
Solar Cell Type	monocrystalline
Solar Cell Size (mm)	156 x 156
Solar Cell Size (in)	6 x 6
Dimensions (L x W x H mm)	1636 x 992 x 45
Dimensions (L x W x H in)	64.41 x 39.06 x 1.77
Weight (kg)	19.5
Weight (lbs)	43.0
Module Efficiency (%)	15.4
Connector Type	MC4 or equivalent

THERMAL CHARACTERISTICS		
NOCT	(°C)	+ 45 ±3
Temperature Coefficient	I_{SC} (%/°C)	+ 0.047
Temperature Coefficient	V_{OC} (%/°C)	- 0.31
Temperature Coefficient	P_{mp} (%/°C)	- 0.41



30 YEAR Power Guarantee

Unmatched 30–Year Performance Guarantee

Intertek UL1703 | FSEC | CEC | 61215 61730

MAGE SOLAR USA
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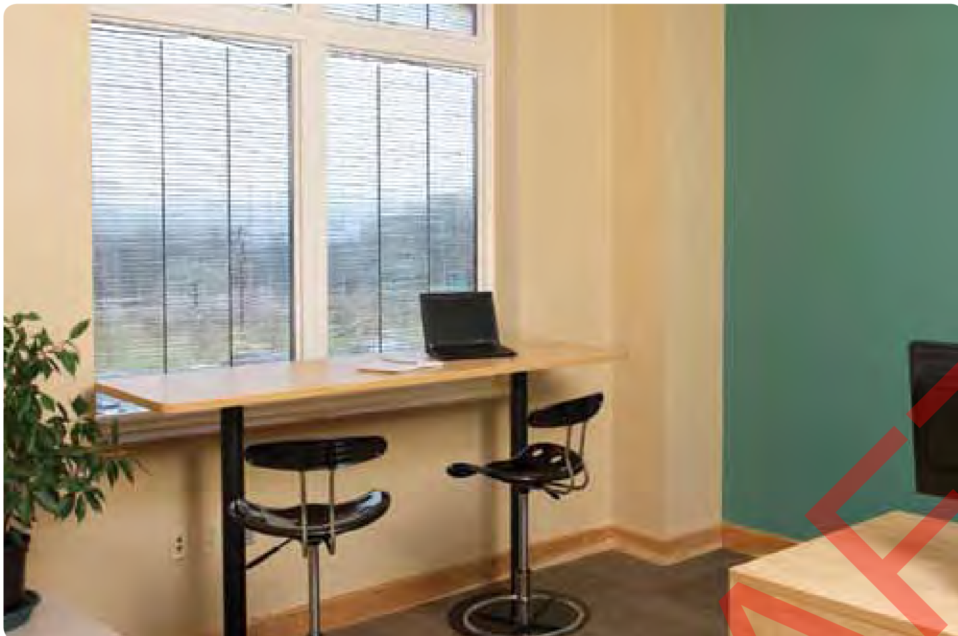
info@magesolar.com · www.magesolar.com

Appendix H

Product Brochure for
Photovoltaic Glass Unit

Solar Window



Innovative, scalable high-power PVGU delivers triple-value benefit

- > Energy efficiency
- > High-density solar power generation
- > Optimized daylighting

Industry's first solar window combines energy efficiency with power generation to accelerate the path towards Net Zero Energy buildings

Structured as a standard insulated glass unit (IGU) Pythagoras Solar's photovoltaic glass unit (PVGU) is the only glazing product that combines high density solar power generation with the energy efficiency benefits of an IGU, while providing quality daylighting and preventing direct solar radiation from entering the building. This delivers a new level of design flexibility to the architecture, construction and engineering industries, enabling the creation of cost-efficient, aesthetically pleasing, self-powered buildings. Pythagoras Solar's customers are able to realize the benefits of energy efficiency, generation and daylighting in a single, innovative product that meets today's energy demands.

APPLICATIONS

- > Curtain walls
- > Skylights

PVGU Skylight

Questions?
contact@pythagoras-solar.com
Main number: (650) 357-9093
Toll-free: (855) 357-9093

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Turning Facades Into Generating Assets™

Benefits of Pythagoras Solar's PVGU: Triple Value

PVGU Windows

Generates Solar Power

This PVGU delivers up to four times the power density of comparable BIPV technologies with an unmatched level of energy generation per unit area.

Improves Building Energy Efficiency

The PVGU provides a more effective solution for optimizing solar heat gain and daylighting than traditional glazing solutions. By selecting light based on its angle of incidence the PVGU can block direct sunlight from heating up the building and allow the more useable diffused light to illuminate the space. This combination of shading and daylight provides for energy savings from both reduced lighting and cooling costs, and creates an enhanced, comfortable work environment.

Offers Architectural Design Benefits

The prismatic optics allow for a high level of transparency and adaptable design in a sustainable solution with fast ROI, turning facades into energy generating assets. Built into the standard form factor of an IGU, Pythagoras Solar's PVGU is simple to install and is available through glazing and glass companies. For project inquiries please contact us at projects@pythagoras-solar.com.

Pythagoras Solar PVGU products are:

- Architecturally appealing
- Designed to meet advanced building codes
- Eligible for incentives due to the energy and environmental benefits
- High quality through standard methods and materials
- Economically attractive with a typical 3-5 year ROI
- Easy to design-in and install

Technical Metrics

METRIC	RATING
U-value	0.30
Solar Heat Gain Coefficient (SHGC)	0.14 (for angles > 25° above normal) 0.41 (for angles < 25° above normal)
Visual Light Transmittance (VT)	0.00 (for angles > 25° above normal) 0.49 (for angles < 25° above normal)
Maximum Power Density	120 Wp/m2 (11.15 Wp/ft2)

About Pythagoras

Founded in 2007, Pythagoras Solar provides solar window products that enable the architecture, engineering and construction sectors to design buildings with renewable energy generation, increased energy efficiency and optimized daylighting, thereby increasing real estate value. Pythagoras Solar has delivered the industry's first transparent and high-density PVGU, combining the modularity and insulating benefits of the insulating glass unit (IGU) with the industry's highest-density power generation. It is advancing the deployment of distributed generation, making Net Zero Buildings a wider reality and having a lasting impact on construction and urban planning. | Pythagoras is a privately held company with operations in the United States, Israel and China. Contact our sales team for more information about Pythagoras Solar and its 'triple value' BIPV: http://www.pythagoras-solar.com.

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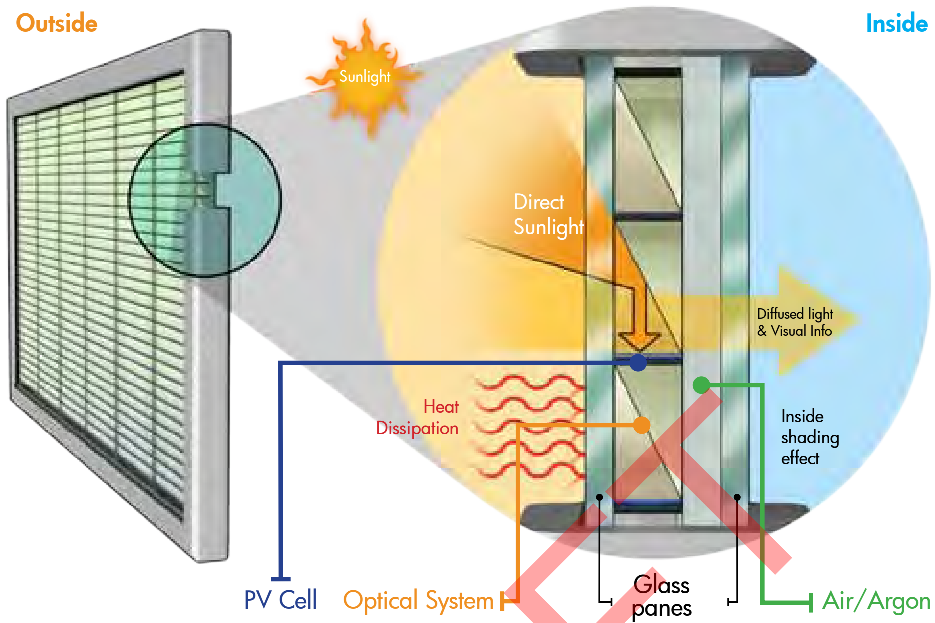
Pythagoras Solar

Pythagoras Solar

Photovoltaic Glass Unit (PVGU)

> TECHNICAL SPECIFICATION



Solar windows: a world of benefits

Pythagoras Solar's photovoltaic glass units (PVGUs), or more simply solar windows, are designed to replace conventional insulated glass units (IGUs) in curtain wall, window and skylight systems. It is the first product to simultaneously provide energy efficiency, solar energy generation, and optimized daylighting. This is achieved through patent-pending optics, high-efficiency crystalline silicon solar cells, advanced materials science, and proprietary software design tools.

The PVGU is designed around the form factor of a standard insulated glass unit (double paned window). A system of optics and photovoltaic cells is adhered to the inner surface of the outer glass pane (surface #2). The optical elements are designed to separate light according to the angle at which it hits the glass, concentrating all direct sunlight onto PV cells which are mounted perpendicular to the glass panes. At the same time, diffused light is transmitted through the unit and into the building. This allows the PVGU to simultaneously provide a high level of energy generation (up to 12.0% efficiency) while acting as a high-performance shading device (SHGC as low as 0.14).

PVGU:

- Transforms building facades into energy generating assets
- Seamlessly integrates into conventional curtain wall, window, and skylight systems

Key Technical Metrics

- Solar Heat Gain Coefficient (SHGC) as low as 0.14
- Module Efficiency as high as 12.0%

PVGU Windows

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Turning Facades Into Generating Assets™

Designing PVGU Projects

Architects and building owners looking for value-added architectural glass products need to choose between BIPV glass products and various "tunable" or "smart" windows, which provide energy efficiency without power generation. Current BIPV products suffer from low power conversion efficiencies and low light transmission and inacceptable aesthetics, which have kept them from becoming a mainstream architectural product. Smart windows have long held the promise of delivering excellent insulation and optimized daylighting, but their inability to produce power reduces the economic benefit and prevents them from fully addressing the Net-Zero-Energy challenge. In contrast, the PVGU delivers an unmatched combination of energy efficiency, power generation and daylighting.

Pythagoras' PVGUs are custom made per project just as an IGU would be. The units can be made in any size required. The standard window units come with a ¼" ultra-clear outer lite and a ¼" low-e inner lite, but can be made with any glass specified (see technical specifications below).

Pythagoras Solar has teamed up with a number of leading glass manufacturers, glazing contractors, and solar integration firms to develop a seamless integration process of its products into existing building design and construction practices. We can work with a contractor who is already involved in a project or recommend one of our industry partners. A typical project requires a glazing contractor to provide the design and installation of the glazing system and a solar contractor to design and integrate the electrical system including wiring and inverters.

PVGU Window

Scalable high-power photovoltaic glass unit (PVGU) delivers triple-value benefit

- Energy efficiency
- High-density solar power generation
- Optimized daylighting

PVGU Skylight

General PVGU Window Specifications

ELECTRICAL SPECIFICATIONS	
Maximum Power Density	120 Wp/m² (11.15 Wp/ft²)
Module Efficiency	up to 12.0%
Tested Operating Temperature	-40°C – 85°C
Maximum System Voltage	600 V DC
Maximum Series Fuse Rating	15 amps
Power Tolerance	+/- 5%
TEMPERATURE COEFFICIENTS	
Nominal Operating Cell Temperature (NOCT)	53°C
Temperature Coefficient of P_{mpp}	-0.55%/°C
Temperature Coefficient of V_{oc}	-0.36%/°C
GLAZING SPECIFICATIONS	
Outer Glass**	6mm (1/4”) ultra-clear
Inner Glass**	6mm (1/4”) low-e coated
U-Value*	0.30
Solar Heat Gain Coefficient (SHGC)***	0.14 (for angles > 25° above normal) 0.41 (for angles < 25° above normal)
Visual Light Transmittance (VT)***	0.00 (for angles > 25° above normal) 0.49 (for angles < 25° above normal)
UV Transmittance (UVT)***	0.00 (for angles > 25° above normal) 0.28 (for angles < 25° above normal)
MECHANICAL CHARACTERISTICS	
Solar Cells	mono crystalline PV cells
Weight/unit area*	~41.6 kg/ m² (~8.5 lb/ ft²)
Junction Box (see figure below)	Top edge mounted
Output Cables (see figure below)	Length per requirements – MC3 connectors
Unit Thickness**	28mm-36mm (1 1/8” – 1 7/16”)

LOCATION	ANNUAL ENERGY YIELD (KWH/FT² (KWH/M²))****
Atlanta	9.63 (97.99)
Chicago	9.50 (96.70)
Denver	11.97 (121.84)
Los Angeles	10.41 (105.93)
New York City	9.51 (96.77)
Phoenix	11.85 (120.61)
San Francisco	10.57 (107.61)
Seattle	8.37 (85.17)

*Determined by unit thickness and glass type
**Determined by unit dimensions and project requirements
***See Glazing Transmission Specification

****Estimates only: Based on south orientation.
Will change based on project specifics and final unit design.

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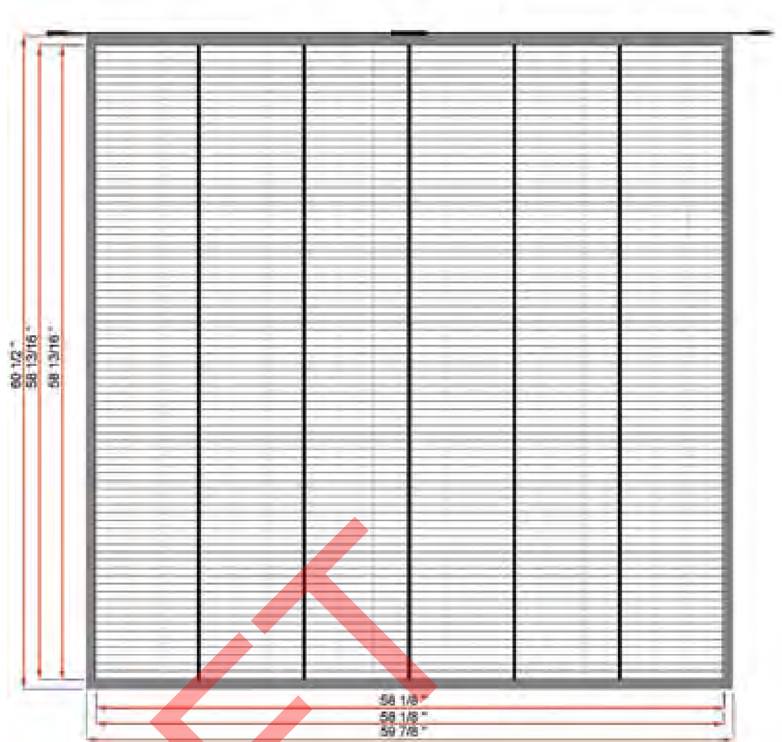
Typical PVGU Window Specification

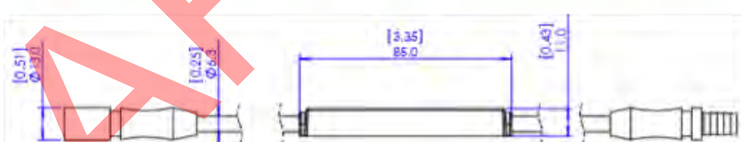
UNIT MECHANICAL SPECIFICATIONS	
Length	60" (1524mm)
Width	60" (1524mm)
Thickness	1 ¼" (32mm)
Weight	209 lbs (95 kg)

UNIT ELECTRICAL SPECIFICATIONS	
$Power_{mpp}$	252.8 W
V_{mpp}	48.4 V
V_{oc}	58.2 V
I_{mpp}	5.2 A
I_{sc}	5.6 A
Tested Operating Temperature	-40°C – 85°C
Maximum System Voltage	600 V DC
Maximum Series Fuse Rating	15 amps
Power Tolerance	+/- 5%

UNIT GLAZING SPECIFICATIONS	
Outer Glass	1/4" (6mm) ultra-clear
Inner Glass	1/4"(6mm) low-e coated
U-value*	0.30
SHGC***	0.14 (for angles > 25 above normal)
VLT***	0.49 (for angles < 25 above normal)
UVT***	0.28 (for angles < 25 above normal)
Maximum System Voltage	600 V DC
Maximum Series Fuse Rating	15 amps
Power Tolerance	+/- 5%

ELECTRICAL COEFFICIENTS	
Nominal Operating Cell Temperature (NOCT)	53°C
Temperature Coefficient of Pmpp	-0.55%/°C
Temperature Coefficient of Voc	-0.36%/°C
Temperature Coefficient of Isc	0.03%/°C

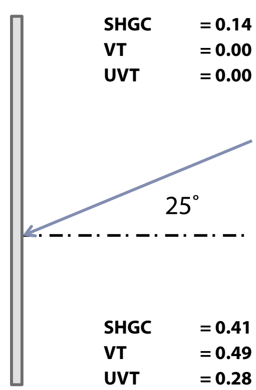




Junction Box Dimensions: mm (inches)

Glazing Transmission Specifications

The PVGU's patented optical design accepts light from a range of angles and concentrates it onto solar cells. This unique ability allows the PVGU to obtain glazing transmission metrics unlike any product on the market today. For angles where direct sunlight would be incident on the window the PVGU blocks all direct sunlight thus creating a very low solar heat gain coefficient (SHGC). At the same time diffused light is transmitted at a rate corresponding to the visible transmittance (VT) of the glass specified. It is this optimization of SHGC and VT that allows the PVGU to achieve an effective light-to-solar-gain (LSG) unmatched by any glazing product on the market today.



*Glazing metrics are a function of angle and are generalized by the above drawing for illustration purposes.

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Pythagoras Solar

Appendix I

UIUC Review Comments