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Development of Solar Experiments with Remote Laboratory Capability for Engineering Education of the Future

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DEVELOPMENT OF SOLAR EXPERIMENTS WITH REMOTE LABORATORY CAPABILITY FOR ENGINEERING EDUCATION OF THE FUTURE

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Abstract

Development of Solar Experiments with Remote Laboratory Capability for Engineering Education of the Future

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Educating future engineers will be handled differently as this modern society has various methods of doing so and a plethora of knowledge to pursue. The availability of computers and internet has changed many things. A subject that is relevant in today's world but not common to most people and some engineers is solar energy. As part of a grant from the National Science Foundation that was awarded to Louisiana State University (LSU), Florida State University (FSU), and the University of Nevada, Las Vegas (UNLV), the UNLV Center for Energy Research partnered with them to create solar application based learning modules.

Two solar water heating systems have been constructed to operate in the Las Vegas climate, specifically, a system with an evacuated tube collector and another with a flat plate collector. Another experiment that characterizes the performance of four different photovoltaic panels has been repurposed to our needs. Finally, an Amonix concentrating photovoltaic system that is a part of the Center for Energy Research at the University of Nevada-Las Vegas is part of

our effort. The purpose of these three types of experiments is to provide data in a manner like students would receive conducting an experiment in a laboratory, but it will be available to them remotely over the internet. This ability allows others to learn and analyze information from a system that most do not have physical access to. In addition to the mentioned systems future ones can be added, for example, a concentrating solar thermal system like a solar oven, solar dish, or parabolic trough. When this capability is combined with the related ones being developed at LSU and FSU, where each school is developing unique experiments, it will make a variety of remote experiences available.

Another aspect is that this remote laboratory capability gives a student an exploratory mindset that there is more out there than what is available in laboratories on campus/available to them in-person. The systems have data logging so there is constant recording and availability to prospective users, which makes this laboratory quite robust. Its data will be available online along with resources on the system, subject, and analysis. This will be in a module type compilation, for educational purposes, because it was established as a part of the aforementioned partnership with other universities to provide materials on a website. Assistance can be sought out by prospective users who are having trouble with the subject matter, and if users want to try something different on the systems, they could request that.

As part of the changing educational environment, it will be discussed how this approach with possible other modules would affect engineering education. The effectiveness of this education and experimentation will take time to evaluate, and it will be outlined here how this can be characterized. Recommendations for integrating these types of experiments and capabilities into education will be proposed and analyzed.

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Chapter 1: Introduction

1.1 Background

Applications of engineering systems can be utilized in student education of core principles and technical aspects. In higher education engineering classes theory and problem solving are taught; in laboratory classes experimentation takes place. Sometimes these experiments are comprehensive, teach effectively, and interest students. Solar experiments at UNLV have been set up as part of a NSF grant. Due to UNLV's location and expertise solar experiments are the focus of efforts to fulfill the NSF grant and expand the Energy Sustainability Remote Laboratory (ESRL) idea.

UNLV has expertise with solar subjects. Photovoltaic (PV) panels are an application solar energy known as solar power and solar collectors for water or air heating are solar thermal applications. Both are topics that engineers and students may know about but have not had any education on. At UNLV PV systems and water heating systems have been researched for years.

An addition to the physical apparatus learning materials must be made as well and presented and distributed. This is part of a remote laboratory experience, like an in-person laboratory. The educational aspects of this experiment are different than normal because the student is not physically around the system, possibly does not have a teacher for the subject matter, and can work at their own pace and at their convenience.

1.1.1 Objectives

The establishment of a long term solar water heating system with two different collectors and the necessary measurement instruments was the initial objective. This would begin the fulfillment of UNLV's portion of the NSF grant. It would also not be as easy as expected. Meeting this objective requires the system to be very autonomous and reliable. Going beyond the water heating system, it is also an objective to look at other solar experiments to add to UNLV's portion of the ESRL project.

Once the system has been constructed the managing of the data is the next objective. The first step is experimental data is recorded and taken for analysis. To get data from the location here at UNLV to anyone who wished to analyze it is the concept of a remote laboratory. This could be done in a variety of ways. However, the internet is the best medium for data transfer.

The goal is for students to learn about collectors and the efficiency associated with them, and that creates the objective of effectively educating on this subject. That means resources exist for students to understand the mathematics and physics. These resources would be available when an individual is ready to take data and analyze it instead of having the individual search for facts. Assembling the information in a fashion that an individual will be able to retain and apply the knowledge is key to the success of this project.

1.2 Solar

Numerous resources exist on solar applications. The physics that have been developed to characterize the sun and the radiation from it are well documented [1, 2]. Irradiance is the term used to describe the "amount of solar radiant energy falling on a surface per unit area and per unit time" [2]. The solar energy that strikes the Earth's surface in one hour is the equivalent to the amount of energy humans use in one year [3]. The irradiance that the Earth experiences is suitable for many purposes. Plants utilize it, humans make electricity and hot water from it and enjoy it. As implied before, irradiance is well understood.

However, irradiance is not equal in all locations, in fact, vast differences can be seen over the surface of the Earth. Las Vegas, Nevada, is in the Mojave Desert and has a dry, warm, and sunny climate. This is going to show high performance from a solar collector and other solar equipment. Compared to 237 other cities in the United States, Las Vegas is in the top five of the average daily global horizontal and direct normal solar radiation values [4]. Las Vegas has a higher value than major and popularized sunny cities like: Phoenix, Arizona, Miami, Florida, and Honolulu, Hawaii.

1.3 Literature Review

A plethora of experience and knowledge exists for Engineering and Education. In the modern day journals and other resources contain a vast amount of this experience and knowledge. The majority of the references for this thesis have been found on internet based journal databases that UNLV's library has subscription to, namely: ScienceDirect from Elsevier and Academic Search Premier from EBSCO Host.

1.3.1 Engineering

The mathematical and physical principles of solar water heating can be found from numerous sources. Work from Elmer Streed and James Hill in the mid and late 1970's on the performance of solar collectors has provided a benchmark of what needs to be accomplished with the solar water heating systems. They published articles on their work testing collectors and their work has proven useful to this project [5, 6]. Development of how to characterize collectors began before them, most notably with the Hottel-Whillier-Bliss representation [2]. The efficiency of collectors generates a curve at different environmental and system conditions and as stated this is a goal of this experiment for students to learn and produce.

1.3.2 Remote Laboratory Capability

Researching what other people and institutions have done with remote laboratories produces results that are both engineering and educational in scope. Some of the research done would only describe the work and results of establishing a remote laboratory: detailing the construction, operation, data management, and conclusion and not elaborate on the educational aspects. Then some were analyzing just the educational impact on students who had instruction through a remote laboratory. Others did both.

In 2004 at the Higher Technical Institute, Nicosia, Cyprus, a group working in the engineering department developed a solar water heating remote laboratory to work with the Leonardo D Vinci MARVEL project, which had as its aim to test remote experimenting and education [7, 8]. Their papers discuss the system overall, the web interface, and what was garnered from the experiment. They had a very well done remote laboratory.

1.3.3 Education

Engineering education has been analyzed many ways by numerous people as can be seen by the variety of journals associated with this topic. The analysis that is usually done is on the effectiveness of current or new methods of education. Articles exist on the education that students receive from web based learning/teaching and, more specifically, there are reports on the effectiveness and outcomes of conducting setup experiments on remote laboratories [9].

The Accreditation Board for Engineering and Technology, Inc. (ABET) is an organization that accredits programs that institutions offer for engineering and technology degrees. For example, UNLV's Mechanical Engineering Program is accredited by ABET and that makes it understood that the program meets the standards of the profession. In ABET's 2016-2017 Criteria for Accrediting Engineering Programs remote laboratories have a small mention in that they can be "employed in place of physical access when such access enables accomplishment of the program's educational activities." [10]. This warrants a mention because this project will need to be suitable to meet that criterion.

1.4 Project Details

As the title says, solar experiments are to be developed with this project that can have data collected from them and presented on the internet for a laboratory education experience. This project is funded through NSF Grant Number 1323202. Dr. Carl Knopf at LSU is the originator of the Energy Sustainability Remote Laboratory (ESRL) idea.

Dr. Robert Boehm is a Distinguished Professor at UNLV and was reached out to be a part of the ESRL and contribute modules. Dr. Boehm is also the director for the Center for Energy Research (CER) at UNLV and that brings resources to the project. These resources include the members of the CER, facilities, and equipment.

This project was subject to a review by UNLV's Institutional Review Board (IRB) because the procedures developed had to be approved for use on Human Subjects. The IRB gave approval March 8, 2016. The reason this project needed approval is that any projects funded by the Education Directorate of the NSF have to be evaluated in this manner. Each grant of this type implicitly, if not explicitly, works with human subjects. The work with Human Subjects can be very close to normal classroom activities or they can be much more involved, possibly dealing with enhanced learning approaches involving IQ or other factors that may not be personally innocuous. It was determined by the IRB that the project had to have specific measures in place to protect user's identities and information. These requirements were instituted.

Chapter 2: Solar Experiments

2.1 Solar Water Heating Systems

2.1.1 Flat Plate Collector

A flat plate collector is characterized as having a large plate like surface to absorb solar energy and transfer it to a moving fluid. In the majority of cases the fluid is water or a water based solution, the absorbing surface is a very dark color and material that is effective in absorbing the solar radiation, and then this heat is transferred to the components, usually pipes, which contain the fluid. See figure below.

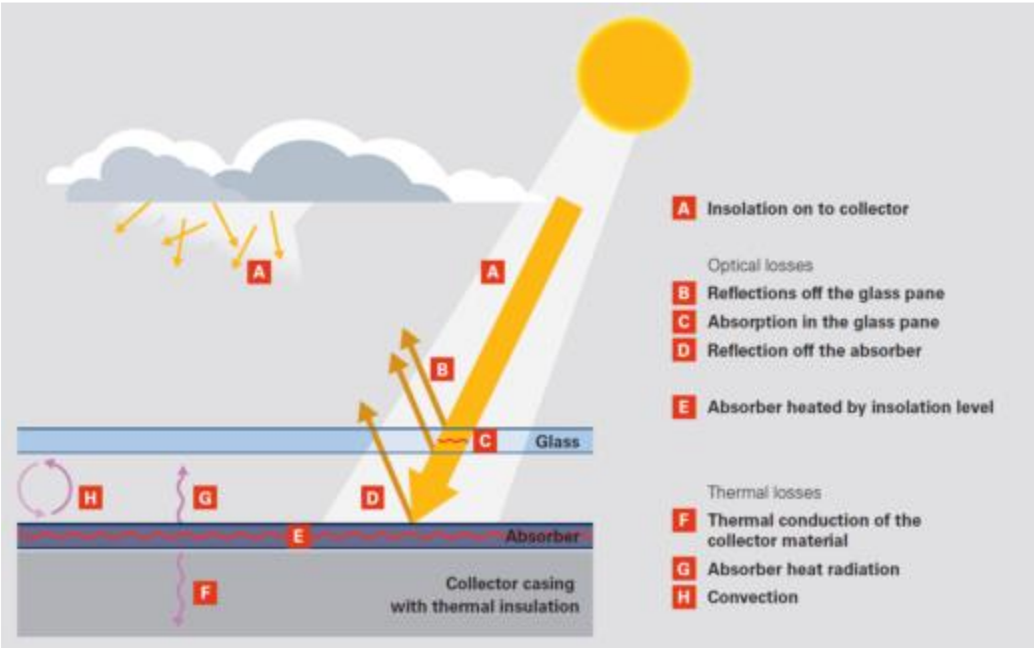

Figure 1: Graphic Representing a Typical Collector and Situation [11]

In Figure 1, pipes are not shown where a fluid would flow through the collector, they would be a part of the absorber. See Figure 2 below. The absorber plate can have a variety of designs, materials, and coatings [11].

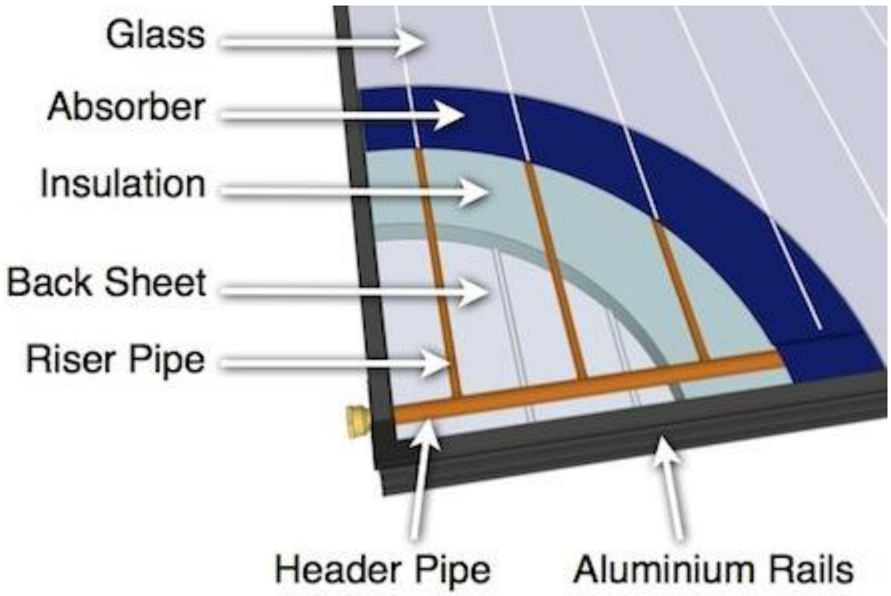

Figure 2: Diagram of an Assembled Flat Plate Collector [13]

2.1.1.1 KIOTO Clear Energy FP 1.20.0 HE sc ab Collector

The flat plate collector that was chosen is the KIOTO Clear Energy FP 1.20.0 HE sc ab, which will be referred to as the FPC. KIOTO Clear Energy is part of a group of European companies that makes solar products like collectors and PV panels. Their experience and knowledge in harnessing solar energy has been attained through European research into renewable energy and high efficiency.

This FPC was manufactured in Mexico, weighs only 29 kilograms (64 pounds) due to lightweight aluminum, and has a high stagnation temperature of 200 ^{o}C (392 ^{o}F). The copper manifold and riser pipes are laser-welded to the absorber plate that has a "high selective vacuum coating (PVD)" [14]. KIOTO takes pride in their laser-welded construction and offers a 10 year warranty.

The FPC is certified by the SRCC, see Figure 3 below. Only the information on the first page of the certification is needed. Black rectangles are placed over important parameters on the certification. An equation for the efficiency of this collector as determined by the SRCC in their testing is seen in the third rectangle down on the figure. This is important to have to compare to. See Appendix A for the FPC's product manual [14].

CERTIFIED SOLAR COLLECTOR

SUPPLIER:
KIOTO Clear Energy S.A. de C.V.
Los Altos, Carretera a El Castillo 2000
El Salto, 45860 Mexico
www.kioto.com

In Accordance with:
SRCC Standard 100-2008-02

BRAND:	KIOTO Clear Energy
MODEL:	FP 1.20.0 HE sc
COLLECTOR TYPE:	Glazed Flat Plate
CERTIFICATION #:	2009077A
Original Certification:	May 18, 2010
Expiration Date:	March 30, 2022

The solar collector listed below has been evaluated by the Solar Rating & Certification Corporation™ (SRCC™), an ISO/IEC 17065 accredited and EPA recognized Certification Body, in accordance with SRCC OG-100, Operating Guidelines and Minimum Standards for Certifying Solar Collectors, and has been certified by the SRCC. This award of certification is subject to all terms and conditions of the Program Agreement and the documents incorporated therein by reference. This document must be reproduced in its entirety.

COLLECTOR THERMAL PERFORMANCE RATING							
Kilowatt-hours (thermal) Per Panel Per Day				Thousands of Btu Per Panel Per Day			
Climate -> Category (Ti-Ta)	High Radiation (6.3 kWh/m².day)	Medium Radiation (4.7 kWh/m².day)	Low Radiation (3.1 kWh/m².day)	Climate -> Category (Ti-Ta)	High Radiation (2000 Btu/ft².day)	Medium Radiation (1500 Btu/ft².day)	Low Radiation (1000 Btu/ft².day)
A (-5 °C)	8.6	6.6	4.5	A (-9 °F)	29.5	22.4	15.3
B (5 °C)	7.8	5.8	3.7	B (9 °F)	26.8	19.6	12.5
C (20 °C)	6.6	4.6	2.6	C (36 °F)	22.6	15.7	8.8
D (50 °C)	4.6	2.6	0.9	D (90 °F)	15.6	8.9	2.9
E (80 °C)	2.7	1.1	0.0	E (144 °F)	9.4	3.6	0.0

A- Pool Heating (Warm Climate) B- Pool Heating (Cool Climate) C- Water Heating (Warm Climate)
D- Space & Water Heating (Cool Climate) E- Commercial Hot Water & Cooling

COLLECTOR SPECIFICATIONS					
Gross Area:	2.031 m²	21.86 ft²	Dry Weight:	28 kg	62 lb
Net Aperture Area:	1.886 m²	20.30 ft²	Fluid Capacity:	1.4 liter	0.4 gal
Absorber Area:	1.809 m²	19.48 ft²	Test Pressure:	1500 kPa	218 psi

TECHNICAL INFORMATION		Tested in accordance with:			
ISO Efficiency Equation [NOTE: Based on gross area and (P)=Ti-Ta]					
SI UNITS:	η= 0.679 - 3.58850(P/G) - 0.00261(P²/G)	Y Intercept:	0.680	Slope:	-3.754 W/m².°C
IP UNITS:	η= 0.679 - 0.63245(P/G) - 0.00026(P²/G)	Y Intercept:	0.680	Slope:	-0.662 Btu/hr.ft².°F

Incident Angle Modifier							
θ	10	20	30	40	50	60	70
Kτα	1.00	1.00	1.00	0.99	0.97	0.92	0.72

Test Fluid:	Water	
Test Mass Flow Rate:	0.0212 kg/(s m²)	15.61 lb/(hr ft²)
Impact Safety Rating:		

REMARKS:

Jim Huggins
Technical Director

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Figure 3: SRCC Certification for Selected FPC [15] Used with Permission

2.1.2 Evacuated Tube Collector

Another design for absorbing solar energy is known as an evacuated tube collector. This device is an assembly of tubes that consist of an outer glass tube and inner glass tube that has had the space between them put under a vacuum, and then within the inner tube different configurations can be had to transfer heat.

One design for the tubes consists of a closed heat pipe. The fluid within the heat pipe is not the fluid that is in the system, it is contained by the heat pipe and bulb. This fluid when heated becomes vapor and the thermodynamic effect of heat rises because of density change occurs and then once dissipated, it is cool and condenses and returns to the bottom of the pipe to repeat the process. Having a vacuum between the tubes that contains this is “to virtually eliminate heat loss by conduction and convection” [16].

Another design for the tubes consists of direct flow of the fluid through pathways in the inner tube. The fluid enters the collector through the header pipe and goes through these pathways to absorb heat and travel to the exit. Just like the other design a vacuum exists between the inner and outer tube to minimize heat loss. Within the inner tube there is a variety of absorbing materials and layouts that can be had. See Figures 4-6 below for visual representations of the descriptions given.

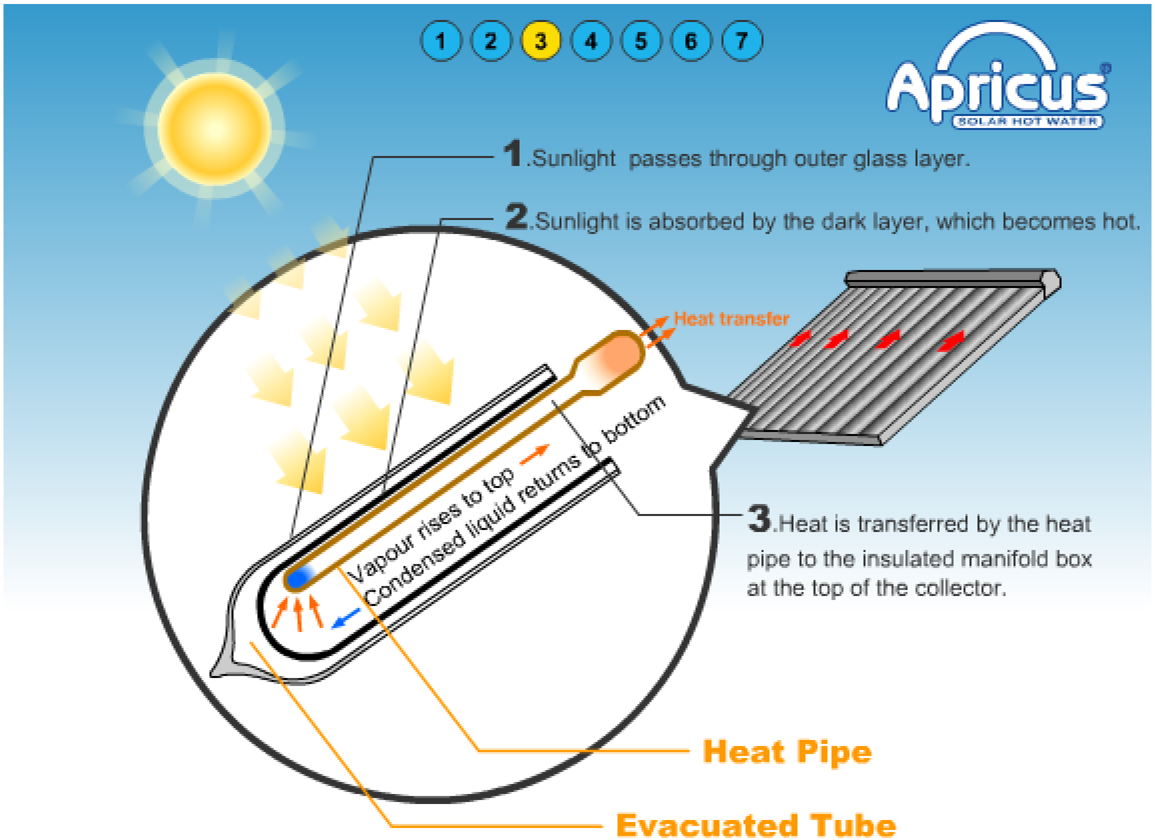

Figure 4: Graphic from Apricus Representing the Typical Operation of an Evacuated Tube Collector [17]

Used with Permission

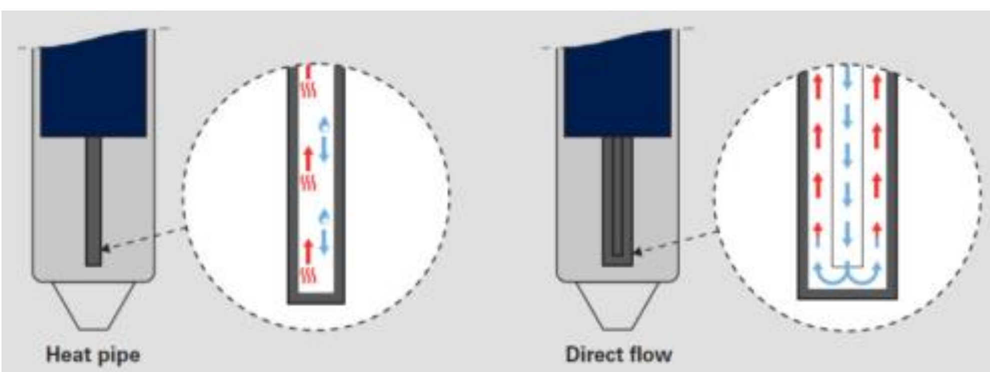

Figure 5: Graphic Showing Difference of Heat Pipe and Direct Flow Tube [11]

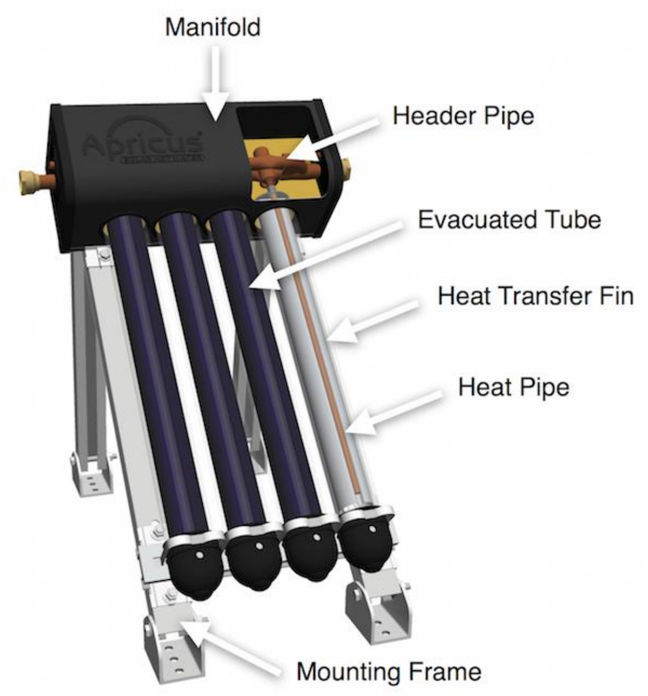

Figure 6: Diagram of an Assembled Evacuated Tube Collector from Apricus [17] Used with Permission

2.1.2.1 SEA Group Ltd. SEA-FZ58-18 Collector

The evacuated tube collector this project has is SEA (Solar Energy Applications) Group's SEA-FZ58-18, which is a heat pipe design, which will be referred to as the ETC. The company is focused primarily on solar thermal. As an American division of an international group they have supported projects in locations near to them and providing quality products to consumers interested in solar applications. One of the solar tanks we have was purchased from a local SEA Group distributor. The evacuated tube collectors they offer can have 12, 18, or 24 tubes, designated by the last number in the model name; this project has the 18 tube collector. They also offer direct flow collectors with 18, 20, or 24 tubes [18].

As with the FPC, this ETC has been certified by the SRCC, see Figure 7 below. Only the information on the first page of the certification is needed. Black rectangles are placed over important parameters on the certification. An equation for the efficiency of this collector as determined by the SRCC in their testing is seen in the third rectangle down on the figure. This is important to have to compare to.

CERTIFIED SOLAR COLLECTOR

SUPPLIER:
SEA Group Ltd.
5830 N. Jones Blvd.
Las Vegas, NV 89130 USA
www.sea-groups.com

In Accordance with:
SRCC Standard 100-2008-02

BRAND:	SEA
MODEL:	SEA-FZ58-18
COLLECTOR TYPE:	Tubular
CERTIFICATION #:	2009095A
Original Certification:	August 15, 2011
Expiration Date:	July 07, 2022

The solar collector listed below has been evaluated by the Solar Rating & Certification Corporation™ (SRCC™), an ISO/IEC 17065 accredited and EPA recognized Certification Body, in accordance with SRCC OG-100, Operating Guidelines and Minimum Standards for Certifying Solar Collectors, and has been certified by the SRCC. This award of certification is subject to all terms and conditions of the Program Agreement and the documents incorporated therein by reference. This document must be reproduced in its entirety.

COLLECTOR THERMAL PERFORMANCE RATING							
Kilowatt-hours (thermal) Per Panel Per Day				Thousands of Btu Per Panel Per Day			
Climate -> Category (Ti-Ta)	High Radiation (6.3 kWh/m².day)	Medium Radiation (4.7 kWh/m².day)	Low Radiation (3.1 kWh/m².day)	Climate -> Category (Ti-Ta)	High Radiation (2000 Btu/ft².day)	Medium Radiation (1500 Btu/ft².day)	Low Radiation (1000 Btu/ft².day)
A (-5 °C)	6.5	4.9	3.3	A (-9 °F)	22.3	16.8	11.3
B (5 °C)	6.3	4.6	3.0	B (9 °F)	21.3	15.9	10.4
C (20 °C)	5.8	4.2	2.5	C (36 °F)	19.7	14.2	8.7
D (50 °C)	4.7	3.1	1.5	D (90 °F)	16.1	10.7	5.3
E (80 °C)	3.5	1.9	0.5	E (144 °F)	11.9	6.5	1.8
A- Pool Heating (Warm Climate) B- Pool Heating (Cool Climate) C- Water Heating (Warm Climate) D- Space & Water Heating (Cool Climate) E- Commercial Hot Water & Cooling							

COLLECTOR SPECIFICATIONS					
Gross Area:	2.812 m²	30.27 ft²	Dry Weight:	56 kg	123 lb
Net Aperture Area:	1.800 m²	19.38 ft²	Fluid Capacity:	1.3 liter	0.3 gal
Absorber Area:	1.436 m²	15.45 ft²	Test Pressure:	1103 kPa	160 psi

TECHNICAL INFORMATION		Tested in accordance with:			
ISO Efficiency Equation [NOTE: Based on gross area and (P)=Ti-Ta]					
SI UNITS:	η= 0.308 - 0.93730(P/G) - 0.00516(P²/G)	Y Intercept:	0.311	Slope:	-1.247 W/m².°C
IP UNITS:	η= 0.308 - 0.16519(P/G) - 0.00050(P²/G)	Y Intercept:	0.311	Slope:	-0.220 Btu/hr.ft².°F

Transverse Incident Angle Modifier							
θ	10	20	30	40	50	60	70
Kτα	1.02	1.08	1.18	1.32	1.49	1.59	0.98

Longitudinal Incident Angle Modifier at 50°:		
Test Fluid:	Water	
Test Mass Flow Rate:	0.0196 kg/(s m²)	14.48 lb/(hr ft²)

REMARKS:

Jim Huggins
Technical Director

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Figure 7: SRCC Certification for Selected ETC [19] Used with Permission

2.1.3 Construction and Components

As stated earlier there was not a permanent solar water heating system established already at UNLV; there was, however, a Unistrut mounting platform assembled on the roof of the Thomas T. Beam Engineering Complex (TBE) that had been used for other solar collector experiments. This platform is at inclined angle of 36º, the same as the latitude for Las Vegas, and an orientation due south. This fixed configuration will 'see' the sky and especially the sun very well all year long. The two solar collectors were mounted on the platform next to each other, leaving enough room for each's piping requirements.

Two solar hot water tanks were positioned on the north side of the platform and then piping was laid out to estimate how all the connections were to be made. ¾ inch copper pipe would be used for all the piping. Space was left for the flowmeters, pumps, and valves. With these components laid out and fittings like elbows, tees, and unions placed accordingly it was then possible to solder and complete the system. Insulation was placed around the piping and fittings to reduce heat losses.

A Campbell Scientific enclosure was put on the northeast side of the platform as well and it houses the data logger, a CR1000, other components that go with the data logger, most of which are Campbell Scientific products, and a power outlet. There is also another enclosure that contains the relays to control power to the pumps when the data logger directs it. Pictures for these descriptions will be in Chapter 3.

On the northwest side is a pole that is about 12 feet tall that holds an anemometer and wind vane at the top, an ambient air temperature sensor, and an extending rod out to the south with a pyranometer mounted horizontally. On the west side there is another pyranometer in the plane of the platform. This meteorological station, the collection of the equipment mentioned, is pictured in Chapter 3. Two elbows on each system, at the inlet and outlet of the collectors, have ports for the thermistors to go into. These instruments and the flowmeter are wired back to the first enclosure to be connected to the data logger.

2.1.4 Pictures and Diagrams

Figure 8: Picture of System Looking North

Figure 9: Picture of System Looking South

Figure 10: Picture of System Looking Southwest

Figures 8 through 10 were all taken on the same day within minutes of each other, but in Figure 10 a cloud interfered with the sun creating a darker picture so in this moment there would have been a decrease in performance of the collectors. In these figures many of the components can be seen. These pictures were taken on the TBE roof and that is where other experiments are located as well.

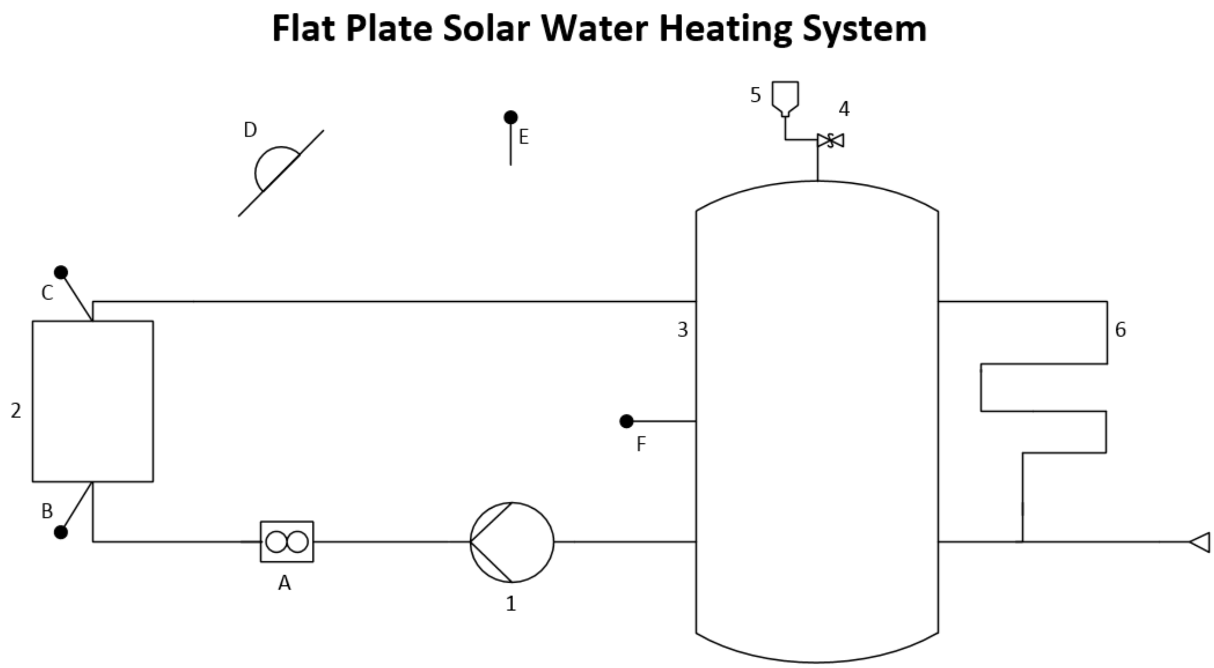


Figure 11: Visio Diagram for Flat Plate Solar Water Heating System

Table 1: Legend for Figure 11

Legend				
Diagram			Measurements	
Identifier	Object	Model	Value	Units
A	Flow Meter	Omega FTB4705		gallons/minute
B	Inlet Thermistor	Omega TH-44004-1/4NPT-80		°C
C	Outlet Thermistor	Omega TH-44004-1/4NPT-80		°C
D	Pyranometer	LI-COR LI-200X		$Watts/meter^2$
E	Air Temperature Sensor	Campbell Scientific HMP45C-L		°C
F	Tank Thermistor	10k Thermistor		°C
1	Pump	Grundfos UP15-10F	UNLV Center for Energy Research	
2	Flat Plate Collector	KIOTO FP 1.20.0 HE sc	Energy Sustainability Remote Laboratory	
3	Hot Water Tank	Stiebel Eltron SB 200 S	Solar Water Heating System	
4	Pressure Relief Valve	Cash Acme NCLX-5	Flat Plate Collector	
5	Expansion Tank	Elbi DXT-8		
6	Heat Rejection Piping	3/4" Copper Piping		

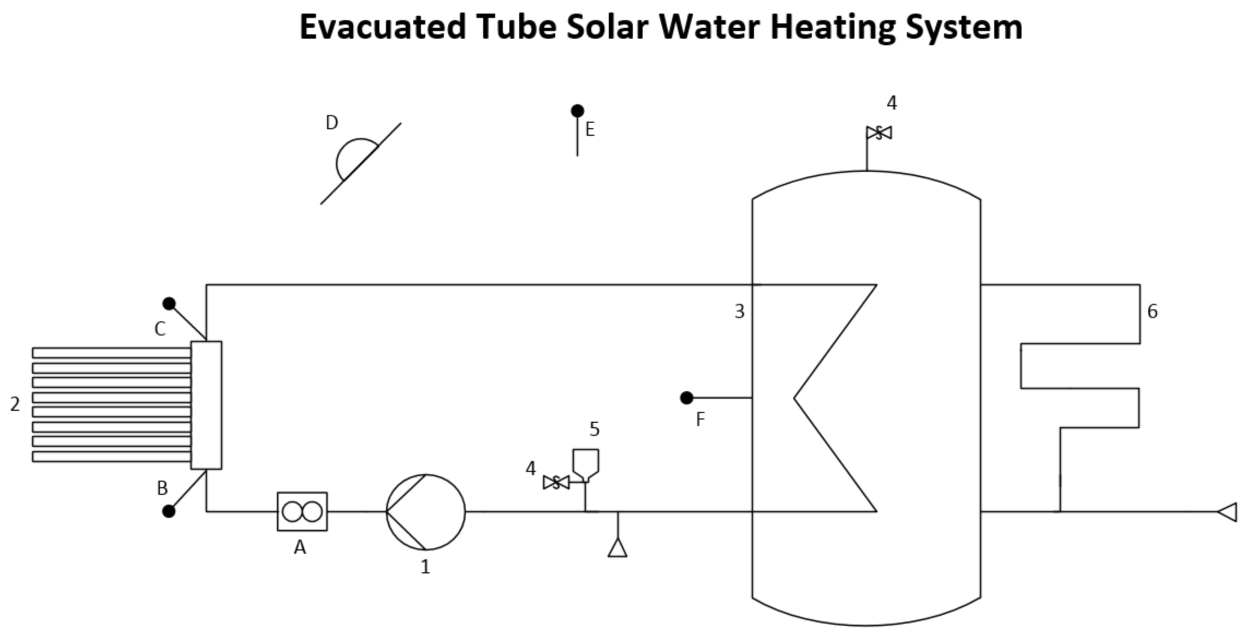


Figure 12: Visio Diagram for Evacuated Tube Solar Water Heating System

Table 2: Legend for Figure 12

Legend				
Diagram			Measurements	
Identifier	Object	Model	Value	Units
A	Flow Meter	Omega FPR204-PS		gallons/minute
B	Inlet Thermistor	Omega TH-44004-1/4NPT-80		°C
C	Outlet Thermistor	Omega TH-44004-1/4NPT-80		°C
D	Pyranometer	LI-COR LI-200X		Watts/meter^2
E	Air Temperature Sensor	Campbell Scientific HMP45C-L		°C
F	Tank Thermistor	10k Thermistor		°C
1	Pump	Grundfos UP15-10F	UNLV Center for Energy Research Energy Sustainability Remote Laboratory Solar Water Heating System Evacuated Tube Collector	
2	Evacuated Tube Collector	SEA-FZ58-18		
3	Hot Water Tank with Internal Heat Coil	SEA Group Tank		
4	Pressure Relief Valve	Cash Acme NCLX-5		
5	Expansion Tank	Elbi DXT-8		
6	Heat Rejection Piping	3/4" Copper Piping		

Figures 11 and 12 and Tables 1 and 2 represent the systems in a diagram format. On the website for the remote laboratory these will have real time data values in the table and near the instrument in the diagram. This will be useful for visualizing the operation of these systems to the outside observer. The tables also list the specific components used.

2.1.5 Differences from Traditional Setup

If a system is installed on a residential site it may not have instruments on it that read temperatures, flow, or irradiance. This setup does not interface with a controller like one would that uses the hot water. At this time the electric heating elements in the tank are not in use. There is also only one collector per each system, and the only reason this is brought up is because in a lot of situations multiple collectors are often installed in series. This can be seen in pictures of residential, commercial, and industrial systems.

In Figures 8 and 9 denoted as item 6 is the heat rejection piping, which a normal system would not have or want because it is desired to keep heat. This difference is to give the ability to cool the water in the tanks. This will allow for measurements at varying temperatures.

2.2 PV Comparison System

Approximately five years ago another group with the CER investigated four different types of PV panels with the intention of comparing their performance and economic potential "for utility scale installations" [20]. Their experiment is still on the roof of TBE and up until November 2015 was not working. It has been repurposed to ESRL's needs.

Like the water heating systems this system faces south. The tilt angle is approximately 30º. The panels are on two mounting racks that Panels 1 and 4 connect. Each panel has been wired separately so measurements are not interfered by the other panels. More discussion on the system's measuring and data management is in Chapter 3.

The function of this laboratory will be extensive, there will be resources on: the different technology in the panels, current-voltage (I-V) curves, and efficiency. The data would show what the short-circuit current (I_{sc}), open-circuit voltage (V_{oc}), maximum power point (P_{mp}), and the current (I_{mp}) and voltage (V_{mp}) at this point. This is actual data for participants to see and learn from, and then apply the knowledge to determine efficiency and observe the effects of the dynamic environment the panels are in.

2.2.1 Pictures and Diagrams

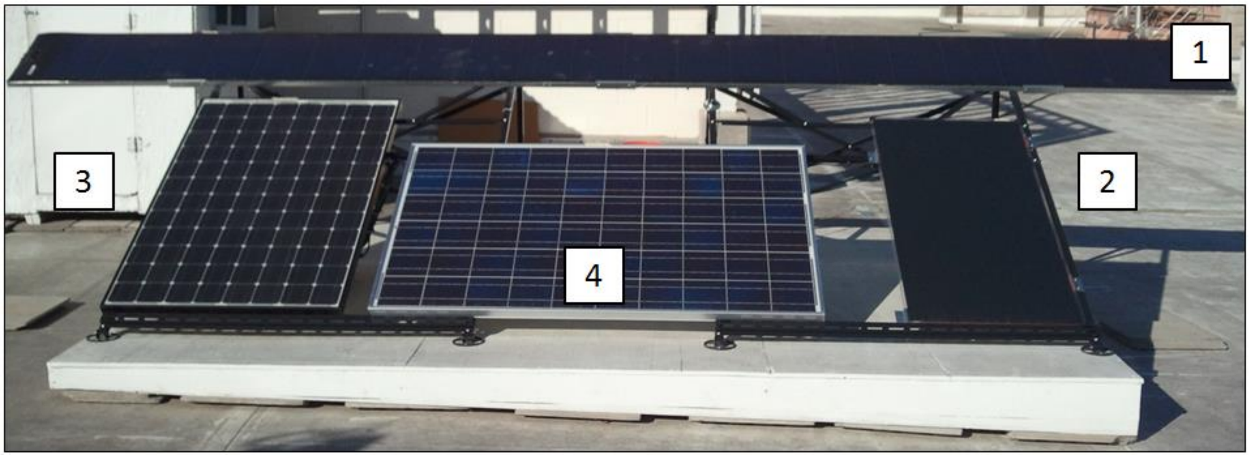


Figure 13: Picture of System from Realmuto et al. Depicting Rooftop Setup of Panels [20]

Table 3: Legend for Figure 13 and PV Panel Information

PV Panel Information					
Panel	Manufacturer (Model)	Technology	Area, $\mathbf{A_p}$ (m^2)	Rated Power, $\mathbf{W_p}$ (W)	STC Efficiency, $\boldsymbol{\eta}_{\mathbf{STC}}$ (%)
1	UNI-SOLAR (PVL-144)	amorphous silicon, triple junction (a-Si TJ)	2.16	144	6.67
2	EPVSOLAR (EPV-42W)	amorphous silicon (a-Si)	0.79	42	5.32
3	SANYO (HIP-186BA19)	heterojunction w/intrinsic thin layer (HIT-Si)	1.16	186	16.03
4	SHARP (ND-224UC1)	polycrystalline silicon (poly-c-Si)	1.63	224	13.74

In Table 3 it can be seen that each panel is from a different manufacturer and has different technology to convert sunlight to power. Figure 13 is identical to how the setup looks to this day, see Figure 14.

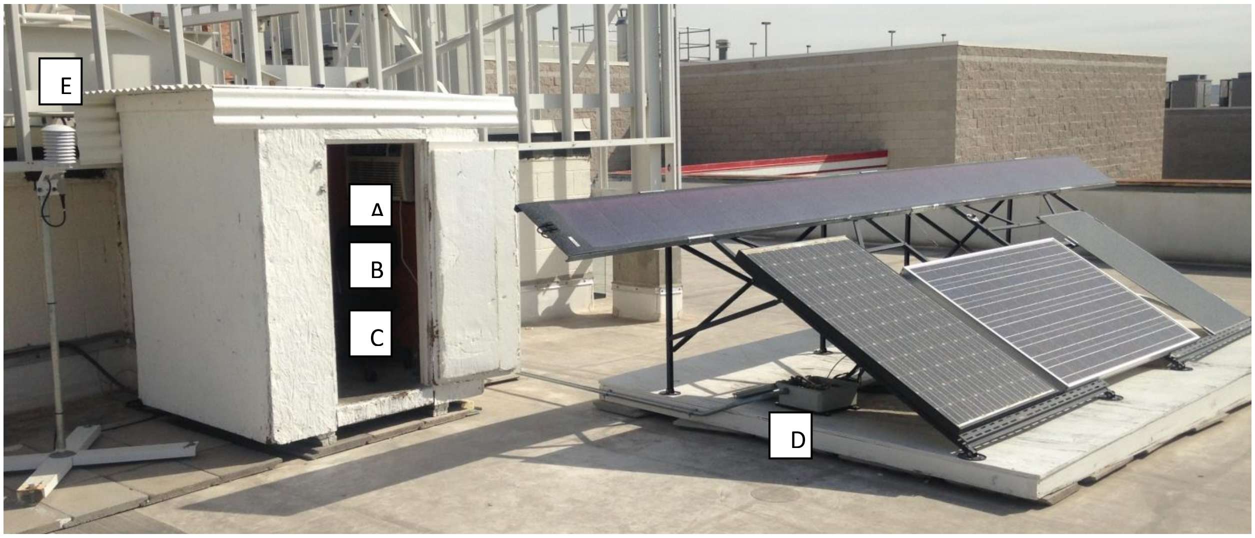


Figure 14: Picture of System Looking Northeast, Letters are Detailed in Figure 15

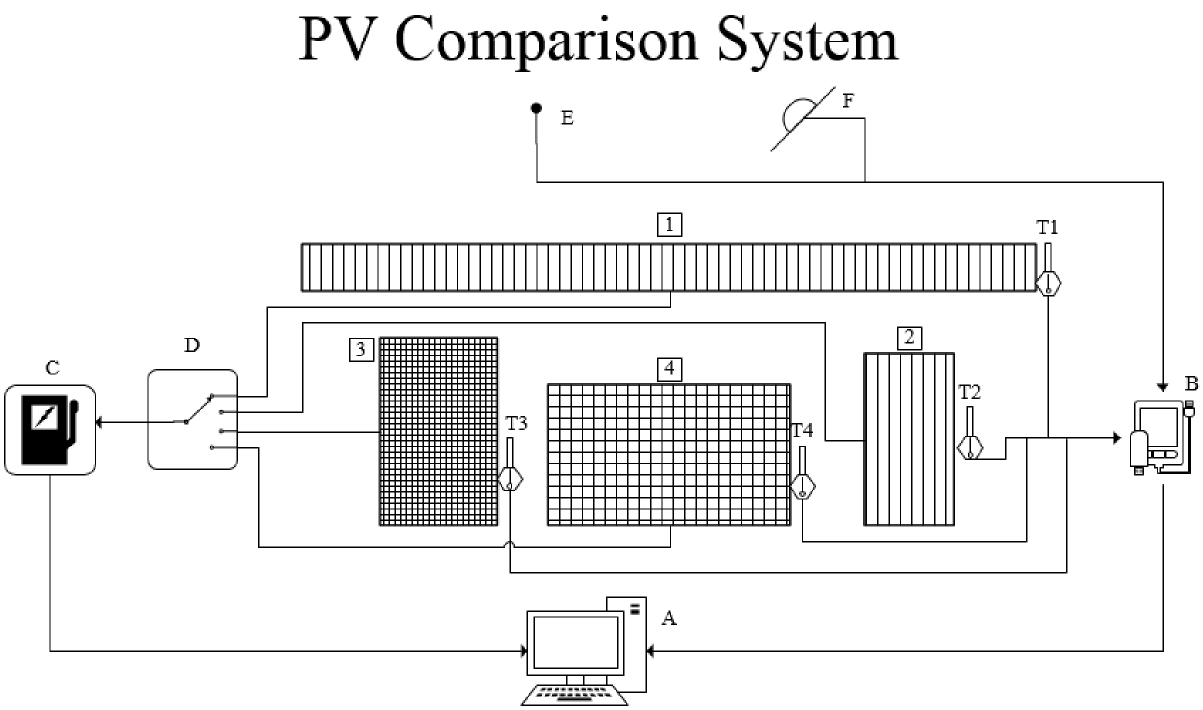


Figure 15: Visio Diagram for PV Comparison System

Table 4: Legend for Figure 15

Legend	
Identifier	Object
$\boxed{\#}$	PV Panel
A	Computer
B	Measurement Device
C	Programmable DC Load
D	Relay Box
E	Ambient Air Temperature
F	Pyranometer
T#	Temperature of PV Panel

Figure 15 was made in Visio to diagram the whole system since one picture is not capable of doing so. Figures 13-15 and Tables 3 and 4 describe this system effectively. They will be a part of the educational module.

2.3 Amonix Concentrating Photovoltaic System (CPV)

At Taylor Hall one of the Amonix Concentrating Photovoltaic systems is able to have data recorded from it and will represent the subject of concentrating photovoltaic power generation in our experiments. This subject is somewhat like an expansion on the module that will be for photovoltaic education that will use the equipment mentioned before this section. The structure of the Amonix 7700, which is the specific model, is very large, deceivingly so. See Figure 16 below and note the men in the picture are over 6 feet tall and that the picture is showing the back side of the unit.

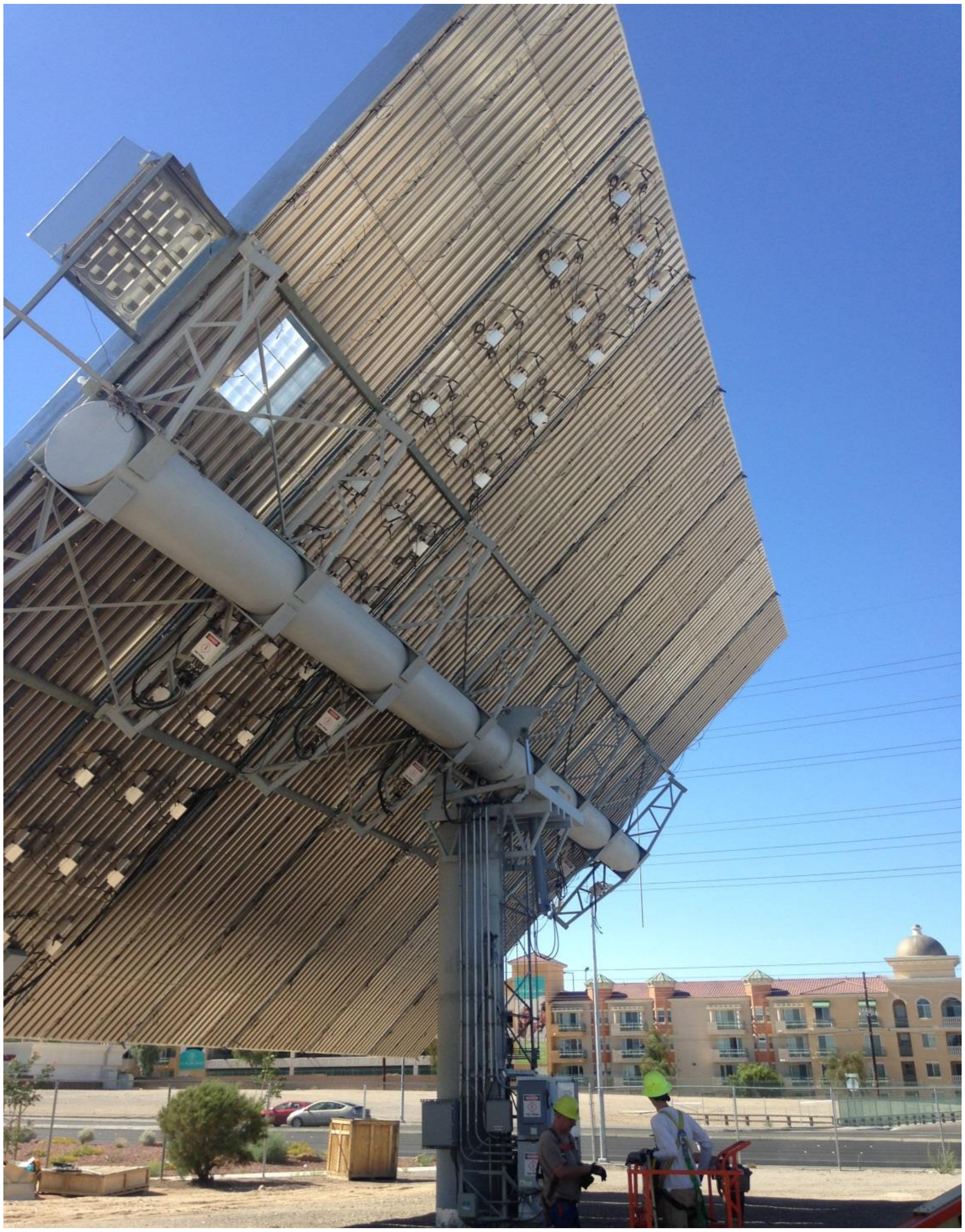


Figure 16: Amonix 7700 at Taylor Hall

Concentrating PV can achieve high efficiencies. The educational module for this subject and system will focus on the mathematics of the Fresnel lens concentrating irradiation onto the solar cells that then creates a current and then power through the electrical equipment that can harness the current. The equipment that is on the Amonix 7700 is necessary in the data collection too because that equipment can handle the amount of energy this system outputs. At this time, this is not completed. When this system is incorporated into the project it will be detailed how this was accomplished and how to provide real time and current data from what the equipment records.

Chapter 3: Remote Laboratory Capability

3.1 Definition

Usually a student gets laboratory experience by performing in-person tasks in a laboratory, and these are related to a course, e.g. chemistry. Remote laboratories change that. They put the individual/group behind a computer and through the internet provide the education and data of an experiment that occurs for them or has occurred to which they need to analyze it. The website that this is done through can be simple or quite involved. It may require little effort or concerted interaction from the participant(s).

3.2 UNLV Resources

3.2.1 Overview

UNLV's Center for Energy Research (CER) has experience with solar energy and has facilities to pursue projects of this kind. As stated when describing the solar water heating system the roof of TBE is a location that can be used for experiments. Taylor Hall is another site that can be used and, in fact, that is what Taylor Hall is for; there are two concentrating photovoltaic systems and a concentrating solar dish on site and the hall itself has equipment, supplies, and space for research.

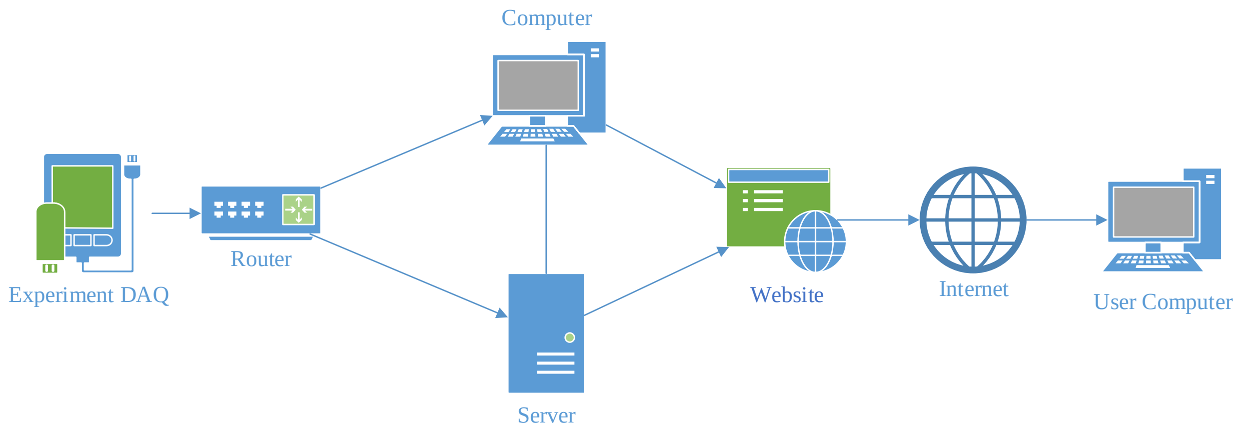


Figure 17: Representation of Data Pathway

UNLV ESRL will provide data to users in a manner presented by Figure 17. Each experiment has its own data collection which is accessible by a computer on UNLV's network. With the computer and server, data can be stored and prepared for the website. The website is created on the computer and hosted on the server which is on the internet. UNLV's Office of Information Technology took appropriate actions to make the website viewable outside of the school network so users can participate.

3.2.2 Solar Water Heating Systems

Chapter 2 describes the two systems that were installed at the beginning of this project. This apparatus' data will be available because that is how it was constructed with the appropriate instruments installed. The educational module for this solar experiment will have all the pertinent information and the objectives to learn about this subject.

As described in Chapter 2, Campbell Scientific equipment is used to record data and control the pumps. Omega solid state relays are used to interpret the commands from the program in the CR1000 and control the power to the pumps. See Figure 18.

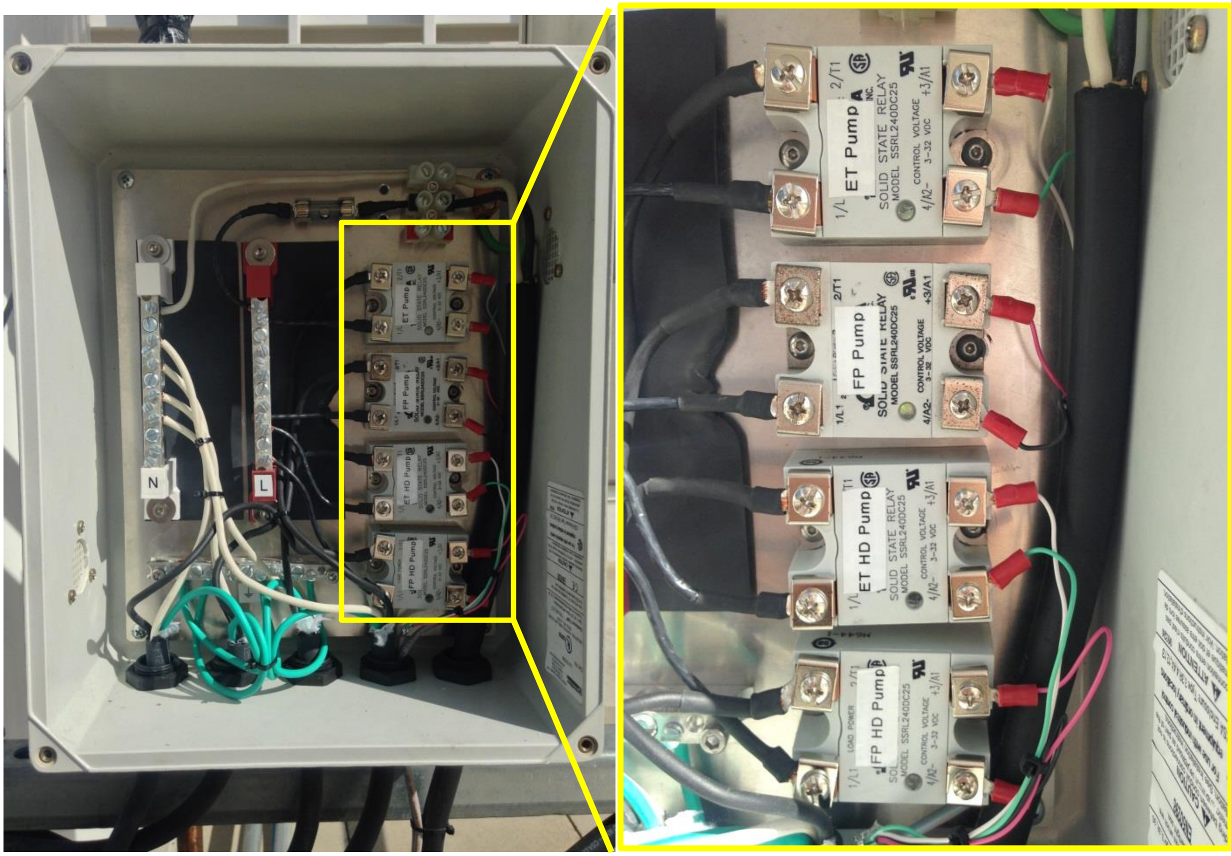


Figure 18: Picture of Solar Water Heating System Relay Box

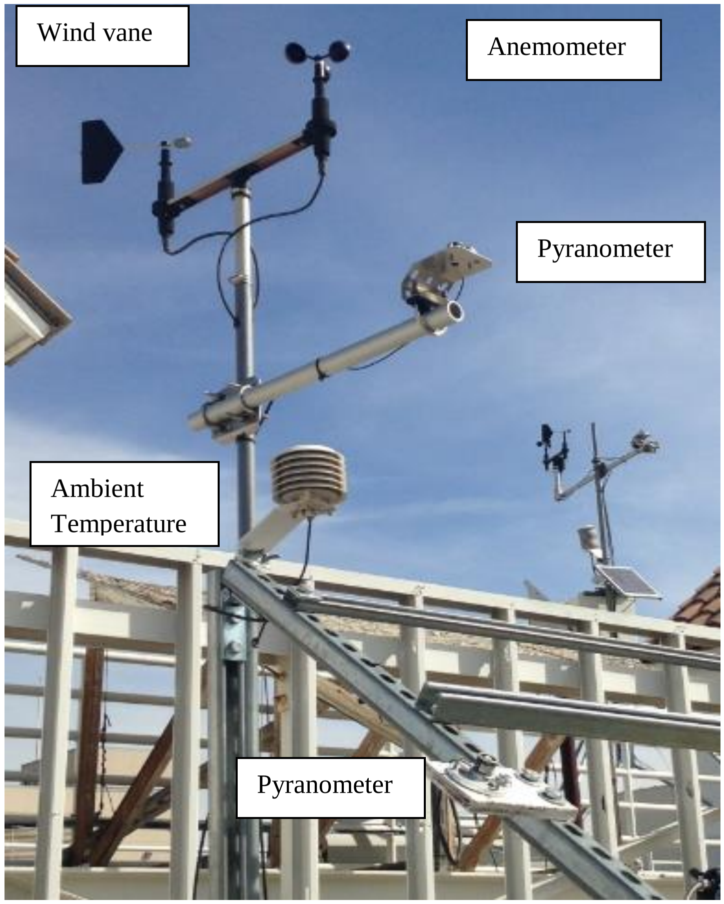


Figure 19: Meteorological Station for the Water Heating Systems and Another in the Background

The instruments in this laboratory are necessary to provide appropriate data for analysis. They are similar to equipment in experiments in many laboratories. Pictured in Figure 19 is the meteorological station for reference. The readings from this station, and the other instruments, are recorded by the CR1000, pictured below.

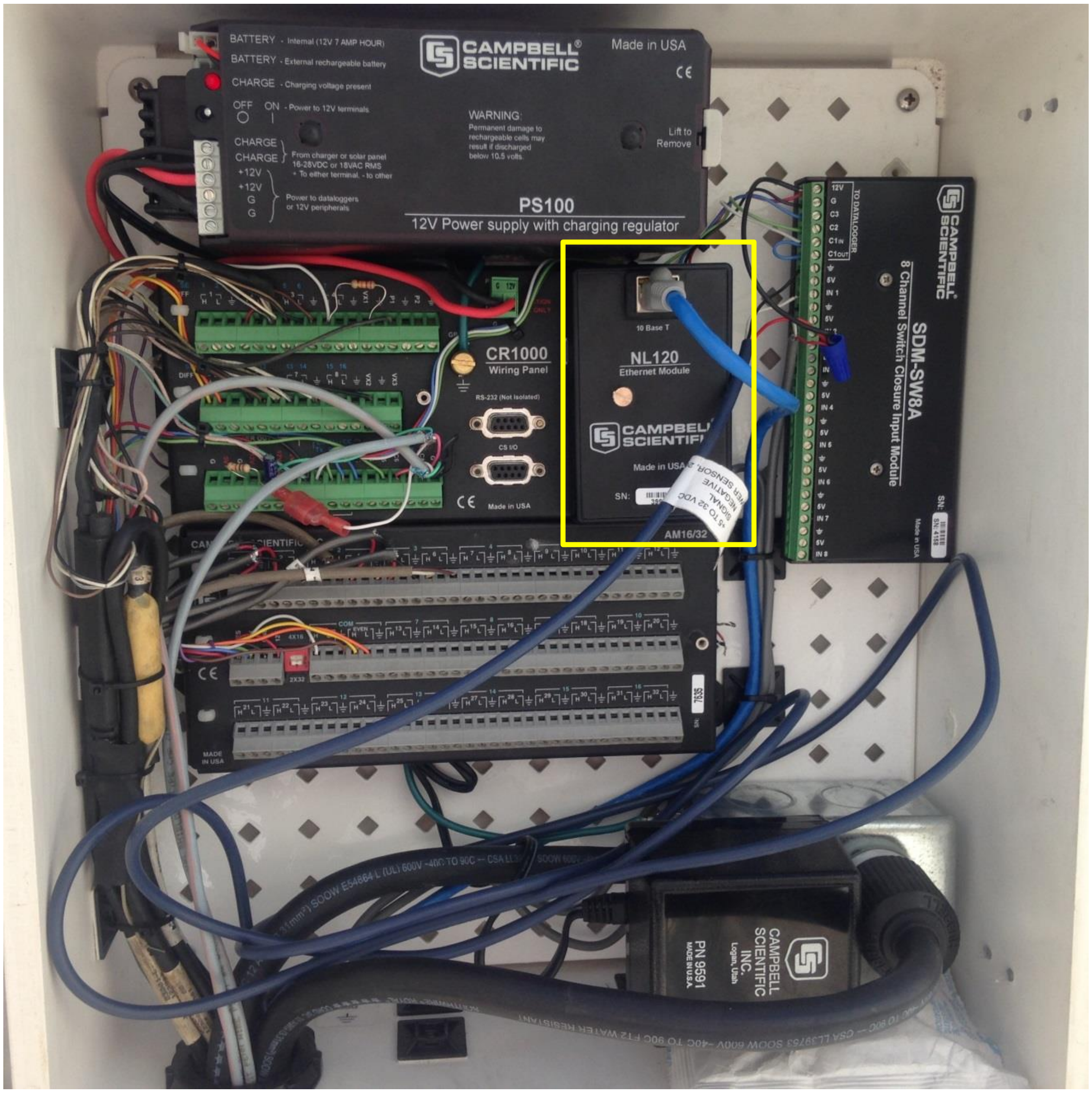


Figure 20: Inside of Enclosure that Houses Data Recording Equipment for Solar Water Heating Systems

Figure 20 displays the equipment for data acquisition, DAQ. The wiring takes up a lot of space but is necessary since there are a plethora of instruments and components to connect to the logger. In the yellow rectangle in the figure is the NL120 Ethernet Module that allows communication to the CR1000 over the UNLV network, if this module wasn't installed manual collection of data and communication would take place through the 9 pin ports slightly to the left of the module and that would be less convenient. This is the way remote laboratory capability was established on the water heating system.

3.2.3 PV Comparison System

The PV system has its own DAQ, most of which is from the original project. Descriptions and pictures below reveal how the apparatus works. As mentioned the system was not working when it was inspected to see what repurposing would need to happen. The wiring and placement of the major equipment was all moved and redone. From the original project, the programming was taken and rewritten by Adam Betemedhin, since the programming was one of the working problems and needed to be remedied. The original programming worked for the originators, from late 2010 to mid-2011 because that data is available [20].

The measuring device measures the temperature of each panel’s thermistor and the plane of array irradiance from the pyranometer. Through programming, relays are controlled that allow a Programmable Direct Current Load to measure the above mentioned currents and voltages and then apply a load, iteratively to decrease the voltage. It does this on one panel and then switches to another panel until all four panels have been characterized. It then repeats this after a break of fifteen minutes. A computer that is connected to the Load runs the program that controls this process and the data collecting.

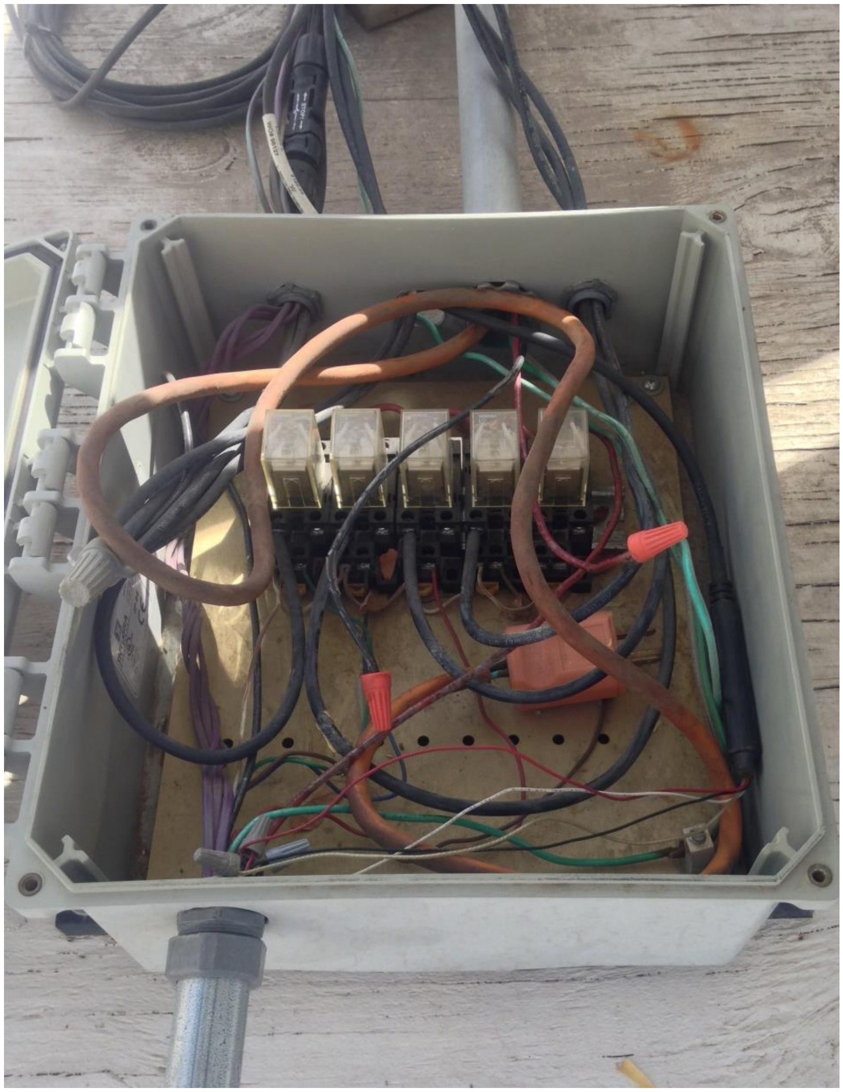


Figure 21: Picture of PV Comparison System Relay Box

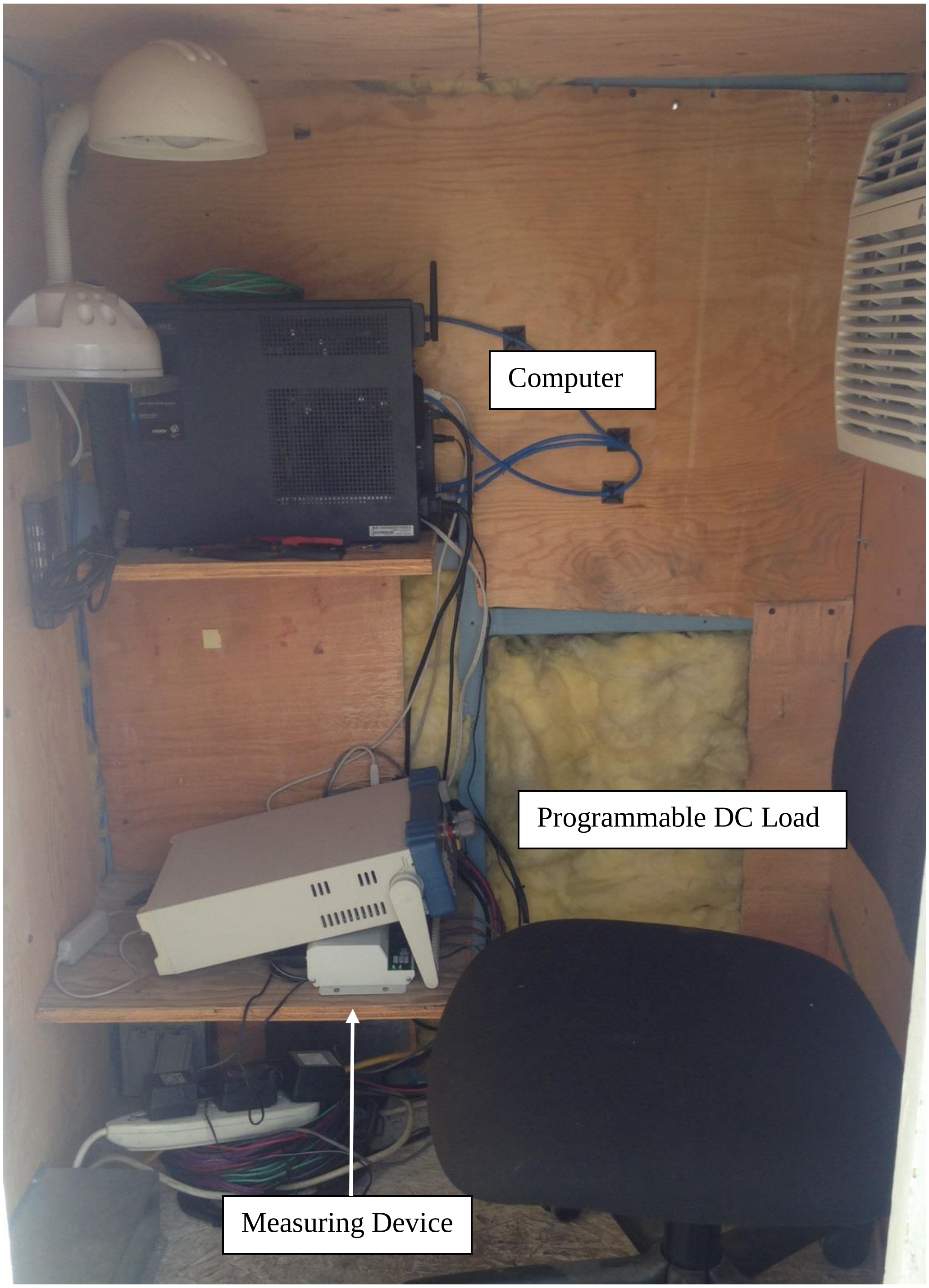


Figure 22: Location of DAQ for PV System

The relay box in Figure 21 is underneath panel 3 and the wires in the top section of the picture are the leads from the panels. Conduit in the bottom of the picture leads to the room in

Figure 22. The Measuring Device and Programmable DC Load record their readings and send those values to the Computer to be saved in the data file. The computer can be accessed over the UNLV network. The Ethernet cables connect the computer to a router that allows for ease of data collection and communication with this system like the water heating systems. For this system the computer is like the CR1000 for the water heating systems. This way the PV system has remote laboratory capability.

Chapter 4: Engineering Education

European knowledge in educational research and techniques are quite abundant in journals. In the literature review most of the articles that were found pertinent to the topic of engineering education came from European Journals. American journals on this subject have numerous articles as well and perhaps a paper of the work presented in this thesis will be accepted by one of them.

4.1 Current Higher Education Experience

To complete an undergraduate degree in an engineering program requires completion of specific requirements like: courses, projects, exams, etc. For example, the mechanical engineering program at UNLV requires completion of general education and program specific courses totaling approximately 122-128 credits. Usually one of the last courses taken is Senior Design, which entails a project started from a concept and finished with a produced object after the analysis, design, and building process. The Fundamentals of Engineering Exam (FE) is required to be taken to attain the degree at UNLV.

This is similar to the experience at many other colleges. The amount of credits is nearly the same and so is course selection. An undergraduate degree typically takes 4 to 5 years, in some cases shorter or longer. Please see Appendix B for UNLV’s mechanical engineering flowchart [21] and Appendix C for Berkeley’s mechanical engineering flowchart [22].

Lecture and laboratory classes are prevalent through an engineering program. Lecture classes sometimes have a laboratory component to them, for example UNLV’s ME 421 is Automatic Controls class and ME 421L is Automatic Controls Laboratory, otherwise lecture classes are standalone, and in some cases laboratory classes are standalone. Lectures usually have homework, exams, and projects; and lab classes usually have lab reports and a finale, which might be an exam, project, or practicum. During lectures a student is most likely taking notes about theory and problem solving on a certain subject, whereas in a laboratory a student gets an overview and procedure that leads them into the practical application or experiment that usually involves trials, data collection, calculations, etc.

4.2 Possible Changes in Education Curriculum

The state of education has been one of constant analysis with many parties suggesting change and reform. The goal is to improve the education and experience the student receives. These changes are suggested at multiple levels of academia.

In 2008, a large group of researchers at the Sustainable Futures Institute (SFI) at Michigan Technological University discussed how a global perspective should be integrated into education along with concepts of sustainability. The group is part of the Civil Engineering and Environmental Systems department at their university and their concentration is on courses in those subjects along with some other electives. They have created a Certificate in Sustainability that students can receive as well as their diploma with the right coursework. It is said initiatives like this will increase competency and other educational institutions should think about having programs like this [23]. At UNLV there are some renewable energy electives, environmental courses, and a minor in Solar and Renewable Energy. The ESRL, both here at UNLV and other institutions could be a part of a change like that presented by these researchers from the SFI.

An Engineering Educational Network in Europe and North Africa comprises of online labs on a plethora of subjects. "A consortium of sixteen partners from seven different countries" make up this network. They are focusing on higher technical education. Their research outlined how to evaluate the education that this network provides. In the future this information will be useful, what was useful at this time was learning of the consortium [24]. It can be compared to the ESRL partnership and it is a possible change that could occur where more universities cooperate as networks, consortiums, partnerships, or other grouping titles in providing education.

A group from Finland looked at an approach to increase university and industry cooperation. Back in 2007 this group stated the future of engineering education will be different than what it was currently. “Industrial companies are working together with educational institutions for renewal and redirection of engineering education.” This quote is directly from their paper and with other context from what they researched and worked to, a change where more cooperation and interaction between universities and the private sector is crucial to education [25]. In the future, the ESRL may be able to network with companies and jointly work on a remote laboratory or learning module. There may be in general a change in academia that educates and promotes on networking.

4.3 Anticipated Impact of this Project

This project’s goal to develop multiple educational modules dealing with solar subjects is still in progress. Here at UNLV, mechanical engineering classes and labs may be able to incorporate the modules that we have here, the engineering departments at the partner universities could also follow suit. The engineering departments here at UNLV may be able to utilize the modules that partnering universities are working to establish. Depending on subject, these modules could also be useful to physics, chemistry, biology, etc. Referring to 1.4 Project Details expanding the ESRL idea to be used in laboratory education is another impact.

Looking to Nickerson, et al. [26] this project will hopefully receive feedback that is positive and decent scores on the experiment assignment(s). Also, this project will hopefully agree with the suggestion by Nickerson, et al. that “remote labs can be effective educationally” [26]. This project will impact the education of students in a beneficial way, in that users will learn about the subjects, perform adequately on assignments, and repeat. Efforts have been put forward and will continue to be made to do these things.

Chapter 5: Results and Discussion

UNLV's ESRL project still has work to be done and the results that will be presented here are from what has been established and accomplished up to this point. The discussion will entail how results were attained and how the next things to determine might be pursued. This chapter will present a considerable amount of information.

5.1 Experimental Systems and Remote Laboratory Capability

5.1.1 Solar Water Heating Systems

It has been a long process to get the solar water heating systems to the point that acceptable data is generated by the instruments. Constructing the systems was finished in mid May 2015, but refitting and fixing occurred throughout the rest of 2015 and the beginning of 2016 and will continue for the Evacuated Tube System. The refitting that was done on the Flat Plate and Evacuated Tube System includes: replacing the older pumps with new ones and replacing the spring check valve with a gate check valve. The Flat Plate System was concentrated on to determine what the issues were. The Flat Plate System had these additional refits: installed a Y-Strainer Filter, replaced old tank with new tank, replaced ball valve with globe valve, and replaced the flowmeter. Each of the refits improved consistency and performance. See the graphs below.

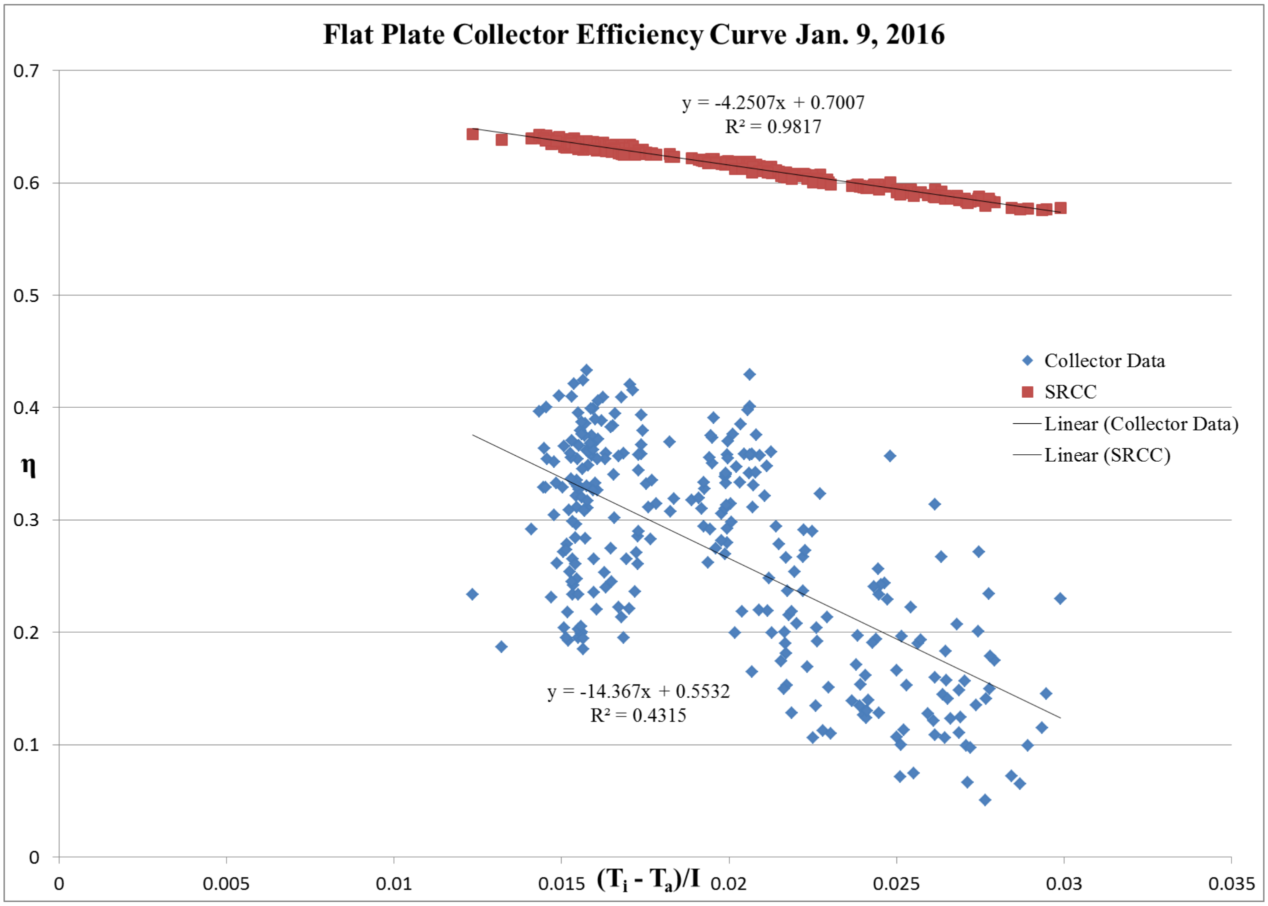


Figure 23: Graph of Flat Plate Data before Last Retrofit

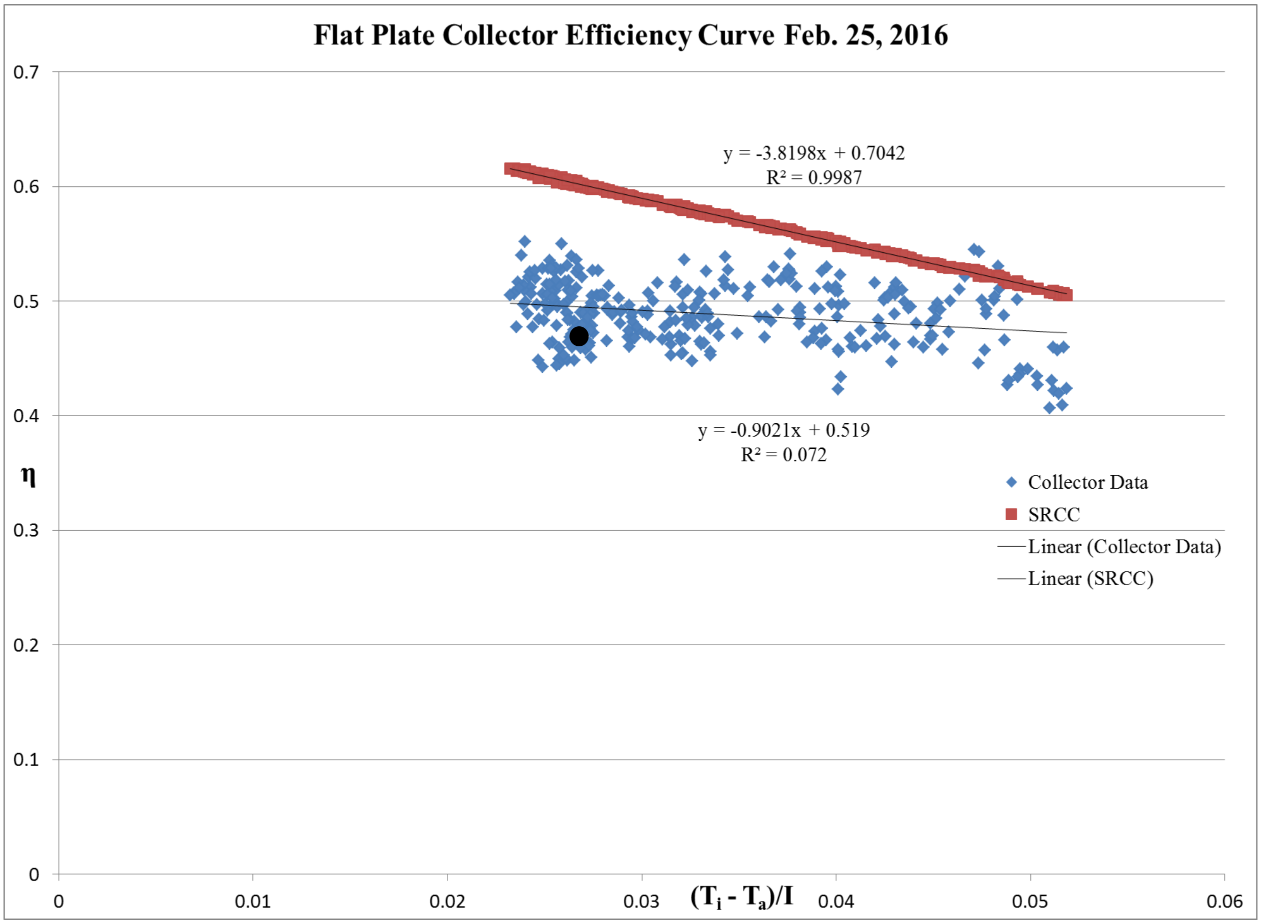


Figure 24: Graph of Flat Plate Data after Last Retrofit

Figures 23 and 24 shows calculated values from data on two different days, with similar weather conditions. The data that the analysis is done at is at irradiance over 800 W/m^2 and in Figure 23 this constitutes 291 consecutive data points on Jan. 9th, 2016 and in Figure 24 there are 321 consecutive data points on Feb. 25th, 2016. The difference between these two days is the flowmeter that was used to record flow quantities. The flowmeter used after its installation on Feb. 19th, 2016 has provided more accurate and consistent values which propagate to the calculated value of efficiency. It is expected with more data that the trendline will near the SRCC equation driven efficiency line. Figure 23 has been the norm since the system became operational. And now that Figure 24 is the new norm this data is acceptable to use in the educational module.

The equation for collector efficiency is: $\eta_c = \frac{q_{useful}}{A_c I_c} = \frac{\dot{m} * c_p * (T_{fluid\ out} - T_{fluid\ in})}{A_c I_c}$. The efficiency of a collector is the useful heat, which is the mass flow rate, $\dot{m}$, multiplied by the specific heat, c_p, and the change in temperature from the inlet and outlet of the collector, $T_{fluid\ out}$-$T_{fluid\ in}$, divided by the incident irradiance, I_c, and collector area, A_c. An example calculation is as follows: $\frac{0.044\frac{kg}{s} * 4180\frac{J}{kg * °C} * (50.76°C - 44.62°C)}{1102\frac{W}{m^2} * 2.031\ m^2} = 0.5057$. The values entered into the example calculation are from Wednesday, February 24, 2016, at 12:00 P.M. and this point is approximately where the black point is in Figure 24. Users of the educational module will use this equation with the given data just like it's been presented in the above figures. The SRCC efficiency is also graphed in the figures to be a reference and those points use the data as well but are calculated with an equation that is specific per collector, the flat plate's: $\eta = 0.679 - 3.58850 * \left(\frac{P}{G}\right) - 0.00261 * \left(\frac{P^2}{G}\right)$ where P is the inlet temperature minus the ambient temperature and G is the incident irradiance. At this time users are not required to compare to the SRCC values.

The Evacuated Tube System will need more work for its data to become acceptable. For that system almost the same refits will be made to it with the exception of a new tank and a Y-Strainer Filter. None of the evacuated tubes seem to be damaged or ineffective which is good.

The datalogger is recording data without incident. That data can be downloaded at any time by people who have access to the datalogger through software that can communicate with it over the internet or by directly connecting to it. Before becoming available to a prospective user the data still need to be processed into the form it is desired for the user to view. As data is logged now a simple program could be created to remove unnecessary points, calculate flow from the pulse counts of the flowmeter, and to move columns of data to better positions. Then in the future a program could be put into place that will update the available data on the website. At this time data can be manually inserted to the download section of the website.

The remote laboratory capability for the Flat Plate System is a success at this current stage. The datalogger has been problem free and suitable data is available on the website. Future work will expand on this success.

5.1.2 PV Comparison System

The Four PV Panel System that has been on the roof for a number of years has been restored to working condition. This required repair or replacement of the temperature sensors, relays, pyranometer, computing devices, and computer that was recording data. A cleaning of the panels was also needed to remove the dirt, dust, and other blemishes to allow for optimum performance.

All the panels are performing like they did in late 2010. The Current-Voltage (IV) curves for the panels are presented in Figures 25 and 26. Creating these graphs is simple because current and voltage are recorded. The four different panels, as detailed in Table 3 and pictured in Figure 13, have different current and voltage characteristics, thus the different curves. In Figure 26, a slight drop in the curve for panel 4 can be seen, in the span of those few data points the irradiance could have fluctuated, and the readings responded accordingly, and then returned to normal.

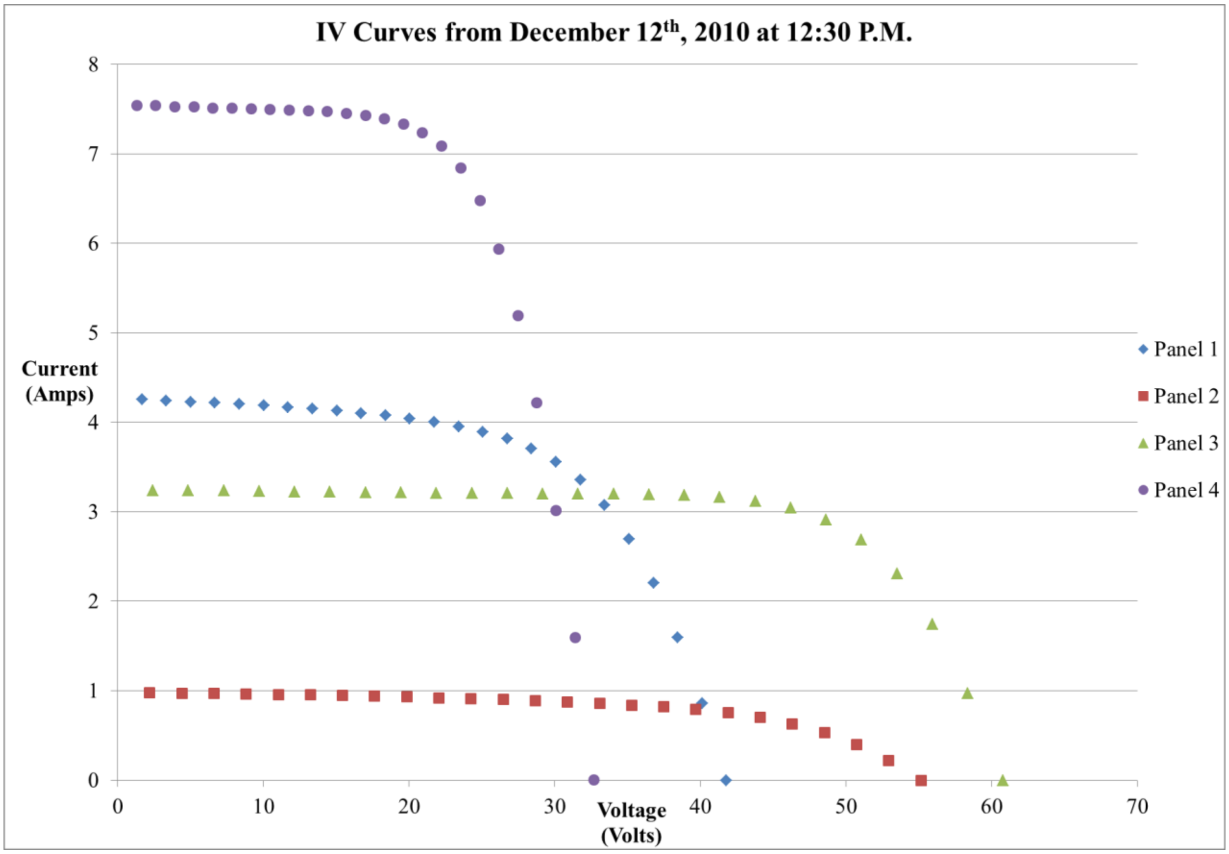


Figure 25: IV Curves for Data from 2010

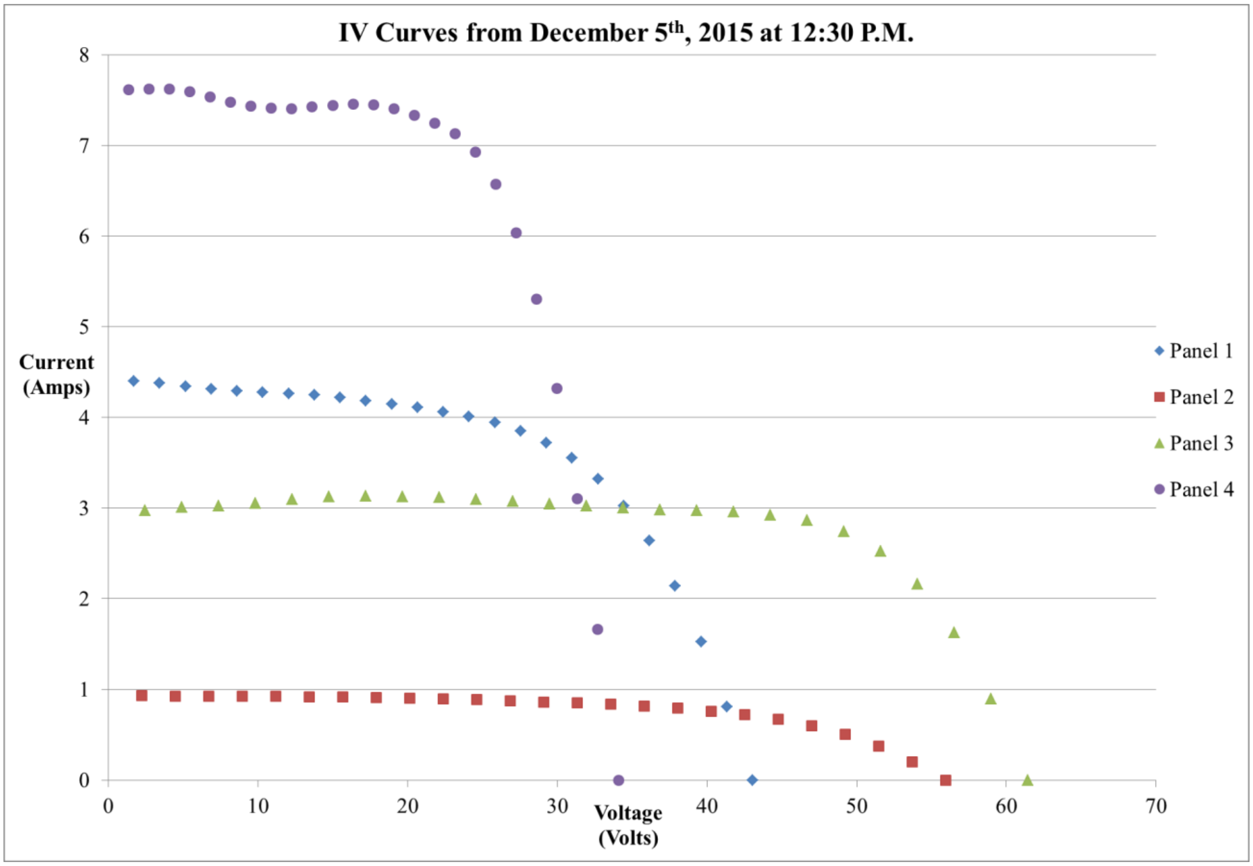


Figure 26: IV Curves for Data from 2015

The equation for PV panel efficiency is: $\eta_p = \frac{I*V}{G_p*A_p}$. PV panel efficiency is the power, which is current (I) multiplied by voltage (V), divided by the incident irradiance, G, and panel area, A_p. Performance Ratio (PR) is calculated by dividing panel efficiency by standard test conditions efficiency (STC), $PR = \frac{\eta_p}{\eta_{STC}}$. Fill Factor (FF) is calculated by multiplying max power current and voltage and then dividing by max current and voltage, $FF = \frac{I_{mp}*V_{mp}}{I_{sc}*V_{oc}}$.

Educational materials for this module will include descriptions of how PV panels work, what calculations and quantities are part of this subject, and how to perform a graphical analysis on the data from this apparatus. The calculations that participants will do include efficiency, PR, and FF. The graphical analysis participants will do include developing IV curves and Power-

Voltage (PV) curves. Figure 27 below displays a PV curve that uses the same data from Figure 26, but plots power instead of current.

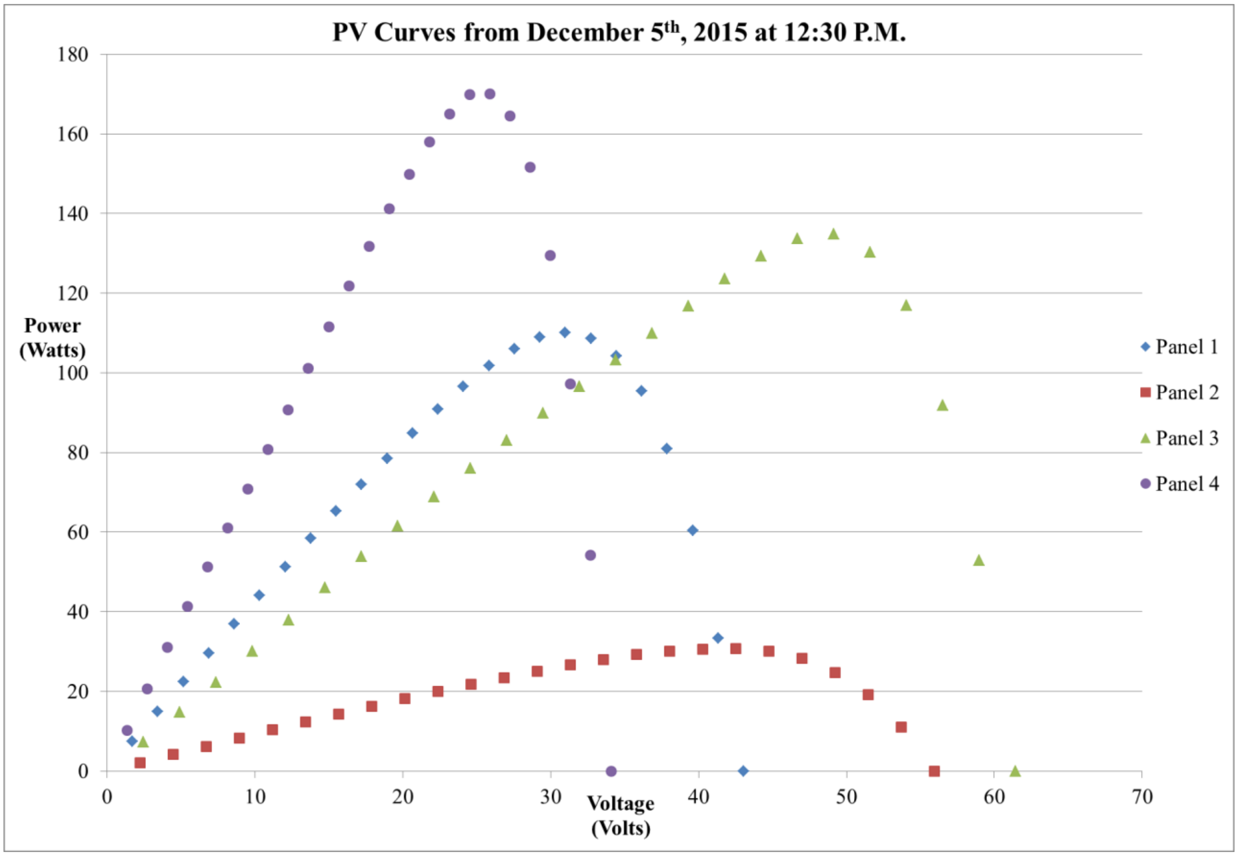


Figure 27: PV Curves for Data from 2015

5.1.3 Amonix Concentrating Photovoltaic System (CPV)

At Taylor Hall the Amonix Concentrating System has operated since 2004 and while it isn't as efficient as it used to be the data can still present an excellent learning opportunity. At this current time it has only been discussed to make this module a part of ESRL. It has been thought how to record the data but not implemented.

5.2 UNLV ESRL Website

The website was created using WordPress, which is a web software that can be used to create websites. It is the most popular way to create and host blogs on the web. Another member of the Center for Energy Research, Adam Betemedhin, is the expert on this subject. He was able to handle the program, setup the parameters to create the webpages for the website, and utilize a server here at the Center to host everything that is needed for the website. He utilized necessary programing tools and WordPress's free program to complete most of the initializing work on the website. Then he requested UNLV's Office of Information Technology to change the URL from the IP address the website started on to esrl.unlv.edu. WordPress was picked because of its simplicity in creating websites. When this was all finished pages could be created and filled with content. WordPress has resources and help available in using the software.

The website's banner and top menu are simple and lead to their appropriate pages. See Figure 28 below. The Home text is in red because that is the page that the user is on. On the Home page there will be description of the ESRL project and how to use the website. On the Overview page there will be a description of the individuals involved in the project, along with the general details of what UNLV has done. The Resources tab is a dropdown menu that leads to individual laboratory pages. Currently there are three pages: Solar Water Heating, PV Power Fundamentals, and Solar Concentrating PV. The Partners page will have links to the other universities' websites that are participating in the ESRL, along with any other institutions or companies that join that are supportive or perhaps have provided resources to the project. The last tab currently is the Contact Us page where pertinent information will be displayed about the people involved and a form that will send inquiries to a specific user who can handle them. See Figure 28 below.

Figure 28: Banner for UNLV's Website

LSU's ESRL website is more established and has more pages. See Figure 29 below. In comparing UNLV's website to LSU's a few differences can be seen just from looking at their menus. Next to the Resources tab there is the Active View tab, and that is how LSU decided to present their real time data feed. On UNLV's, real time data will be presented on the individual resource page, for example, on the Solar Water Heater page the system diagrams will be near the bottom of the page after other sections that are on that page. LSU has a Downloads tab where they have tools that are needed for some of their cogeneration educational modules. Their Faculty Resources and Expert Support have information on the procedure an educator would take to have students use these educational modules and how expert knowledge has created the resources on the subjects that these modules cover.

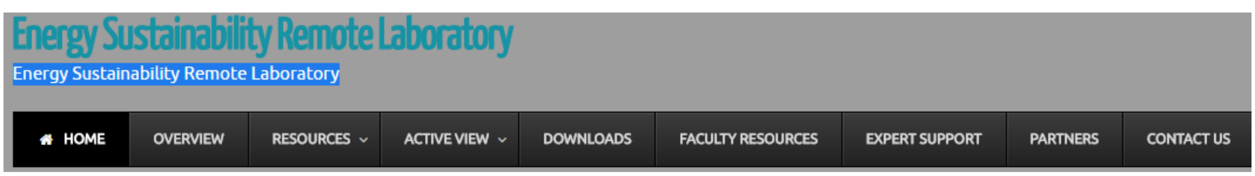


Figure 29: Banner for LSU's Website

LSU's website is still under development like UNLV's as can be seen by the blue highlighted text in the figure that shows there is a repeat of the ESRL acronym in small font underneath the bold, teal title. The UNLV's ESRL website is intended to be compact and simple. Pages will contain the content, in the hopes that once a user is on a page they shouldn't have to leave the page. In addition to this, the content will be very thorough and informative so users don't struggle with the subject and proceed with their analysis.

A planned feature for the website is another page for pictures entitled Gallery. In addition to the pictures, videos, and pdf downloads on their specific pages this page could have albums sorting related media that show more than just the general items on the specific pages. Since these media items can be quite large and all stored on one page it may not be a good addition to the website if it slows down access. If not, then an album page would be beneficial to the site and provide more to view.

5.3 Engineering Education

5.3.1 Educational Materials

For each of the modules some form of educational material needs to be available. It was thought that the knowledge would be conveyed through the webpage and the data would be downloaded; the consensus changed though to convey the description of the module on the website along with any informative videos, and have an educational lecture and lab manual to download along with the data. The lecture is a PDF that was created first in PowerPoint with information about the topic and questions for students to answer. The lab manual is also a PDF that was created with PowerPoint and focuses more on the analysis of the specific data and the quantities to be calculated. The webpage for each module is simplified by having the lecture and lab manual as downloads. The videos on the webpage allow for someone to see and listen to the information, as well as the actual people, places, and equipment. The first video is on the lecture and the second video is a description of the experimental apparatus.

At the time of this writing the Solar Water Heating and PV Comparison modules are almost complete in regard to their webpages and materials. The lecture video for the Solar Water

Heating module is 19 minutes and 24 seconds long, the video about the apparatus is almost 6 minutes long, and the educational lecture is 12 slides. The lecture video for the PV Comparison module is 22 minutes long, the video about the apparatus is 2 minutes long, the educational lecture is 19 slides, and the lab manual is 15 slides.

5.3.2 Educational Access

As a remote laboratory a website is necessary to have for users to interact with. This requires a user to have access to a computer with internet service. A user's computer would also need Microsoft Excel, MATLAB, or another program that can open data files and perform calculations. A PDF reader is also required to view the lecture and lab manual. These are most likely readily available to any student in an engineering or technology program.

The website and educational materials are written in English. It is accessible to anyone at this time, that can be changed if needed. It is anticipated that courses will use modules to garner knowledge and data to complete the assignment that goes with it, which then will be factored into the course's grading. Solutions have been developed that could be given to an instructor to grade the students' submissions against. Instructors would need to reach out to attain this information, or develop their own solutions.

The Center of Energy Research will not be able to grade all the submissions if this becomes very popular and attracts many users. It is possible the Center can help with some users who need assistance in their analysis or learning the material. Efforts have been made though to make the educational materials effective.

Selected data for the collectors will be available since a full dataset contains a large amount of data that is in a more primitive format. On the website this data will be available for download and possibly the full datasets from the systems. They will be individually available.

The same is true for the PV Comparison System, except there are four panels instead of two collectors.

One of the educational features on the website pages for the systems are their diagrams that show real time data. The diagrams are simple line diagrams drawn in Visio with a table accounting for the components and measured value of a sensor if applicable, please refer to Chapter 2 to see the figures. The programing is very involved to generate these figures and put them on the website.

5.3.3 Learning Evaluation

In March 2016 students in UNLV's ME 315 Thermal Engineering Laboratory class were offered 5% extra credit to their grade in the class and $20 to work through ESRL's Solar Water Heating Module. Students in this laboratory class have taken ME 311 Thermodynamics and ME 314 Heat Transfer as prerequisites, thus germane to have them participate, and are usually juniors and seniors in the degree program. Since this project is funded by NSF and had to undergo an IRB board review due to human test subjects, which is described in 1.4 Project Details, the Teaching Assistant for ME 315 has to collect the responses from the students in the class and then remove identifiers before anyone on this project can see the students work.

The results of this first set of users are not presented here because the students have not all attempted the module. While comments, concerns, and suggestions weren't required they will be noted and addressed. The users' work, when anonymized, will be reviewed to see where deficiencies lie. At this current time there is not a pretest, only the assignment to analyze the data and graph the correct values, and somewhat of a posttest which has four short questions that should be easily answerable because the information is readily available. What is received from the users will be useful to improving the website, learning materials, data presentation, questions and testing methods, and possibly other things.

Chapter 6: Future Work

6.1 Expansion at UNLV

Additional experiments can be set up at UNLV to increase the amount of educational modules concerning solar subjects. Some of these subjects and experiments include: concentrating solar thermal using the dish at Taylor Hall or a parabolic trough, solar oven with a commercially produced model or a constructed unit, irradiation experiment with pyranometers, lens experiments with pyranometers, and others that can be installed. These would be new setups and would require time to construct/repair, analyze data, and create educational materials.

The established modules with the solar water heating collectors and PV panels can also be expanded. One expansion for the solar water heating module is the Sunvelope collector that has a unique design. The Sunvelope is like a flat plate collector, however, the pipes that carry the water have been replaced by two pieces of sheet metal that have been spot welded in designed places to create an envelope for water to flow through and let heat transfer to it. Since the PV system has four different types of panels, additional panels would have to utilize different technology to keep the trend of that system.

At UNLV this project has only focused on solar subjects, it is possible in the future other groups may get involved and develop educational modules on other subjects. In example, other modules could focus on programming, controls, electrical circuits, etc. This would involve individuals/groups from other departments here at UNLV. Also, since this project is a collaboration, more interactions with the partners could be possible.

6.2 Recommendations

Developing the website for the learning modules has been made far easier with WordPress and so I recommend it for anyone who is going to make a website and for the continuation of this project. If a new experiment or an expansion is made on this project buying new materials and components is necessary, unless what currently available is in acceptable condition. Utilizing these remote labs at the originating university is a great way to get feedback.

The participating universities should communicate with each other in the continued development of ESRL. This will expedite the process of determining additional modules to implement and which universities will do them. It will allow exchanging of ideas for increasing the effectiveness of this project.

Chapter 7: Conclusion

Solar experiments can add to the breadth of engineering education while at the same time not deter from the conventional subject matter. Combine this with remotely accessing the material and a worthwhile endeavor emerges. As presented by this thesis effort has gone into the beginning of such a thing.

The laboratories have begun to be implemented for the ESRL. A solar water heating system and a PV system have been developed. More work will be done to complete the process and finish the physical apparatus for each experiment, remote capabilities, and educational materials. Each apparatus took time and appropriate development to achieve the desired and normal output. The development of solar experiments has its particular nuances.

Remote Laboratory Capability can be handled in a variety of ways. The end result, referring back to Figure 17 in Chapter 3, is the transfer of data from the system to a user at their discretion. The requirements of programing and communication between all of the equipment makes this aspect challenging. This functionality will be seen more often in use due to the expanding interconnectedness of the world.

Engineering education can incorporate this to expand curriculum. Examining the effectiveness is still in progress, along with increasing student participation. The desired conclusion is that educational modules in this manner can be useful and impact the way students learn.

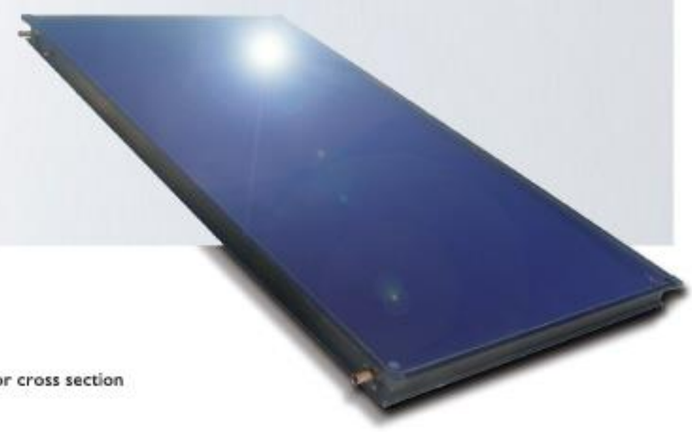
Appendices

Appendix A: KIOTO FP 1.20.0 HE sc ab Collector Data Sheet [14]

Preferred partner of the industry

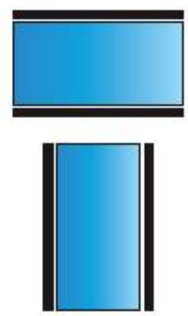
FP 1.20.0 HE sc ab Collector

KIOTO CLEAR ENERGY

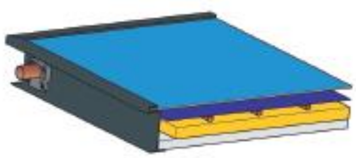


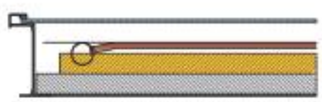
The frame collector FP 1.20.0 HE sc ab is perfectly designed for use in pumped systems. High effi ciency due to the best available materials and newest European technologies paired with top quality makes this light-weight frame collector unique.

FP 1.20.0 HE sc ab



Collector cross section



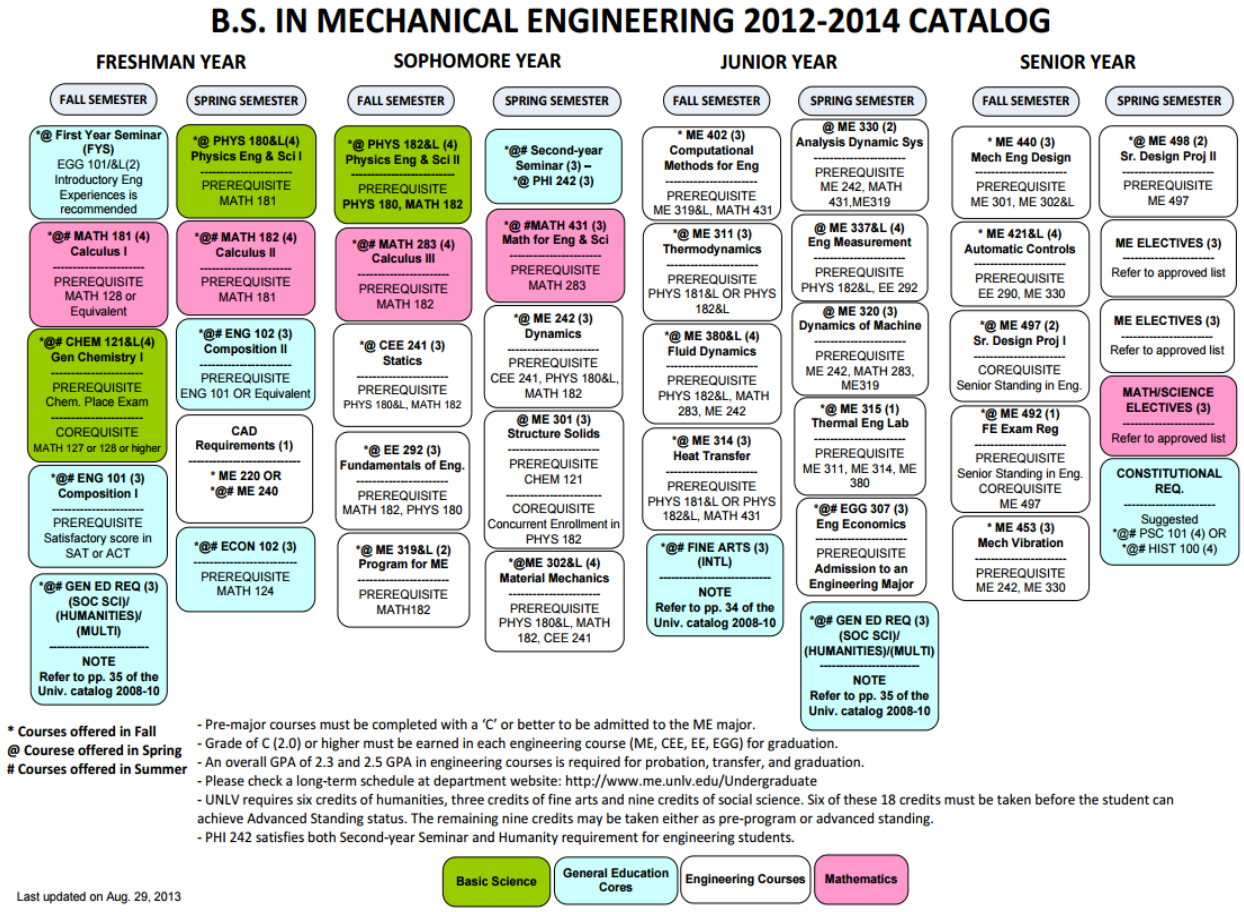


Technical data	FP 1.20.0 HE sc ab US Norm	FP 1.20.0 HE sc ab Metric Norm
Collector type	Al frame collector	
Overall area	22 ft²	2,03 m²
Absorber area	19,5 ft²	1,81 m²
Aperture area	20 ft²	1,88 m²
L x W x H	76.5 x 41 x 3 "	1945 x 1046 x 81 mm
Weight	64 lbs	29 kg
Absorber capacity	0,5 gal	1,84 l
Housing	Al-frame	
Surface	Al, natural or anodized black	
Back plate	Al-sheet	
Absorber sheet (Al)	high selective vacuum coating (PVD)	
Absorption* [%]	94	
Emission* [%]	5	
Ø manifold	3/4"	22 mm
Ø risers	3/8"	10 mm
Connections	blank (compression joint)	
Glass	1/8" tempered low iron glass	3.2 mm tempered low iron glass
Transmittance of glass [%]	89	
Insulation	5/8" PUR plate + 3/4" mineral wool	16 mm PUR + 20 mm mineral wool
Max. stagnation temperature	approx. 392 °F under test conditions	approx. 200 °C under test conditions
Max. operating pressure	145 psi	10 bar
Proper heat transfer medium	Polypropylene glycol/ water mixture	Polypropylene glycol/ water mixture
Standard packaging	individually packaged	

FP 1.20.0 product benefits

- Laser-welded full-surface absorber with a high selective coating.
- 10 years warranty.
- Multi stage quality assurance program.
- Optimal value for the money due to intelligent product design.
- Use of emission-free, recyclable materials only results in a long service life and environmentally friendly product.
- Tempered low iron safety glass.
- Maximum heat transfer between the full-surface absorber sheet and the copper grid due to state-of-the-art laser welding technology.
- Easy transport and installation due to a low total weight of only 29 kg (64 lbs) and a height of 81 mm (3")

Appendix B: UNLV Mechanical Engineering Course Flowchart [21]



Appendix C: Berkeley Undergraduate Program in Mechanical Engineering [22]

Undergraduate Program in Mechanical Engineering*		
Course	Fall	Spring
Freshman Year		
Chemistry 1A and 1AL-General Chemistry or Chemistry 4A-General Chemistry and Quantitative Analysis[1]	4	-
Engineering 7-Introduction to Computer Programming for Scientists & Engineers(2)	-	4
Engineering 25-Visualization for Design[6]	2	-
Mathematics 1A-Calculus	4	-
Mathematics 1B-Calculus	-	4
Physics 7A-Physics for Scientists and Engineers	-	4
Reading and Composition Course from List A[3]	4	-
Reading and Composition Course from List B[3]	-	4
Optional Freshman Seminar or E 92 (Survey Course)	*1*	*1*
Total	**14-15**	**16-17**
Sophomore Year		
Engineering 26-Three-Dimensional Modeling for Design[6]	2	-
Engineering 27- Introduction to Manufacturing and Tolerancing[6]	2	-
Mathematics 53-Multivariable Calculus	4	-
Mathematics 54-Linear Algebra and Differential Equations	-	4
ME 40-Thermodynamics	-	3
ME C85-Introduction to Solid Mechanics	-	3
Physics 7B-Physics for Scientists and Engineers	4	-
Humanities/Social Science Course[3]	3-4	3-4
Total	**15-16**	**13-14**
Junior Year		
EE 16A-Designing Information Devices and Systems I	-	4
ME 104-Engineering Mechanics II (Dynamics)	3	-
ME 106-Fluid Mechanics	3	-
ME 108-Mechanical Behavior of Engineering Materials	4	-
ME 109-Heat Transfer	-	3
ME 132-Dynamic Systems and Feedback	-	3
Technical Electives[4]	3	3
Humanities/Social Science Course[3]	3-4	3-4
Total	**16-17**	**16-17**
Senior Year		
ME 102A-Experimentation and Measurement	4	-
ME 102B-Mechanical Engineering Design	-	4
ME 107-Mechanical Engineering Laboratory	-	3
Technical Electives[4]	6	6
Free Electives[5]	3-4	3
Total	**13-14**	**16**

Appendix D: Image of a Webpage on UNLV's ESRL Website

UNLV · ESRL

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Home Overview Resources Partners Contact Us

ESRL Module 21: Determining the Efficiency of a Solar Thermal Water Heater

Introduction

This module will introduce students to Solar Water Heating. This technology absorbs the irradiation of the sun and converts it to thermal energy by heating water. A mathematical and graphical analysis helps users understand the aspects of this solar subject. The two collectors involved in this laboratory utilize different methods of absorbing solar irradiation. Data from actual collectors, pictured above, are available for download for the required analysis's of this module.

Expected Learning Outcomes:

1. Understand the calculations involved with solar collectors used for water heating.
2. Develop graphical representations of the efficiency's of the collectors with measured data.

Theory

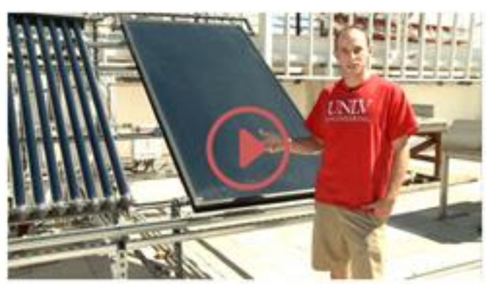
Water heating is a very energy intensive process and using solar irradiation can provide a lot of that energy. Using absorbent materials and efficient construction designs and practices, solar collectors can efficiently convert irradiation to heat that can be transferred to water.

Download Lecture

Experimental Apparatus

A glazed flat plate solar collector faces south on a mounting rack at a tilt angle of approximately 36 degrees, the latitude for Las Vegas. This collector has its own system of components and instruments. A datalogger records instrument readings and controls operation of the system through a program written to our design.

Download Collector Datasheet



Download Selected Data: Flat Plate Collector Lab Data

Appendix E: Image of a Webpage on UNLV's ESRL Website

UNLV · ESRL

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Home Overview Resources Partners Contact Us

ESRL Module 22: Fundamental Power Aspects of PV Cells

Introduction

This module will introduce students to PhotoVoltaic (PV) technology and mathematical computation of important aspects of panels that use PV cells to generate power. A graphical analysis is also presented for the education of users. The technology that is involved in this field can be quite varying, with each panel in this experiment having a different type of cell configuration to convert solar irradiation to electrical power. Data from actual panels, pictured above, are available for download for the required analysis's of this module.

Expected Learning Outcomes:
1. Understand the calculations involved with PV panel electrical power generation.
2. Develop graphical representations of the performance of the PV panels with measured data.

Theory

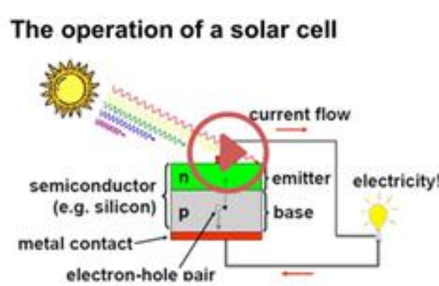
Silicon is a semiconductor and through the right combination of cell structure this material can absorb solar irradiation and convert that energy to electrical power. Many technological advances have been made in photovoltaic panel design and manufacture. Harnessing the photovoltaic effect has become more efficient, cell structure and layer design have become easier to create and more effective at transferring electrons.

Download Lecture

Experimental Apparatus

Four different PV panels face south on a mounting rack at a tilt angle of approximately 28 degrees. Each panel is connected through its own relay to the programmable DC load. The program that controls the system cycles between the panels recording data starting from open circuit voltage with minimal current to short circuit current with minimal voltage.

Download Lab Manual



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Curriculum Vitae

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	(Expected May 2016)

Thesis Examination Committee:

Chairperson, Dr. Robert Boehm, P.E.

Committee Member, Dr. Yitung Chen

Committee Member, Dr. Hui Zhao

Graduate College Representative, Dr. Brendan Morris