# 40th ASES National
# Solar Conference 2011

# (SOLAR 2011)

Raleigh, North Carolina, USA
17-20 May 2011

ISBN: 978-1-61839-427-9

**Printed from e-media with permission by:**

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY  12571

Printed by Curran Associates, Inc. (2012)

American Solar Energy Society
2400 Central Avenue
Suite A
Boulder, Colorado 80301

Phone: (303) 443-3130
Fax: (303) 443-3212

ases@ases.org

**Additional copies of this publication are available from:**

Curran Associates, Inc.
57 Morehouse Lane
Red Hook, NY 12571 USA
Phone: 845-758-0400
Fax: 845-758-2634
Email: curran@proceedings.com
Web: www.proceedings.com

# TABLE OF CONTENTS

## ADVANCING RENEWABLE ENERGY TECHNOLOGIES

## CRAFTING EFFECTIVE POLICY AND ADVOCACY

## DEVELOPING THE CLEAN ENERGY WORKFORCE

## FINANCING AND MARKETING CLEAN ENERGY

## TRANSFORMING THE BUILT ENVIRONMENT

# COPYRIGHT TRANSFER AGREEMENT
# (please complete all information)

**Paper Number and Title:** Effect on System Efficiency from Combining Solar Thermal and Photovoltaic Energy Systems in non-Grid Applications: Phase 1

**To be Published in:** SOLAR 2011 Conference Proceedings

**Principal Author:** David Goodman

**Author's Affiliation:** IUPUI

**Author's Address:** 799 W Michigan St, ET201C, Indianapolis, IN 46202

**Author's Tele. #** _317-274-5381_______ Fax: ___317-278-0789__________

**Co-Author Name and Affiliation:** Daric Fitzwater, IUPUI

**Co-Author Name and Affiliation:** Frederic Zarzecki, ESIEE Amiens

Does Article Contain any Previously © Material?: Circle One: [✓ NO] YES, identify:______

All authors of the Article, individually or through his or her authorized representative identified below (the "Author"), agree with the American Solar Energy Society, Inc. ("ASES") as follows:

The Author hereby transfers to ASES all right, title, and interest in and to the Article, including all rights to copyright in the United States and throughout the world, for the life of such rights. However, the following rights are reserved by the Author:

a. All proprietary rights other than copyright, such as patent rights;
b. The right to use, free of charge, all or part of the Article in future works of the Author's own creation, such as books and lectures; and
c. The right to reproduce the Article for the Author's own purposes.

In any use of the Article under the rights reserved above, the Author agrees to acknowledge ASES for having first published the Article, including the Proceedings title and date.

Each Author represents and warrants to ASES that: (a) he or she has obtained, in writing, all permissions required for the inclusion, use, reprinting, adaptation (if any) and publication, in the Article, of any copyrighted material (including, without limitation, any diagrams, photographs, or figures) and of any quotations attributed to a person or entity; (b) he or she has submitted copies of such permissions to ASES with the Article; (c) all authors of and contributors to the work have been identified above and no commitments have been made to any others with respect to the Article or its use; (d) the Article is original, does not infringe upon any statutory or common law copyright, proprietary right, right to privacy, or any other right of any other person, and is not libelous; and (e) if the Article contains any instructions or practical information, then such instructions or practical information are not potentially injurious to the user and that the Article contains appropriate cautionary and warning language. Each Author hereby indemnifies, holds harmless and defends ASES from and against any and all claims, liabilities, damages, costs and expenses (including attorney fees) arising from or relating to the breach of any representation or warranty made by the Author.

ASES shall have the right to use each Author's name, biography, and likeness in connection with the publication and promotion of the Article and any additional editions or reprints of the Article.

This Agreement and all issues relating to it shall be governed by the laws of the State of Colorado. Any controversy or claim arising out of or relating to this agreement shall be finally settled by arbitration in accordance with the rules of the American Arbitration Association and judgment entered in any court having jurisdiction.

**PLEASE CHECK ONE OF THE FOLLOWING.**

**Check if Applicable:** ☐ The Principal Author is the sole author of the Article and he or she is executing this Agreement below.

**Check if Applicable:** ☐ The Article was written by several authors, each of whom is identified above and is executing this Agreement below.

**Check if Applicable:** ☒ The Article was written by several authors, each of whom is identified above. The undersigned represents and warrants to ASES that he or she is authorized to execute this Agreement on behalf of all authors of the Article.

Name of Individual Signing for All Authors: David Goodman

**Check if Applicable:** ☐ The Article was written as part of duties as an employee or otherwise as a work made for hire. The undersigned represents and warrants to ASES that he or she is an authorized to sign this Agreement on behalf of the employer or other proprietor.
Name of Employer/Proprietor: ______________________________________________________
Name of Individual Signing for Employer/Proprietor: __________________________________

**Check if Applicable:** ☐ The Article was written in the course of employment by the United States Government or the United Kingdom Government (Crown Copyright). Although the copyright to the Article is not transferred to ASES by this Agreement, all other provisions of this Agreement are binding upon the parties. In addition, the undersigned, who represents and warrants to ASES that he or she is authorized to sign this Agreement and grant the rights granted by this Agreement, hereby authorizes ASES to use, publish, reprint and adapt the Article, including (without limitation) in the publication specified above, in reproductions, offprints and reprints of the Article, and in microform, electronic, and other editions of the Article, and to make arrangements with indexing and abstracting services, and negotiate translation rights.

Name of Individual Signing for Employer: ____________________________________________

| | |
|---|---|
| Author or Representative: | Co-Authors (if applicable) |
| David Goodman<br>Signature and Date | ______________________________<br>Signature and Date |
| | ______________________________<br>Signature and Date |

IF YOU DO NOT SUBMIT THIS AGREEMENT ONLINE, **mail** (faxes are NOT acceptable) materials, postmarked on or before **March 14, 2011** to:

American Solar Energy Society
4760 Walnut Street, Suite 106
Boulder, Colorado 80301
USA

# PRESENTATION RELEASE

## THIS DOCUMENT MUST BE COMPLETED AND RETURNED WITH YOUR FINAL PAPER

IMPORTANT: This form must be signed and returned by the person preparing and giving the presentation at the SOLAR 2011 Conference.

During the course of the conference, all electronic presentations are captured by the Conference Organizers and loaded onto the computers in the session rooms. For past conferences, the presentations have been discarded after being given. However, there is increasingly the feeling that the presentations are a very valuable part of the conference, and that the conference proceedings are incomplete without them.

We are asking your permission to save and publish the presentations after the conference. The presentations will be converted to PDF files. Publication may be one of the following:

On the ASES Website
On a CD with the Conference Papers
On a CD containing all of the Conference Presentations only
In a hard-copy document

ASES may sell the presentations, in whatever form they are published. Proceeds will help to offset the costs of the conference, and to further ASES' mission.

Consent is NOT required, but making a selection, and signing and returning the form with the other materials with the final paper packet IS required.

If you have any questions, please contact Kate Hotchkiss, khotchkiss@ases.org or Joel Moore, jmoore@ases.org

**Paper number: 0260**

**Title:** Effect on System Efficiency from Combining Solar Thermal and Photovoltaic Energy Systems in non-Grid Applications: Phase 1

__X__ Yes, I give my permission for ASES to save and publish my presentation given at the SOLAR 2011 conference under the conditions listed above.

_____ No, ASES may not save and publish my presentation.

___David Goodman_____________________________________
Name of Presenter (please print)

David Goodman
Signature

____03/13/11____________
Date

## AUTHOR CHECK LIST

## THIS DOCUMENT MUST BE COMPLETED AND RETURNED WITH YOUR FINAL PAPER

**DUE DATE**
**March 14, 2011**

**Paper#: 0260**
**Title:** Effect on System Efficiency from Combining Solar Thermal and Photovoltaic Energy Systems in non-Grid Applications: Phase 1

---

Corresponding Author: ___David Goodman, dwgoodma@iupui.edu__________________

Person presenting paper:

Name ___Daric Fitzwater and Frederic Zarzecki and/or David Goodman__________________________________

E-mail address ____ dwgoodma@iupui.edu _____________________

_x__ I certify that the person presenting the paper has registered for the SOLAR 2011 conference

**The following materials have been submitted on or before March 14, 2011.**

_x____ final paper in PDF format

__x___ submittal form (available and filled out on-line)

___x__ SOLAR 2011 Conference Registration

**The enclosed package, postmarked on or before the due date listed above and mailed to ASES, includes:**

__x___One print-out of the final version of the paper (PDF document printed and proofread)

__x___Signed transfer of copyright

__x___Signed presentation release form

__x___ This completed checklist

IF YOU DO NOT SUBMIT THESE DOCUMENTS ONLINE, **mail** (faxes are NOT acceptable) materials, postmarked on or before **March 14, 2011** to:

American Solar Energy Society
4760 Walnut Street, Suite 106
Boulder, Colorado 80301
USA

# EFFECT ON SYSTEM EFFICIENCY FROM COMBINING SOLAR THERMAL AND PHOTOVOLTAIC ENERGY SYSTEMS IN NON-GRID APPLICATIONS: PHASE 1

David Goodman
Indiana University-Purdue University Indianapolis
799 W. Michigan St. ET 201C,
Indianapolis, IN 46202-5160
email: dwgoodma@iupui.edu

Daric Fitzwater
Indiana University-Purdue University Indianapolis
799 W. Michigan St. ET 201C,
Indianapolis, IN 46202-5160
email: dfitzwa@iupui.edu

Frederic Zarzecki
ESIEE University at Amiens, France
14 Quai De La Somme
Amiens, France 80082
email: frederic_zarzecki@hotmail.com

## ABSTRACT

This project will study the amount of energy that can be collected through the use and combining of photovoltaic (PV) and solar thermal (ST) systems in the Midwest. The results will be used specifically to inform the energy design for a modular home made from a recycled shipping container and more broadly what appears to be a gap in scholarly articles about combined or hybrid solar energy systems. A LabView™ simulation, based on National Oceanic and Atmospheric Administration (NOAA) solar insolation tables for our latitude, was used in phase 1 to determine the amount of energy that can be collected from solar photovoltaic modules for electricity and evacuated tubes with heat pipes for thermal energy. In phase 2, the physical systems will be tested separately and then combined for further testing.

This project will determine if an efficiency increase can be achieved by integrating two different solar power systems, using the excess energy from the PV system to supplement the thermal energy captured by the ST collectors. Efficiency increase will be measured as the useful application of heat that would have been rejected to the atmosphere if the two systems were separate. The method for measuring efficiency will follow ASHRAE 93 and IEC 61724 guidelines. The authors hypothesize that by using PV generated energy that would otherwise have been wasted, because it was not immediately needed to charge batteries or energize loads, to augment the ST system to heat and store hot water, waste can be avoided and the overall system efficiency can be increased. Additionally, it is anticipated that the combined system will supply ample energy and may require a separate dump load during peak hours to prevent overheating of the thermal system but may still improve overall efficiency.

## 1. INTRODUCTION

The aim of the whole *Eco-Ready Shelter* research project is to study the suitability of a shipping container for the development and creation of a sustainable (green), self sufficient, energy efficient and zero emission dorm room for two students on the IUPUI campus. Although several options are available to power this kind of building, the most attractive is the use of solar energy. This paper is a sub-study of the *Eco-Ready Shelter* project and is meant to study a combined system of thermal and photovoltaic (PV) solar systems. These systems will supply all of the required energy that is to be used in self-sufficient housing. The purpose of the study is to determine the feasibility of connecting solar photovoltaic and solar thermal systems for use as an energy provider to housing markets, mainly to determine the amount of energy that can be collected and stored, and the system efficiencies.

Energy systems built around photovoltaic cells will have fluctuations in the output based on surrounding conditions. When an energy deficit is incurred, addition energy can be supplied from another source such as a battery or the grid. When too much power is generated by the system, energy can be initially dumped into a battery for latter use when needed. However, once the battery is fully charged, the power must be removed or routed elsewhere lest the battery be damaged. This research seeks to harness the excess energy and use it to supply hot water to the *Eco-Ready Shelter* or other eco-friendly housing.

## 2. PATENT AND LITERATURE SEARCH

An online patent search with the Patent Storm[1] did not yield any results of previous patents using a load dump resistor from a PV system in conjunction with a thermal collector system as a means of heating water. Several sources were found that did propose similar ideas, but did not possess any mention of patents or previous research[2,3]. Similarly, there were no articles found in academic journals or conference proceedings.

## 3. SYSTEM SPECIFICATION

The combined system that is the subject of this research consists of a solar photovoltaic system that works together with a solar thermal system. The picture shown below in Fig.1 shows the basic design of such a system (battery system not shown). This is the system that could be implemented for housing purposes.

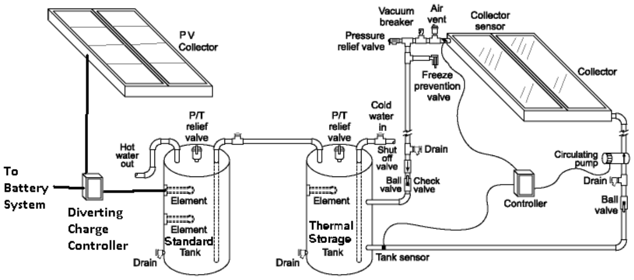


Fig. 1: Design of Combined Solar Thermal System

The thermal side of the system is comprised of a set of thirty evacuated tube-type solar collectors, meanwhile, the PV side is comprised of fourteen 62.24"x 31.85" x 1.57" photovoltaic modules. A solar collector is a device that absorbs thermal energy from the sun and converts it into usable heat. The solar collectors are of the active system, where a transfer fluid (50% Water-50% Glycol) is used to transfer heat form the collectors to the water system. The thermal collectors will only be used for the water heating system, meanwhile, the photovoltaic system will be providing mainly all the power required for the dorm room, storing some in the battery system and "dump" excess energy to the water heating system, supplementing the solar collectors.

## 4. METHODOLOGY

### 4.1 Solar Photovoltaic System

For the photovoltaic system, it was too costly to actually purchase the fourteen 62.24"x 31.85" x 1.57" photovoltaic modules. To overcome this hurdle, a simulation was done. The simulation was done on a computer program which runs simulation called MATLAB. In order to run the simulation, it is necessary to know the amount of electrical energy that would be needed from the system and more importantly, the amount of energy that could be supplied. The circuit model of a theoretical photovoltaic cell is shown below in Fig 2.

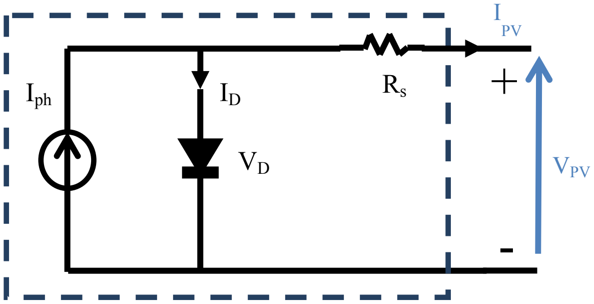


Fig. 2: PV cell

The theoretical equations that characterize a PV cell are shown below in equations (1) – (5).

$$I = I_{ph} - I_D \tag{1}$$

$$I_{PV} = I_{ph} - I_0 . \left( e^{\frac{q.\left(V_{PV}+I_{PV}.R_S.\frac{N_S}{N_P}\right)}{N_S.A.k.(T_C+273.15)}} - 1 \right) \tag{2}$$

$$I_{ph} = \left(\frac{G}{G_{ref}}\right) . N_P \\ .\left[I_{sc} + K_i\left((T_c + 273{,}15) - \left(T_{cref} + 273{,}15\right)\right)\right] \tag{3}$$

$$I_0 = \frac{I_{SC}}{e^{\left(\frac{q.V_{OC}}{N_S.k\,A.(T_C+273{,}15)}\right)}-1} . \left(\frac{T_C+273.{,}15}{T_{cref}+273{,}15}\right)^3 \tag{4}$$

$$. e^{\left(\left(\frac{q.E_g}{N_S.k.A}\right)\left(\frac{1}{(T_{cref}+273,15)}-\frac{1}{(Tc+273,15)}\right)\right)} . N_P$$

$$V_{PV} = \frac{N_S.A.k.(T_C+273,15)}{q} \quad (5)$$
$$. \ln\left(\frac{I_{ph} - I_{PV}}{I_0} + 1\right) - I_{PV}.R_s.\frac{N_S}{N_P}$$

The definitions of the notation and variables used in the above equations are given as:

- $I_D$ is the diode current;
- $I_{ph}$ is the photoelectric current related to a given condition of radiation and of temperature;
- $V_{PV}$ is the output voltage [V];
- $I_{PV}$ is the output current [A]
- $I_0$ is the saturation diode current [A]
- A is the form which represents an index of the cell failing;
- $R_s$ is the series resistance of the cell [Ω];
- q is the electron charge ($1.602 \times 10^{-19}$C);
- k is the Boltzmann constant ($1.38 \times 10^{-23}$ J/K);
- $T_c$ is the module temperature [°C];
- $T_{cref}$ is the module temperature under standard conditions [°C];
- $E_g$ is the energy gap of the material with whom the cell is made (for the silicon it's 1.12 eV);
- G is the radiation [W/m²];
- $G_{ref}$ is the radiation under standard conditions [W/m²];
- $K_i$ is the temperature coefficient of the short-circuit current [A/K];
- $N_S$ the number of series modules;
- $N_P$ is the number of parallel modules.

For modeling the photovoltaic panels, we use the block diagrams on the software MATLAB SIMULINK™. After that, we enter the data that you can see in Table 1 of the PV Module GSA221 from the manufacturer's website[5]. The program used in the simulation can be seen in Fig 3, 4, 5.

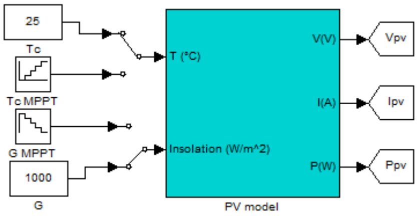


Fig. 3: Matlab™ PV model

TABLE 1: TECHNICAL DATA USED AS INPUT FOR THE PV MODULE GSA211.[4]

| | |
|---|---|
| Nominal peak power (W) | 210 |
| Nominal voltage (V) Vmpp | 38.8 |
| Nominal current (A) Impp | 5.42 |
| Open-circuit voltage (V) Voc | 46.6 |
| Short-circuit current (A) Isc | 5.78 |
| Nominal Operating Cell Temp (°C) | 46 |
| Temperature Coefficient of Isc (A/°C) | 0.0023 |
| Cell Type | Monocrystalline |

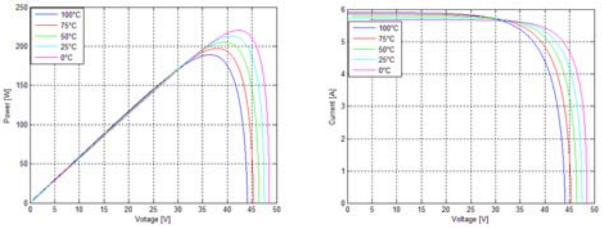


Fig. 4: Curve with G=1000W/m²

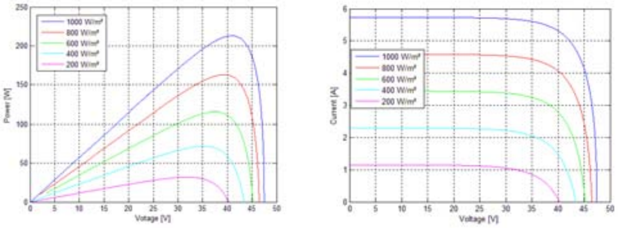


Fig. 5: Curve with T=25°C

After determining the amount energy that could be supplied by this photovoltaic system, as mentioned earlier, it had to be determined whether the amount energy supplied by the photovoltaic system is adequate for the amount of energy needed by the unit. When initial planning was conducted, energy demands were the first consideration since these parameters determine the rest of the specifications of the entire project. After much brainstorming, the following appliances in Table 2 were confirmed to be certain items that will be used. Meanwhile, Table 3 shows the final actual energy needed after correction.

TABLE 2: THE DAILY USAGE OF APPLIANCES IN THE UNIT

| Load Description | Q T Y | Load Current (A) | | Load Voltage (V) | | DC Load Power (W) | | AC Load Power (W) | | Daily Duty Cycle (Hrs/Day) | | Weekly Duty Cycle | Power Conversion Efficiency | | Nominal System Voltage | | Amp-Hour Load (AH/Day) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Lights (DC) | 4 | X | 6.667 | X | 12 | = | 80 | | N/A | X | 7 | 7/7 | ÷ | .9 | ÷ | 48 | = | 13 |
| Fan (DC) | 2 | X | 3.333 | X | 12 | = | 40 | | N/A | X | 15 | 7/7 | ÷ | .9 | ÷ | 48 | = | 14 |
| Cell Phone (DC) | 1 | X | 0.417 | X | 12 | = | 5 | | N/A | X | 2 | 4/7 | ÷ | .9 | ÷ | 48 | = | 0.14 |
| 19” LCD TV(AC) | 1 | X | 0.417 | X | 120 | | N/A | = | 50 | X | 5 | 7/7 | ÷ | .85 | ÷ | 48 | = | 6.2 |
| Laptop (AC) | 1 | X | 0.417 | X | 120 | | N/A | = | 50 | X | 8 | 7/7 | ÷ | .85 | ÷ | 48 | = | 10 |
| Mini fridge (AC) | 1 | X | 0.333 | X | 120 | | N/A | = | 40 | X | 24 | 7/7 | ÷ | .85 | ÷ | 48 | = | 24 |
| Microwave (AC) | 1 | X | 6.250 | X | 120 | | N/A | = | 750 | X | 0.75 | 7/7 | ÷ | .85 | ÷ | 48 | = | 14 |
| Toaster (AC) | 1 | X | 6.667 | X | 120 | | N/A | = | 800 | X | 0.25 | 7/7 | ÷ | .85 | ÷ | 48 | = | 5 |
| Hair-Dryer (AC) | 1 | X | 10.00 | X | 120 | | N/A | = | 1200 | X | 0.5 | 7/7 | ÷ | .85 | ÷ | 48 | = | 15 |
| | | Total Power | | | | $125W_{DC}$ | | $2890W_{AC}$ | | | | | | Total AH/Day Load | | | 74.12 | |

TABLE 3: THE FINAL ENERGY REQUIRED

| Total DC Load Power (W) | Total AC Load Power (W) | | Nominal System Voltage (V) | | Peak Current Draw (A) | | Total AH/Day Load (AH/Day) | Wire Efficiency Factor (decimal) | | Battery Efficiency Factor (decimal) | | Corrected AH Load (AH/Day) | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 125 | + | 2890 | ÷ | 48 | = | 62.82 | 74.12 | ÷ | 0.85 | ÷ | 0.85 | = | 102 |

4.2 <u>Solar Thermal System</u>

Similar to the photovoltaic system, a simulation using LABVIEW was done in order to proceed without conducting a physical test. Actual operating data was used from past experiments with thermal collectors by one of the authors. The data consisted of the flow rate of the glycol/water mixture and the inlet and outlet temperatures of the mixture. From this data, the rate of energy gathered could be calculated using the equation (1) below.

$$P = \dot{m}c\,(T_{out} - T_{in}) \qquad (1)$$

In this equation, P is power and c is specific heat of the glycol/water mixture. $T_{out}$ stands for the temperature of the mixture at the outlet while $T_{in}$ stands for the temperature of the glycol at the inlet to the solar thermal collector. From the power, the daily energy can be easily calculated by finding the area under the power curve.

4.3 <u>The Combined System</u>

A simulation of the combined system was run on LabView software. The LabView program was used to combine the collected inputs of the two systems and control how the power was used. The power was managed such that when the average power demand of the shelter exceeds what is collected, power is drawn from the battery to make up the remainder. When power taken in exceeds what is needed, the energy is first fed into the battery. When the battery is fully charged, the power is dumped into the thermal system. The block diagram of the program is shown in Fig 10 in the Appendix. The front panel of the same program is shown in Fig 11 in the Appendix. The calculations made by the program are discussed in the Results section. An actual solar thermal collection system comprised of one set of thirty evacuated tube solar collectors is being assembled for further testing in phase 2, along with an array of sixteen photovoltaic panels.

## 5. RESULTS

The solar simulation used one day of valid data, per ASHRAE 93 standard, to produce a power curve as well as values for every half hour between 11:00am and 3:00pm. The resulting values from the simulation are shown in Table 4. A graph of the power per PV module is shown in Fig 6.

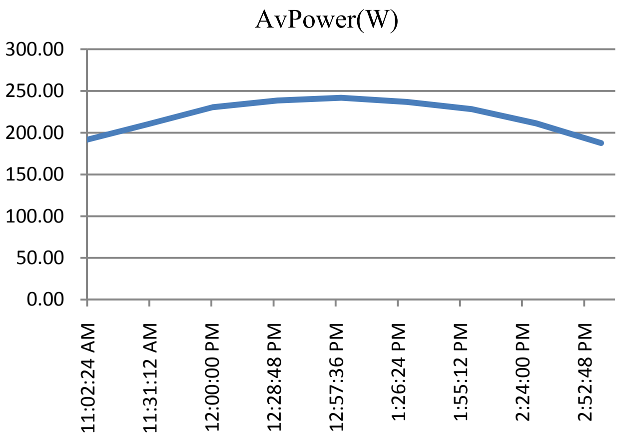


Fig. 6 - Power Curve from MATLAB SIMULINK solar simulation program

TABLE 4: RESULTS FROM THE PV MODEL

| Time | AvgOAT (°F) | AvgOAT (°C) | AvgInt (W/m²) | AvgPower (W) | AvgCurrent (A) | AvgVoltage (V) |
|---|---|---|---|---|---|---|
| 2/26 11:00:36 AM | 27.996 | -2.22 | 895.062 | 190.51 | 4.8 | 40.17 |
| 2/26 11:30:36 AM | 28.814 | -1.77 | 977.618 | 210.19 | 4.9 | 43.01 |
| 2/26 12:00:36 PM | 28.847 | -1.75 | 1041.187 | 230.49 | 5.3 | 43.50 |
| 2/26 12:30:38 PM | 29.507 | -1.39 | 1070.603 | 238.64 | 5.5 | 43.40 |
| 2/26 1:00:08 PM | 30.345 | -0.92 | 1080.054 | 241.77 | 5.6 | 43.17 |
| 2/26 1:30:38 PM | 30.389 | -0.90 | 1062.595 | 236.96 | 5.6 | 42.31 |
| 2/26 2:00:38 PM | 30.612 | -0.77 | 1034.902 | 228.19 | 5.5 | 41.51 |
| 2/26 2:30:35 PM | 30.791 | -0.67 | 981.898 | 211.26 | 5.2 | 40.71 |
| 2/26 3:00:35 PM | 30.883 | -0.62 | 900.501 | 187.55 | 4.9 | 38.32 |

The results from the LABVIEW™ simulation show the interaction between the PV and solar thermal systems. The operation of these systems was set to be from 11am to 3pm. Each time point represents a 30 minute interval. The results show the system operation characteristics, such as: the power graph, Fig 7, gives the instantaneous power available to the system. The thick solid blue line shows that the PV panels collect a maximum of 2.89kW at solar noon and stores the energy in the battery (dotted green line) from 11am to 2pm and then diverts the power into the solar thermal tank element (thin solid purple line). After 2pm the battery is fully charged and all the PV power is diverted and the total thermal power collected (dash-dot-dot-dash brown line) rises rapidly.

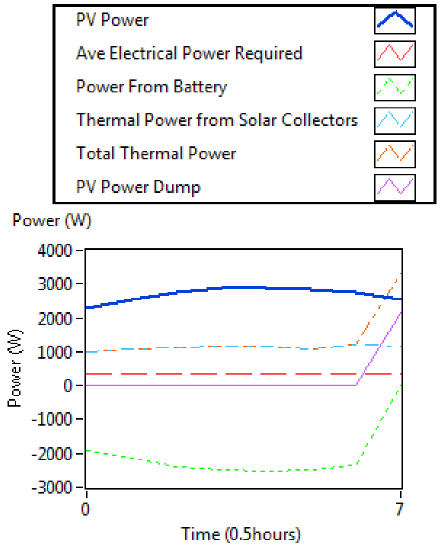


Fig. 7: The Power Graph

The energy graph, Fig. 8, shows the total amount of energy collected at a given time. The power graph shows that the combined system will be able to operate in the expected manner**;** the battery can be refilled completely before being needed again; the deficit will not build. Excess energy from the photovoltaic system will raise the temperature of the water for the hot water system. The energy graph shows that the total amount of energy will exceed what is needed for normal operation.

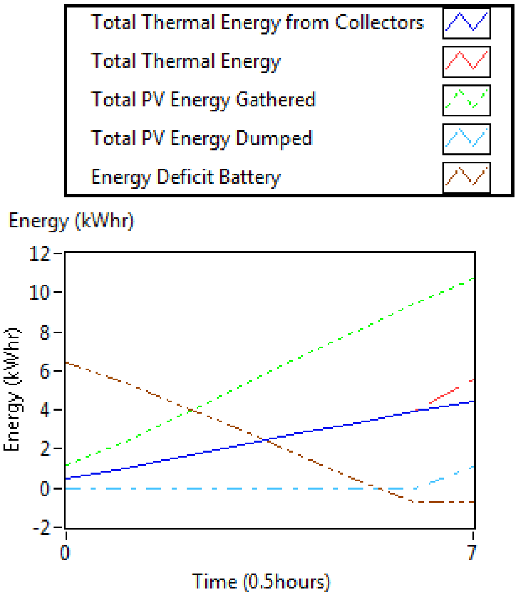


Fig. 8: The Energy Graph

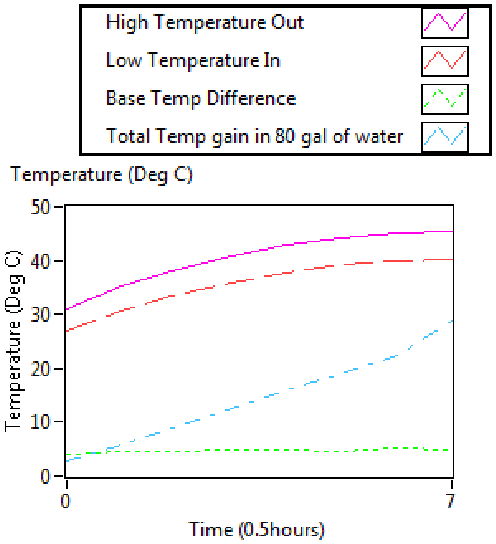


Fig. 9: The Temperature Graph

The temperature graph, Fig. 9, illustrates actual fluid temperatures in a physical collector and the simulated temperature in a storage tank.

TABLE 5: RESULTING NUMBERS

| | |
|---|---|
| Total PV Energy Collected (kWhr) | 10.73 |
| Total PV Energy Needed (kWhr) | 8.9 |
| Total PV Energy Dumped (kWhr) | 1.83 |
| Total Energy from Thermal Collectors (BTU) | 15295 |
| Total Thermal Energy Collected (BTU) | 21539 |
| Percent Increase in Thermal Energy (%) | 28.99 |

## 6. CONCLUSIONS

The data reveals that the thermal system is undersized during the harshest time of year and that the PV system is properly sized for the worst month. Diverting causes a 29% increase in thermal energy collected. This method requires the addition of a DC heating element and an additional diverting charge controller, however using a moderate 10¢/kWhr, the system has a simple payback of four years. In fact, the PV system may require a separate dump load or shunting during peak season to prevent overheating of the thermal system. Further testing is planned for the PV and thermal collectors on the Eco Ready Shelter from April-July, 2011 to verify the simulation and prove the savings.

## 7. REFERENCES

(1) Patent Storm, Retrieved 10 Dec 2009 from <http://www.patentstorm.us/>

(2) Diversion Loads, Survival Unlimited. Retrieved 10 Dec 2009 from <http://www.survivalunlimited.com/diversionloads.htm>

(3) Diversion Load, altE Store, Retrieved 10 Dec 2009 from <http://solar.altestore.com/energy/Diversion%20Load>

(4)Trina Solar, Retrieved 03 March 2011 from <http://www.trinasolar.com/products.php>

## 8. APPENDIX

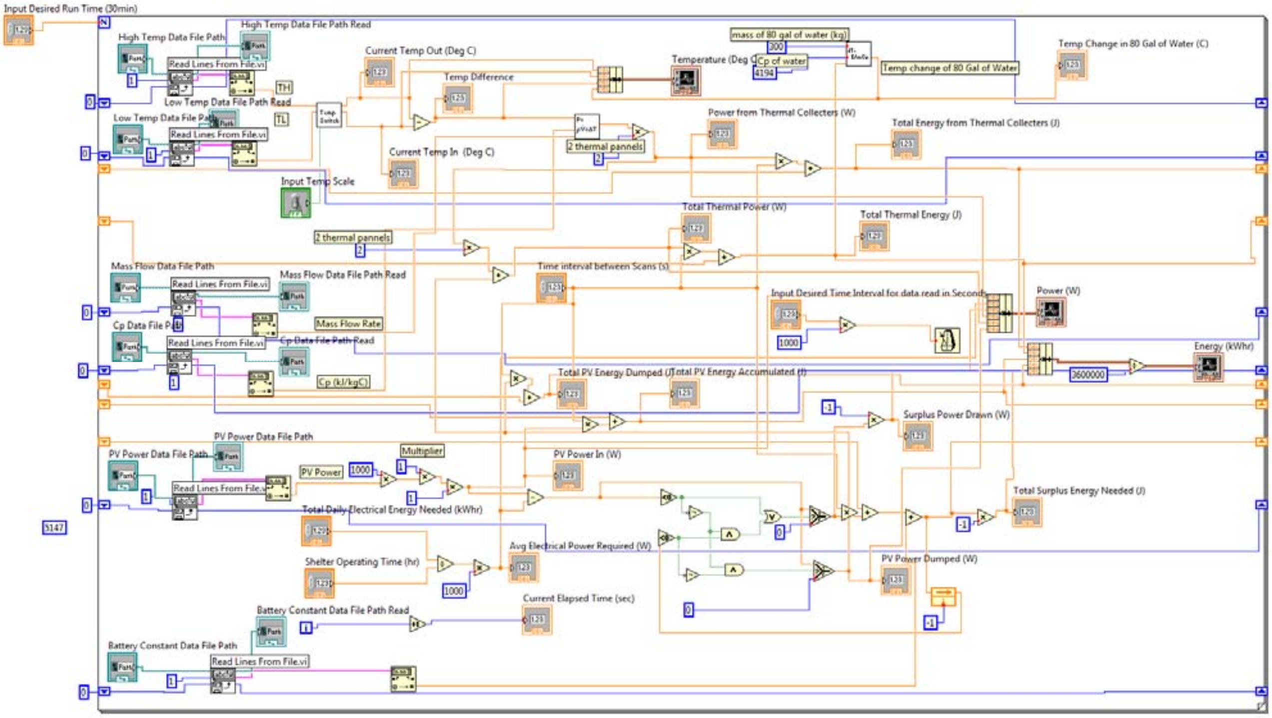
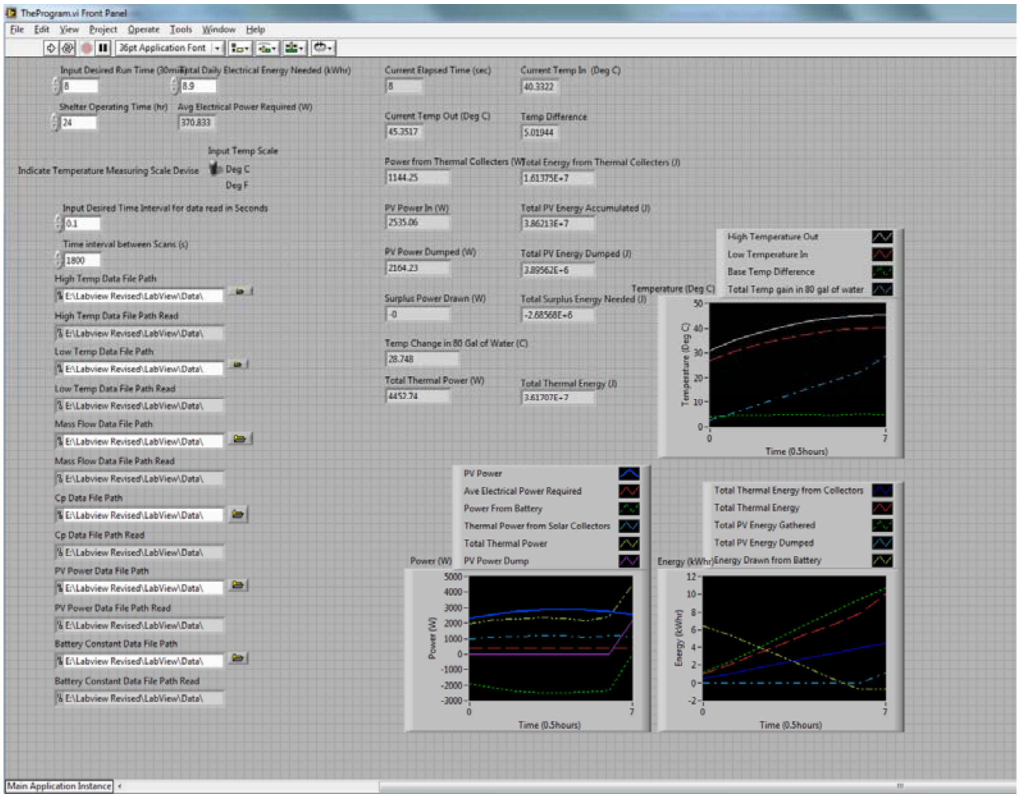


Fig. 10: Block Diagram of LabView™ Program for Combined System



Input Desired Run Time (30min): 8
Total Daily Electrical Energy Needed (kWhr): 8.9
Shelter Operating Time (hr): 24
Avg Electrical Power Required (W): 370.833
Input Temp Scale
Indicate Temperature Measuring Scale Devise: Deg C / Deg F
Input Desired Time Interval for data read in Seconds: 0.1
Time interval between Scans (s): 1800
High Temp Data File Path: E:\Labview Revised\LabView\Data\
High Temp Data File Path Read: E:\Labview Revised\LabView\Data\
Low Temp Data File Path: E:\Labview Revised\LabView\Data\
Low Temp Data File Path Read: E:\Labview Revised\LabView\Data\
Mass Flow Data File Path: E:\Labview Revised\LabView\Data\
Mass Flow Data File Path Read: E:\Labview Revised\LabView\Data\
Cp Data File Path: E:\Labview Revised\LabView\Data\
Cp Data File Path Read: E:\Labview Revised\LabView\Data\
PV Power Data File Path: E:\Labview Revised\LabView\Data\
PV Power Data File Path Read: E:\Labview Revised\LabView\Data\
Battery Constant Data File Path: E:\Labview Revised\LabView\Data\
Battery Constant Data File Path Read: E:\Labview Revised\LabView\Data\
Current Elapsed Time (sec): 8
Current Temp In (Deg C): 40.3322
Current Temp Out (Deg C): 45.3517
Temp Difference: 5.01944
Power from Thermal Collecters (W): 1144.25
Total Energy from Thermal Collecters (J): 1.61375E+7
PV Power In (W): 2535.06
Total PV Energy Accumulated (J): 3.86213E+7
PV Power Dumped (W): 2164.23
Total PV Energy Dumped (J): 3.89562E+6
Surplus Power Drawn (W): -0
Total Surplus Energy Needed (J): -2.68568E+6
Temp Change in 80 Gal of Water (C): 28.748
Total Thermal Power (W): 4452.74
Total Thermal Energy (J): 3.61707E+7

Fig. 11: Front Panel of LabView™ Program for Combined System