Solar Powered Electric Clothes Dryer

A Senior Project

presented to

the Faculty of the Electrical Engineering Department

California Polytechnic State University, San Luis Obispo

In Partial Fulfillment

of the Requirements for the Degree

Bachelor of Science Electrical Engineering

by

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Solar-Powered Electric Clothes Dryer

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Introduction

This project aims to provide an alternate solution to the wall-powered electric clothes dryer by designing one which operates entirely off the grid. This project entails building a large black box with a window, which helps collect heat. On the inside of this black box will be internal hardware to dry the clothes. The internal hardware will run from a battery storage charged by a solar panel. On the outside of the box lies the control panel which consists of switches and a timing mechanism.

Background

One way to reduce one's carbon footprint and "go green" is to reduce power consumption at home. Appliances that consume the most energy in a household usually involve heating, and an electric clothes dryer is one such appliance, consuming up to 4KW of power. Finding an alternative way to dry clothes can help reduce energy costs. The most environmentally friendly way is to hang clothes outside to dry, a natural solar and wind powered method that has been used for centuries, but unfortunately most people are unable to do so because of where they live. People living in apartments, for example, usually do not have access to an outdoor space, or even a window that receives sunlight. Some neighborhood communities do not allow the hanging of laundry outside as it is regarded as "unsightly" and should be kept away from public view. Even people who are physically able to do so are prohibited by rules of the homeowner association of their community.

Requirements

The battery system that powers the dyer should be able to deliver enough power for it to run for at least 45 minutes, which is the average drying time for a typical “medium” load of laundry of about 10lbs (wet), 2 cubic feet. The dryer drum must be large enough, and the motor used must be powerful enough to support such a load requirement. The user must be able to use the system at least once a week, which means the solar panel must be large enough to be able to charge the battery/batteries in less than seven days while being small enough to be practical for apartment use (as well as cost-effective reasons).

Alternate Design Consideration

An alternative way to power an electric dryer off the grid is to develop an electrical system that can not only deliver 4KWh (120VAC supply) for 45 minutes, but also be able to recharge in less than a week. Such a system is costly and inefficient, as it involves more high-powered components to meet the 4KW requirement.

Below is a cost-analysis of such a system. Using commercially available components, the system will require the following components (all prices are estimated and averaged):

<u>Deep-cycle batteries (12V, 160AH):</u> 2x $150

Two 12V deep-cycle batteries rated at 160AH (min) are needed to deliver 4KW output for at least 45 minutes (see Table 1 below).

<u>Solar panel (80W):</u> $500

The panel has to have a power rating of 40W minimum in order to charge the batteries described above in less than seven days, assuming 8h of sunlight per day (see Table 1 below).

<u>Solar Charge Controller:</u> $20

This is a relatively inexpensive device that interfaces between the solar panel and batteries to control charging and prevent over-charging.

Inverter: $400

A power inverter capable of handling 4KW is needed, which is the reason for the high cost.

The total cost of the above components (including cables) is about $1230. These components are for a system that is able to deliver 4KW of AC power needed to power a small (2-3 cu.ft. of laundry) electric household dryer (~$300) for at least 30 minutes. The reason for the high cost is attributed to the large power requirements of the household dryer.

Table 1: Power Calculations for Alternate Design Consideration **Charge Time**
80W/12V = 6.67A For 160Ah battery, charge time = 160/6.67 = 24h 24/6 = 4h min. avg. sunlight per day to satisfy operating requirement (6 days charging + 1 day discharging)
Discharge rate
Battery discharges in 1h (drying cycle ~45min), for 160Ah battery: P = 160*12V = 1.92KW

Design

The best way to approach this project is to design a custom dryer that completely runs on a 12VDC supply. This means selecting components that are rated at 12VDC. This will not only greatly reduce the power consumption of the dryer (12VDC vs. 120VAC), but the cost as well as costly components like high-power inverters or transformers will not be needed. A more detailed cost analysis is outlined in the "Alternate Design Consideration" section above.

The final design incorporates an extremely frugal and resourceful approach. Obtaining cheap and even free components is pivotal as part of the project focuses on conservation. Craigslist and talking to various friends and acquaintances can go a long way. As most of the components were recycled, some of the details in the Bill of Materials (Appendix A) could not be completed.

The mechanical construction will be centered on a dryer drum. All dimensions will be referenced around this drum and the dryer shell will be built around it. Key features will include a door to access the drum, clear windows for sunlight, space for components, and a back panel that allows for airflow.

The electrical design ensures all components including wires and switches are able to handle the power requirements for the system. The user will be able to operate the dryer by selecting different modes of operation from a control panel. The system also protects the battery from being both over-charged and completely drained.

Test Plan

Testing (as well as construction) is divided into two main parts, mechanical and electrical.

Mechanical

Testing the mechanical system involves making sure the dryer drum is able to spin. This involves aligning all the bearings and making sure the supporting structure (side panels, 2x4" reinforcements) are strong and secure enough to hold the drum in place while allowing it to freely spin. This also involves aligning the belt system around the drum, tensioner, and motor, making sure it is set up correctly.

Electrical

Testing the electrical system involves checking all the switches and relays to make sure the user is able to control all dryer functions via the control panel. This includes functions such as charge, run, auxiliary on, and system off. The respective LED indicators should alert the user of the current state of the dryer, outlined in Table 2 below.

Table 2: Control Panel LED Indicators

Name	Color	Description
Charge	Green	Battery is being charged.
Dryer	Green	Dryer is powered and ready.
Low Batt	Red	Battery is low. Dryer will not run.
All LEDs	OFF	Entire system is not powered.

Low battery is defined as battery voltage dropping below 10.5V. If a 12V deep-cycle battery's voltage drops below 10.5V, it could damage the battery and shorten its life. The low-battery detector circuit in the electrical system should prevent the dryer from operating to prevent further draining the battery when the voltage of the battery reaches or drops below 10.5V.

Development and Construction

Prior to project construction, a dryer drum is required. This allows the measuring of the box and efficient planning of placement for the motor and heating unit. The dryer drum comes from an old gas dryer purchased from Craigslist. Taking apart a drying machine doubles both as a form to retrieve the drum as well figure out how the mechanics inside work.

Mechanical Construction

The drum measuring 27.5 inches in diameter and 21 inches in width helps determine the dimensions of the box – a three foot cube. Home Depot visits become necessary during this project's course. Luckily, at the Home Depot, the lumber yard will cut pieces of wood for free. This makes obtaining perfectly cut three-by-three foot squares of plywood extremely accessible. Various 2" x 4" wood studs provide support for the frame of this machine. Furthermore, many corner braces (L-brackets) are exceedingly useful for strengthening the joint materials. With possession of these aforementioned materials, basic construction can begin.

Creating the base of the drying machine is the first step. Figure 1 below shows how the base assembles.

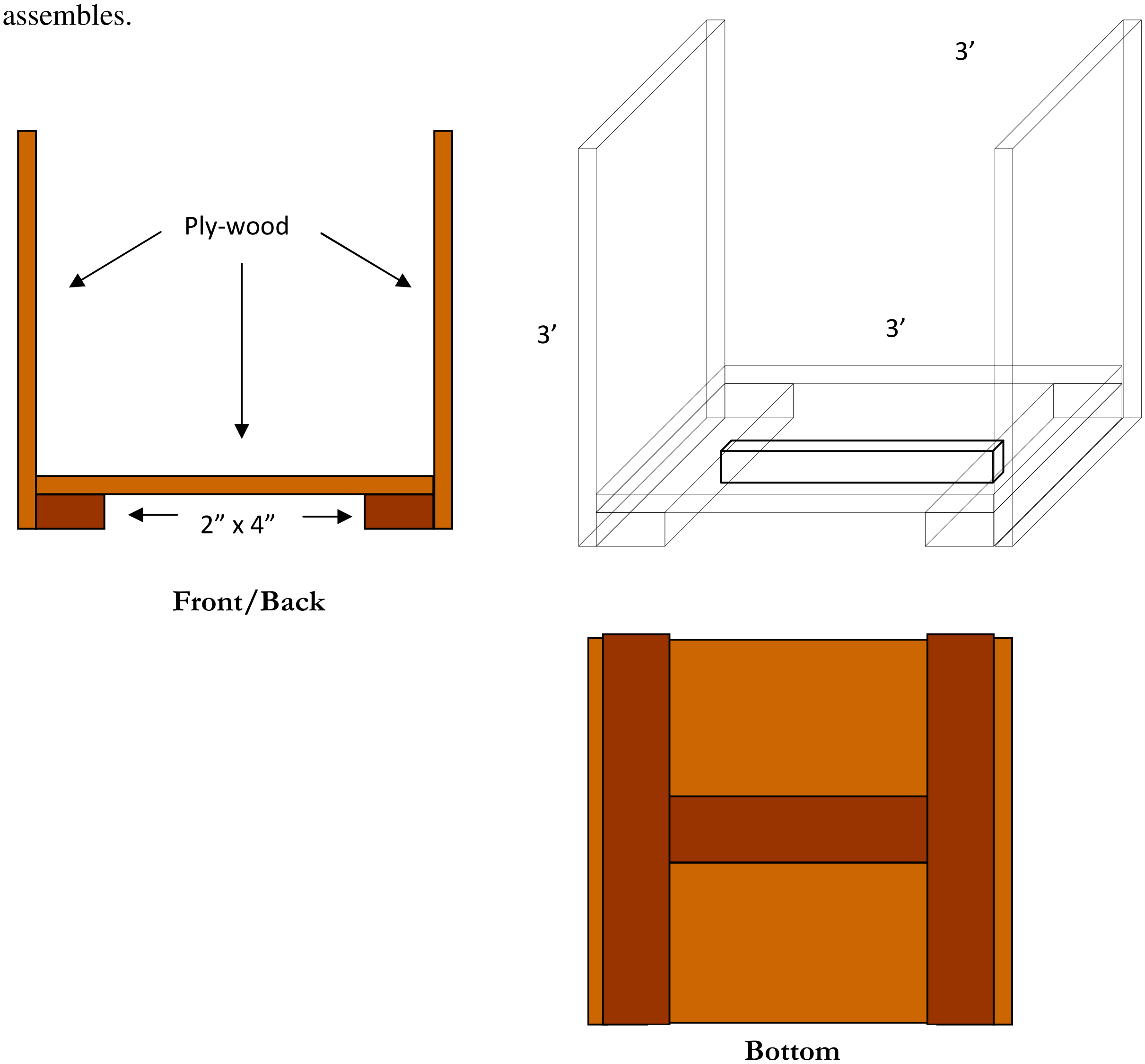

Figure 1 – Dimensions and assembly of dryer base.

The next step involves installing the back panel that supports the dryer drum. This requires various 2" x 4" pieces of wood for support. The back panel is taken from the old gas dryer. The following pictures show the setup of the panel.

Figure 2 – Support setup of dryer drum back panel. (L) Left side of setup. (R) Right side of setup.

This back panel is beneficial for several reasons. First, it provides support for one half of the dryer drum with its two wheels. Furthermore, it provides a clean passage way for heat to transfer into the drum from the heat source. The following photo will show the back panel in its entirety within the box.

Figure 3 – Support setup of dryer drum back panel.

With the back panel now set in place, installation of the front wheels for drum support may begin. Using wheels of old roller blades and L-brackets make solid support for the front of the dryer drum. These wheels fit perfectly into the groove of the drum to allow smooth spinning. The following pictures will show the source of the wheels, setup with L-bracket, and installation into dryer.

Figure 4 – Roller blade wheels for spinning support of dryer drum.

The L-brackets for the wheel mechanism are three-inch braces (significantly larger than the one-inch braces used for wood support). The wheel has an axel screw that comes out easily. After removing this screw, place the L-bracket between the wheel and the screw and reclose. This picture shows how the wheel connects to the corner brace.

Figure 5 – Support setup of dryer drum back panel.

In order to secure the L-bracket wheels, 2" x 4" studs come into play to provide the appropriate height for the wheel as well as stable support. There needs to be two of these wheel setups, one for each side of the dryer drum. The following pictures will show how to install these sets of wheels.

Figure 6 – Wheels for spinning support (left and right sides) of dryer drum with respective 2" x 4" reinforcement.

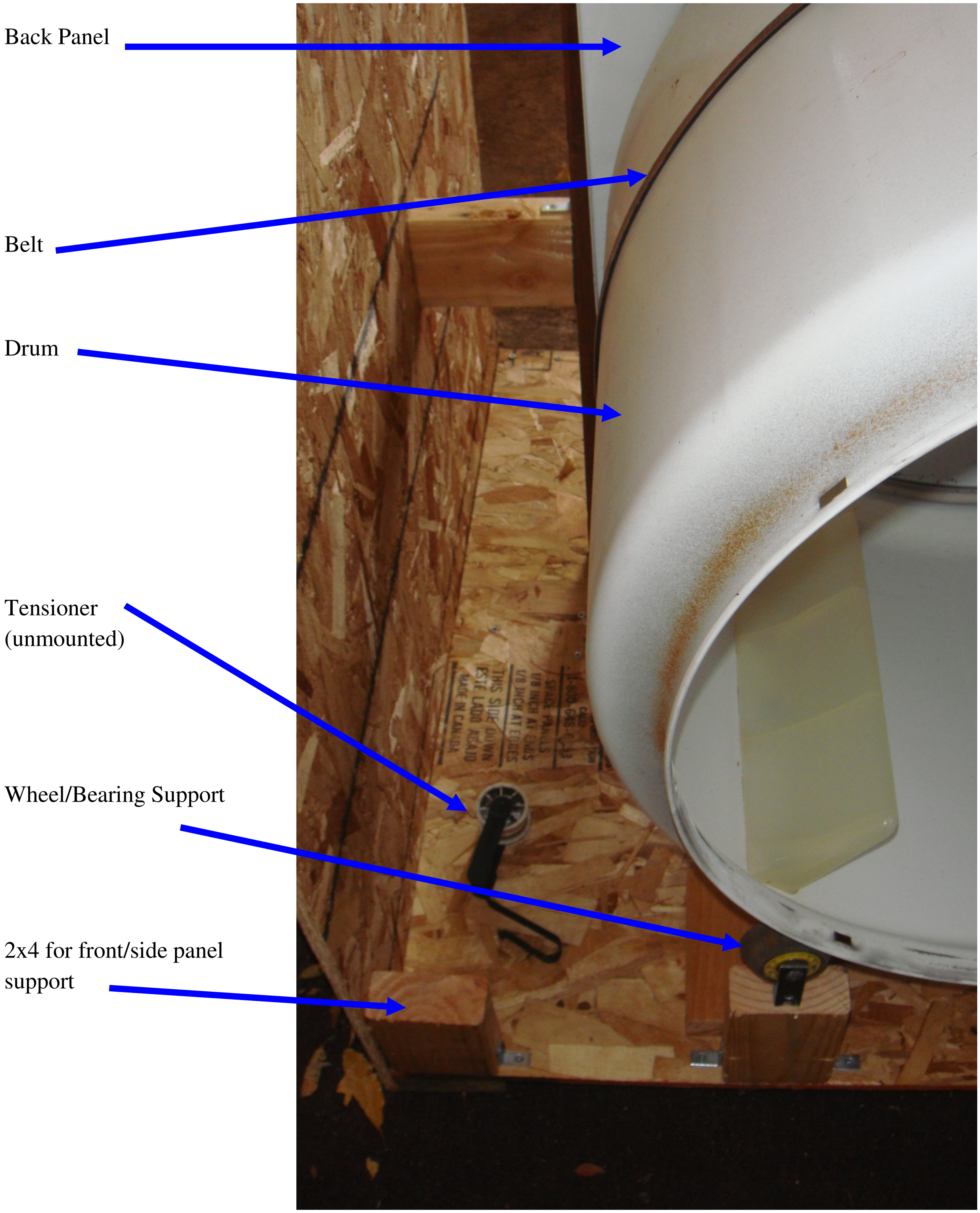

Figure 7 – Dryer drum assembly including wheel supports and respective 2" x 4" reinforcement.

With the drum support complete, implementing the motor comes next. A Black and Decker 12V cordless power drill provides the motor for this dryer. This motor is deal because of its powerful torque and space efficiency. The drill draws a total of 8A when in operation. Figure 8 shows installation of the drill and tensioner (from purchased gas dryer).

Figure 8 – Motor secured into the base of the dryer with tensioner for band.

The tensioner helps create more tension for the band to allow for better grip of dryer drum while compensating for mechanical tolerances as the drum spins. A drill bit consisting of a long screw, two washers, and three nuts form the gear that pulls the dryer band as seen below in Figure 9-1. The next picture shows this apparatus combined with the tensioner. Rubber bands fill the groove between the two washers to provide more friction and grip for the band.

Figure 9 – Motor secured into the base of the dryer with tensioner for band with drill-bit gear.

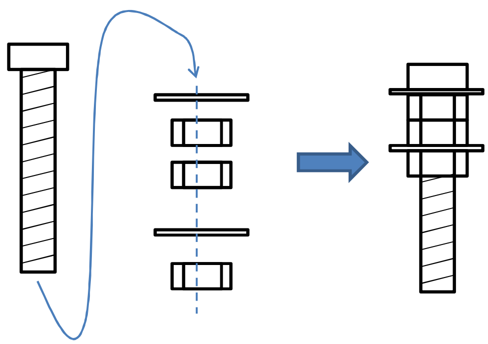

Figure 9-1 – *Custom drill bit assembly*

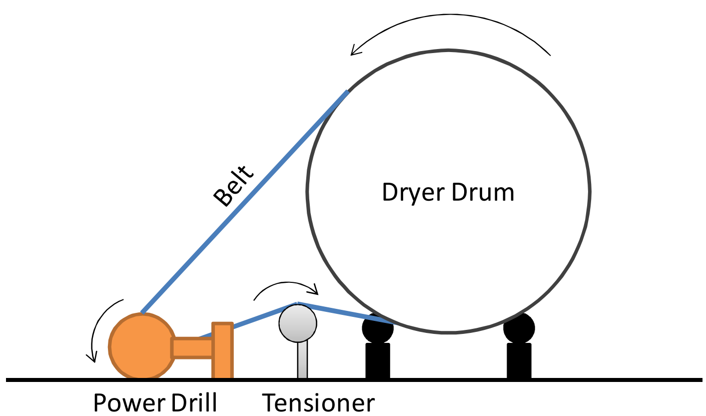

Figure 9-2 – *Spin direction (front view)*

The spin direction was chosen so that it exerts an equal and opposite downward force on the base of the drill towards the ground (Figure 9-2). This helps secure the drill in place and prevents the belt from going out of alignment when the dryer is running. The drill is also tied down as seen in Figures 8 and 9 by zip-tie and an L-bracket, and propped up by a wheel in Figure 9 for both stability and to increase tension on the belt.

Now the base and inside components are set into place, the front panel can be installed next. Cut out a rectangle of the plywood with a saw to make space for the plexiglass door. With the purchased hinges and cabinet door fastener, install the door. The door is held shut by two magnets. The accompanying pictures show the implementation of the plexiglass door.

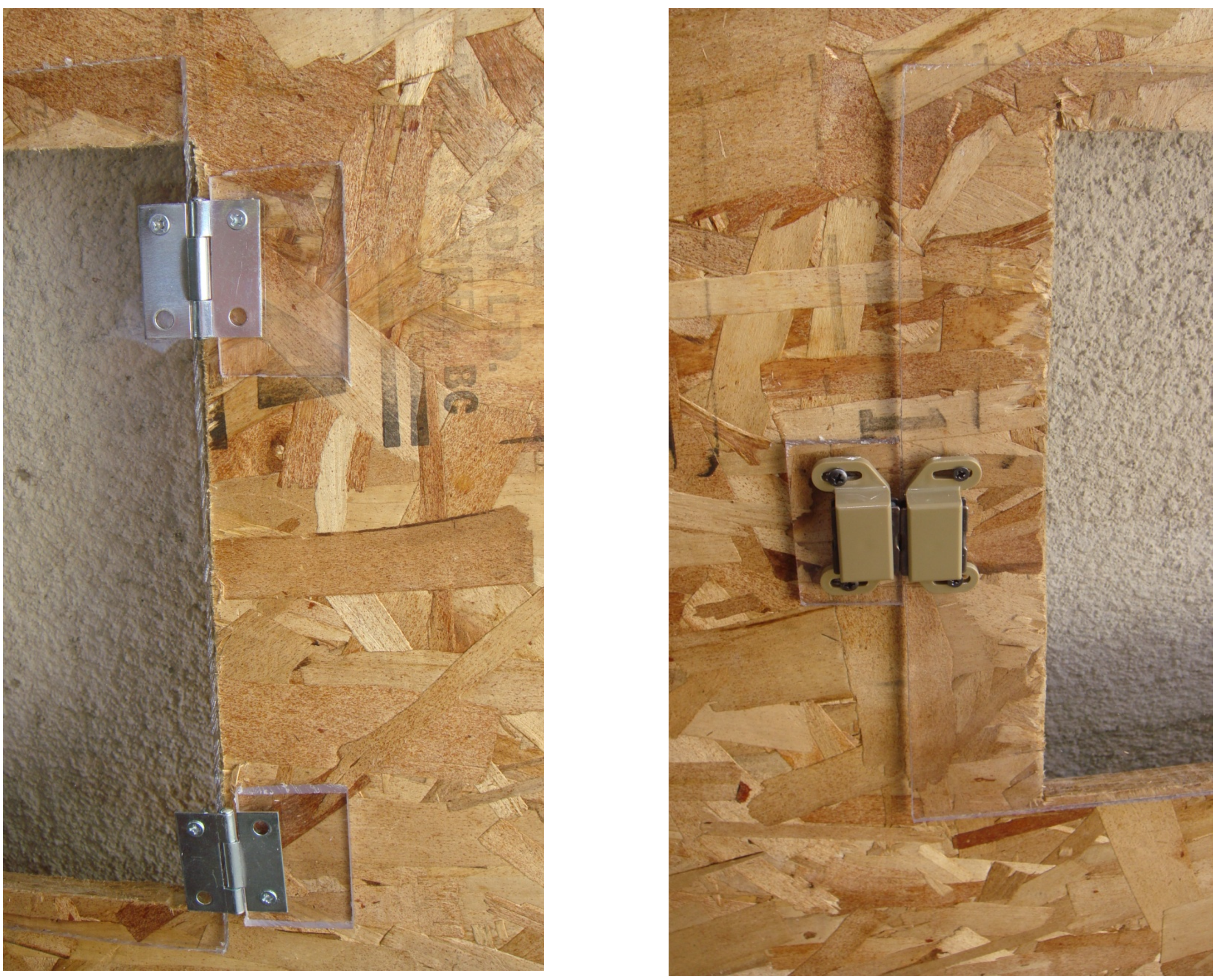

Figure 10 – Both sides of plexiglass door: (L) door hinges and (R) cabinet door fastener.

This picture shows the entire front panel with completed hinges and fastener.

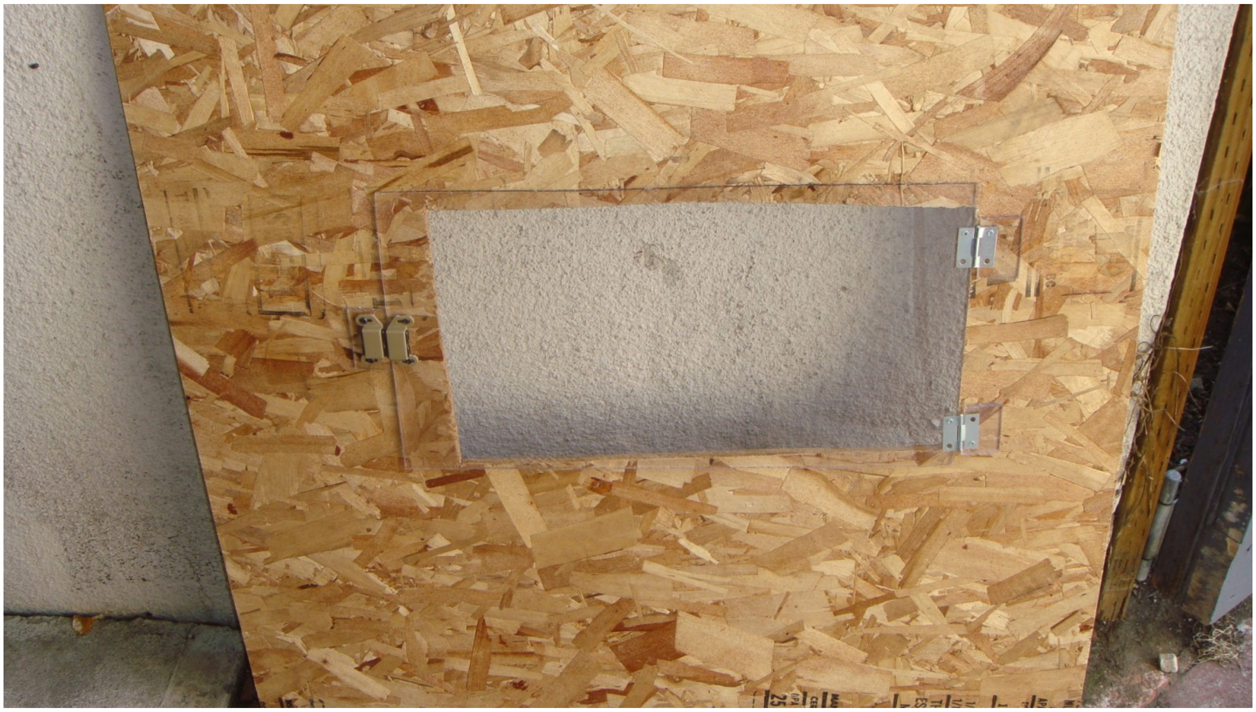

Figure 11 – Completed plexiglass door on front panel.

Figure 12 – Finished windows and control system on the top panel of dryer.

The next part of the project consists of the top panel. This design has three plexiglass windows to absorb sunlight and create a greenhouse effect within the dryer, heating up the inside. Furthermore, the control panel with external circuitry lies on the top of the panel. Figure 12 shows the top panel design. The three-panel design was chosen not just for looks but for structural strength as well. While a full plexiglass top would let in the most sunlight, a complete plexiglass top panel would sag too much. Instead, holes were cut into the plywood for the top panel to mount the plexiglass without compromising strength of the structure.

With each panel and inside setups completed, the dryer box can be assembled and painted. To help absorb heat from the sun, in addition to adding clear panels, the whole dryer is painted black where it is not covered by plexiglass. This helps absorb and retain heat from the sun.

The back panel of the dryer is a 2'x3' plywood instead of the regular 3'x3' pieces used for the other panels. A space is left at the bottom of the back and serves two purposes: 1) it creates a current flow of air by allowing cool air to enter the dryer from the bottom to be heated up by convection, and 2) allows user access to the space heater (or other standard 12V cigarette lighter devices rated up to 20A). The user simply flips a switch to auxiliary mode, turn the space heater around, and the space heater is used for its original purpose (as opposed to heating up clothes for drying).

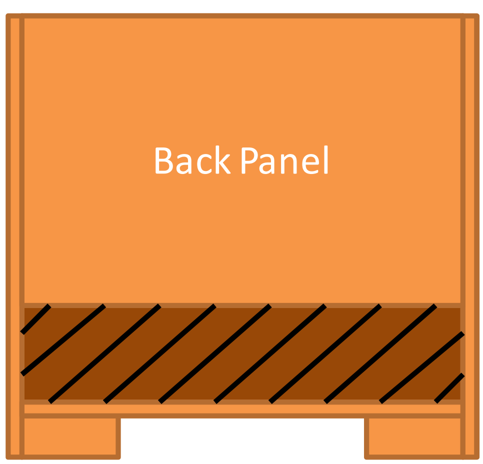

Figure 13-1 – Back of dryer.

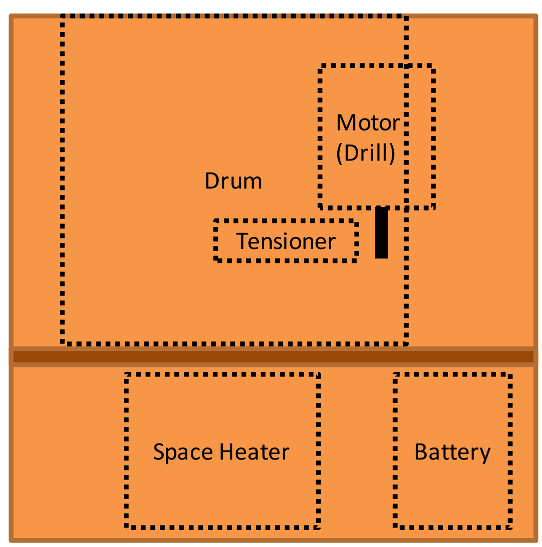

Figure 13-2 – Layout of dryer base (top view).

The finished product looks as so:

Figure 14 – Finished and painted final product.

Figure 15 – Finished final product with open door and view of inside dryer drum.

Electrical Construction

The dryer and its functions are controlled via a control panel as shown in Figure 16. The control panel and electrical components were designed to suit the user's needs to operate a clothes dryer, with some added features.

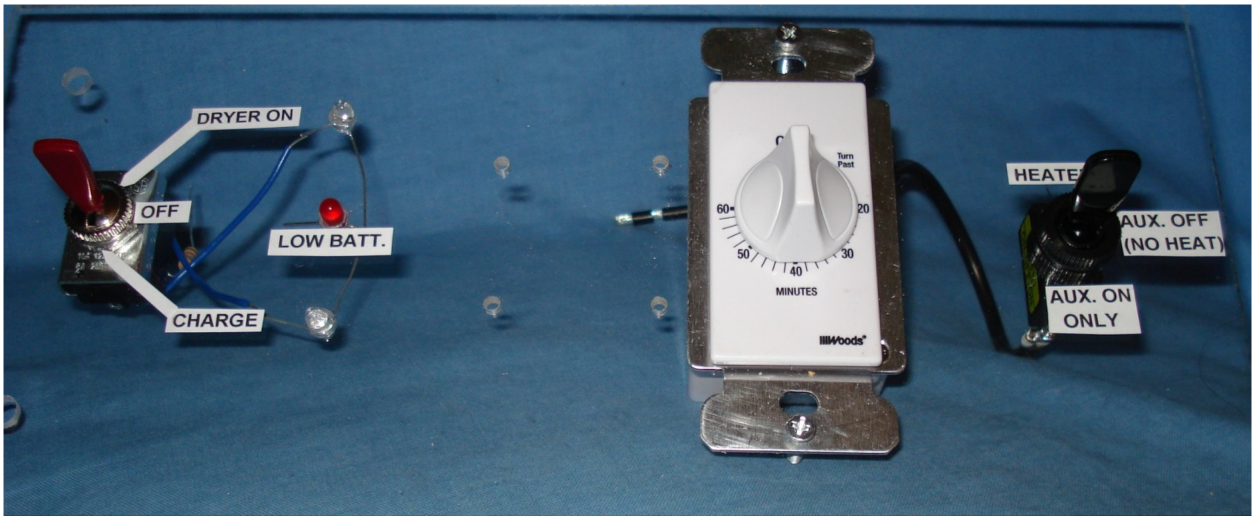

Figure 16 – Control Panel

To start, the user is able to select between three modes using the DPDT switch: DRYER ON, OFF, and CHARGE.

<u>CHARGE</u>: All functions of the dryer are disabled and the battery is connected to a 15W solar panel/charge controller for charging. The corresponding green LED lights up to indicate dryer is in CHARGE mode. This is the mode the dryer is normally in when not in use.

<u>OFF</u>: The battery is completely disconnected and isolated. Usually, the battery is in CHARGE mode when not in use, but the all-OFF mode is useful for performing maintenance tasks.

<u>DRYER ON</u>: Connects the battery to the dryer (motor and heater components). The user then sets the timer to activate the motor and heater.

There is also a separate SPDT switch that controls the heater (right of Figure 16). Normally, this is left in the HEATER mode ("up" position), which turns on the heater when the dryer is on and the timer is set. The heater can be turned off during the drying cycle by setting the switch to the AUX. OFF (NO HEAT) or center position.

AUX. ON ONLY – Using the dryer as a space heater: In addition to providing heat for drying clothes, the space heater can be used for its original purpose: to warm up living space. Simply turn the heater around so that it faces the back panel and heat is directed out under the back panel rather than the intake holes to the dryer drum. Then, set the SPDT switch to the AUX. ON ONLY (bottom) position. In this mode, the heater will turn on whenever the dryer is on (DPDT switch set to DRYER ON position) and will remain on until the user manually switches it off or the battery is low. The timer need not be set in this mode, and the heater is controlled independently from the dryer drum motor.

Since the space heater is connected to the battery via a standard 12V cigarette lighter socket (like the one found in automobiles), it can be replaced by a number of standard useful devices listed in Appendix B. In addition to powering a dryer, the 12V battery can be used to power or charge devices such as cell phones, music players, laptops, etc. when in AUX. ON ONLY mode.

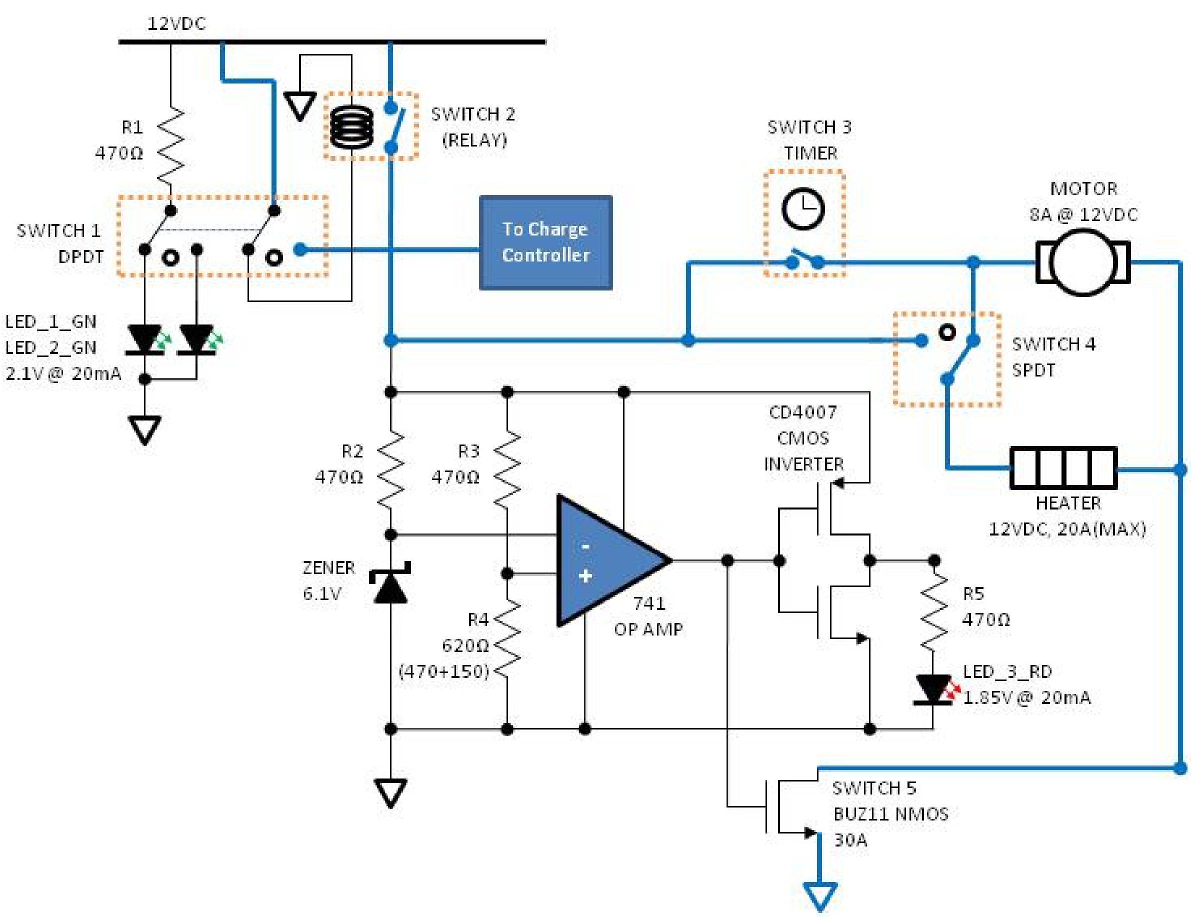

Figure 17 – System schematic

During DRYER ON mode, the battery voltage is actively monitored by an op-amp, used as a comparator in this application. The comparator checks to see if the battery voltage is above 10.5V, and terminates connection to the motor and heater via an NMOS switch when it detects a low battery voltage. A CMOS inverter is used to invert the signal from the comparator to light up a red LED to indicate a low-battery condition.

The full system schematic is in Figure 17 above. As the system draws a maximum of 30A, 12AWG wire is used for wiring the main components indicated by the blue traces in Figure 17. All components were soldered onto a PCB and connections to switches and relays were made using standard ¼" quick-disconnects. Connections to other components were done using quick-disconnects, or simply soldered together. The final control panel assembly is seen in Figure 18 below:

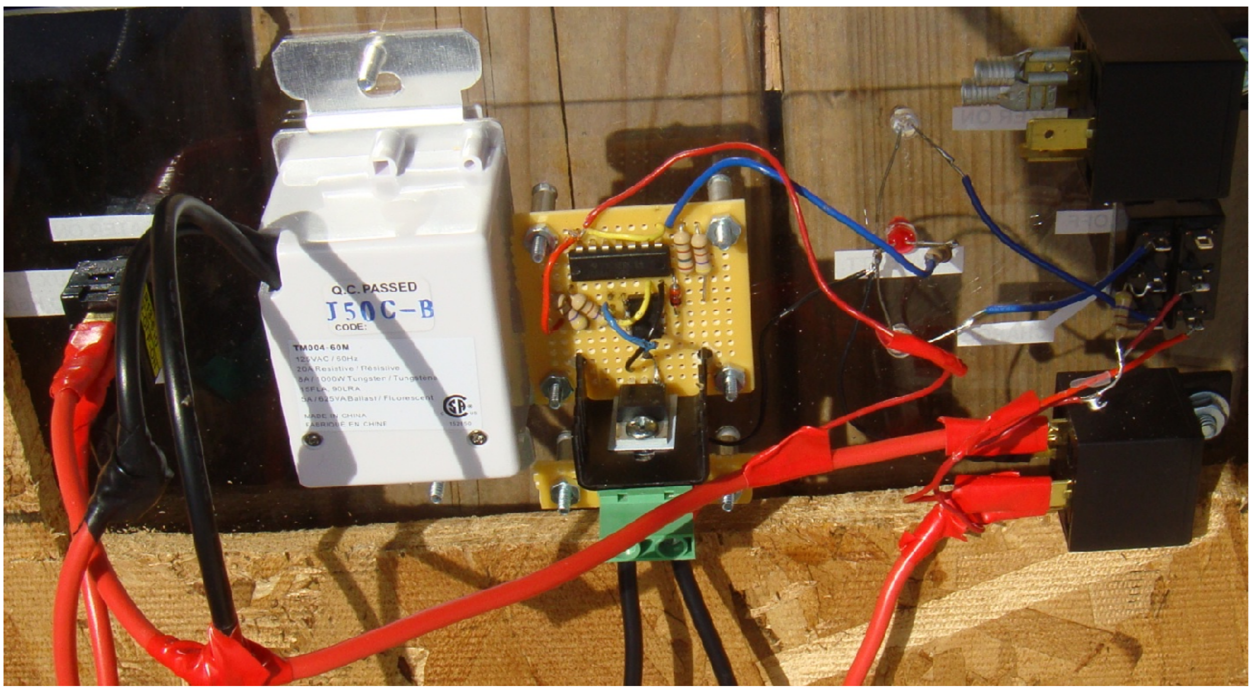

Figure 18 – Control panel with PCB.

The 15W solar panel is designed to meet the power requirements of the dryer and should be able to fully charge the battery in less than seven days after each drying cycle. This allows the user to perform a drying cycle on a load of laundry once a week. Further analysis and calculations of the power breakdown is in Table 3 below.

Table 3: Power Breakdown Calculations (maximum values)			
Property		Units	
V	12	V	System operates on 12VDC
A(max)	30	A	Maximum current drawn by system
P(max)	360	W	Maximum power consumed by system
Battery	70	Ah	Battery capacity
t(max)	2.333333	h	Maximum operating time at max. power before battery drains
Solar Panel			
Power	15	W	Solar panel size
I(chg)(max)	1.25	A	Maximum charging current (direct sunlight or max. insolation)
t(chg)	56	h	Min. charging time at I(chg)(max)

The battery used has a capacity of 70Ah, which means it is able to run the dryer at maximum power for about 2h 20min when fully charged. A 15W solar panel provides a maximum charging current of 1.25A, which takes approximately 56 hours to fully charge a 70Ah battery that has been completely discharged (but not to the point of damage). This translates to about 9h 20min. of direct sunlight for six days. However, as a drying cycle is defined as 45min. to 1h, this reduces the charge time by more than half. Operating the dryer for 1h would require 24h of charging in direct sunlight with a 15W solar panel, which translate to about 4h per day for six days, which is a very reasonable amount of sunlight in an average week.

While a larger capacity battery can run higher power components and provide a longer run time, a larger, more powerful solar panel is needed to charge the battery if the user wishes to have the battery charged in under a week.

Integration and Test Results

The motor is definitely powerful enough to turn the drum with a full load of wet laundry. However, as it is the motor from a power tool, it is also a high-rpm motor, which causes a lot of slipping between the drill bit attachment and the dryer belt. A variety of materials ranging from metal, plastic, and rubber have been tried. The best solution to increase friction between the belt and the drill bit is by winding rubber bands around the bit. While this is an effective solution, there is still a lot of stress on the drill bit and the rubber band(s) have to be replaced every once in a while, depending on the quality of rubber used. The drum initially takes a few seconds to start spinning due to the slipping, and slowly gains speed.

When left out in the sun, the plexiglass windows do a good job in warming up the box in conjunction with the black paint of the box. However, the inside of the dryer drum is not heating up as well as the box. It takes a while for the inside of the drum to warm up as the drum itself is enclosed, and heat is still insulated from the inside of the drum.

The circuitry seems to be able to handle the power requirements of the system and there have not been any problems in this area (all components are up to their specifications).

All switches are in working condition. All LED indicators light up according to the respective dryer modes.

The low-battery monitoring circuitry (op-amp comparator) cuts off power to the components when the battery voltage drops below 10.8V. Although this is higher than the 10.5V absolute minimum battery voltage, it is ideal as it leaves room for error to prevent damage to the battery by over-discharging it.

We were unable to verify the charge time of Table 3 from a complete battery drain as the battery used was kept on a battery tender throughout the project and never allowed to fall below 10.5V.

Conclusions and Ideas for Future Work

The dryer consumes a maximum of 360W, significantly less than current electric dryers that consume 2-4KW. The dryer runs directly off a 12VDC supply with components rated at 12VDC, which eliminates the need for components that drain energy such as transformers and inverters. Both the motor and heater consume significantly less power than those found in commercial dryers. The motor is a 12VDC power drill that operates at 8A (96W) and has plenty of torque to spin the drum. However, it is a high rpm motor as well and tends to slip a lot, as opposed to high-torque low-rpm motors more suited for this purpose. The heating unit is a simple space heater used for RVs and automobiles. A powerful 2KW heater is not needed in this case as part of this project is using solar power not just in powering the solar array to charge the battery, but in harnessing the sun's heat as well. The dryer's windows and black paint trap heat to create a greenhouse effect in the dryer, which eliminates the use for a more powerful heating unit as some of the heating is done by the sun. Currently, the dryer can handle heating units up to 240W, but can be easily modified to handle more powerful devices.

Further improvements to the dryer can be made to perform its task more effectively. Currently, only the outside of the box is painted black. The inside of the box and even the outside of the drum can be painted black as well to increase heat absorption. More windows can be added to the sides and back panel to increase intake of sunlight. While rubber bands work well as an effective (and cheap) solution to the slipping of the motor with the dryer band, a longer lasting solution is needed as it is troublesome to swap out the rubber bands every time they burn out. Perhaps industrial strength rubber with the same quality and durability as automotive tires could be used instead, or a different belt or chain system could be incorporated to better suit the motor type.

The safety of the electronics can be further improved by incorporating fuses to the circuits. A 20A fuse or circuit breaker can be placed at the standard cigarette lighter adapter to protect the appliance in the event the user uses a device which exceeds the current limit. If the user wishes to incorporate a more powerful motor or heater, the gauge of wire has to be changed (currently 12AWG is used to support a maximum of 30A). The ratings of switches and relays have to be

checked to ensure they are able to handle the higher current load. Currently, the relays are rated at 50A and the NMOS at 30A.

We were never able to get the temperature of the inside of the dryer to be hot enough, but should the need arise for a temperature sensor, an IC like the TC622 shown in Figure 19 could be easily incorporated into the electronics. This will be connected to an NMOS switch in series with the heater and will shut of the heating device when dryer temperatures reach above 155F, or 341K. The IC is setup in Figure 19 with a 150KΩ resistor, which triggers a signal when temperatures reach 155F.

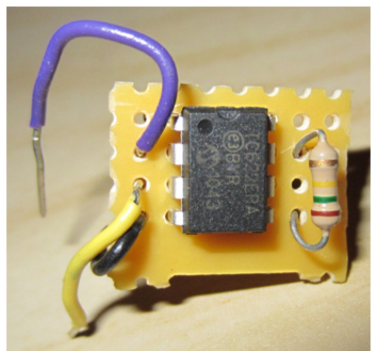

Figure 19 – TC622 Temperature Sensor with 150K Resistor (trips at 155F).

Appendix A – Bill of Materials

Item	Cost	Rating	Notes
Gas Dryer – Craigslist	$ 25		
Black & Decker Drill	FREE	12 V @ 8A	
Car Battery	FREE	12V DC	
Relay	$ 6.79	12V @ 30A	Group - 01
Relay	$ 6.79	12V @ 30A	Group - 01
Relay	$ 6.79	12V @ 30A	Group - 01
Battery Clips	$ 3.99	30A	Group - 01
DPDT Switch	$ 3.99		Group - 01
PCB (blank)	$ 1.99		Group - 01
Wire – Black – 20’	$ 5.29	12 AWG	Group - 01
Wire – Red – 20’	$ 5.29	12 AWG	Group - 01
Tax for Group – 01	$ 3.58		Group - 01
PCB (blank)	$ 2.16		
3’ x 3’ Plywoods – 9	$ 23.39		
Three ¼” nuts	FREE		
¼” bolt	FREE		
3” L-Brackets – pack of 4	$ 4.10		
1” L-Brackets – pack of 20	$ 7.48		Group – 02
#8 x 1- ¾ ” Wood Screws	$7.25		Group – 02
#6 x ½” Wood Screws	$ 3.82		Group – 02
Door Hinges	$ 2.27		Group – 02
Tax for Group – 02	$ 1.82		Group – 02
Rubber Bands	$ 1.62		
Resistors	$ 2.15	05 x 470, 05 x 150	
Temperature Sensor	$ 6.41	02 x TC622EPA	
Acrylic Sheets	FREE	1/8” thick	
Timer	$ 13.01	60 minute timer	
12V Car Adapter	$ 5.99		
Screws – 10-32	FREE		
Washers – #10	FREE		
Nuts – 12x10-32	$ 1.28		
DPDT Switch	$ 3.47	20A @ 12V DC	
Spacers	$ 2.60	10 x #4, ½“	Group – 03
Terminal (female)	$ 3.72	20x12-10AWG	Group – 03
Tax and Shipping for Group – 03	$ 5.42		Group – 03
LEDs	FREE	2V, 20 mA	
Machine Screws	$ 2.57	#4-40 x ½”	
NMOS	$ 4.76	BUZ11	
Disconnects	$ 2.60		
Terminal (screw)	$ 3.00		

Table 4 – Bill of Materials showing item, cost, and details.

Appendix B – List of Suggested Appliances

The dryer has a standard 12V cigarette lighter connector where the heater plugs in. As this is a standard automotive connector, a variety of accessories and appliances can be used with it (**up to 20A**).

<u>Space Heaters</u>

There are a variety of 12V space heaters that plug into the standard automotive cigarette lighter. They are mostly for RV use, and are compact in design. Here are a few examples:

RoadPro RPSL-681	15A
ThermTec Road Worthy Auto Heat	12.5A
HF Tools Heater 0096144	13A

<u>Suggestions for Other Useful Accessories/Uses</u>

Charging/powering electronic devices
    Cellphones, laptops, PDAs, music players, etc.

USB adapter for USB devices (see Figure A1)

Figure A1 – USB car charger

Fan for hot days

Lighting
    Ambient lighting (low-power LED)
    Emergency lighting
    Reading light / nightlight

Battery charger

… and many more!

Appendix C – Analysis of Senior Project Design

Project Title: Solar Powered Electric Clothes Dryer

Student's Name Alan Swe, Roger Mai Student's Signature ____________________________

Advisor's Name ______________________ Advisor's Initials _____________

• Summary of Functional Requirements

The dryer runs on a 12V deep-cycle battery and is able to run for at least an hour at maximum power to dry one load of laundry (2 cu.ft.). The battery is charged by a 15W solar panel, which allows the user to use it once per week with at least 4h of direct sunlight per day to recharge the battery.

The dryer is meant for dry-weather, outdoor use as it needs sunlight to both recharge the battery and to warm up the interior, which saves power by allowing the use of a smaller heating unit.

• Primary Constraints

The focus of this project is conservation both monetary costs and energy. The entire system must be able to run off a battery large enough to satisfy the power requirements yet small enough to be able to recharge in less than a week with a 15W solar panel. As sustainability is a key factor as well, the system is completely off the grid and self-sufficient, needing only sunlight.

• Economic

The original estimated cost was $1230 (see "Requirements: Alternate Design Consideration" section). A large part of this project is finding ways to reduce this cost. The final cost of the project is slightly over $100 (Appendix A: Bill of Materials) as we were able to obtain some major components through salvaging used parts and donations (solar panel, for example). The system was redesigned numerous times to find ways to reduce power, which enabled us to take out expensive and energy inefficient components such as the inverter in the original design. Having a low-power design also means cheaper and fewer components. No special tools or equipment were needed for development of this project.

The original estimated development time was 20 weeks, which includes designing and manufacturing. The actual development time was exactly 20 weeks. Ideas for improvements that we were unable to get to are addressed in "Conclusions and Ideas for Future Work".

• If manufactured on a commercial basis:

This product will have to compete with existing commercial clothes dryers. Although it can be used indoors, it works best outdoors, which could be a limiting factor for most people. It will appeal mostly to homeowners with a place where the device has access to direct sunlight.

Total manufacturing cost is estimated to be $400. The dryer alone without the battery and solar panel is estimated to be about $200. If old dryers were salvaged and modified, it would save more on materials and the estimated cost for the device would drop to $100. The device is expected to sell at a price competitive to other dryers of the same capacity, which is about $200-$300 just for the dryer or $500 for the entire system. Customers will have the option to purchase their own solar panel and battery as the device is designed to be compatible with any 12V deep-cycle battery and solar panels up to 20W.

The device costs nothing for the user to operate as it runs completely off the grid.

• **Environmental**

The device has mostly positive impacts on the environment as the clothes dryer is one of the household appliances that consume the most power. Being completely off the grid, the device saves about 3KWh of power every time it is used. The manufacture of the device is a recycling program for old dryers and motors (see "Manufacturability" below), which helps reduce waste on the environment.

Users have to exercise responsibility in the proper disposal of deep-cycle batteries used with the device once they are no longer useful.

• **Manufacturability**

Ideally, old dryers would be taken apart, leaving only the shell, drum, belt, and tensioner. The motor and heating unit will be replaced and holes cut throughout the shell to allow sunlight in to warm up the system. This will save at least $50 on material costs per dryer as these components would not have to be manufactured. Furthermore, the overhead for production will be reduced as well as infrastructure for gutting and modifying an existing dryer requires a simpler (cheaper) setup than to manufacture one. As all dryer shapes and sizes are different, a standardized manufacturing procedure or assembly line would be more difficult to implement, which could raise costs in this aspect.

• **Sustainability**

The system requires little to no maintenance. The only major problem encountered is the wearing of the contact bit between the belt and the motor, which can be resolved by using a stronger rubber (see

“Conclusions and Ideas for Future Work”). The system is designed to prevent the battery from over-charging/discharging, which means little to no work on the user’s part other than remembering to flip the switch to set it to “charge” mode.

The project’s impact on the sustainable use of resources is addressed in the “Manufacturability” and “Environmental” sections above.

Upgrades to the design are addressed in the section “Conclusions and Ideas for Future Work”. It includes electrical safety upgrades, plans for a more powerful design while still maintaining sustainability requirements, suggestions to improve belt tension, heat sensor, and addition of more clear panels to improve heat absorption/retention. Upgrading the design to support a more powerful motor or heater will mean using a higher gauge wiring, which will increase manufacturing costs. Also, it will mean a larger battery capacity is needed, which means a larger solar panel to charge it if the user wishes to use the device at least once a week. While all this is feasible if user is willing to pay the cost, it defeats the purpose of sustainability and the low-power consumption of the device.

• **Ethical**

The device contains electrical components that must be properly disposed of. As it is classified as a household appliance, it must be properly disposed of as such, and should be use only for its intended

• **Health and Safety**

The device requires the use of a deep-cycle battery, which contains harmful chemicals and should be handled and disposed of with care.

> Describe any health and safety concerns associated with design, manufacture or use of the project.

• **Social and Political**

> Describe any social and political concerns associated with design, manufacture or use.

• **Development**

Describe any new tools or techniques, used for either development or analysis that you learned independently during the course of your project.