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Solar Evaporative Fan Coil Unit

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Solar Evaporative Fan Coil Unit

Heat Coil

By

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ABSTRACT

The purpose of any engineering project is to anticipate a need and meet that need through prediction analysis and design. Over 70% of the nation's energy is consumed by building infrastructure such as HVAC systems, electrical, etc. HVAC systems use boilers to generate hot water or steam to heat buildings and evaporative chillers to provide air conditioning, much like the central plant here on campus. The project included the construction of a solar collector that will heat water to 140F in order to run it through a heat exchanger that can have air passed over it. An evaporative chiller was also designed to harness the latent heat of vaporization to chill a heat exchanger that can then have water passed through it. The circulation pump and any temperature sensors will be powered by a photovoltaic array so that no electricity is needed to power the device. The air from the ducted fan can then be passed over this heat exchanger in order to generate hot air for a room, and the same for the cold air with cold water. Testing will consider input and output water temperature, as well as input and output air temperature in order to compare the changes and develop a value for efficiency. Initial testing has found that 140F heating water can provide enough load in a heat exchanger to provide 85F leaving air temperature. Water that has been cooled to 40F by the evaporative chiller can provide a leaving air temperature of 55F.

INTRODUCTION

Engineering Problem

This project was motivated by the need for energy efficient HVAC solutions in residential and commercial buildings, as they consume over half of the energy in the nation. Renewable energy solutions are being considered more often when designing large scale projects as the technology improves and the mechanical processes become more efficient.

Function Statement

In order for hot air to be produced by a fan coil unit, hot water must be piped through a coil in a ducted air stream. The water will be heated by the sun, so concentration of conduction and maximization of convection within the collector must be achieved. Since the sun is out for an unpredictable amount of time, storage of this heated water will be critical as well, so that the thermal mass can be used on demand for a longer period of time. Control of fluid flow within the coils, in conjunction with control of the air flow being drawn across the coils, shall provide the necessary heated air to a space.

Requirements

In order to fulfill the function statement, the project will meet the following requirements:

- A pipe material must be selected that has an overall heat transfer coefficient of 200 BTU/h-ft^2-ºR or more to maximize conductive and convective heat exchange from the sun to the water in the piping.
- Parabolic mirrors must be placed behind the piping in order to concentrate the sun's irradiance to the center of each pipe in the array by a factor of 16.
- The sheet metal frame for the coil will be constructed to house the collector piping and provide support for the fully filled pipes at a weight of 100 lb.
- The frame must allow a minimum of 1 inch of air space around all the piping so that convection can take place along the pipe walls.
- The insulation on the inside of the frame will be at least 1 inch thick with an R-Value of at least 17 to minimize heat loss from re-radiation.
- The primary equation that will model energy transfer will be $Q = mdot(Cp)(\Delta T)$. Subsequent analysis are based on this basic equation with additional factors of heat exchanger size and overall heat transfer using $Q = U(A)(\Delta T_{lm})$.
- A Secondary equation will be R Value calculations, $R = \ln(D_o/D_i)/2\pi kL$.

Success Criteria

The success of the project will be defined by how efficiently it meets a heat load generated in a room with conditioned air, and the measurable result will be the temperature in the room throughout the day and how close it is to the set point of 75ºF. This will also be measured in how many Watts/meter of sunlight are necessary to produce the desired heat transfer to our working fluid, and how well we translate that heat transfer to a temperature increase or decrease and subsequent air flow over the heating coils.

Scope

The scope of the project will be to design a heating coil that can house 6 liters of water, and that will take heat from the sun and transfer that energy to the water to heat it up to saturation temperature (refer to Saturation Table in Appendix B). The natural buoyancy of lower density hot water will allow it to rise above the colder, higher density water, and provide a thermo-syphon effect to discount the need for a pump to circulate the water. The frame will be sized to house the heat coils and parabolic troughs that are in turn sized to meet the heating requirements discussed above.

Benchmark

Solar water heaters on the market today mostly use induction to draw electricity through a material that can radiate heat to the water. This method is almost always preferred due to the lower energy consumption, and with the use of a storage tank the hot water can be used on a more "on-demand" basis. Our system will use a totally passive solar heating effect, while also taking advantage of the concentrating factor of a parabolic reflective surface and convection around the piping itself.

Success of the Project

Our AC unit will work at least 20% more efficiently through the use of highly thermal conductive material, and save at least 20% of the energy normal heating units consume. This will make our product competitive with any unit available on the market today through the use of the sun as the primary energy source. Optimization will include ideal heat transfer rates from the sun to the water through the piping in the solar collector, from the fluid to the air within the duct, as well as control of the air flow across the heat coil. The UW EIC competition will allow us to showcase our project, talking about both its engineering merits and potential marketability to industry professionals. Competing against other schools that are designing their own ideas on how to meet an environmental problem with engineering will motivate us to continually improve our idea throughout the project. Last year our team was the first ever to represent Central Washington University at the competition, but this year we intend to win.

DESIGN & ANALYSIS

Motivation

I have taken a great interest in how HVAC systems are designed and implemented, and found that the energy use by these systems is immense. This opened the door for me to think of new ways of providing creature comfort within a room using less energy. The renewable energy market is also becoming more affordable and efficient, so this idea will also be considered in the design of the device.

I looked at how a commercial air handling unit works; steps through dehumidifying, cooling, heating, and filtering outdoor air that will be then blown to separate spaces using immense fan systems (Figure 1). Normally the cold and hot water that is driven through pipes to pass air across is created through use of a boiler or chiller, which consume the majority of the energy required to run a buildings mechanical systems.

This led me to think about how easily a renewable energy solution to heating a space could be leveraged through a passive solar heat coil that is sized according to the heat load that is necessary for a given space (Figure 2). Even if a boiler could be taken offline for a portion of the year with an economizing passive system, the amount of money that could be saved over the long run would be significant.

Proposed Solution

Replacing the heat coil in an air handling unit with a passive solar heat coil will not only save energy across the entire system, but provide an economizing supplement to a large commercial boiler system. Sizing of the heat coil for our particular unit will be decided by analysis of the necessary heat needed in our particular test environment of a 10x10x10 room at 2200 BTU/h (1 human operating 1 computer over the period of a day losing heat through the walls and windows).

Analysis of design has been conducted in the following steps:

- Copper was chosen as the material for the insert over steel and aluminum because of its high U-value (215 BTU/h-ft^2-°F), which takes into account the convection from the air to the metal, the conduction of heat through the metal, and the convection of heat from the metal to the water inside the pipe (refer to Appendix A, "Hot Water Timing").
- A parabolic mirror will be sized and implemented behind each pipe section in the solar collector to optimize incident solar radiation (refer to Appendix A, "Parabolic Mirror").
- The size of the coil will be designed to meet the heating requirements discussed in the previous section. This will require 8 feet of piping for each pass of coil for a total of 10 passes to provide the heat transfer necessary to increase the air temperature that will be blown across the coil by the optimized 20°F ΔT (refer to Appendix A, "Solar Collector Sizing").
- The size of the frame will house this 2.45 foot long, 10 pass solar collector, making it 36 x 45 x 4.5 inches in size (refer to Appendix A, "Solar Collector Sizing").
- Frame construction will take into account the weight of the coil (approximately 100 lbs), the insulation requirements (R17 or higher), and any mounting to an existing structure will require a 2mm x .4 pitch A36 carbon steel bolt (refer to Appendix A, "Load Safety Factor and Frame Construction").
- The angle of attack for the solar collector relative to the sun will be adjustable in order to optimize solar collection on any given day (refer to Appendix A, "Solar Collector Angle").
- A schematic of pipe distribution and valves will be designed and implemented to provide control over fluid flow through the coils to the storage tank and through the duct coil.

Sketches

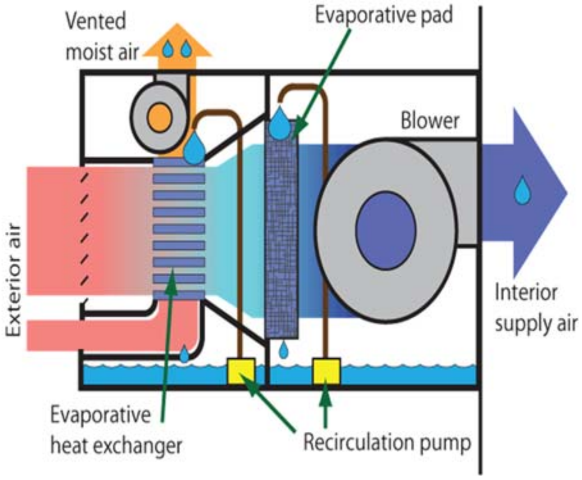


Figure 1 Evaporative Cooler Schematic

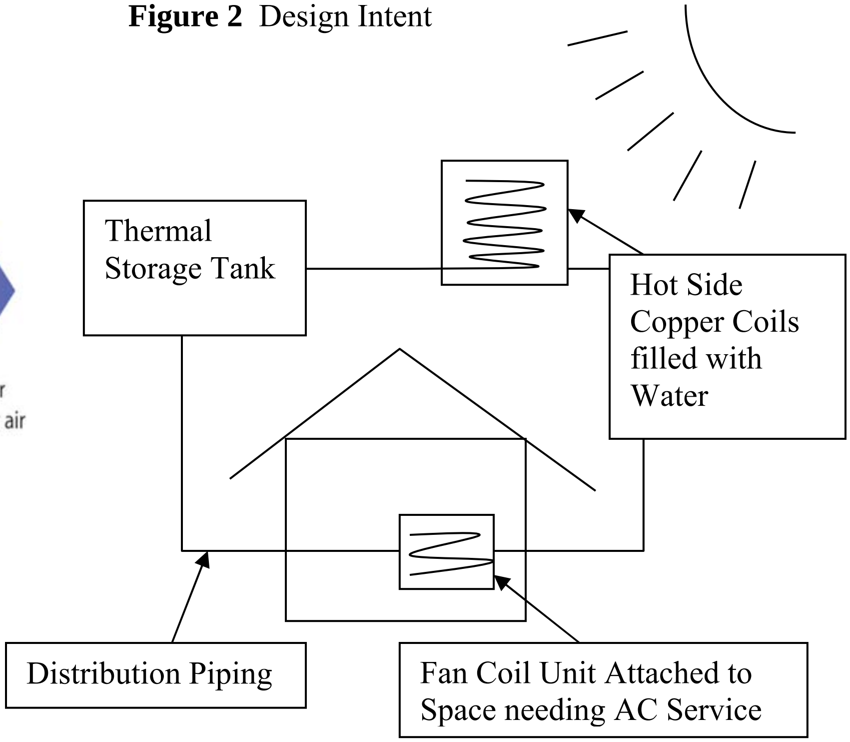


Figure 2 Design Intent

Proposed Sequence

The engineering merit involved with this project will be realized through analyses of both the heat transfer of the sun to the working fluid, the fluid flow rate required to meet a heat load in a space, and the volumetric air flow rate to deliver the air necessary to meet that heat load. This will facilitate the increase in air temperature to our set point of 75 degrees F. Storage of the thermal mass of water that has been heated will be necessary to carry our heating system functionality through the day without the need for constant sunlight. Recirculation of heated water will be provided by the natural thermo-syphon of buoyant hot water, which will not only meet the fluid flow demand but discount the need for a recirculation pump. The size of the bolt necessary to hang the device from a structure was calculated to be 2x.4 (mm x pitch) A36 carbon steel bolt (refer to green sheet 4 in “Wall Mounting”).

Calculated Parameters

On a sunny day, the irradiance from the sun is known to be from 800-1000 Watts/m^2. The amount of sunny hours through the heating months in the northwest region of the United States (October through March) is predicted by local almanacs to only be 3 per day on average (Cengel 410). In order to optimize heat transfer, this irradiance can be multiplied up to 16 times by sizing a parabolic mirror (refer to green sheet 1 in “Parabolic Mirror”) to concentrate the sunlight onto the 1.125 in. outside diameter copper piping to heat the water that it contains. This water will then be stored in a 20 gallon storage tank to be pumped through the fan coil unit when needed to facilitate in the heating of a space.

Copper piping will be the preferred material because of its high overall heat transfer coefficient, or U-value (up to 215 BTU/hr-°F-ft² for pure copper) compared to aluminum and steel which are rated at 140 and 55 BTU/hr-°F-ft² respectively (Jacobs 115).

`The structure of the frame for the housing of the heat coil will be 1/8 inch thick sheet metal to take into account the weight of the pipes fully loaded with water at approximately 100 lbs. The size of the frame will be 96 inches tall to accommodate the 10, 8 foot section lengths of pipe in the array (refer to "Solar Collector Sizing" in Appendix A), 75 inches wide to account for the 4.5 inch wide parabolic mirrors per pipe (refer to "Parabolic Mirror" in Appendix A), and 4.5 inches deep allowing for mirror depth and convective air space.

Device Shape and Assembly

The frame will be constructed of Aluminum U-Channel Bracketing at the correct angle to optimize solar collection during the particular day of testing (refer to Appendix A "Solar Collector Angle"). The collector will be an array of tube assemblies that will direct heat collected from the sun through the vacuum sealed tube to prevent ambient conditions to affect the transfer of heat from the sun to the copper insert through the aluminum sheet (Figure 3). A small amount of alcohol inside the copper insert will draw this collected heat towards the top of the collector into the copper manifold that will have water running through it.

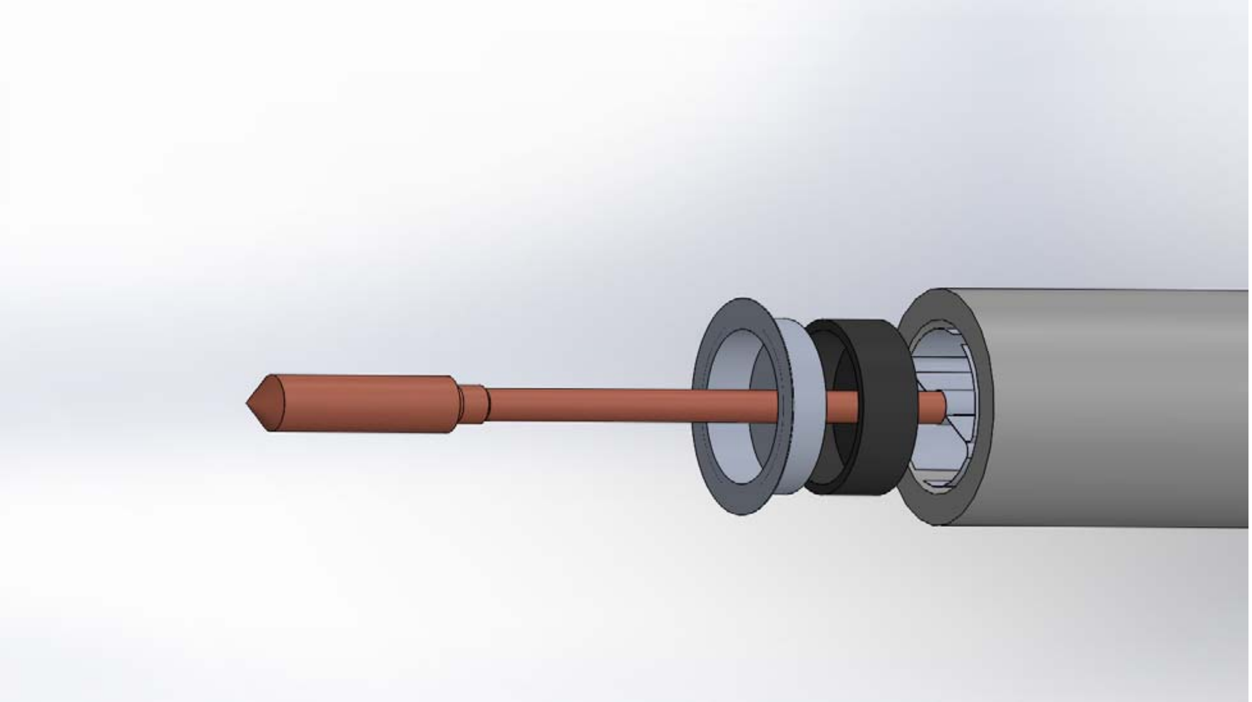


Figure 3 Exploded View of Solar Collector Tube

Predictions

The outcome of the device will be the heating of water from room temperature to saturation temperature and stored for “on-demand” use in the coil in the ducted air space. This cycle will be regenerative, in that the circulation of water through the solar collector will be stored in the 20 gallon thermal storage tank to be used throughout the day in the fan coil unit. This will allow for regulated use of the device all day without the need for constant sunlight. Maintaining a slow fluid flow (.5 gpm) to maximize heat transfer from the copper to the water and the water to the air will be important in able to predict a leaving air temperature of 85°F with a supply air flow of 200 CFM.

Failure Mode

The technical risk associated with this device is primarily due to the great amount of heat generated by the solar collector and transferred to the water. To mitigate this risk, any part that the water touches is to be constructed of metal. The manifold where the initial transfer is copper, which can withstand over 1000°F before failure, and the connections to the heat coil are corrugated stainless steel, which can withstand even higher temperatures. The tank in which the hot water is to be stored will be a household hot water tank equipped with measuring devices like thermocouples, which will also withstand the high water temperatures.

The failure mode that is associated with the structure of the solar collector itself was defined in Appendix A, A6 “Load Safety Factor”, which calculates the design load the aluminum frame can withstand. This portion of the analysis also derives the safety factor of 4 that was chosen to ensure safe operation of the device under extreme conditions like snow and ice buildup. The critical load was calculated for the aluminum framing being used, and compared to the predicted load on the frame from the device, and with a safety factor of 4 there is still room for failure prediction stemming from unknown loading like natural disasters such as an earthquake.

METHODS & CONSTRUCTION

This project was conceived at Central Washington University by a motivated team of individuals looking to improve the energy efficiency of HVAC systems. All the parts of our system will be designed and drawn using school resources such as MDesign and SolidWorks (Refer to Appendix B for Drawings). The calculations involved with design will be included in this report, and checked for quality control.

Construction

The frame for the solar collector will be constructed of aluminum u-channel brackets held together with 2 inch hex bolts. It will be made to the drawing angles in order to optimize solar collection (i.e. the collector will be 90 degrees to the sun at solar noon for any particular day). The angle will be adjustable through a number of holes in the supporting member so that the hex bolts can be removed and re-inserted to provide the proper angle.

A low volume pump will supply water through the copper manifold at the top of the solar collector at a rate of .5 gpm in order for the copper to transfer the maximum amount of heat to the water before it is pumped onward to the heat coil in the ducted air space.

This unit will be ducted to the space needing air conditioning, either through a window mounted system or a standalone system that can be ducted to the space. The duct work will be sheet metal as well, with joints to be soldered and sealed with dope to ensure air tightness.

Device Operation

Once constructed, the device will routinely take heat from the sun throughout the day, transferring that heat into the water which will then be ported to the fan coil unit. Air will be blown across the heated coils that are arrayed within the duct at a rate that meets the heat demand in the room being cooled. The temperature in the room shall remain close to 75°F set point.

Manufacturing Issues

Bolting the frame together at the proper angle will take a little consideration as it is being assembled. Hole locations have been calculated and included in the drawings, but exact locations may change as issues with tolerances and connections arise. The other issue will be fittings and connections for all hoses. The heat coil in the ducted air space may be a different OD than the copper manifold, so an array of connections will be considered.

The biggest issue that was overcome was the constant attention to leaks in the system of PEX and fittings. The intense range of temperatures for the working fluid made for adjustments to the type of fittings used (shark bite) and the way the system was connected to minimize the amount of tubing. There was a tremendous amount of heat loss through the PEX tubing before it could be exchanged within the ducted air space, so insulation was added to all the tubing to minimize that transfer of heat where it was not desired.

Benchmark Comparison

The device will heat water without the need for electricity, which will ensure it will also use less energy than any ac unit on the market. Common air conditioners use 2000 kW-hours/month, and with electricity rates varying from 6-20 cents per kW/hour, that can cost almost $5000 per year. The device will only use less than half that amount of energy to provide the same amount of heating to a space. This will not only lower the cost of the device, but it will also reduce the carbon footprint of the system as well. The control of our air flow in relation to our fluid flow will ensure an improvement on heat transfer rate efficiency across all material mediums, and will be compared to the common air conditioners performance throughout a normal heating day.

TESTING METHOD

Test Plan

The testing process will involve measuring water temperature at several spots along the solar collector itself, as well as air temperature entering and leaving the ducted air space. These measurements will be taken at regular intervals during days with different ambient air temperatures and weather conditions. The data that is gathered will then be compared to the predicted value in the analysis and graphically displayed to communicate any correlations of heat transfer between water temperature and air temperature within the system itself.

The requirements of this test will be as follows:

- All thermocouples must be placed within the water stream being measured, and calibrated to within +/- .5F.
- The anemometers will be placed in the center of the air stream and calibrated to the area of the duct for both entering and leaving openings within +/- 20 CFM.
- Power that is supplied to the circulation pump by the photovoltaic array must be between 15 and 30 watts.
- All measurements must be taken at regular intervals (based on the time constant calculated in the initial analysis for the size of the system) in order to develop trends throughout the day.
- Testing will be done on days with different types of weather and solar irradiance so that efficiency can be normalized and compared.

The predicted performance of the device will be a leaving water temperature of the manifold within the solar collector of 140F, and a leaving air temperature of the ducted air space of 85F. Storage of any extra thermal generation within the circulation line will be stored in a water tank consisting of 25 gallons, and will be measured for overall temperature as well. The temperature of the tank is predicted to be 95F and carry the system through the evening into the night as solar irradiance drops off.

The schedule consists of testing both heating of the water and the exchange of energy to the air being passed over the heat exchanger (refer to Schedule in Appendix E). Hours of each task will be reported to the nearest tenth of an hour, and notes will be taken about issues with any specific tasks.

Method and Approach

The solar collector will be brought to the south patio outside Hogue Hall on the CWU campus and piped through the water tank and connected to the heat exchanger within the ducted air space. All connections are done with cross-linked polyethelene (PEX) tubing with shark bite fittings, and the circulation line will be filled with water supplied by the school at the site. A thermocouple will be placed within the water stream at the leaving end of the manifold, within the storage tank, at the entering end of the heat exchanger and the leaving end of the heat exchanger. Anomometers will be placed at the entering and leaving end of the ducted air space as well to supply air speed and temperature during testing. The photovoltaic array will supply power to the circulation pump, and the pump will be switched on once all other parts of the system are connected and tested for leaks.

Test Documentation and Deliverables

A spreadsheet detailing temperature data points throughout the day (refer to Appendix F) with graphs showing fluctuations and trends will be developed for every test day. Comparisons can then be made to improve our control over the fluid and air flow to provide the most energy efficient heated air to the space.

The first test was undertaken during a typical cloudy day (solar irradiance = 500 W/m², www.solar4rschools.com) which the performance predictions were based on. Looking at the tank/circulation line as a large shell and tube heat exchanger, the time constant for the Arrhenius heat transfer equation can be back calculated to be approximately 24 min (Appendix A5, "Hot Water Timing Analysis). To be conservative the regular time intervals that the data is taken at during the warm up process was chosen to be 30 minutes. The testing was started at 10 am and data for both air and water temperature was taken every 30 minutes until 5 pm (Figure 4).

Figure 4: Raw Test Data

Date: 4/15/2015
Solar Irradiance 500 W/m²
Ambient Air Temp: 55°F

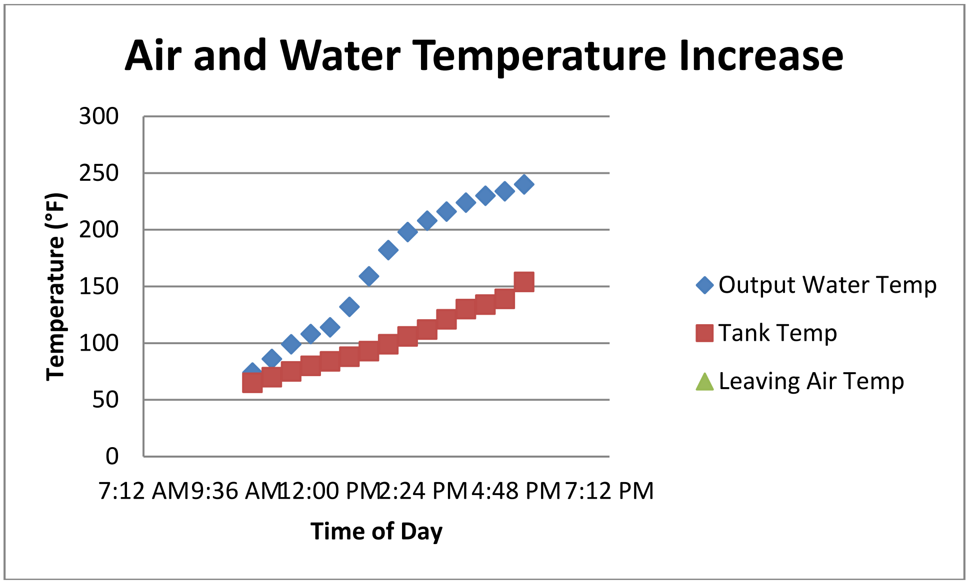
Time of Day	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM
Input Water Temp (°F):	65	68	72	76	82
Output Water Temp (°F):	74	88	96	106	118
Tank Water Temp (°F):	65	66	68	70	72
Air Flow Speed (CFM):	320	320	320	320	320
Leaving Air Temp (°F):	55	58	62	66	70

Time of Day	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM
Input Water Temp (°F):	86	92	94	96	100
Output Water Temp (°F):	121	123	126	127	128
Tank Water Temp (°F):	76	80	84	85	86
Air Flow Speed (CFM):	320	320	320	320	320
Leaving Air Temp (°F):	74	78	84	88	90

Time of Day	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM
Input Water Temp (°F):	104	109	112	116	124
Output Water Temp (°F):	128	130	131	131	132
Tank Water Temp (°F):	90	92	93	96	99
Air Flow Speed (CFM):	320	320	320	320	320
Leaving Air Temp (°F):	92	93	93	92	93

The input water temperature is the re-circulated water coming back from the heat exchanger in the ducted air space, and the output water temperature is leaving the solar collector manifold. Looking at the tank water temperature, the 20 degree increase that was predicted to be under 4 hours was achieved, and acts as less of a resistance to the circulated water with the air load on it. As the output water temperature climbed throughout the day, the air load from the ducted air space and the tank load slowed it down, but it still achieved a 60 degree temperature change throughout the day. This built up thermal energy can then be stored in the tank and used after the sun goes down, so that hot water can be supplied to the heat exchanger into the night.

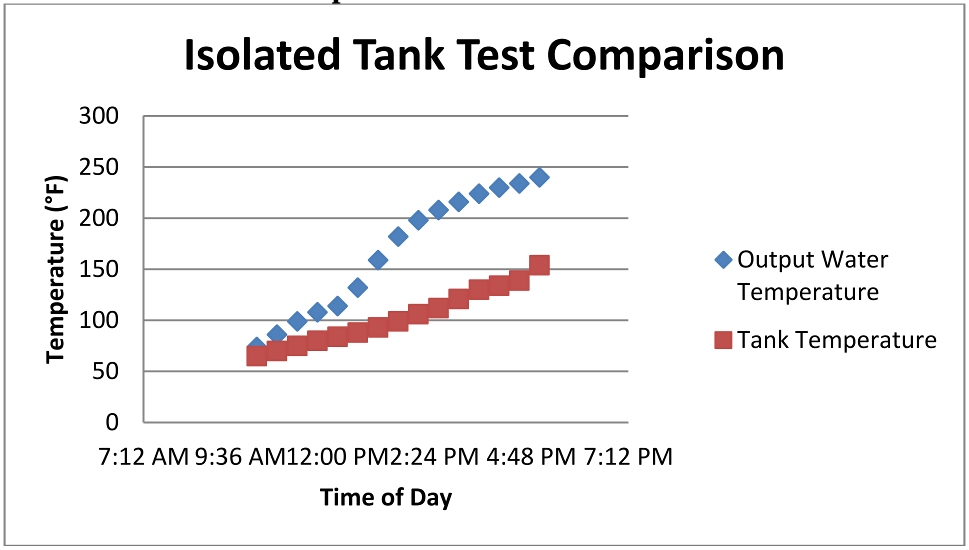
Figure 5: Air and Water Temperature Increase



As you can see from Figure 5, the output water temperature increases rapidly, but starts to plateau as the limit of solar irradiance during the day is reached. The leaving air temperature starts to climb to tank temperature fairly quickly, and then follows that trend throughout the day.

The next test involved just heating the water in the tank with the circulation line without the air load, to see what the limits of the system were and how much the resistance of the tank would affect the output water temperature. Using the same test data sheet and recording output water temperature and tank temperature, a correlation can be seen (Figure 6).

Figure 6: Isolated Tank Test Comparison



The output water temperature is allowed to increase much quicker without an air load on it, and the limit of 240°F is due to the pressure relief valve being set to go off at 70 psi, which is the saturation pressure for that water temperature. The tank temperature climbs steadily throughout the day as well, and this built up thermal energy can be used to power a heat exchanger in the ducted air space throughout the evening and into the night. All raw test data and charts can be found in Appendix G as well.

BUDGET

Proposed Budget

The proposed cost of our project is estimated at $1004 for all parts, labor, and resources for both building and testing, of which the heat coil portion comprises $49.95 for fasteners (refer to Appendix C). Our biggest supplier is University Mechanical Contractors that contributed their scrap metal for several parts on the project. They also allowed the use of their purchasing account, which allowed for pricing of material at warehouse cost. Jeff Greear owns his own solar collector installation company and is willing to donate material as well (www.ellensburgsolar.com).

Sequencing the collection of the material for the project will be crucial, as a frame will need to be constructed before any piping can be implemented. Sheet metal will be purchased in advance so that it is readily available after design is complete and building of the project is ready to start. Copper piping will then need to be ordered so that once the frame is built, the routing and welding of pipe into the frame can be done right away. Any fasteners and connections will need to be purchased during this second phase so that any problems that arise from interoperability can be addressed as they happen.

Estimating Cost

All cost estimates were done using a comparison method that took prices from several sources and compared their cost and reliability/construction to help pick the best option.

Although copper piping is expensive, it has the best thermal conductivity of almost any metal (save silver and diamond) and will be used throughout the project for this reason. Estimates of copper piping prices are based on the price of copper on the day this proposal was written, and it must be noted that this price will change as the project progresses (refer to Appendix D).

Funding Sources

The biggest source of funding for this project will come from the University of Washington and its Environmental Innovation Challenge. This provides prototype funding for student projects that wish to compete in the competition and meet the only requirement that it is addressing an environmental issue with engineering innovation. We expect over $2000 in funding from this source, with more funding than expected cost to make sure any overage costs are met.

SCHEDULE

The schedule for this project will last 415 hours, which will fall within the requirements for MET 495 Senior Project while being further constrained by the schedule set down by the UW EIC competition. The proposal will be finished by February 1st, but our business plan will be submitted to UW by November 20th. Prototype construction will continue through February (refer to Construction Task Schedule in Appendix E), and testing will be conducted through March (refer to Overall Schedule in Appendix E). An updated schedule will be furnished to reflect work done throughout the build and testing process, and time will be reported down to the tenth of an hour.

When the project was fully completed, the total hour count was 460.4, which was slightly over the estimated 415 hours. This was due to unaccounted for troubleshooting during testing such as leak fixes and testing apparatus construction. Overall the project stayed on schedule throughout the entire process.

Tasks

The tasks required to bring this project to completion will include defining and submitting the proposal of the project, construction of the object itself and testing its function, with iterations of improvement and optimization. All tasks will be defined before construction begins, and planned according to available time and resources in order to keep the project on schedule. Additional time will be planned into the project schedule in order to account for any unforeseen problems that may arise during construction and testing.

EXPERTISE AND RESOURCES

This project will be successful because our team of engineers is driven and productive, with a real interest in improving our environment through engineering. The resources at our disposal will be utilized with skill, knowledge, and grace.

Human Resources

The personnel within Hogue Hall, including professors and tech's will be asked questions whenever it is appropriate. Their real world experience will be invaluable to the completion of our project.

The staff that organizes the UW EIC competition also avail themselves as a source of information and collaboration. Many workshops and opportunities to learn more about entrepreneurship and engineering merit are available at UW Foster School of Business throughout the school year. These classes are particularly targeted towards those individuals participating in the competition, such as ourselves.

Physical Resources

The physical resources that are available to us include the machine shop at CWU campus in Hogue Hall. We also will have access to the fabrication shop at University Mechanical's Mukilteo office in order to perform any welding and construction of our device that we would otherwise be unable to perform elsewhere.

DISCUSSION

Design Evolution

Our first design involved a compression/expansion of ammonia that would harness the Rankine Cycle for refrigeration. This turned out to be a risky design, as putting ammonia under high pressures would involve leaks that could be harmful to humans. Water was a more suitable choice for our working fluid, although it is not as efficient a heat transfer medium, it is much cheaper and safer to work with.

The next evolution involved concentrating on just cooling, using the heating coil to generate water at saturation temperature to aid in generating humidity in the evaporative cooling unit. This idea was not feasible because the heat that followed water at saturation temperature would negate any cooling effects the humidity increase would have in the chamber.

Using the heat from the sun to passively replace a heat coil in a fan coil unit was deemed to be the best approach to our device operation. The storage of the heated water was later implemented in our design in order to provide heated water throughout the day, even when the sun was not shining. This is also consequently when heating is needed in any given space more often than not.

A donor by the name of Jeff Greear was able to provide the project with tubing meant for solar collection, with a blackbody coating and a double walled thermos containment of the water to optimize heat transfer (www.suntasksolar.com). A manifold that allows for conduction of heat between the copper inner tube of the collector array and the copper tubing holding the water to be heated will need to be manufactured. Storage of this thermal mass will be held in the water tank obtained from the thermo-fluids lab (1 cubic meter in volume), otherwise known as "Bertha". All connections between the devices will be CSST tubing and PEX tubing, also donated by Mr. Greear

Conclusion

In conclusion, the Solar Fan Coil Unit was successful because it delivered hot water to a ducted coil on demand to provide hot air to a room and maintain a comfortable temperature. It did so more efficiently than common air conditioners through the use of passive solar collection, which was analyzed and designed to heat water to saturation temperature in a minimum amount of time from sunrise. The thermal conduction of solar irradiance to the water running through the manifold will allow for hot water to be generated very quickly (in about 20 minutes from full solar irradiant conditions) so that heat can be supplied to a room when needed. The rate of heat transfer will be greater than common air conditioning applications that use induction instead of conduction because all the components are copper. The passive solar collection system will use less energy than a common air conditioner as well, because there is no heating element to be powered, and the small circulation pump will be powered by a solar photovoltaic cell.

ACKNOWLEDGEMENTS

UW Environmental Innovation Challenge

Participating in this competition sponsored by University of Washington's Foster School of business will allow us to procure prototype funding.

University Mechanical Contractors

With the added advantage of an internship with UMC, our project will enjoy the ability to use their purchase account to shop vendors and secure discounted prices for equipment.

Faculty and Support Staff

We would also like to thank Dr. Craig Johnson, Professor Charles Pringle, and Professor Roger Beardsley for their mentorship involved with this project.

Outside Sources

Jeff Greear was instrumental in helping this project come to fruition, both through his donated material and expertise in the area of solar collection.

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http://www.matweb.com

http://en.wikipedia.org/wiki/Copper

http://www.ellensburgsolarenergy.com/

http://www.solar4rschools.com

APPENDIX A – Analyses

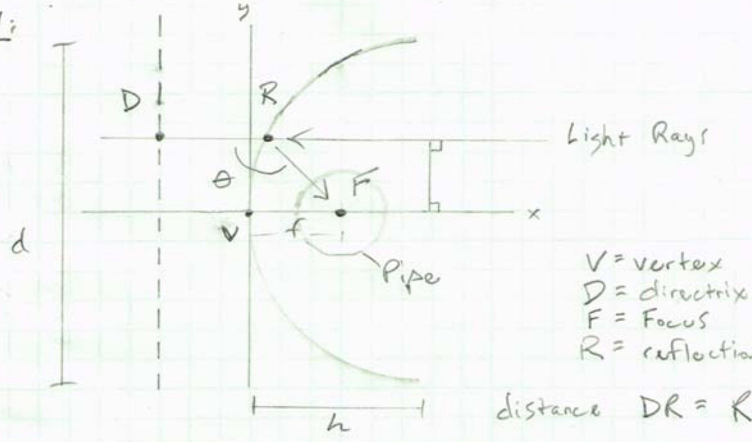
A1 Parabolic Trough Design

Sam Budnick | MET 495 | 11/8/2014

GIVEN: 1.125 in. OD copper pipe is to be placed within the focus of a parabolic mirror in order to concentrate the sun's irradiance and heat water within the pipe.

FIND: The equation for a parabola that would optimize solar concentration at the center of the pipe, and dimensions of that parabolic trough to be made of reflective material.

SOLN:



V = vertex
D = directrix
F = Focus
R = reflection point

distance DR = RF

parabola equation => $y^2 = 4fx$ f = distance VF

- for dimensions, h is the distance from V to aperture and d is the aperture diameter.

Ideal rim angles for solar concentrators (θ) are 90° due to sun rays coming in at parallel directions to the axis of the parabola. (ideal f/d ratio = .25)

In order to optimize the focus of sun rays on the center of a 1.125 OD pipe, f = 1.125 in. and d = 4.5 in.

$$h = \frac{d^2}{16f} = \frac{(4.5\text{ in.})^2}{16(1.125\text{ in})} = 1.125\text{ in.} \quad \left(\frac{f}{d} = .25,\ \text{so } d = \frac{f}{.25}\right)$$

- For every foot of pipe/trough array, the solar concentration is equal to:

$$\frac{\text{Area of Trough}}{\text{Area of Pipe}} = \frac{\pi f^2}{\pi\left(\frac{r}{2}\right)^2} = \frac{\pi(1.125)^2}{\pi\left(\frac{.5625}{2}\right)^2} = \text{16 times the power of the sun!!!}$$

(r = radius of pipe)

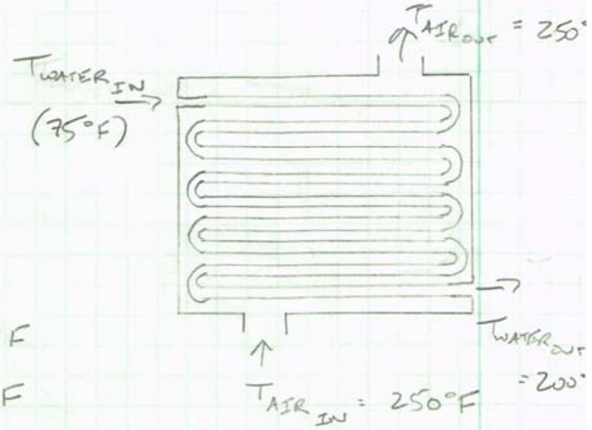
A2 Solar Collector Sizing

Sam Budnick | MET 495 | 11/8/2014

GIVEN: Water enters a heat exchanger at room temperature that is being heated by 250°F air.

FIND: Size of heat exchanger for water exit temp. = 200°F

SOLN: $\Delta T_{lm} = \dfrac{\Delta T_1 - \Delta T_2}{\ln(\Delta T_1 / \Delta T_2)}$



$\Delta T_1 = T_{AIR_{OUT}} - T_{WATER_{IN}}$

$\Delta T_2 = T_{AIR_{IN}} - T_{WATER_{OUT}}$

$\Delta T_1 = 250°F - 75°F = 175°F$

$\Delta T_2 = 250°F - 200°F = 50°F$

$$\Delta T_{lm} = \frac{(175°F) - (50°F)}{\ln(175/50°F)} = 99.78°F$$

$U_{COPPER} = 200\ \text{BTU}/h \cdot ft^2 \cdot °F$ (overall heat transfer coefficient taking into account convection and conduction)

$\dot{Q} = \dot{m}(C_p)(\Delta T)$

$\dot{Q} = (.1\ gpm)(1.000\ \text{BTU}/lb_m \cdot R)(125°R)\left(\frac{60\ min}{hr}\right)\left(\frac{1\ lb_m}{8.34\ gal}\right) = 899.2\ \frac{\text{BTU}}{hr}$

$\dot{Q} = UA\Delta T_{lm}$

$199.2\ \frac{\text{BTU}}{hr} = \left(200\ \frac{\text{BTU}}{h \cdot ft^2 °F}\right)(\text{Area})(99.78°F) = .045\ ft^2$ $(6.5\ in.^2)$

With 1.125 inch OD copper pipe, $(2\pi r) = 3.53\ in$

- Every foot of pipe has $(3.53\ in)(12\ in) = 42.4\ in^2$.

- CONTINUED on NEXT SHEET →

A3 Solar Collector Sizing Continued

Sam Budnick | MET 495 | 11/8/2014

- 6.5 in² of copper pipe is needed to exchange enough heat to meet a 2200 BTU/h load per hour.

- Only 1 hour of full sunlight is available per day, on average, across the heating months (Oct → Mar)
- Typical solar efficiency is 15% (www.PSE.com/solar)
- the thermal mass of heated water must be stored in a tank to be used across the whole day.

$$\left(\frac{6.5 \text{ in}^2}{\text{hr cycle}}\right)\left(\frac{24 \text{ hr}}{1 \text{ day}}\right)\left(\frac{1 \text{ day}}{.15 \text{ eff}}\right) = 1040 \text{ in}^2 \text{ of pipe}$$

$$\frac{1040 \text{ in}^2}{42.4 \text{ in}^2/\text{foot}} = 24.5 \text{ feet of pipe}$$

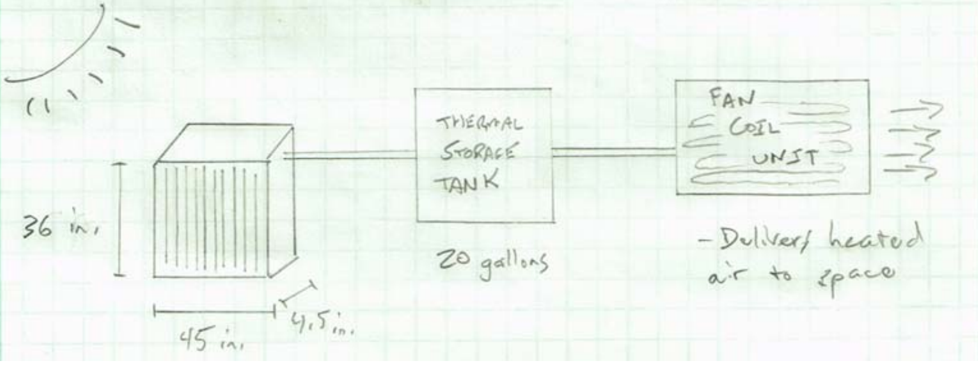
$$\frac{24.5 \text{ feet of pipe}}{10 \text{ pipe array}} = \boxed{\text{10 sections of 2.45 foot copper pipe.}}$$

FRAME SIZE:

3 feet tall (to accomodate pipe length)

10 pipes (4.5 in./pipe for parabolic mirror) = 45 in. wide

Depth => (1 inch insulation + 1 inch on each side of pipe for convection
+ 1.125 in pipe
+ 1.125 in, mirror depth) = 4.5 in deep

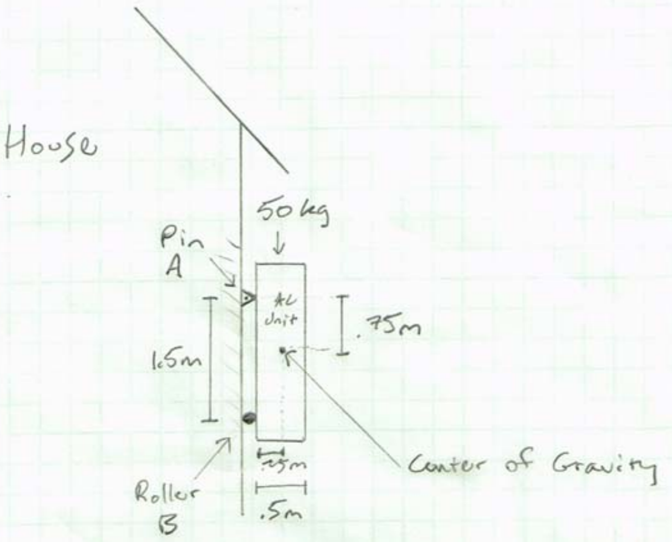


- Delivers heated air to space

A4 Wall Mounting the Unit

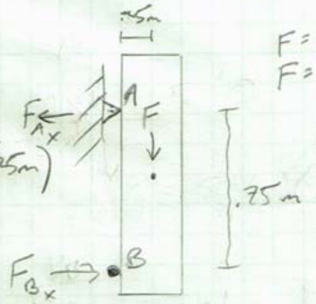
Sam Budnick | MET 495 | 10/20/2014

GIVEN: An Air Conditioner weighing 50 kg is to be hung from the side of a house.



FIND: In order to pick the correct size screw to attach the unit to the house, the forces on the pin must be determined.

SOLN: FBD $^{y}\!\llcorner_{x}$



$F = (50\,kg)(9.81\,N/s^2)$
$F = 490.5\,N$

(@ center of gravity)

$$\Sigma M_B = 0 = F_{A_x}(.75m) - (490.5N)(.25m)$$

$$F_{A_x} = \boxed{163.5\,N}$$

$$\Sigma F_x = 0 = -163.5N + F_{B_x}$$

$$F_{B_x} = 163.5\,N$$

- If a carbon steel bolt is to be chosen (A36 with a yield strength of 248 Mpa) the stress in the bolt must be less than the yield to prevent failure. (d = diameter of bolt)

$$\sigma = \frac{P}{A} = \frac{163.5N}{\frac{\pi}{4}(d)^2} < 248\,Mpa$$ solving for d = .916 mm

- with a SF = 2, a 2 × .4 (mm × pitch) bolt will work!

A5 Hot Water Timing Analysis

Sam Budnick | MET 495 | 10/20/2014

GIVEN: The sun's irradiance on a bright day is known to be 1000 watts/m².

FIND: The time it takes to heat water in copper piping

SOLN: $\dot{Q} = \dot{m}(C_p)(\Delta T) = U(A)(\Delta T) = \frac{\Delta T}{R}$

$\dot{Q} = 1000\ W/m^2$ (sun's known irradiance)

C_p = Specific Heat of water = 1.87 kJ/kg °K

$$R_{PIPE\ WALL} = \frac{\ln(D_o/D_I)}{2\pi k L}$$

where
D_o = outside diameter (3c
D_I = inside diameter (2.54c
k = thermal conductivity (385.8 W/m² °K for copper
L = Length of piping

U = Overall Heat Transfer Coefficient
- takes into account
  - inner convection
  - conduction
  - outer convection

A = Surface Area of pipe (πDL)

$$\Delta T = (1000\ W/m^2)\left(\frac{\ln(.03/.0254\ m)}{2(3.14)(385.8\ W/m^2 °K)(1\ meter)}\right) = .07\ °C/meter\text{-}se$$

- For a 3 foot length of pipe (1 meter)

It will take 20 minutes to heat .0005 m3 of water from 20°C to 100°C,

ΔT = room temp to saturation temp = 100 - 20°C = 80°

$\frac{.0254}{2} = r$, $\pi r^2 (L)$ = volume = .0005 m3 of water per pipe

$$\frac{80°C}{\frac{.07\ °C/meter\text{-}sec}{1\ meter\ pipe}} = 1165\ seconds = \boxed{20\ minutes}$$

A6 Load Safety Factor and Frame Construction

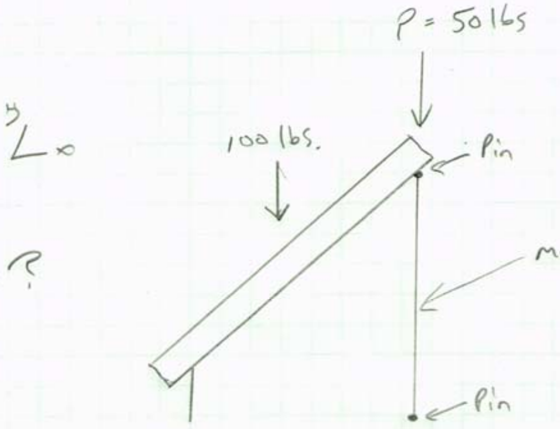
Sam Budwick | MET 419 | 1/25/2015

GIVEN: the weight of the solar collector is determined to be 100 lbs.

FIND: A suitable frame material to prevent buckling and support the collector during operation.

SOLN:

FBD



Safety Factor ?

Pinned - Pinned ⟹ K = 1.0 (Fig 6-3, pg 215 in Mott)

$P_{ALLOWABLE} = P_{CRITICAL} / \text{Safety factor}$

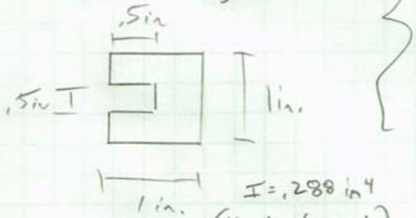
$$P_{CR} = \frac{\pi^2 E A}{(KL/r)^2}$$

Assuming Aluminum Struts w/ Area = .75 in²

$E_{AL} = 10 \times 10^6$ psi
$A = .75$ in²
$r = .61968$ in.
$K = 1.0$
$L = 83$ in.

$$r = \sqrt{I/A}$$

$$r = \sqrt{\frac{.288 \text{ in}^4}{.75 \text{ in}^2}}$$



I = .288 in⁴
(Al U-channel)

$$P_{CR} = \frac{\pi^2 (10\times10^6 \frac{\text{lb}}{\text{in}^2})(.75 \text{ in}^2)}{((1.0)(83 \text{ in})/.61968 \text{ in})^2} = 4126 \text{ lbs.}$$

Safety Factor of 4 will still allow for $P_{ALL} > P$

4126 lbs / 4 = 1031 lbs >> 50 lbs (Good!)

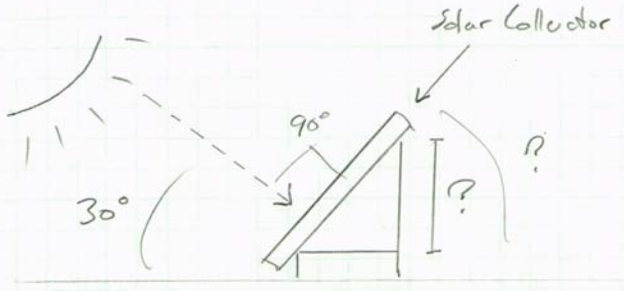
A7 Solar Collector Angle

Sam Budnick | MET 495 | 1/25/2015

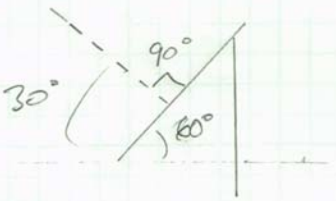
GIVEN: The sun is at a 30° to the solar collector and the ground. (in winter month)

FIND: The angle the collector must be tilted to to maximize the area which the sun reflects.

SOLN:

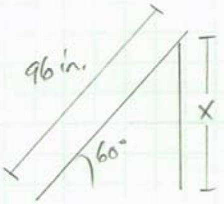


- Using similar triangles, the interior angle between the collector and the ground will be:



$$\phi_{INT} = 180 - 90 - 30 = \boxed{60°}$$

- If the collector is 8 feet long:



$$\sin(60°) = \frac{x}{96 in}$$

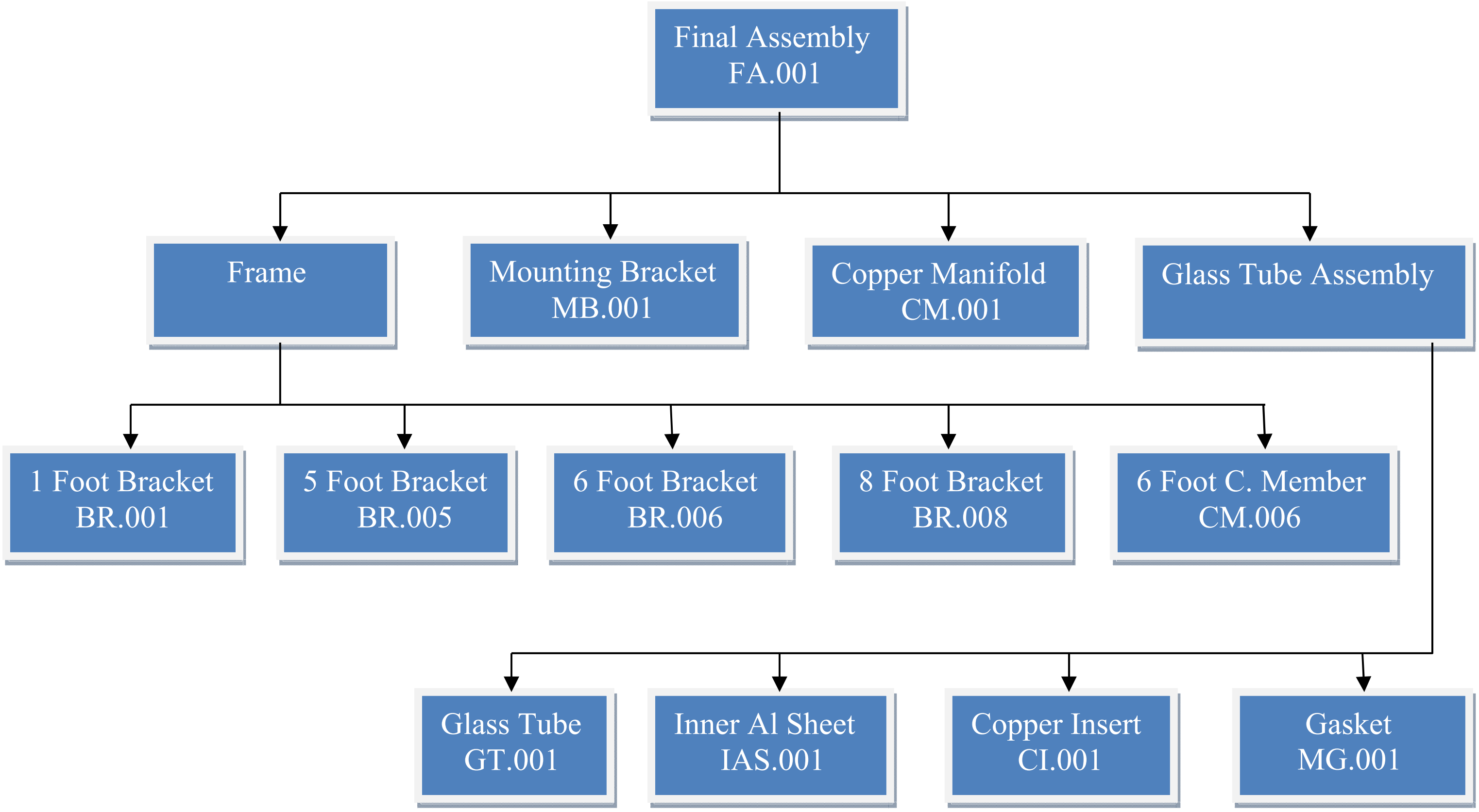
$$x = 96 in(\sin(60°)) = \boxed{83 in.}$$

- The distance between bolts on the frame can be adjusted to match the angle of the suns reflection for any given day (between 25°-75°)

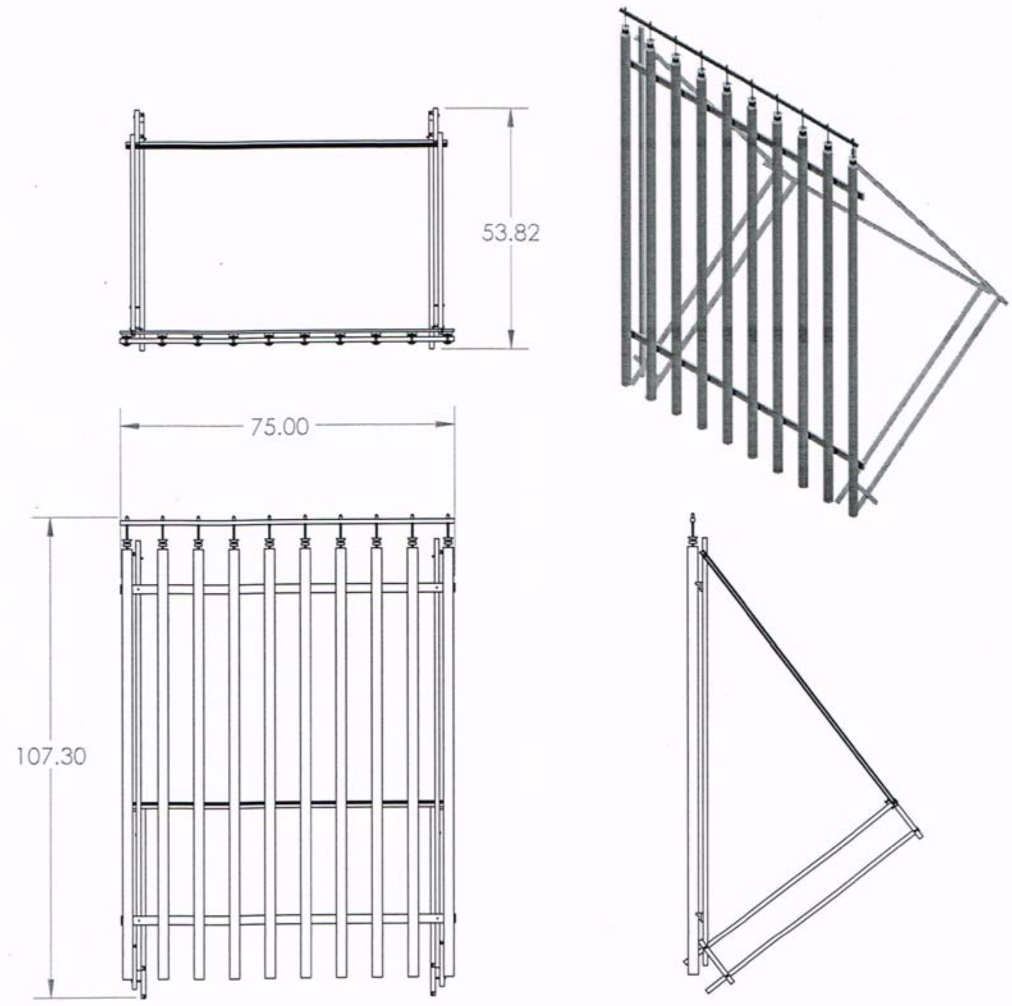
APPENDIX B – Sketches, Assembly drawings, Sub-assembly drawings, Part Drawings

Solidworks Model Rendering

Drawing Tree



Final Assembly



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

MATERIAL

FINISH

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

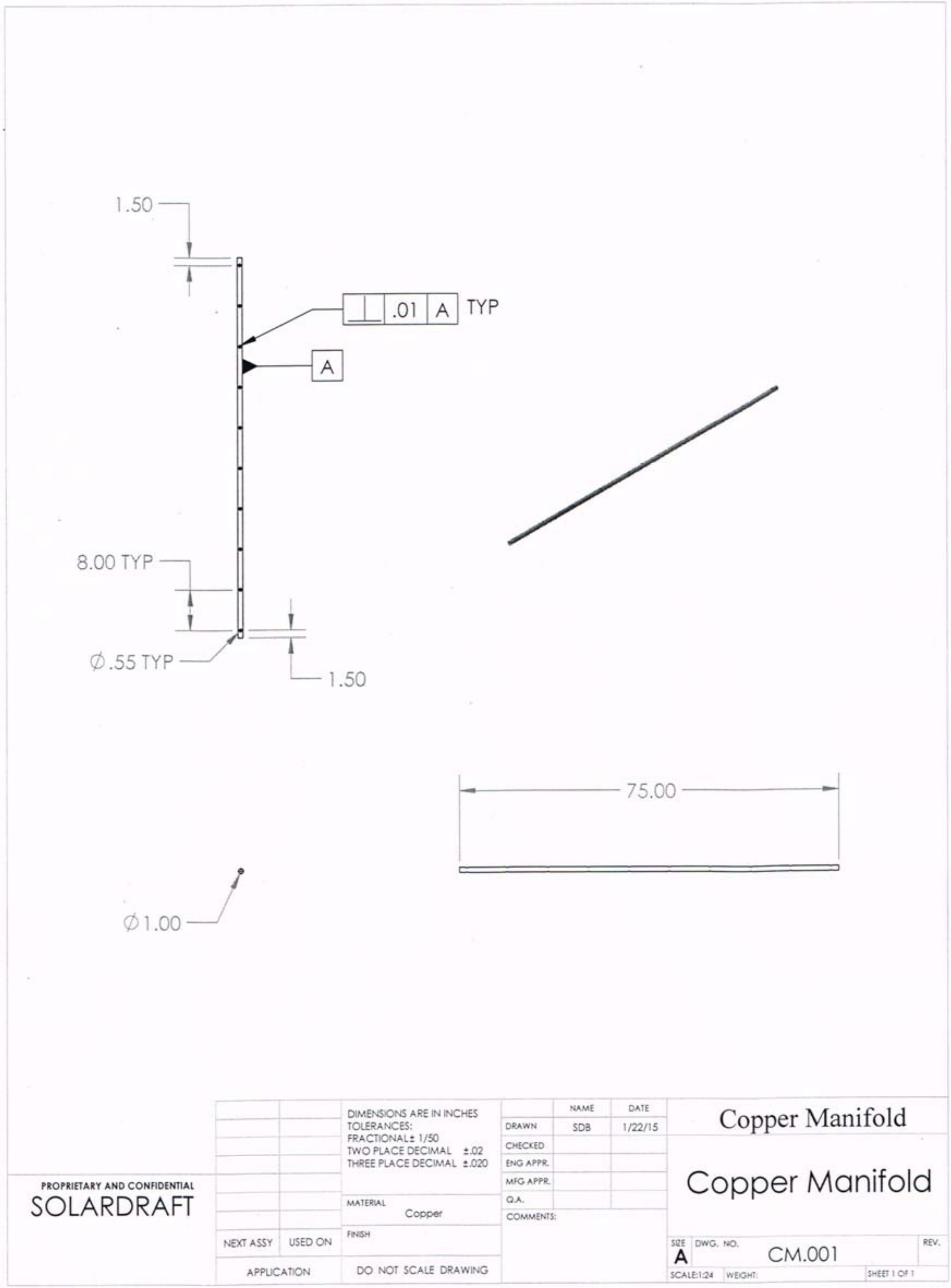
Final Assembly

Solar Collector

SIZE A | DWG. NO. FA.001 | REV.

SCALE:1:32 | WEIGHT: | SHEET 1 OF 1

Copper Manifold



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
Copper

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

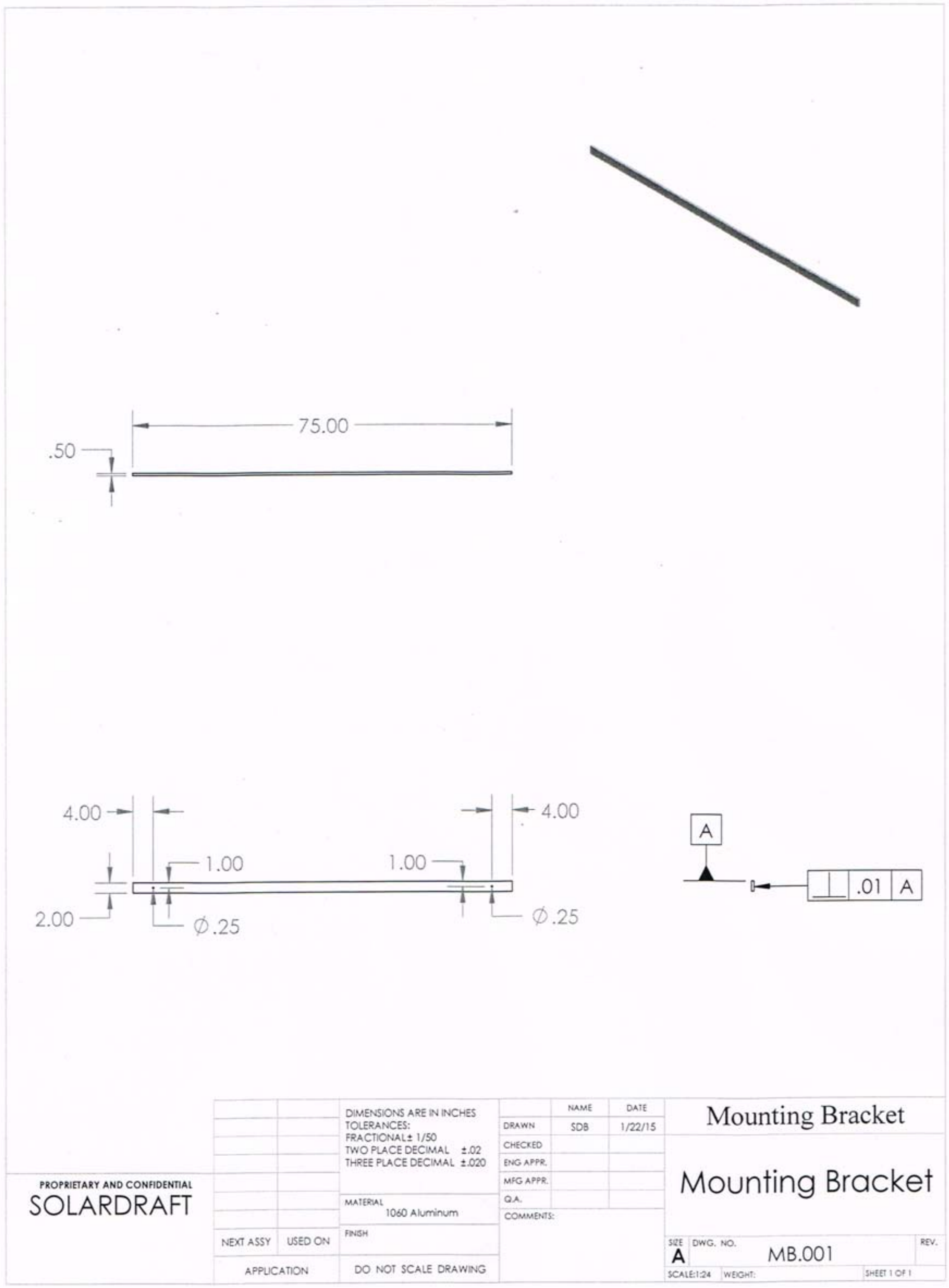
NEXT ASSY
USED ON
APPLICATION

Copper Manifold

Copper Manifold

SIZE A
DWG. NO. CM.001
REV.
SCALE:1:24
WEIGHT:
SHEET 1 OF 1

Mounting Bracket



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SOLARDRAFT

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
1060 Aluminum

FINISH

NEXT ASSY | USED ON
APPLICATION
DO NOT SCALE DRAWING

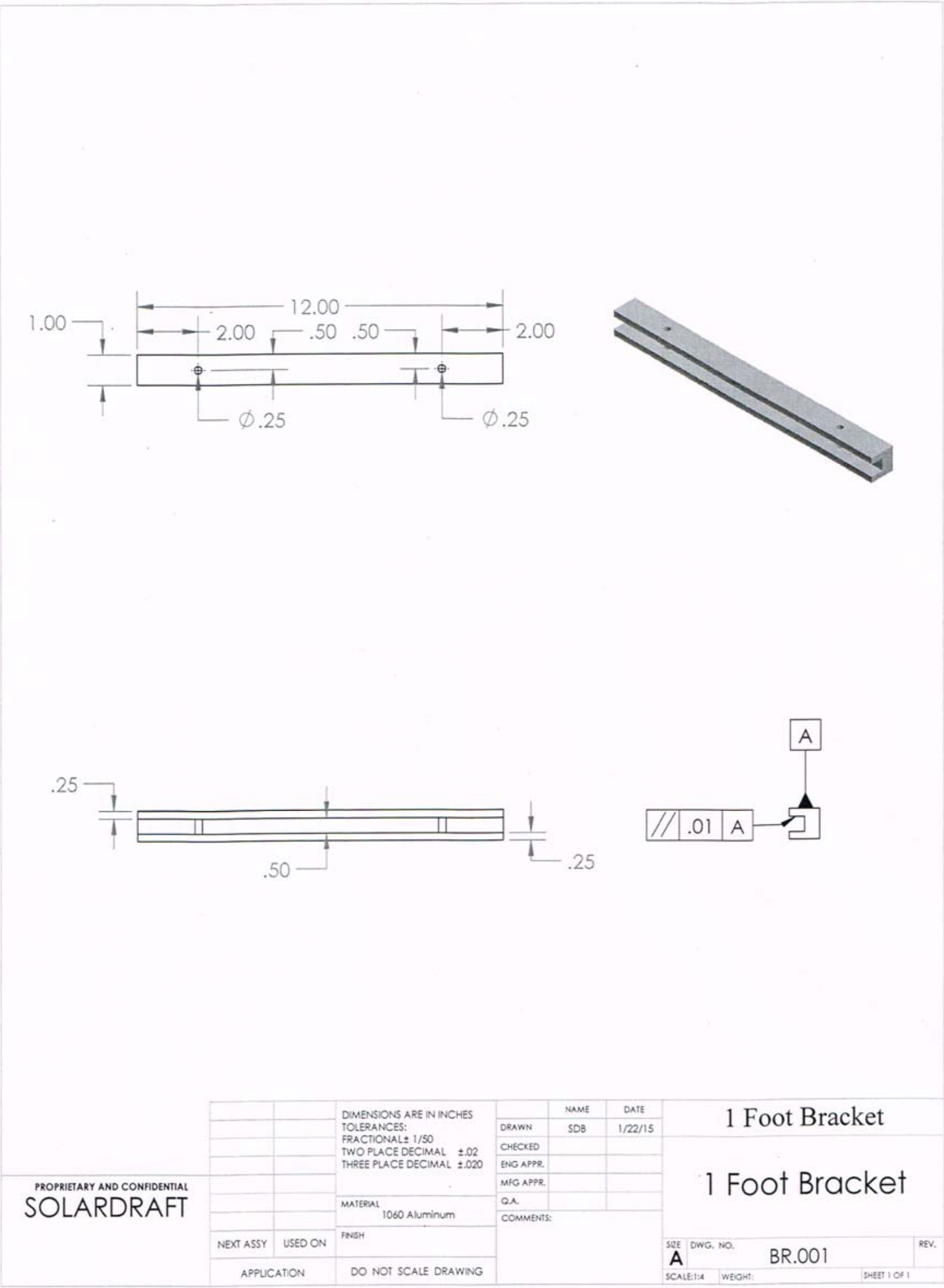
	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

Mounting Bracket

Mounting Bracket

SIZE A
DWG. NO. MB.001
REV.
SCALE:1:24
WEIGHT:
SHEET 1 OF 1

1 Foot Bracket



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
1060 Aluminum

FINISH

NEXT ASSY | USED ON
APPLICATION
DO NOT SCALE DRAWING

PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

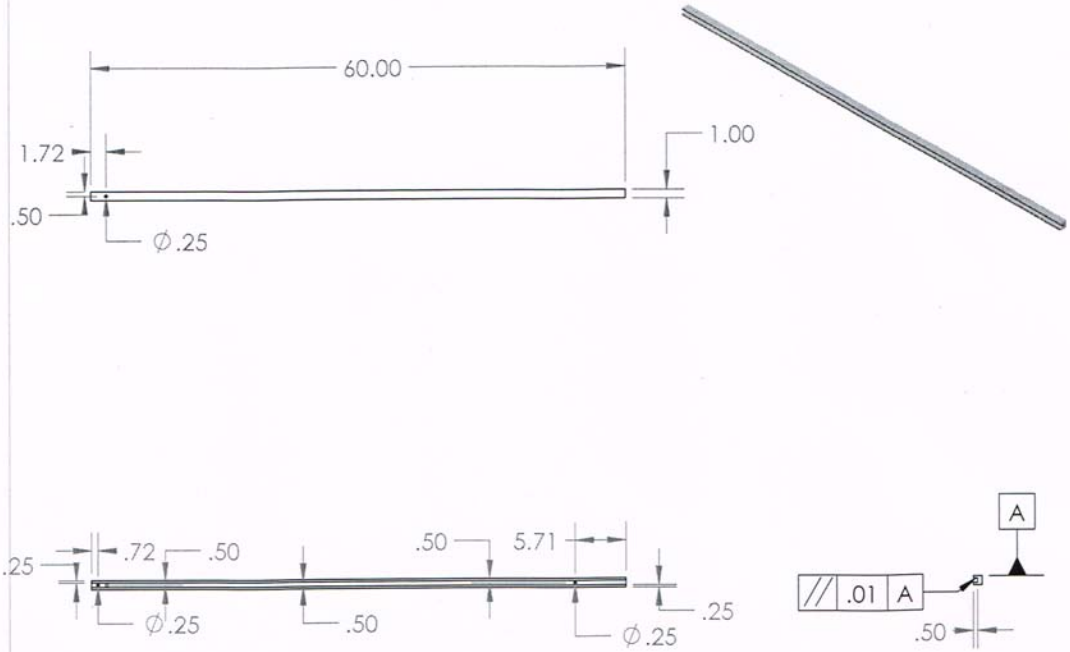
	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

1 Foot Bracket

1 Foot Bracket

SIZE A
DWG. NO. BR.001
REV.
SCALE:1:4
WEIGHT:
SHEET 1 OF 1

5 Foot Bracket



PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
1060 Aluminum

FINISH

NEXT ASSY | USED ON
APPLICATION | DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

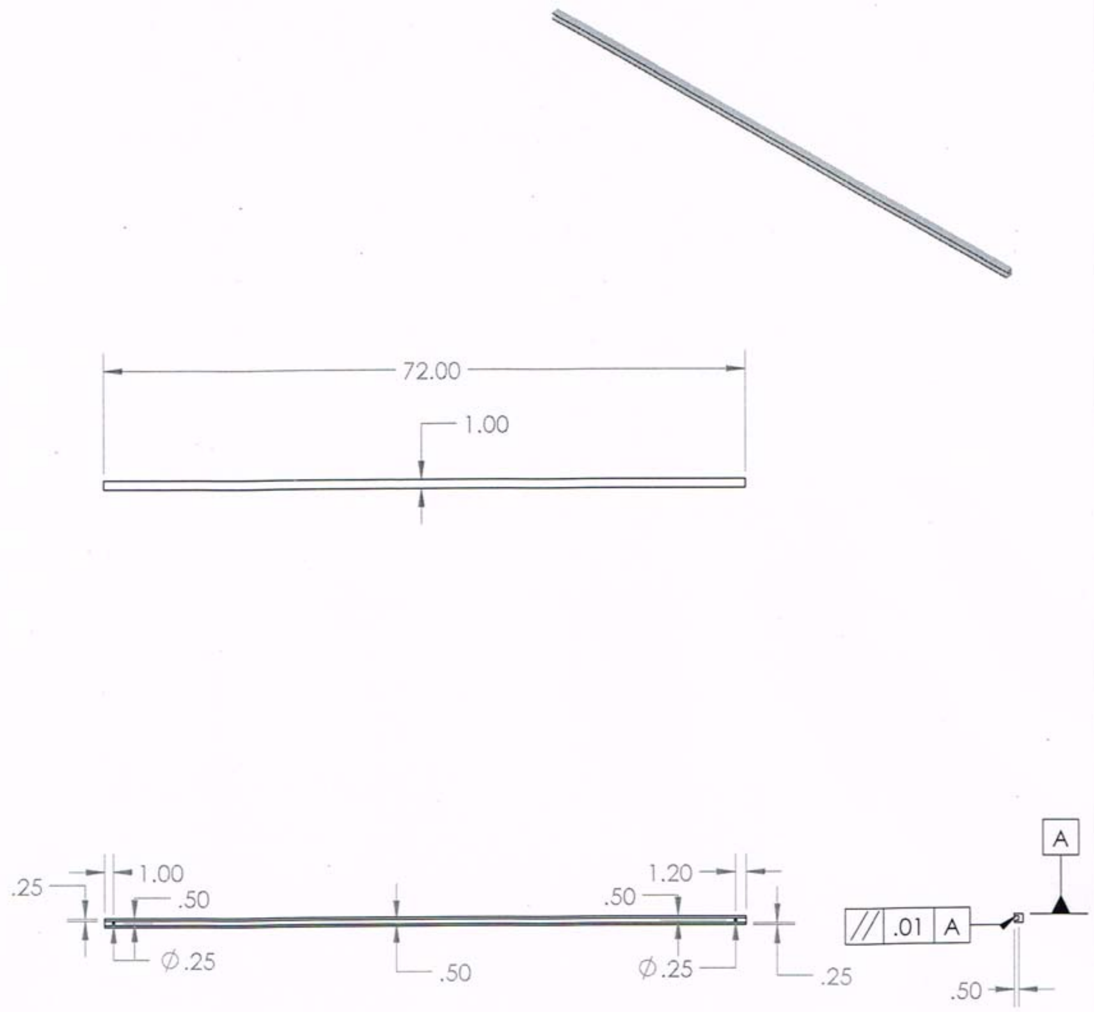
5 Foot Bracket

5 Foot Bracket

SIZE A DWG. NO. BR.005 REV.

SCALE:1:16 WEIGHT: SHEET 1 OF 1

6 Foot Bracket



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
1060 Aluminum

FINISH

NEXT ASSY | USED ON
APPLICATION
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

PROPRIETARY AND CONFIDENTIAL
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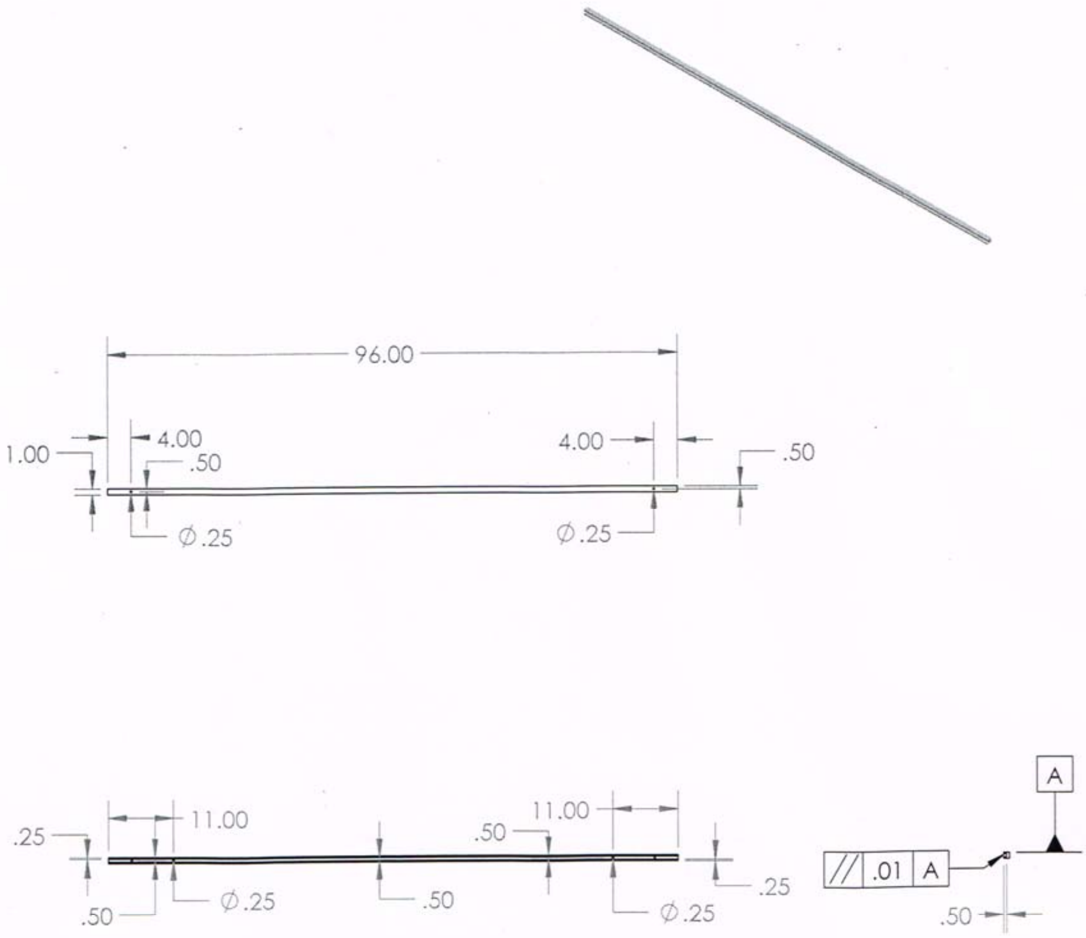
6 Foot Bracket

6 Foot Bracket

SIZE A
DWG. NO. BR.006
REV.
SCALE:1:16
WEIGHT:
SHEET 1 OF 1

8 Foot Bracket



PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

NEXT ASSY | USED ON
APPLICATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
1060 Aluminum

FINISH

DO NOT SCALE DRAWING

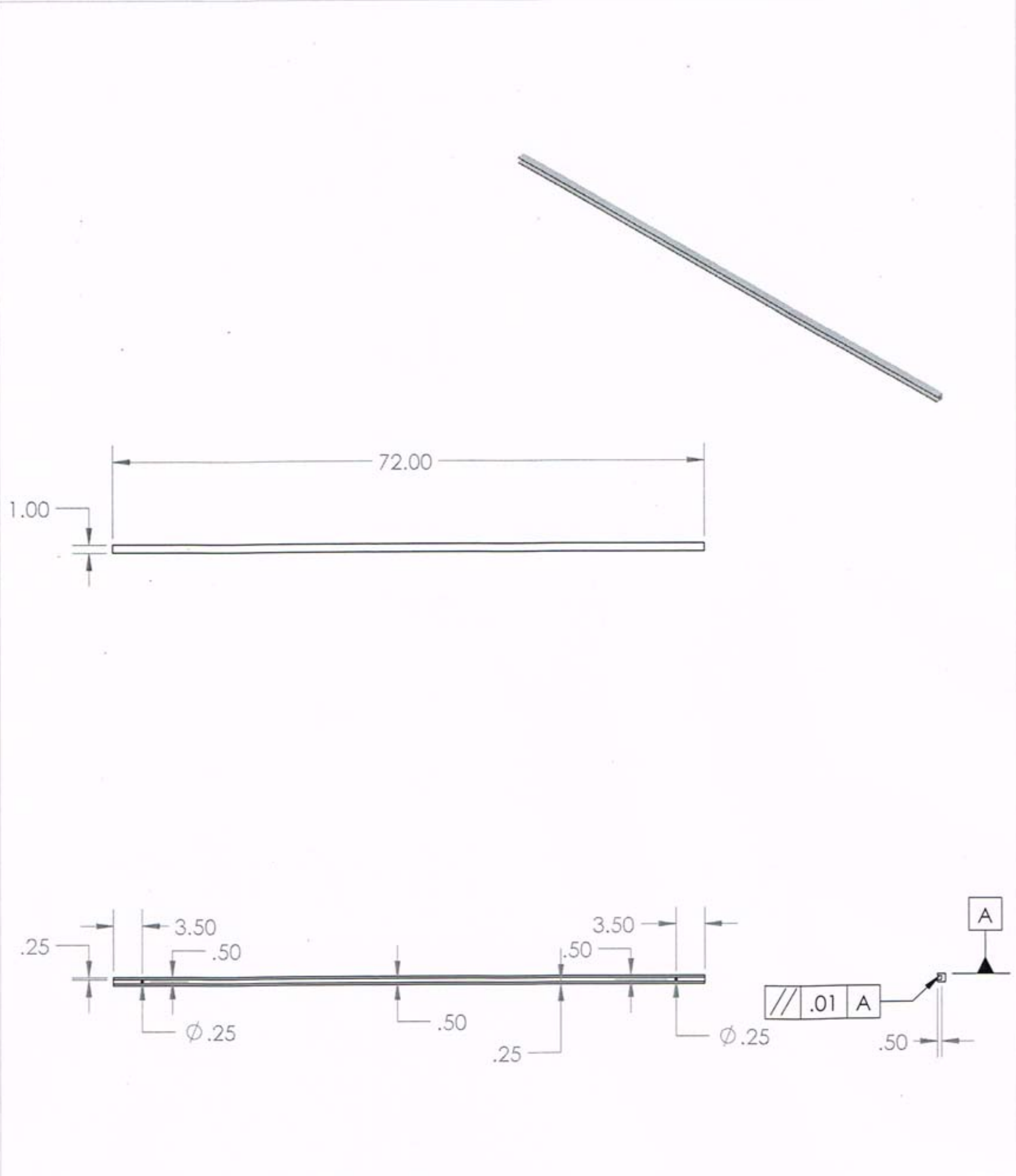
	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

8 Foot Bracket

8 Foot Bracket

SIZE A
DWG. NO. BR.008
REV.
SCALE:1:24 WEIGHT: SHEET 1 OF 1

6 Foot Cross Member



PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

NEXT ASSY
USED ON
APPLICATION

DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
1060 Aluminum

FINISH

DO NOT SCALE DRAWING

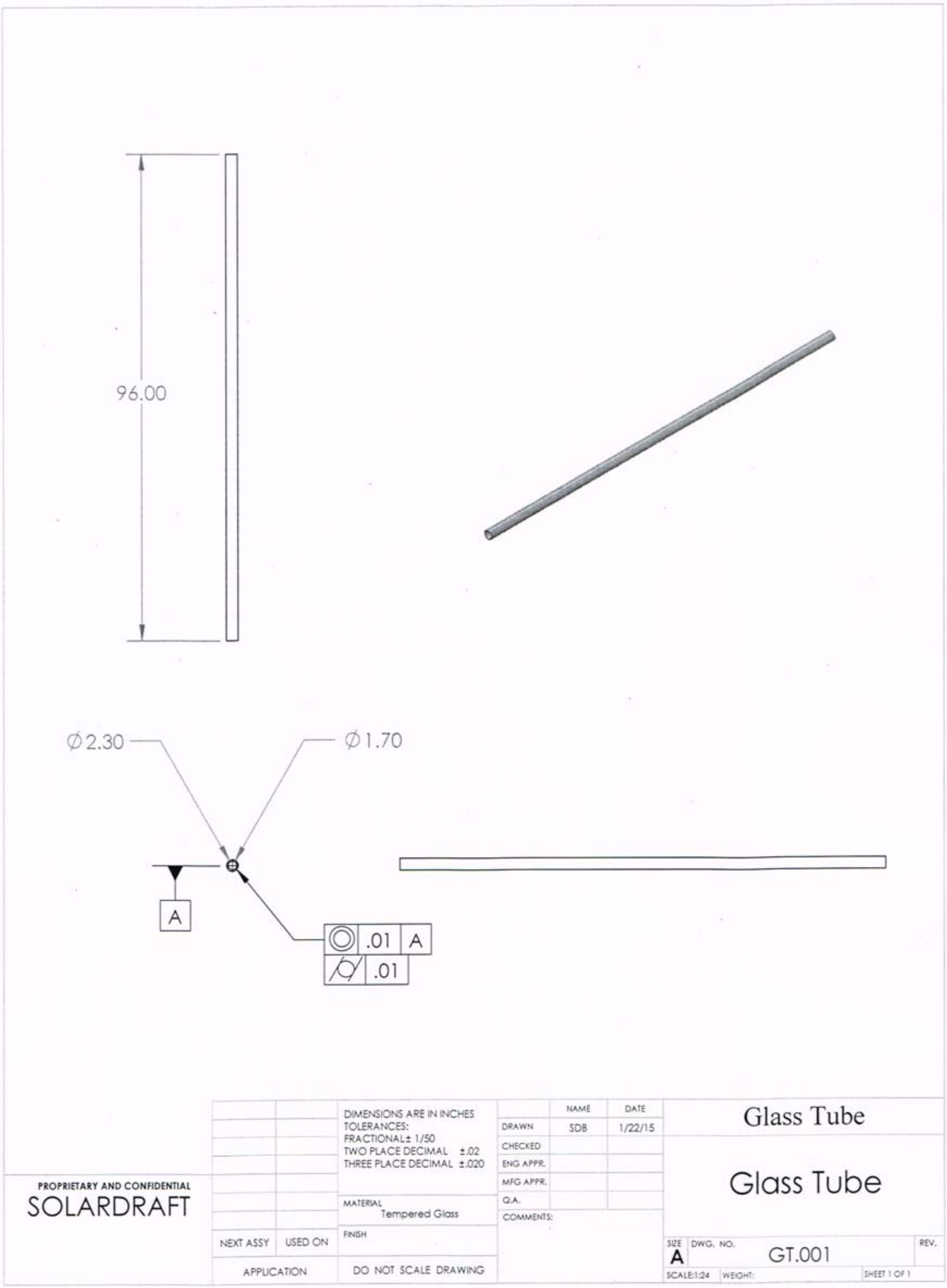
	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

6 Foot Cross Member

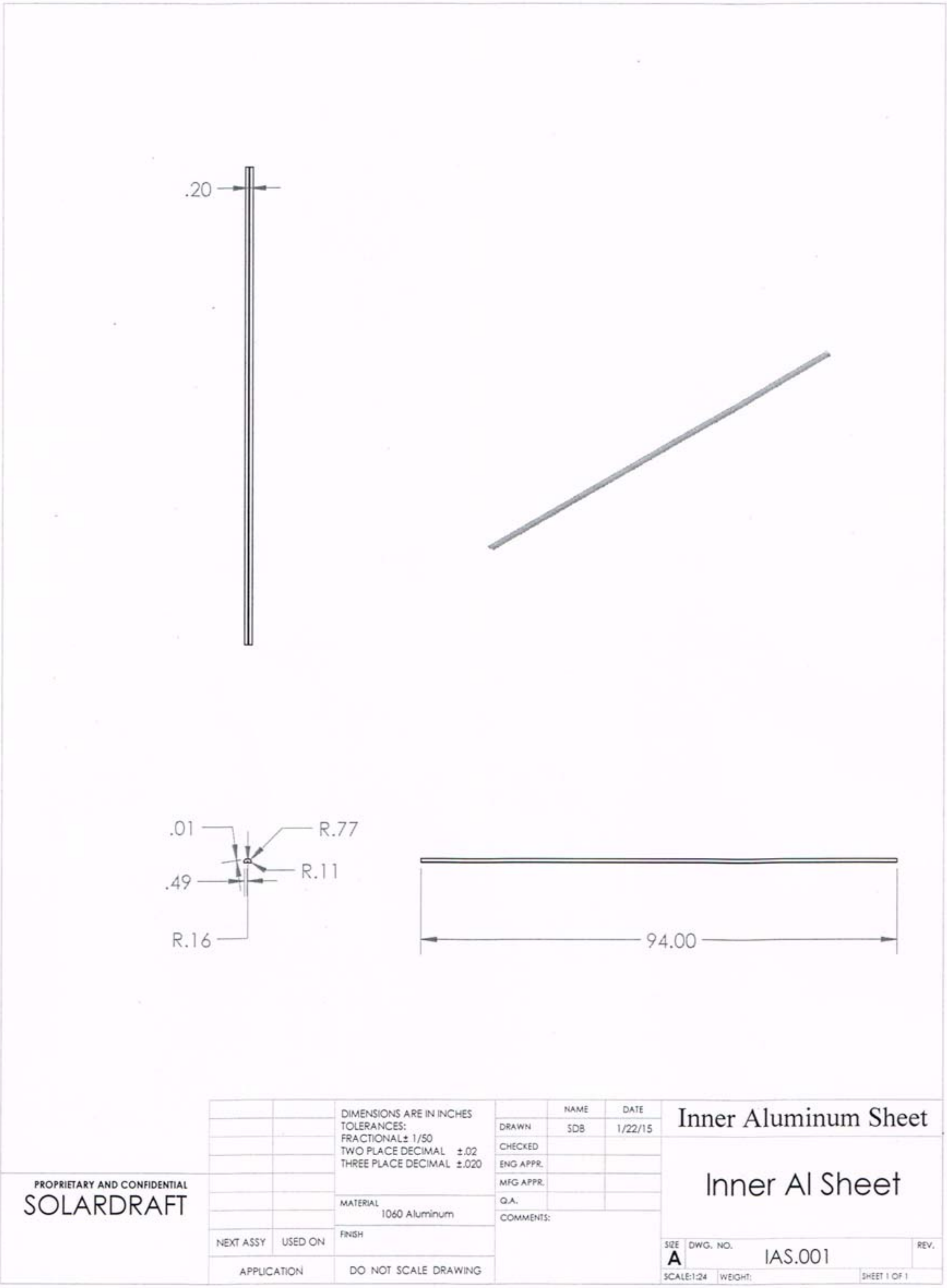
6 Foot C. Member

SIZE A
DWG. NO. CM.006
REV.
SCALE:1:16
WEIGHT:
SHEET 1 OF 1

Glass Tube


96.00
∅2.30
∅1.70
A
.01
A
.01
PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT
NEXT ASSY
USED ON
APPLICATION
DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020
MATERIAL
Tempered Glass
FINISH
DO NOT SCALE DRAWING
NAME
DATE
DRAWN
SDB
1/22/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
Glass Tube
Glass Tube
SIZE
A
DWG. NO.
GT.001
REV.
SCALE:1:24
WEIGHT:
SHEET 1 OF 1

Inner Aluminum Sheet



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Inner Aluminum Sheet

PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

MATERIAL
1060 Aluminum

FINISH

NEXT ASSY | USED ON

APPLICATION

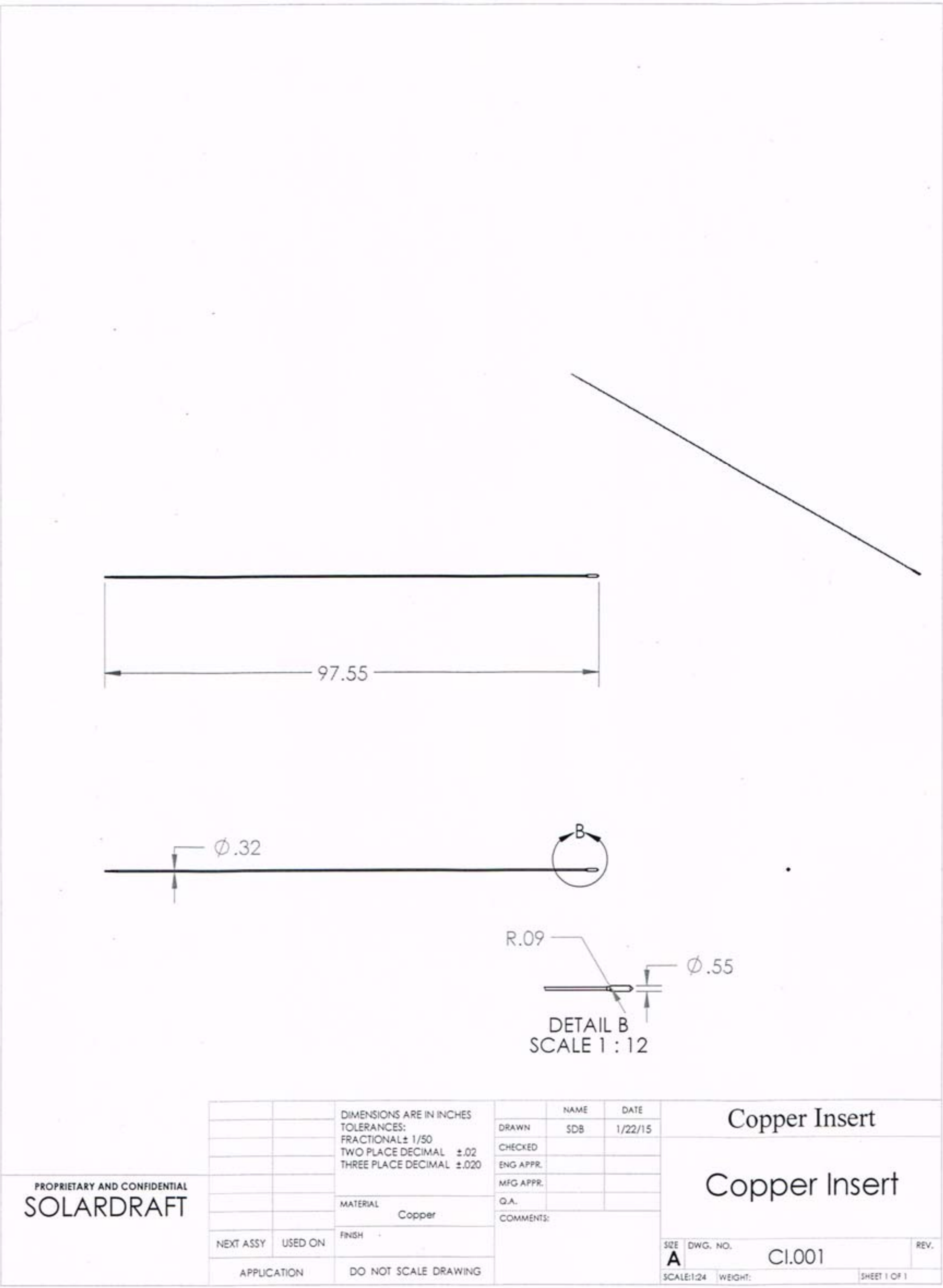
DO NOT SCALE DRAWING

Inner Al Sheet

SIZE A
DWG. NO. IAS.001
REV.

SCALE:1:24 WEIGHT: SHEET 1 OF 1

Copper Insert



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

MATERIAL
Copper

FINISH

NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

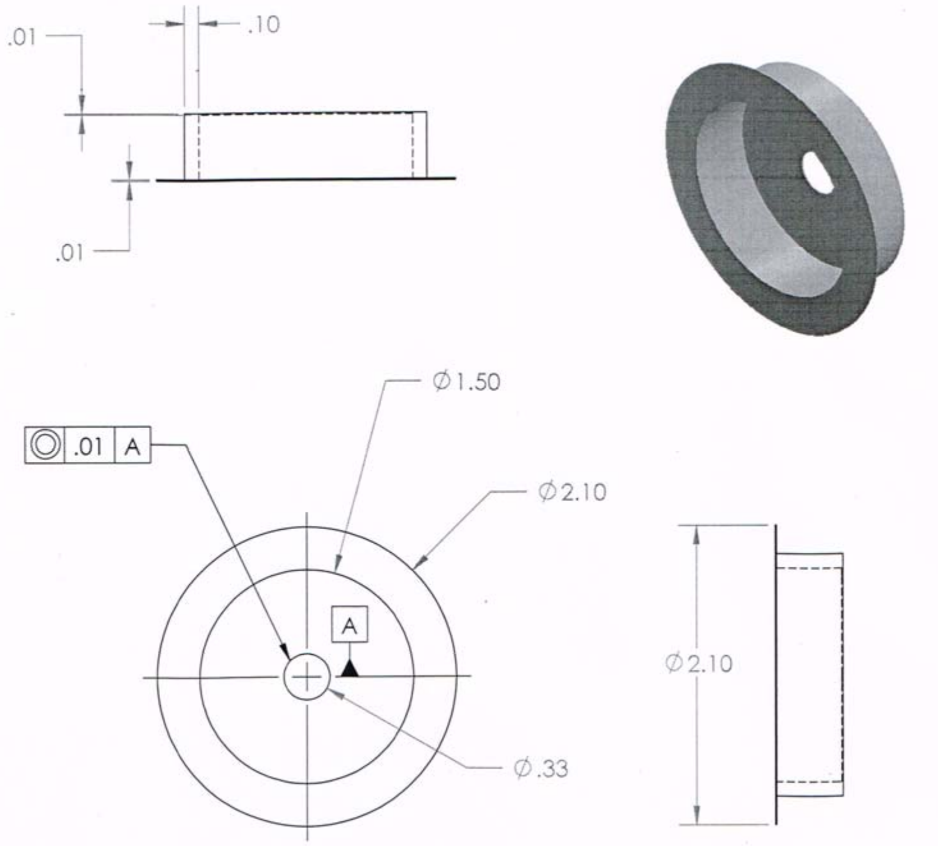
Copper Insert

Copper Insert

SIZE A
DWG. NO. CI.001
REV.
SCALE:1:24
WEIGHT:
SHEET 1 OF 1

PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

Metal Gasket



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

Metal Gasket

PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

MATERIAL
1060 Aluminum

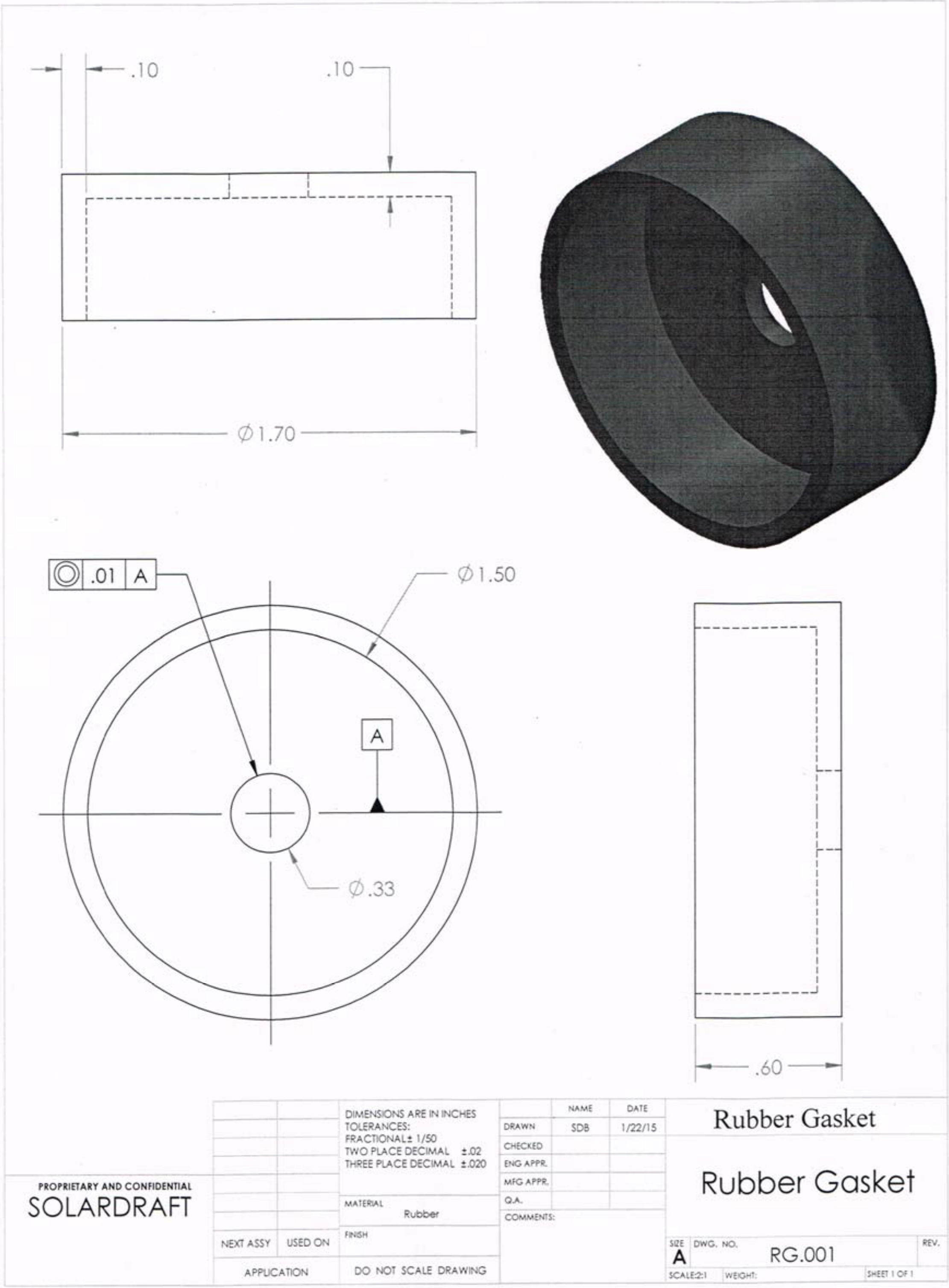
FINISH

NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

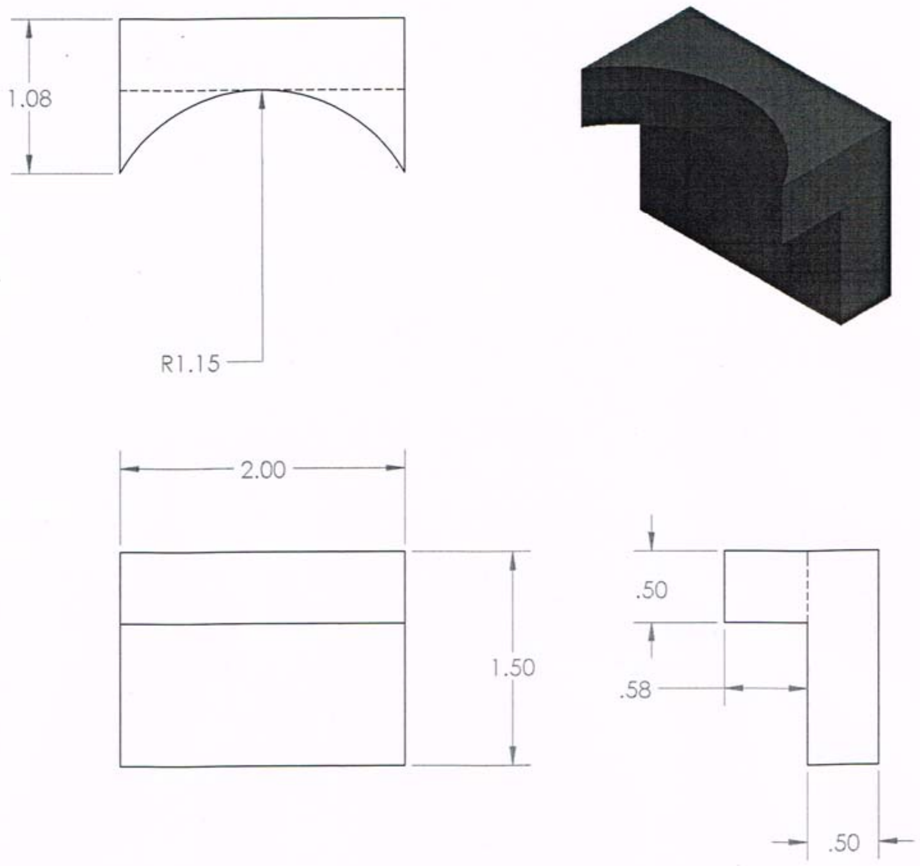
Metal Gasket

SIZE A
DWG. NO. MG.001
REV.
SCALE:1:1
WEIGHT:
SHEET 1 OF 1

Rubber Gasket



Tube Bracket



DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL± 1/50
TWO PLACE DECIMAL ±.02
THREE PLACE DECIMAL ±.020

	NAME	DATE
DRAWN	SDB	1/22/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		
COMMENTS:		

MATERIAL
Rubber

FINISH

NEXT ASSY | USED ON

APPLICATION

DO NOT SCALE DRAWING

PROPRIETARY AND CONFIDENTIAL
SOLARDRAFT

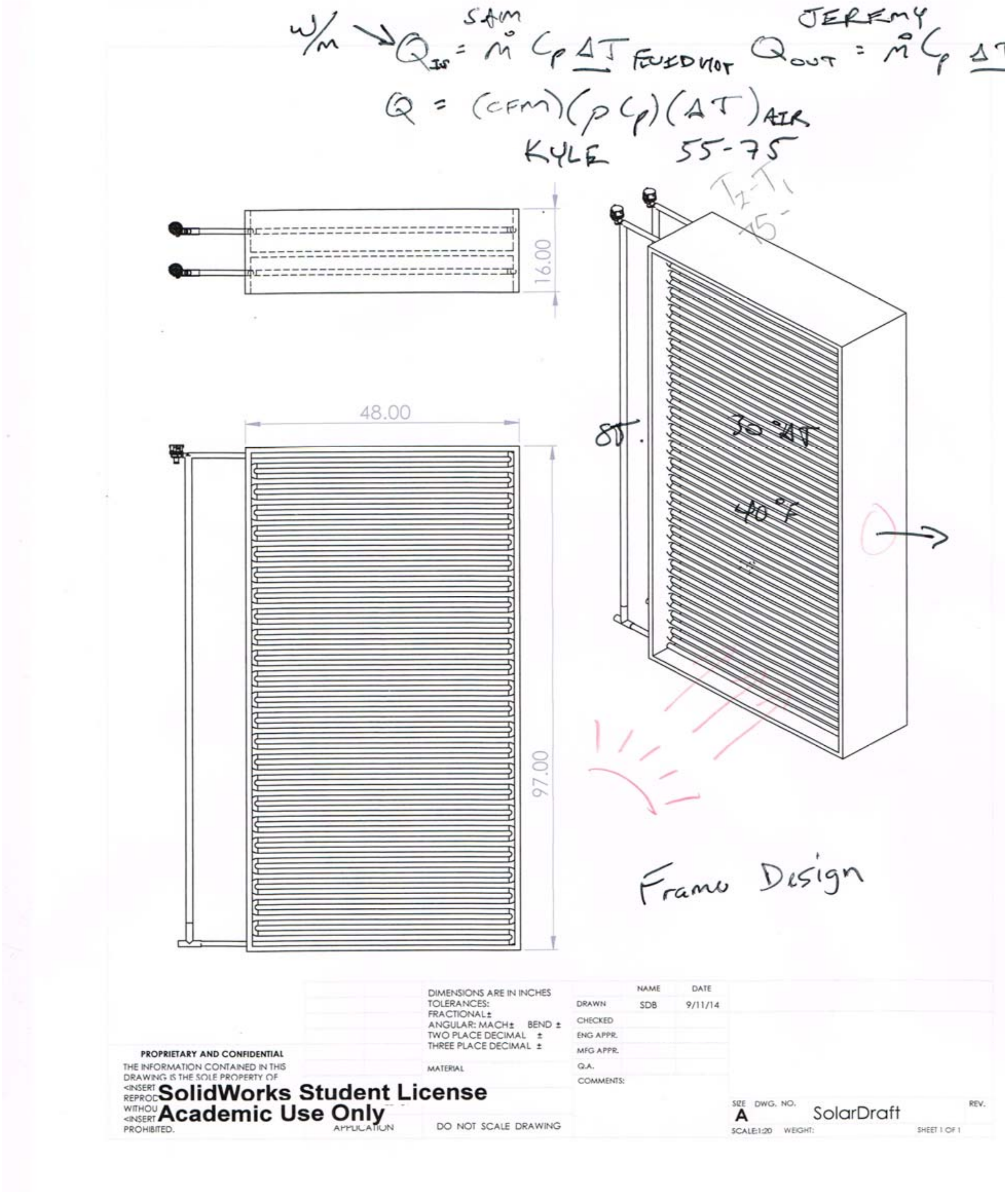
Tube Bracket

Tube Bracket

SIZE A | DWG. NO. TB.001 | REV.

SCALE:1:1 | WEIGHT: | SHEET 1 OF 1

Sketches



SAM

w/m → $Q_{in} = \dot{m} C_p \underline{\Delta T}$ fluid hot

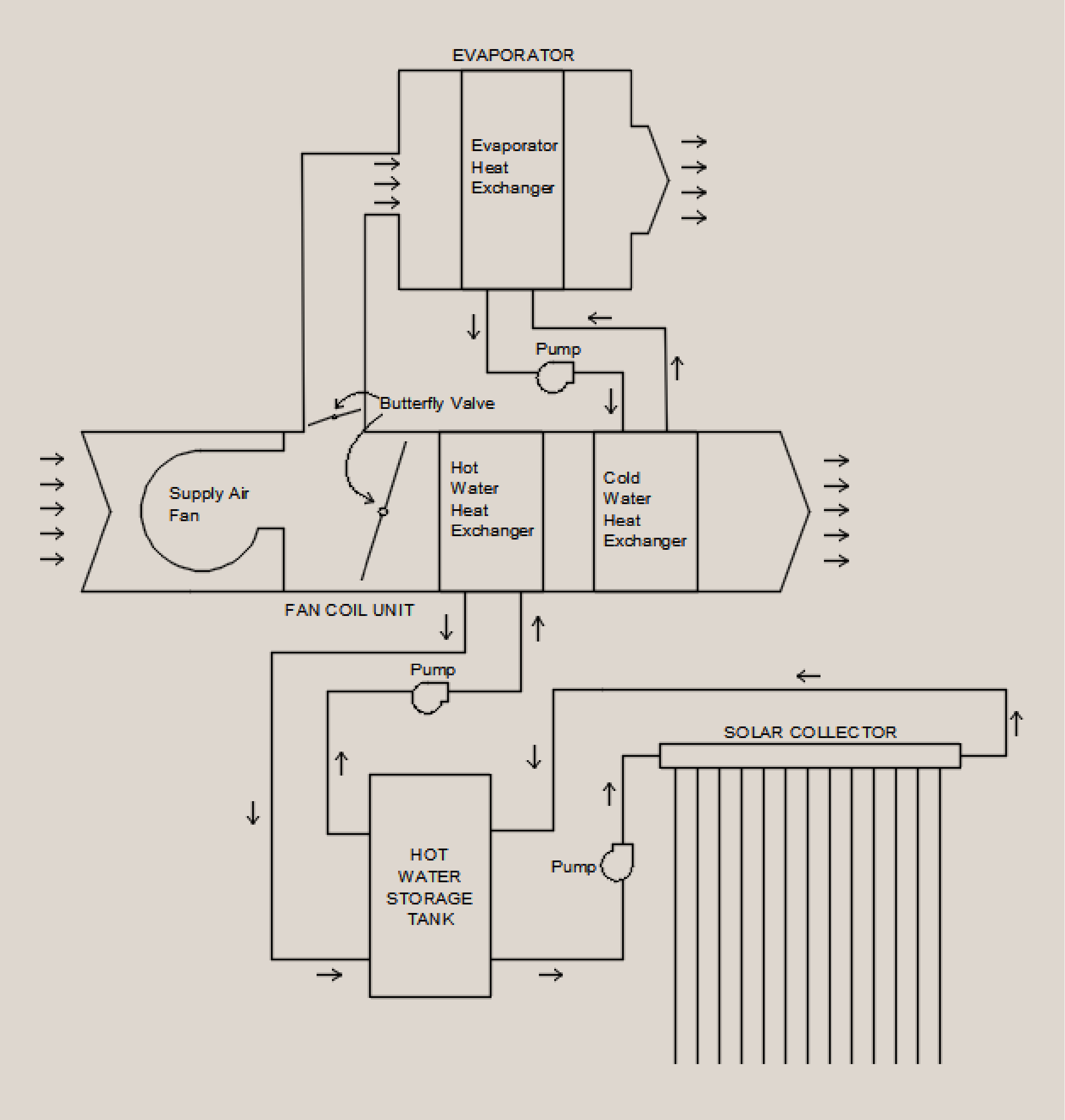
JEREMY

$Q_{out} = \dot{m} C_p \Delta T$

$Q = (CFM)(\rho C_p)(\Delta T)_{AIR}$

KYLE 55-75

System Diagram



Fin Configurations

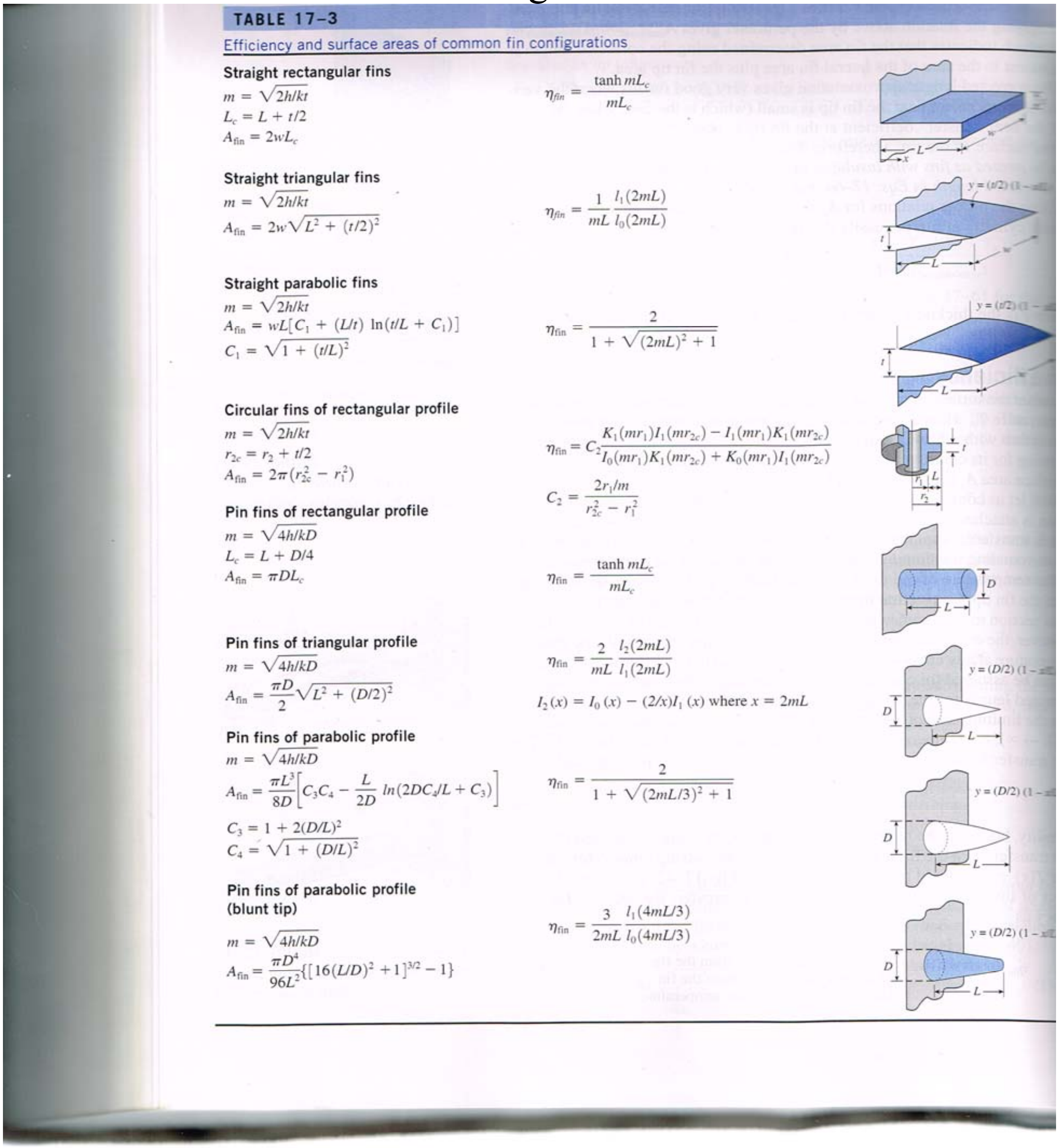


TABLE 17–3

Efficiency and surface areas of common fin configurations

Straight rectangular fins

$m = \sqrt{2h/kt}$

$L_c = L + t/2$

$A_{\text{fin}} = 2wL_c$

$$\eta_{fin} = \frac{\tanh mL_c}{mL_c}$$

Straight triangular fins

$m = \sqrt{2h/kt}$

$A_{\text{fin}} = 2w\sqrt{L^2 + (t/2)^2}$

$$\eta_{fin} = \frac{1}{mL}\frac{l_1(2mL)}{l_0(2mL)}$$

Straight parabolic fins

$m = \sqrt{2h/kt}$

$A_{\text{fin}} = wL[C_1 + (L/t)\ \ln(t/L + C_1)]$

$C_1 = \sqrt{1 + (t/L)^2}$

$$\eta_{\text{fin}} = \frac{2}{1 + \sqrt{(2mL)^2 + 1}}$$

Circular fins of rectangular profile

$m = \sqrt{2h/kt}$

$r_{2c} = r_2 + t/2$

$A_{\text{fin}} = 2\pi(r_{2c}^2 - r_1^2)$

$$\eta_{\text{fin}} = C_2\frac{K_1(mr_1)I_1(mr_{2c}) - I_1(mr_1)K_1(mr_{2c})}{I_0(mr_1)K_1(mr_{2c}) + K_0(mr_1)I_1(mr_{2c})}$$

$$C_2 = \frac{2r_1/m}{r_{2c}^2 - r_1^2}$$

Pin fins of rectangular profile

$m = \sqrt{4h/kD}$

$L_c = L + D/4$

$A_{\text{fin}} = \pi DL_c$

$$\eta_{\text{fin}} = \frac{\tanh mL_c}{mL_c}$$

Pin fins of triangular profile

$m = \sqrt{4h/kD}$

$A_{\text{fin}} = \frac{\pi D}{2}\sqrt{L^2 + (D/2)^2}$

$$\eta_{\text{fin}} = \frac{2}{mL}\frac{l_2(2mL)}{l_1(2mL)}$$

$I_2(x) = I_0(x) - (2/x)I_1(x)$ where $x = 2mL$

Pin fins of parabolic profile

$m = \sqrt{4h/kD}$

$A_{\text{fin}} = \frac{\pi L^3}{8D}\left[C_3C_4 - \frac{L}{2D}\ ln(2DC_4/L + C_3)\right]$

$C_3 = 1 + 2(D/L)^2$

$C_4 = \sqrt{1 + (D/L)^2}$

$$\eta_{\text{fin}} = \frac{2}{1 + \sqrt{(2mL/3)^2 + 1}}$$

Pin fins of parabolic profile (blunt tip)

$m = \sqrt{4h/kD}$

$A_{\text{fin}} = \frac{\pi D^4}{96L^2}\{[16(L/D)^2 + 1]^{3/2} - 1\}$

$$\eta_{\text{fin}} = \frac{3}{2mL}\frac{l_1(4mL/3)}{l_0(4mL/3)}$$

Saturation Table

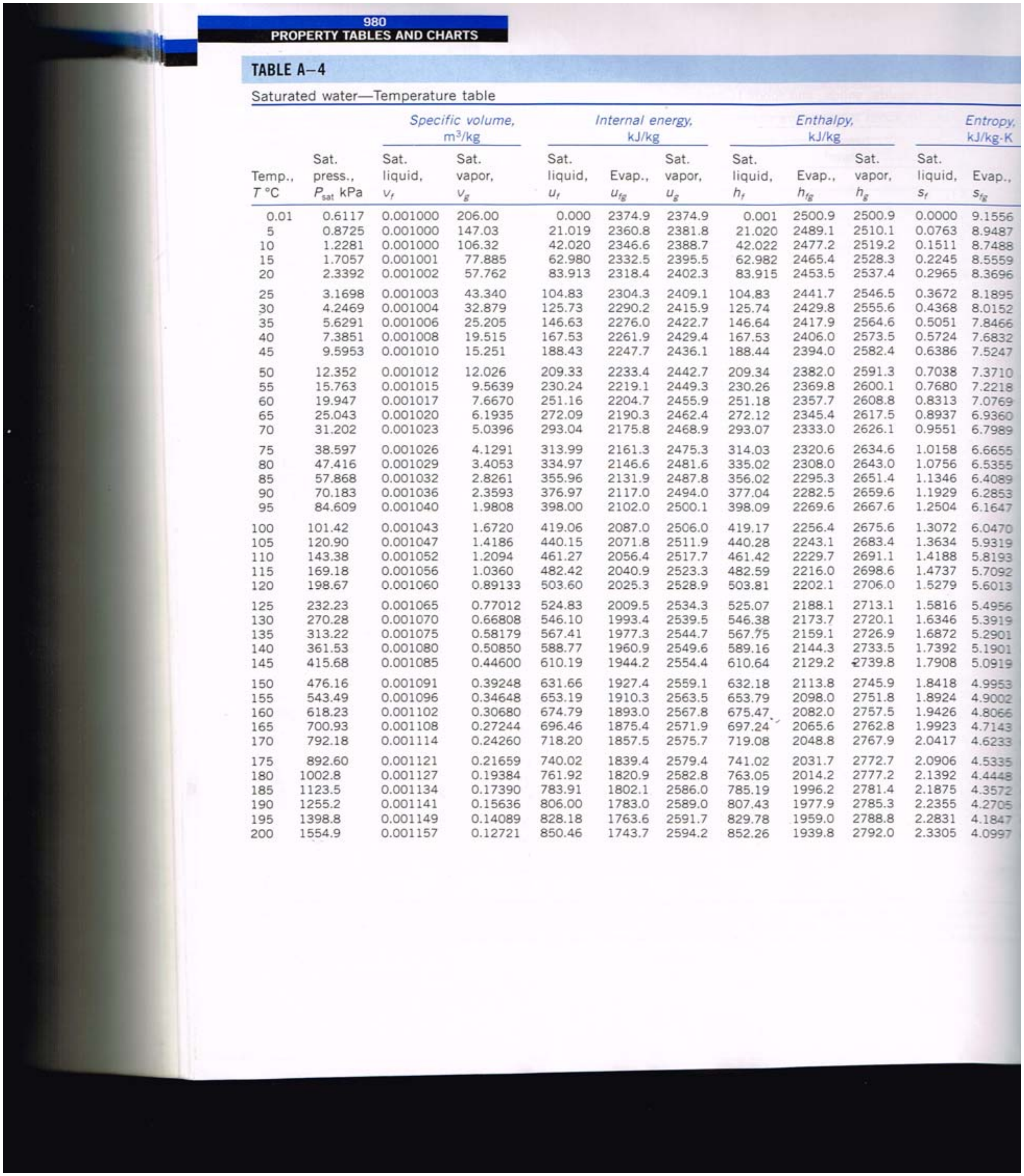


TABLE A–4

Saturated water—Temperature table

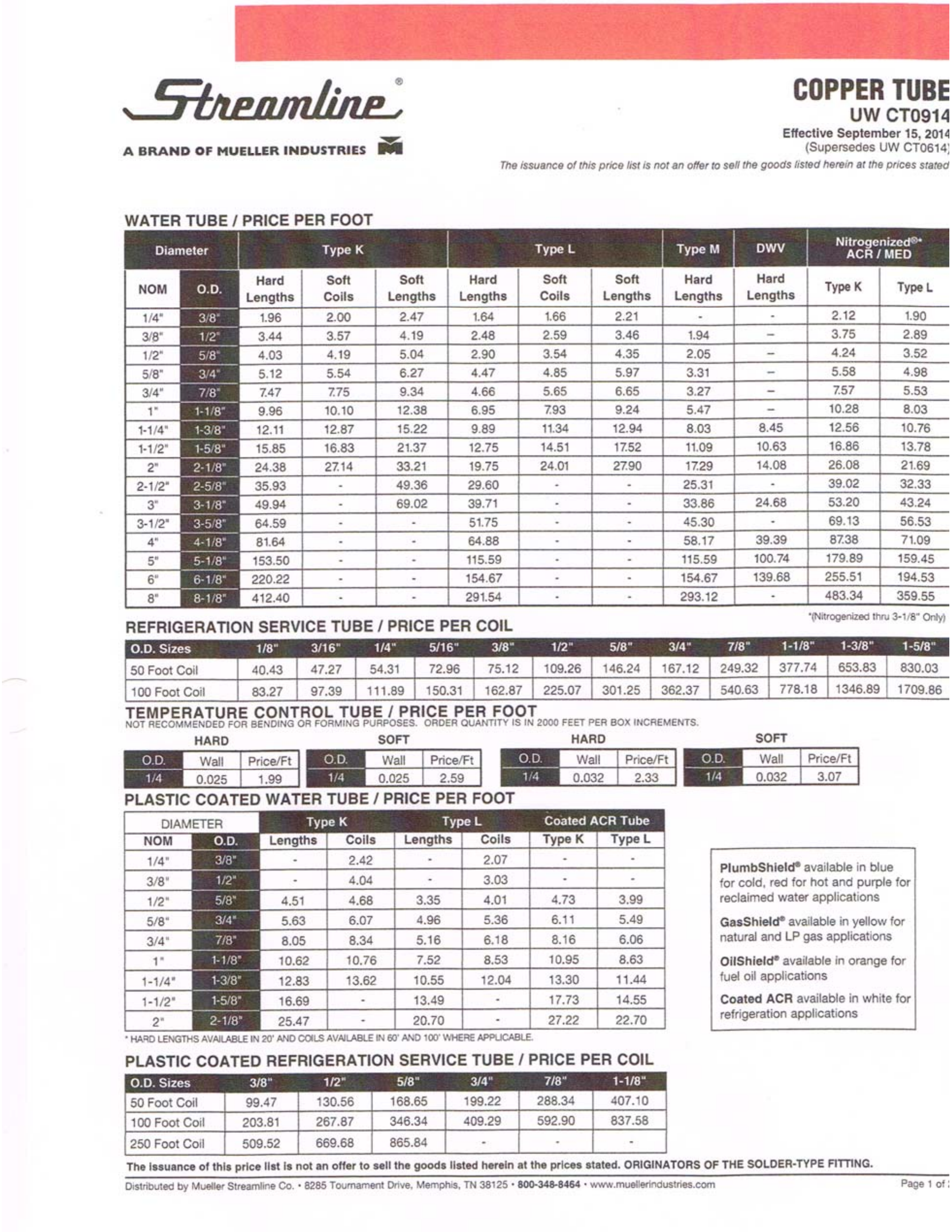
		Specific volume, m³/kg		*Internal energy,* kJ/kg			*Enthalpy,* kJ/kg			*Entropy,* kJ/kg·K	
Temp., T °C	Sat. press., P_{sat} kPa	Sat. liquid, v_f	Sat. vapor, v_g	Sat. liquid, u_f	Evap., u_{fg}	Sat. vapor, u_g	Sat. liquid, h_f	Evap., h_{fg}	Sat. vapor, h_g	Sat. liquid, s_f	Evap., s_{fg}
0.01	0.6117	0.001000	206.00	0.000	2374.9	2374.9	0.001	2500.9	2500.9	0.0000	9.1556
5	0.8725	0.001000	147.03	21.019	2360.8	2381.8	21.020	2489.1	2510.1	0.0763	8.9487
10	1.2281	0.001000	106.32	42.020	2346.6	2388.7	42.022	2477.2	2519.2	0.1511	8.7488
15	1.7057	0.001001	77.885	62.980	2332.5	2395.5	62.982	2465.4	2528.3	0.2245	8.5559
20	2.3392	0.001002	57.762	83.913	2318.4	2402.3	83.915	2453.5	2537.4	0.2965	8.3696
25	3.1698	0.001003	43.340	104.83	2304.3	2409.1	104.83	2441.7	2546.5	0.3672	8.1895
30	4.2469	0.001004	32.879	125.73	2290.2	2415.9	125.74	2429.8	2555.6	0.4368	8.0152
35	5.6291	0.001006	25.205	146.63	2276.0	2422.7	146.64	2417.9	2564.6	0.5051	7.8466
40	7.3851	0.001008	19.515	167.53	2261.9	2429.4	167.53	2406.0	2573.5	0.5724	7.6832
45	9.5953	0.001010	15.251	188.43	2247.7	2436.1	188.44	2394.0	2582.4	0.6386	7.5247
50	12.352	0.001012	12.026	209.33	2233.4	2442.7	209.34	2382.0	2591.3	0.7038	7.3710
55	15.763	0.001015	9.5639	230.24	2219.1	2449.3	230.26	2369.8	2600.1	0.7680	7.2218
60	19.947	0.001017	7.6670	251.16	2204.7	2455.9	251.18	2357.7	2608.8	0.8313	7.0769
65	25.043	0.001020	6.1935	272.09	2190.3	2462.4	272.12	2345.4	2617.5	0.8937	6.9360
70	31.202	0.001023	5.0396	293.04	2175.8	2468.9	293.07	2333.0	2626.1	0.9551	6.7989
75	38.597	0.001026	4.1291	313.99	2161.3	2475.3	314.03	2320.6	2634.6	1.0158	6.6655
80	47.416	0.001029	3.4053	334.97	2146.6	2481.6	335.02	2308.0	2643.0	1.0756	6.5355
85	57.868	0.001032	2.8261	355.96	2131.9	2487.8	356.02	2295.3	2651.4	1.1346	6.4089
90	70.183	0.001036	2.3593	376.97	2117.0	2494.0	377.04	2282.5	2659.6	1.1929	6.2853
95	84.609	0.001040	1.9808	398.00	2102.0	2500.1	398.09	2269.6	2667.6	1.2504	6.1647
100	101.42	0.001043	1.6720	419.06	2087.0	2506.0	419.17	2256.4	2675.6	1.3072	6.0470
105	120.90	0.001047	1.4186	440.15	2071.8	2511.9	440.28	2243.1	2683.4	1.3634	5.9319
110	143.38	0.001052	1.2094	461.27	2056.4	2517.7	461.42	2229.7	2691.1	1.4188	5.8193
115	169.18	0.001056	1.0360	482.42	2040.9	2523.3	482.59	2216.0	2698.6	1.4737	5.7092
120	198.67	0.001060	0.89133	503.60	2025.3	2528.9	503.81	2202.1	2706.0	1.5279	5.6013
125	232.23	0.001065	0.77012	524.83	2009.5	2534.3	525.07	2188.1	2713.1	1.5816	5.4956
130	270.28	0.001070	0.66808	546.10	1993.4	2539.5	546.38	2173.7	2720.1	1.6346	5.3919
135	313.22	0.001075	0.58179	567.41	1977.3	2544.7	567.75	2159.1	2726.9	1.6872	5.2901
140	361.53	0.001080	0.50850	588.77	1960.9	2549.6	589.16	2144.3	2733.5	1.7392	5.1901
145	415.68	0.001085	0.44600	610.19	1944.2	2554.4	610.64	2129.2	2739.8	1.7908	5.0919
150	476.16	0.001091	0.39248	631.66	1927.4	2559.1	632.18	2113.8	2745.9	1.8418	4.9953
155	543.49	0.001096	0.34648	653.19	1910.3	2563.5	653.79	2098.0	2751.8	1.8924	4.9002
160	618.23	0.001102	0.30680	674.79	1893.0	2567.8	675.47	2082.0	2757.5	1.9426	4.8066
165	700.93	0.001108	0.27244	696.46	1875.4	2571.9	697.24	2065.6	2762.8	1.9923	4.7143
170	792.18	0.001114	0.24260	718.20	1857.5	2575.7	719.08	2048.8	2767.9	2.0417	4.6233
175	892.60	0.001121	0.21659	740.02	1839.4	2579.4	741.02	2031.7	2772.7	2.0906	4.5335
180	1002.8	0.001127	0.19384	761.92	1820.9	2582.8	763.05	2014.2	2777.2	2.1392	4.4448
185	1123.5	0.001134	0.17390	783.91	1802.1	2586.0	785.19	1996.2	2781.4	2.1875	4.3572
190	1255.2	0.001141	0.15636	806.00	1783.0	2589.0	807.43	1977.9	2785.3	2.2355	4.2705
195	1398.8	0.001149	0.14089	828.18	1763.6	2591.7	829.78	1959.0	2788.8	2.2831	4.1847
200	1554.9	0.001157	0.12721	850.46	1743.7	2594.2	852.26	1939.8	2792.0	2.3305	4.0997

APPENDIX C – Parts List and Costs

Heat Coil Budget

Part Identifier	Part Description	Part Number	Source	Estimated Cost	Actual Cost
SM-Frame	A653 Galvanized	SM-A653	Online Metals	Donated	$0.00
	5x4 foot Sheet				$0.00
	24 gauge (.024 in.)				$0.00
SC-Tubing	Solar Collector	SC-103	Jeff Greear	Donated	$0.00
	Tubing (10, 3 feet)				$0.00
CT-Fasteners	Copper Tees (1.06 ID)	CT-106	Bob Mennenga	Donated	$0.00
	1.125 x 1.125 x 1.125				$0.00
C90 - Fasteners	Copper 90's (1.06 ID)	C90	Woods Ace	$46.95	$46.95
RM-Isulation	1 in. thick 4x8 foot	RM-148	Home Depot	Donated	$0.00
	Sheet R17 rated				$0.00
GV-Globe Valve	1 inch Globe Valve	KT-211-W-UL	Nibco	Donated	$0.00
	2 (for entry and exit)				$0.00
CP-Piping	Copper Piping	CP-125	Streamline	Donated	$0.00
	1.125 OD Nominal				$0.00
CC-Coil	Copper Coil				$0.00
	50 foot (1.125 OD)	CC-125	Streamline	Donated	$0.00
PT-Parabolic Trough	Mirror Grade Glazed	PT-45	Jim's Glass	Donated	$0.00
Total				$46.95	$46.95

APPENDIX D – Budget References



Streamline®

A BRAND OF MUELLER INDUSTRIES

COPPER TUBE

UW CT0914

Effective September 15, 2014

(Supersedes UW CT0614)

The issuance of this price list is not an offer to sell the goods listed herein at the prices stated

WATER TUBE / PRICE PER FOOT

Diameter		Type K			Type L			Type M	DWV	Nitrogenized®* ACR / MED	
NOM	O.D.	Hard Lengths	Soft Coils	Soft Lengths	Hard Lengths	Soft Coils	Soft Lengths	Hard Lengths	Hard Lengths	Type K	Type L
1/4"	3/8"	1.96	2.00	2.47	1.64	1.66	2.21	-	-	2.12	1.90
3/8"	1/2"	3.44	3.57	4.19	2.48	2.59	3.46	1.94	–	3.75	2.89
1/2"	5/8"	4.03	4.19	5.04	2.90	3.54	4.35	2.05	–	4.24	3.52
5/8"	3/4"	5.12	5.54	6.27	4.47	4.85	5.97	3.31	–	5.58	4.98
3/4"	7/8"	7.47	7.75	9.34	4.66	5.65	6.65	3.27	–	7.57	5.53
1"	1-1/8"	9.96	10.10	12.38	6.95	7.93	9.24	5.47	–	10.28	8.03
1-1/4"	1-3/8"	12.11	12.87	15.22	9.89	11.34	12.94	8.03	8.45	12.56	10.76
1-1/2"	1-5/8"	15.85	16.83	21.37	12.75	14.51	17.52	11.09	10.63	16.86	13.78
2"	2-1/8"	24.38	27.14	33.21	19.75	24.01	27.90	17.29	14.08	26.08	21.69
2-1/2"	2-5/8"	35.93	-	49.36	29.60	-	-	25.31	-	39.02	32.33
3"	3-1/8"	49.94	-	69.02	39.71	-	-	33.86	24.68	53.20	43.24
3-1/2"	3-5/8"	64.59	-	-	51.75	-	-	45.30	-	69.13	56.53
4"	4-1/8"	81.64	-	-	64.88	-	-	58.17	39.39	87.38	71.09
5"	5-1/8"	153.50	-	-	115.59	-	-	115.59	100.74	179.89	159.45
6"	6-1/8"	220.22	-	-	154.67	-	-	154.67	139.68	255.51	194.53
8"	8-1/8"	412.40	-	-	291.54	-	-	293.12	-	483.34	359.55

*(Nitrogenized thru 3-1/8" Only)

REFRIGERATION SERVICE TUBE / PRICE PER COIL

O.D. Sizes	1/8"	3/16"	1/4"	5/16"	3/8"	1/2"	5/8"	3/4"	7/8"	1-1/8"	1-3/8"	1-5/8"
50 Foot Coil	40.43	47.27	54.31	72.96	75.12	109.26	146.24	167.12	249.32	377.74	653.83	830.03
100 Foot Coil	83.27	97.39	111.89	150.31	162.87	225.07	301.25	362.37	540.63	778.18	1346.89	1709.86

TEMPERATURE CONTROL TUBE / PRICE PER FOOT

NOT RECOMMENDED FOR BENDING OR FORMING PURPOSES. ORDER QUANTITY IS IN 2000 FEET PER BOX INCREMENTS.

HARD

O.D.	Wall	Price/Ft
1/4	0.025	1.99

SOFT

O.D.	Wall	Price/Ft
1/4	0.025	2.59

HARD

O.D.	Wall	Price/Ft
1/4	0.032	2.33

SOFT

O.D.	Wall	Price/Ft
1/4	0.032	3.07

PLASTIC COATED WATER TUBE / PRICE PER FOOT

DIAMETER		Type K		Type L		Coated ACR Tube	
NOM	O.D.	Lengths	Coils	Lengths	Coils	Type K	Type L
1/4"	3/8"	-	2.42	-	2.07	-	-
3/8"	1/2"	-	4.04	-	3.03	-	-
1/2"	5/8"	4.51	4.68	3.35	4.01	4.73	3.99
5/8"	3/4"	5.63	6.07	4.96	5.36	6.11	5.49
3/4"	7/8"	8.05	8.34	5.16	6.18	8.16	6.06
1"	1-1/8"	10.62	10.76	7.52	8.53	10.95	8.63
1-1/4"	1-3/8"	12.83	13.62	10.55	12.04	13.30	11.44
1-1/2"	1-5/8"	16.69	-	13.49	-	17.73	14.55
2"	2-1/8"	25.47	-	20.70	-	27.22	22.70

* HARD LENGTHS AVAILABLE IN 20' AND COILS AVAILABLE IN 60' AND 100' WHERE APPLICABLE.

PlumbShield® available in blue for cold, red for hot and purple for reclaimed water applications

GasShield® available in yellow for natural and LP gas applications

OilShield® available in orange for fuel oil applications

Coated ACR available in white for refrigeration applications

PLASTIC COATED REFRIGERATION SERVICE TUBE / PRICE PER COIL

O.D. Sizes	3/8"	1/2"	5/8"	3/4"	7/8"	1-1/8"
50 Foot Coil	99.47	130.56	168.65	199.22	288.34	407.10
100 Foot Coil	203.81	267.87	346.34	409.29	592.90	837.58
250 Foot Coil	509.52	669.68	865.84	-	-	-

The issuance of this price list is not an offer to sell the goods listed herein at the prices stated. ORIGINATORS OF THE SOLDER-TYPE FITTING.

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REFERENCE INFORMATION

COPPER TUBE

		Type K		Type L / ACR		Type M		DWV	
STANDARD* LENGTHS		**HARD** 20' Lengths **COILS** 60' thru 1-1/2 100' thru 1-1/4 40' and 60' - 2" only		**HARD** 20' Lengths **COILS** 60' thru 1-1/2 100' thru 1-1/4 40' - 2" only		**HARD** 20' Lengths **COILS** Consult		**HARD** 20' Lengths	
NOM	**O.D.**	**WALL**	**WGT/FT**	**WALL**	**WGT/FT**	**WALL**	**WGT/FT**	**WALL**	**WGT/FT**
1/4"	3/8"	0.035	0.145	0.030	0.126	0.025	0.106	—	—
3/8"	1/2"	0.049	0.269	0.035	0.198	0.025	0.145	—	—
1/2"	5/8"	0.049	0.344	0.040	0.285	0.028	0.204	—	—
5/8"	3/4"	0.049	0.418	0.042	0.362	0.030	0.263	—	—
3/4"	7/8"	0.065	0.641	0.045	0.455	0.032	0.328	—	—
1"	1-1/8"	0.065	0.839	0.050	0.655	0.035	0.465	—	—
1-1/4"	1-3/8"	0.065	1.04	0.055	0.884	0.042	0.682	0.040	0.650
1-1/2"	1-5/8"	0.072	1.36	0.060	1.14	0.049	0.940	0.042	0.809
2"	2-1/8"	0.083	2.06	0.070	1.75	0.058	1.46	0.042	1.07
2-1/2"	2-5/8"	0.095	2.93	0.080	2.48	0.065	2.03	—	—
3"	3-1/8"	0.109	4.00	0.090	3.33	0.072	2.68	0.045	1.69
3-1/2"	3-5/8"	0.120	5.12	0.100	4.29	0.083	3.58	—	—
4"	4-1/8"	0.134	6.51	0.110	5.38	0.095	4.66	0.058	2.87
5"	5-1/8"	0.160	9.67	0.125	7.61	0.109	6.66	0.072	4.43
6"	6-1/8"	0.192	13.90	0.140	10.20	0.122	8.92	0.083	6.10
8"	8-1/8	0.271	25.90	0.200	19.30	0.170	16.46	—	—

* FOR SPECIAL LENGTHS OR TEMPERS CONSULT FOR PRICE AND AVAILABILITY.

REFRIGERATION SERVICE TUBE

O.D.	WALL THICKNESS	WEIGHT PER FOOT	WEIGHT PER COIL*	COIL DIAMETER	COILS PER MASTER	WEIGHT PER MASTER
1/8"	0.030	0.0347	1.74	14-3/4"	10	17.4
3/16"	0.030	0.0575	2.88	14-3/4"	10	28.80
1/4"	0.030	0.0804	4.02	14-3/4"	10	40.20
5/16"	0.032	0.109	5.45	14-3/4"	10	54.50
3/8"	0.032	0.134	6.70	16-1/2"	10	67.00
1/2"	0.032	0.182	9.10	20"	5	45.50
5/8"	0.035	0.251	12.55	22"	5	62.75
3/4"	0.035	0.305	15.25	25"	3	45.75
7/8"	0.045	0.455	22.75	27-1/2"	3	22.75
1-1/8"	0.050	0.655	32.75	34-1/2"	—	32.75
1-3/8"	0.055	0.884	44.20	39-1/2"	—	44.20
1-5/8"	0.060	1.14	57.00	42"	—	57.00

* STANDARD 50' COIL – 100' COILS ALSO AVAILABLE AS STANDARD STOCK ITEM.

TEMPERATURE CONTROL TUBE

PACKED 2000' PER BOX

O.D.	WALL	WGT/FT
1/4"	0.025	0.0685

O.D.	WALL	WGT/FT
1/4"	0.032	0.0849

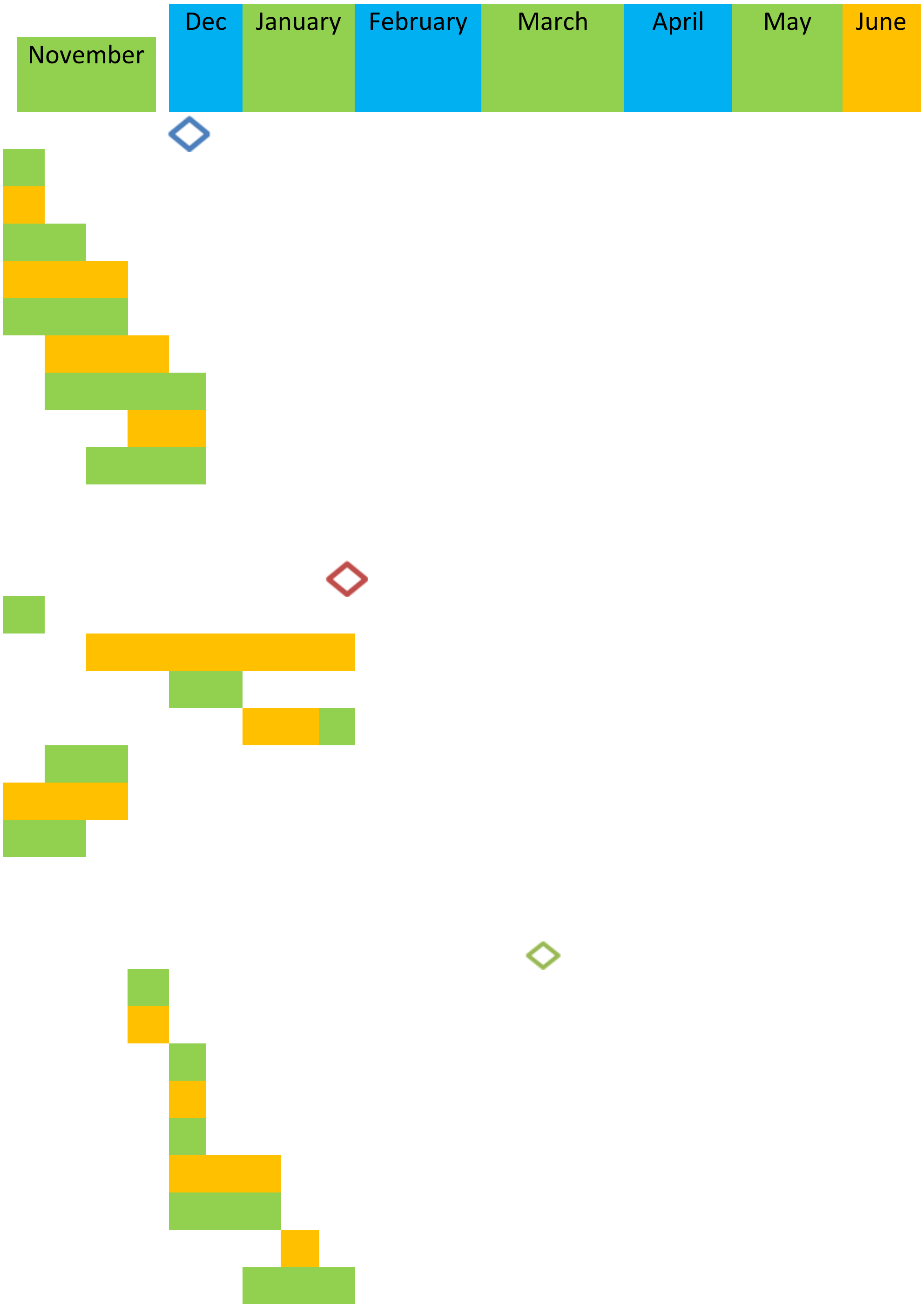
PLASTIC COATED COPPER TUBE

Polyethylene coating made from low density LDPE resin and is extruded at 0.025" minimum wall.

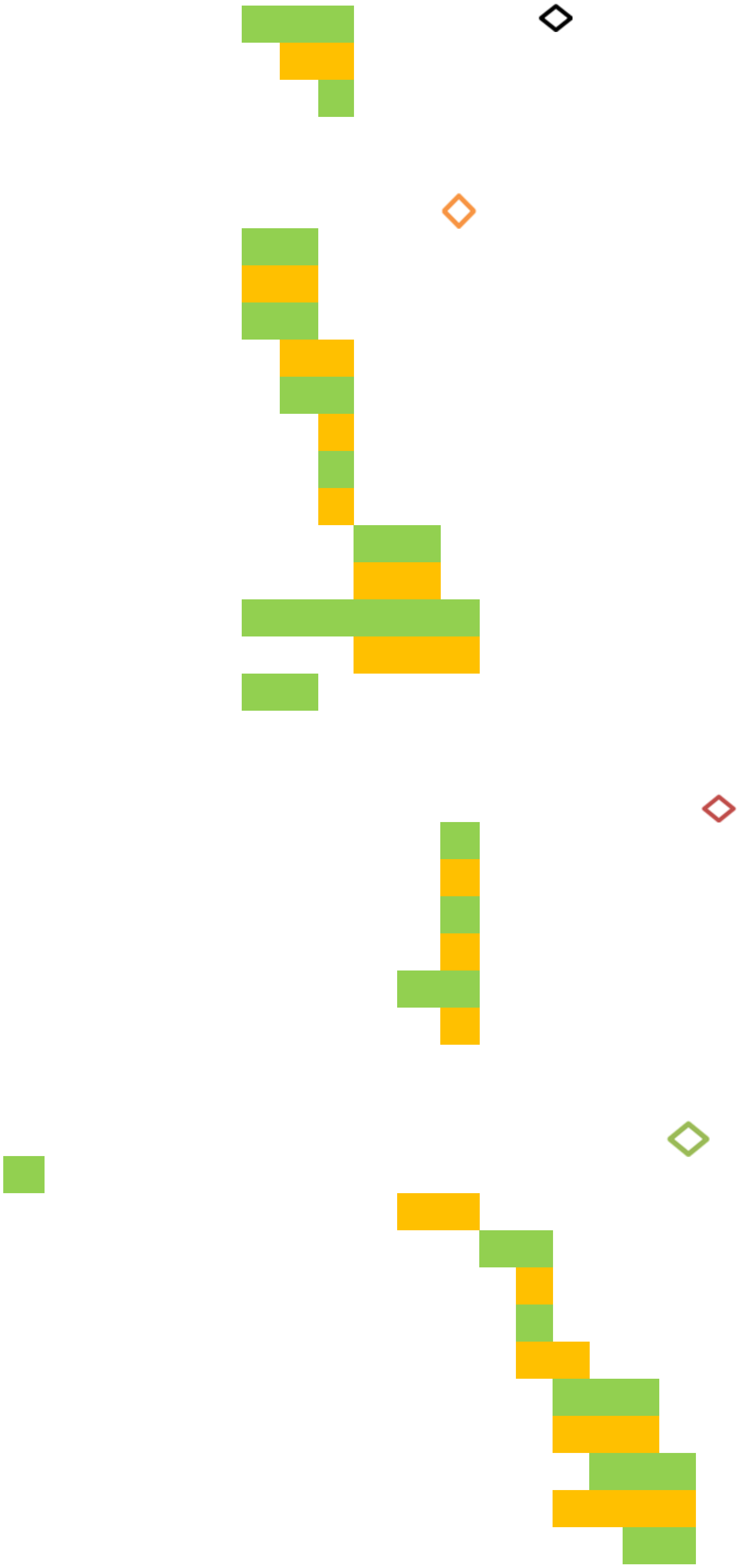
APPENDIX E – Schedule

Senior Project Schedule
PROJECT TITLE: Solar Evaporative Fan Coil Unit "Heat Coil"
Principal Investigator: Sam Budnick

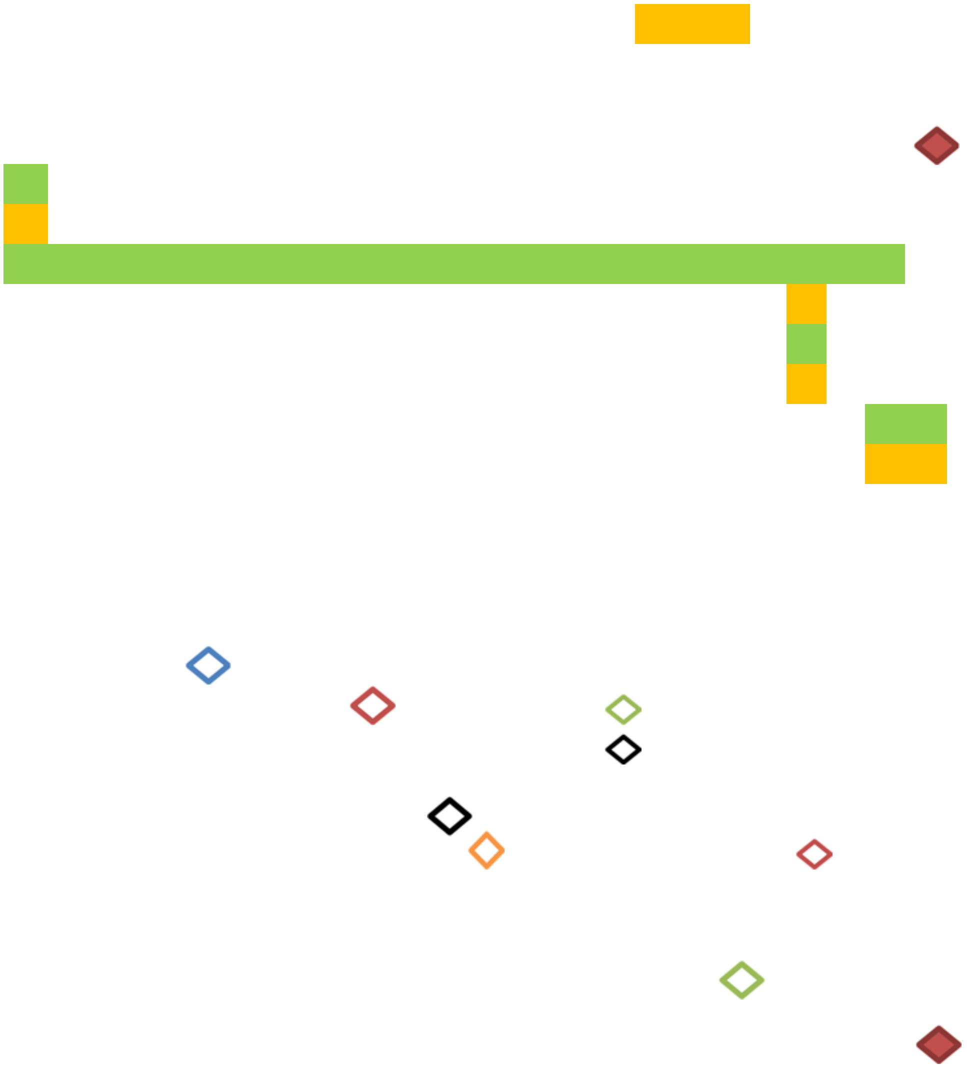
TASK ID:	Description	Est. (hrs)	Actual (hrs)
1	**Proposal**		
a.	Outline	2	1.9
b.	Intro	3	2
c.	Methods	4	5.4
d.	Analysis	40	65.5
e.	Discussion	5	5.6
f.	Parts and Budget	8	12.1
g.	Drawings	40	35.6
h.	Schedule	20	15.4
i.	Summary	10	12.4
	Subtotal:	132	155.9
2	**Analysis**		
a.	Material Specs	1	1
b.	Solidworks dwgs	70	64.5
c.	Drawing Tree	4	2.5
d.	Collector Sizing	10	12.6
e.	Time Analysis	10	14.5
f.	Kinematic	3	2.5
g.	Tolerance	1	1
	Subtotal:	99	98.6
3	**Documentation**		
a.	Pipe Sizing	1	0.8
b.	Fitting Details	1	3.5
c.	Frame Attach.	1	1.4
d.	Frame Sizing	5	5.6
e.	Parabolic dwg	2	2.6
f.	Fluid Flow Diag.	3	2.4
g.	Heat Transfer	3	2.5
h.	ANSIY 14.5 Compl	1	6.5
i.	Update Website	3	2.1
	Subtotal:	20	27.4



4	**Proposal Mods**		
a.	Prod. Assembly	1	3.5
b.	Construction	1	1.2
c.	CDR	1	2.2
	subtotal:	3	6.9
5	**Part Construction**		
a.	Alum. Procure	4	3.4
b.	Frame Bending	4	1.4
c.	Frame Bolting	4	5.6
d.	Drill Input Hole	6	0.8
e.	Drill Output Hole	10	0.6
f.	Main Assembly	2	8.6
g.	Manifold Assem.	2	1.1
h.	Piping Attach.	2	1.2
i.	Attach Fittings	3	2.4
j.	Test Fittings	3	1.1
k.	Panel Bases	1	4.2
l.	Attach CSST	5	1.4
m.	Electrical Conn.	2	1.8
	Subtotal:	48	33.6
6	**Testing Schedule**		
a.	Heating Time	12	9.9
b.	Fluid Flow Spec.	4	6.4
c.	Relations. Eval.	4	6.2
d.	Clean Up	2	6.1
e.	Pictures	1	0.4
f.	Update Website	3	2.4
	Subtotal:	26	31.4
7	**Heating Evaluation**		
a.	List Parameters	1	0.6
b.	Test and Scope	2	1.1
c.	Obtain Resource	2	0.4
d.	Make Test Sheets	1	0.8
e.	Plan Analyses	1	1.2
f.	Check Dimensions	2	0.8
g.	Fluid Testing	3	12.2
h.	Heat Testing	3	13.6
i.	Function Test	4	3.6
j.	Pictures	1	2.6
k.	Report Analysis	4	4.8



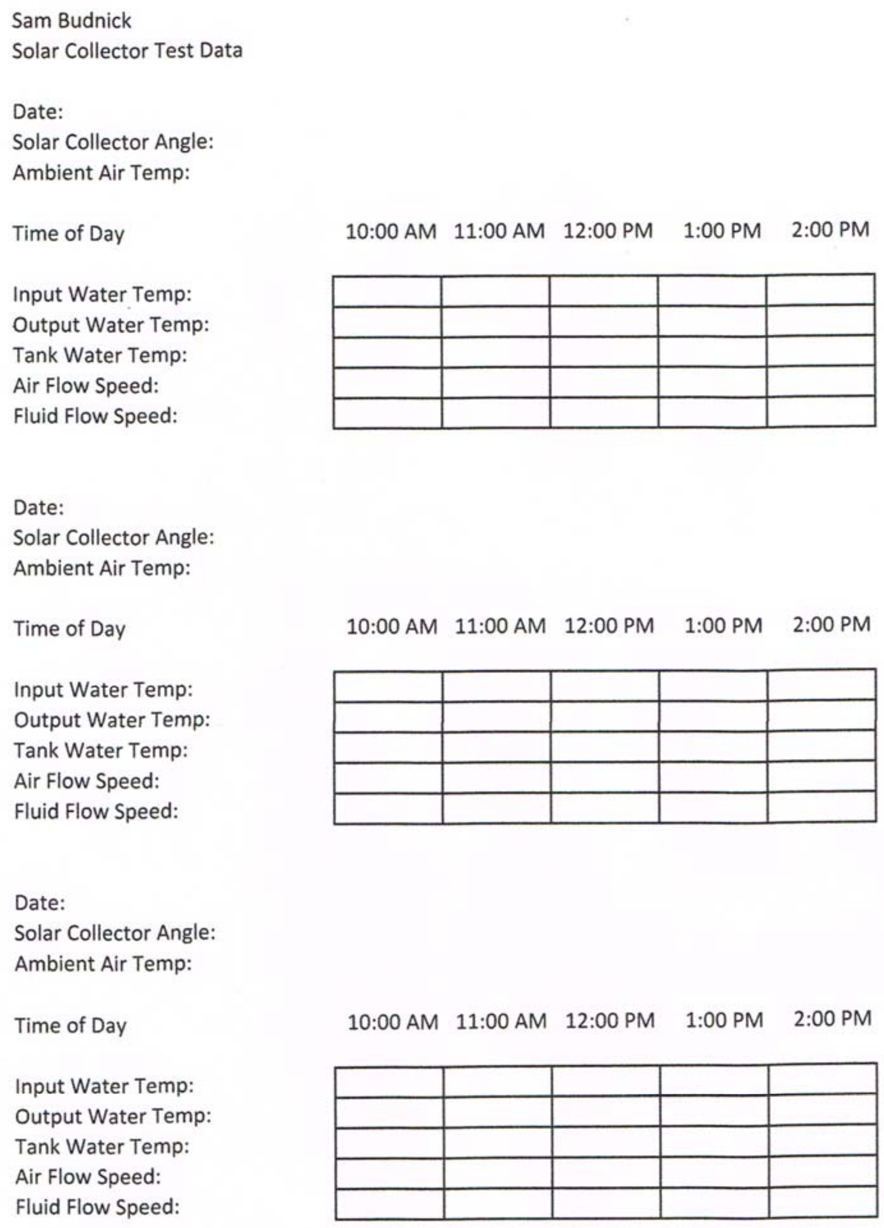
	l.	Update Website	3	2.4
		Subtotal:	27	44.1
11		**495 Deliverables**		
	a.	Get Report Guide	1	1.4
	b.	Report Outline	1	2.6
	c.	Write Report	40	37.2
	d.	Slide Outline	3	2.2
	e.	Video Outline	4	3.6
	f.	Create Present.	2	10.9
	g.	Finalize Video	4	2.2
	h.	Update Website	5	2.4
		Subtotal:	60	62.5
		Grand Total:	415	460.4



Note: **Deliverables***

Draft Proposal ◇
Analyses Mod ◇
Document Mods ◇
Final Proposal
Part
Construction ◇
Testing ◇
Schedule
Heating ◇
Evaluation ◇
495
Deliverables ◆

APPENDIX F – Test Sheet



Sam Budnick
Solar Collector Test Data

Date:
Solar Collector Angle:
Ambient Air Temp:

Time of Day	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Input Water Temp:					
Output Water Temp:					
Tank Water Temp:					
Air Flow Speed:					
Fluid Flow Speed:					

Date:
Solar Collector Angle:
Ambient Air Temp:

Time of Day	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Input Water Temp:					
Output Water Temp:					
Tank Water Temp:					
Air Flow Speed:					
Fluid Flow Speed:					

Date:
Solar Collector Angle:
Ambient Air Temp:

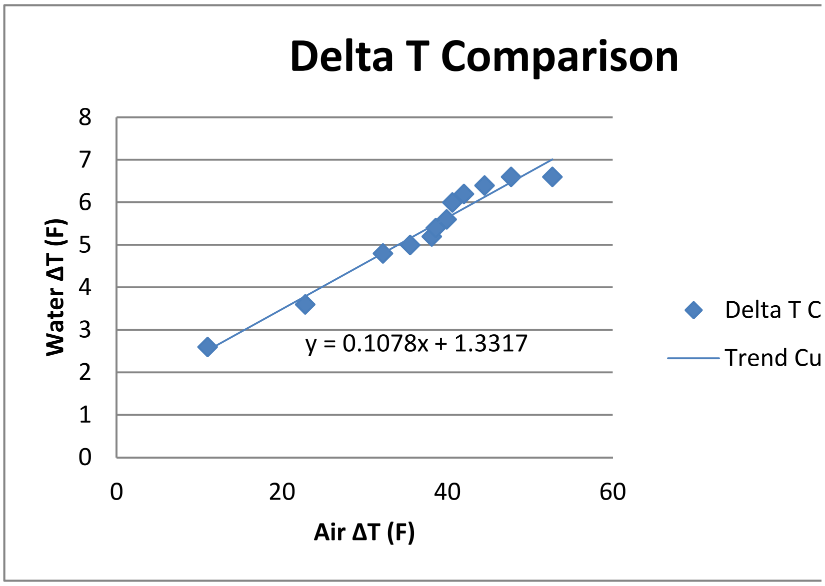
Time of Day	10:00 AM	11:00 AM	12:00 PM	1:00 PM	2:00 PM
Input Water Temp:					
Output Water Temp:					
Tank Water Temp:					
Air Flow Speed:					
Fluid Flow Speed:					

APPENDIX G – Test Data

3/31/2015
10 am start
900 Watts/m^2 irradiance

Elapsed Time	Manifold Temp	Water ΔT	Air ΔT
30	86	2.6	11
45	91.2	3.6	22.8
50	93	4.8	32.2
55	94.8	5	35.5
60	96.4	5.2	38.1
65	98	5.4	38.6
70	98.4	5.6	39.9
75	99.2	6	40.6
85	100.2	6.2	42
115	104	6.4	44.5
120	105	6.6	47.7
135	106	6.6	52.7

200 CFM Out
330 CFM In
Ambient T = 55F
Tank Temp = 94F



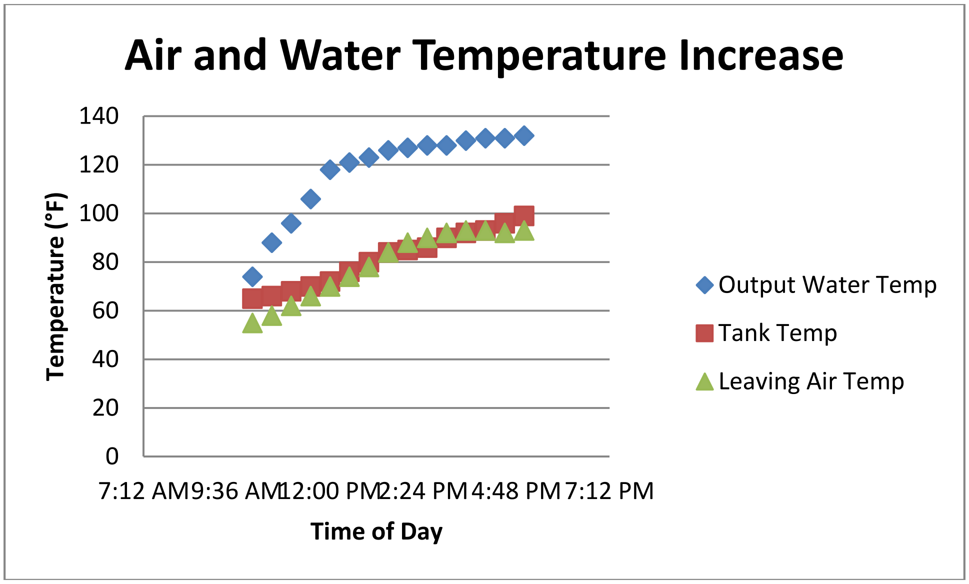
Sam Budnick
Solar Collector Test Data

Date: 4/15/2015
Solar Irradiance 500 W/m²
Ambient Air Temp: 55°F

Time of Day	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM
Input Water Temp (°F):	65	68	72	76	82
Output Water Temp (°F):	74	88	96	106	118
Tank Water Temp (°F):	65	66	68	70	72
Air Flow Speed (CFM):	320	320	320	320	320
Leaving Air Temp (°F):	55	58	62	66	70

Time of Day	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM
Input Water Temp (°F):	86	92	94	96	100
Output Water Temp (°F):	121	123	126	127	128
Tank Water Temp (°F):	76	80	84	85	86
Air Flow Speed (CFM):	320	320	320	320	320
Leaving Air Temp (°F):	74	78	84	88	90

Time of Day	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM
Input Water Temp (°F):	104	109	112	116	124
Output Water Temp (°F):	128	130	131	131	132
Tank Water Temp (°F):	90	92	93	96	99
Air Flow Speed (CFM):	320	320	320	320	320
Leaving Air Temp (°F):	92	93	93	92	93



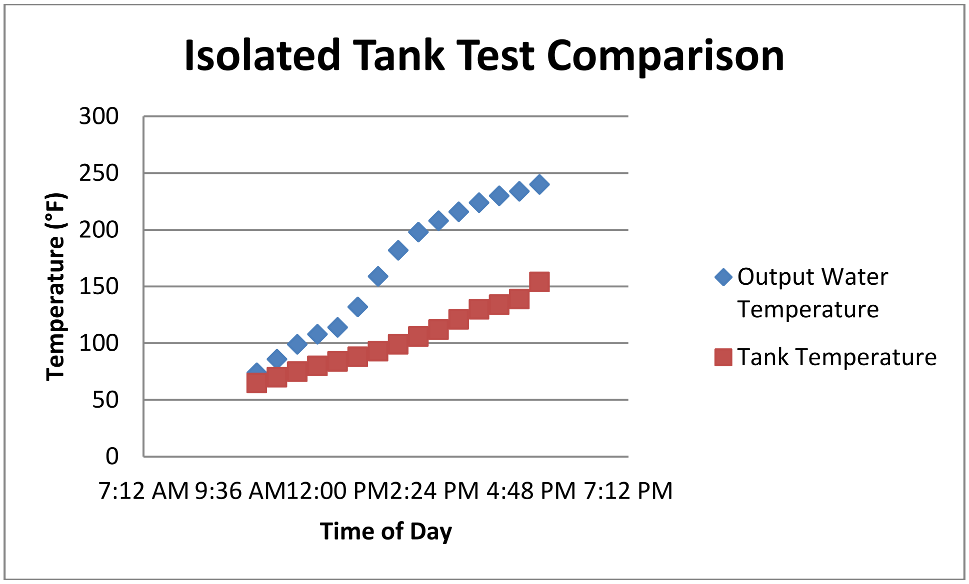
Sam Budnick
Solar Collector Test Data

Date: 4/27/2015
Solar Irradiance 922 W/m²
Ambient Air Temp: 65°F

Time of Day	10:00 AM	10:30 AM	11:00 AM	11:30 AM	12:00 PM
Input Water Temp (°F):					
Output Water Temp (°F):	74	86	99	108	114
Tank Water Temp (°F):	65	70	75	80	84
Air Flow Speed (CFM):					
Leaving Air Temp (°F):					

Time of Day	12:30 PM	1:00 PM	1:30 PM	2:00 PM	2:30 PM
Input Water Temp (°F):					
Output Water Temp (°F):	132	159	182	198	208
Tank Water Temp (°F):	88	93	99	106	112
Air Flow Speed (CFM):					
Leaving Air Temp (°F):					

Time of Day	3:00 PM	3:30 PM	4:00 PM	4:30 PM	5:00 PM
Input Water Temp (°F):					
Output Water Temp (°F):	216	224	230	234	240
Tank Water Temp (°F):	121	130	134	139	154
Air Flow Speed (CFM):					
Leaving Air Temp (°F):					



APPENDIX H – Resume

Sam Budnick

Email: budnicks@cwu.edu
Phone: (425) 418-9336

EDUCATION

2012-2015 Central Washington University — Ellensburg, WA
Pursuing B.A., Mechanical Engineering, 3.89 GPA

2002-2004 ITT Technical Institute — Bothell, WA
B.A., Computer Science

1998-2000 Bellevue Community College — Bellevue, WA
Associates in Arts and Sciences Degree

WORK EXPERIENCE

2014 University Mechanical Contractors Inc. — Mukilteo, WA

Internship under mentor Randy Koetje, PE. Duties included calculation of HVAC heat loads using Trace 700 and implemented an automated permitting sheet, detailing information for reviewers to approve projects. Assisted Design of mechanical systems including duct work, mechanical piping, and plumbing using Autodesk AutoCAD, Navisworks, and Revit.

2007-2012 Teknon Corporation — Redmond, WA

Cable installation technician in charge of pulling, terminating, and Fluke testing CAT5, CAT6, Coaxial, and Fiber Optic cable. Clients included Microsoft, Amazon, and AT&T.

2006-2007 Focus Micro — Mukilteo, WA

Cable installation technician in charge of pulling, terminating, and testing coaxial camera grade cable, along with power cable, to remote security PTZ cameras in Albertsons located in Washington, Oregon, and Idaho.

2004-2006 Microsoft Corporation — Tukwila, WA

Co-location technician in charge of rack server installation, daily reports to clients, and quality control support. Duties included hard drive bay and server installation within a warehouse rack network, Fluke testing, and decommissioning of outdated network servers.

TECHNICAL SKILLS

- ***Proficient in AutoDesk's family of drafting programs including AutoCAD, Navisworks, and Revit; with applications towards MEP coordination and BIM modeling.***

- ***Project management experience including design, purchasing, fabrication and development.***

- ***Leadership experience supervising up to 3 members on a team in a construction sub-contracting environment; reading, interpreting, and installing CAD designed infrastructure.***