ASHRAE Applied Engineering Challenge, 2017

California Polytechnic State University,
San Luis Obispo

Department of Mechanical Engineering,
HVAC&R Concentration

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Table of Contents

BACKGROUND

The federally funded Low Income Home Energy Assistance Program (LIHEAP) provides financial assistance to families whose utility costs represent a significant percentage of their income. This is typically considered 6 percent or more of a family's income. [1] In particularly cold, or hot and humid climates, these bills can exceed 50% of a family's income. Typically, the main reason for increased energy consumption in buildings is energy inefficiency. Accordingly, for a family that is already spending a significant portion of their income on utility costs, the prospect of renovating a home represents an impossible hurdle. Though some of the time these families are renters who do not have the option of changing large-scale aspects of their homes, they all turn to the federal government for aid. In 2010, the LIHEAP represented $4.5 billion of the federal budget, and yet the LIHEAP has yet to meet the needs of many families across the country. [2] Not only has the LIHEAP been unable to assist all families with their energy costs, but it has not reduced their need for assistance. Another point of consideration is that the current political atmosphere threatens a loss, or at least a reduction, of funding for the program. The ideal solution is to increase the energy efficiency of low-income houses and reduce energy expenditure at the source rather than simply supplementing payments. Because of the low-income consideration of the target audience, the goal is to provide a design that requires minimal initial investment, is non-invasive, provides a reduction in the cost of energy associated with cooling, and does not increase other utility costs.

INTRODUCTION

This report details the design of an air conditioning system intended to meet specific design criteria. This design must employ evaporative cooling to reduce utility costs for low income families living in Atlanta, GA. The design must consume no potable water, nor does it assume access to a water source such as a well or spring. The cooling loads on the house should be designed for a 1600 ft^2 low-income residence.

Based on the above criteria an evaporative cooling system has been designed that exclusively uses harvested water, allows comfort conditions year round, and reduces energy consumption for household cooling by more than 20%. This reduction in energy consumption is accomplished through the modification of a typical vapor-compression cycle by using evaporation to precool the air used to pass across the heat rejection heat exchanger. In other words, the system provides a significant boost in efficiency for an AC unit by increasing the temperature difference across the unit's condenser coil.

DESIGN CONDITIONS

In modeling the following systems, three different cases were considered: the ASHRAE location weather data at 99.6 percentile cooling conditions for initial analysis, cooling design day conditions in conjunction with Building Energy Modeling (BEM) for more complex cooling load calculations, and finally, yearly weather data to analyze power and water consumption.[3] The 2013 weather data for Atlanta, GA is the same data used by the building energy model for hourly cooling load calculations.

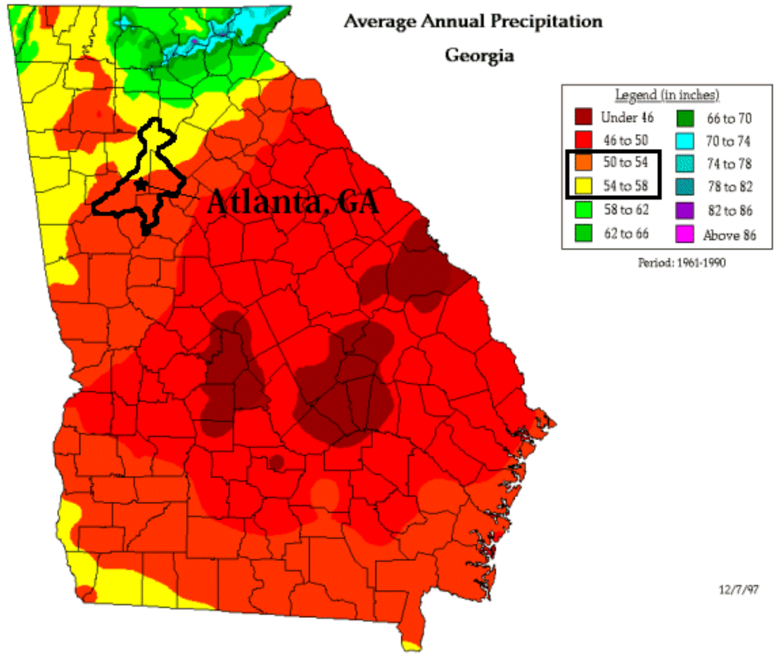

Figure 1. Including suburbs and surrounding counties, Atlanta receives averages of between 50 and 58 inches of rainfall per year. [4]

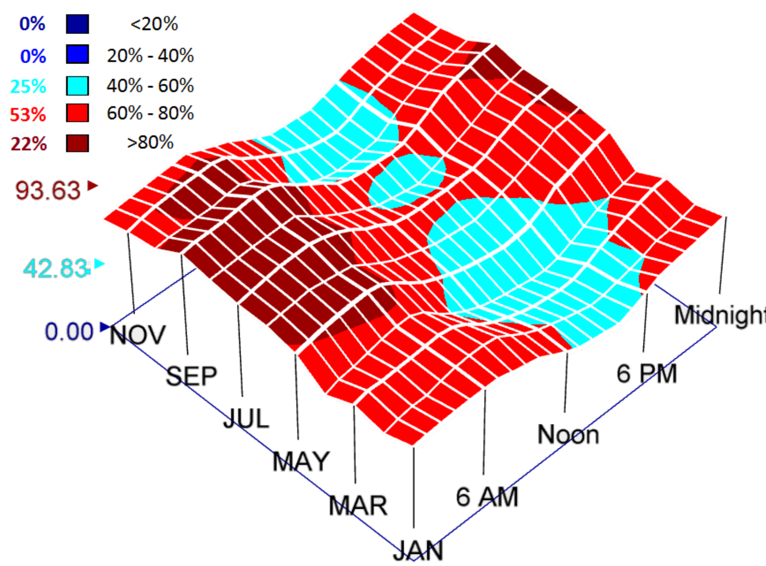

Figure 2. With a minimum relative humidity of 40% in Atlanta the conditions are prohibitive for evaporative cooling.

Weather Conditions

Three climate conditions need to be considered for the proposed design. Rainfall, humidity, and dry bulb temperature will all significantly affect the approach taken in designing an evaporative cooling system. Analyzing rainfall is important for the decision to use reclaimed water, harvested water, or a combination of the two. Humidity levels determine how effective evaporative cooling will be. In conjunction with dry bulb temperature, humidity levels determine during what conditions evaporative cooling will be effective. The dry bulb temperature affects the building loads throughout the day. Ultimately, Building Energy Modeling (BEM) was used to simulate the actual loads on the house throughout the year.

Rainfall

From Figure 1, it can be seen that with Atlanta, GA as the design location it is expected that at least 50 inches of rain will fall per year. An extreme drought could drastically affect this value; however, for the purposes of this design 50 inches of rainfall bodes well for water harvesting. Later in this report, the potential for rainwater harvesting will be compared to the potential of a grey water system and design decisions, as they relate to water usage, will be explained.

Humidity
Daytime relative humidity levels, during major cooling months and during peak cooling hours, range between forty and seventy percent. It is also known that the cooling accomplished by the evaporative process is inversely affected by humidity. At humidity levels this high it is necessary to consider a more detailed analysis of the cooling hours during which conditioning must be provided. To do that it is necessary to discuss the psychrometrics for each design considered later in this report.

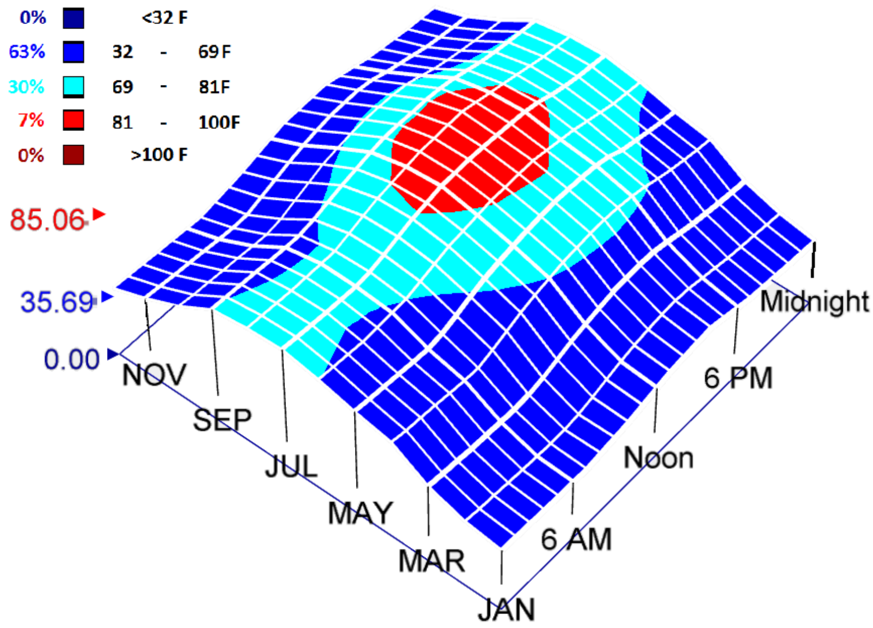

Figure 3. July through September are clearly the main months for cooling design, with peak conditions in August.

Dry Bulb
From Figure 3, it is shown that most of the cooling design hours will occur between June and September and will peak at roughly 100 °F. Comparing this to Figure 2, it can clearly be seen that meeting ASHRAE 55 Standards for comfort year round will be challenging, if not impossible, for a direct evaporative cooling system.

Building Energy Modeling
DesignBuilder was utilized to create a building energy model to obtain the cooling loads a 1600 square foot house in Atlanta would experience. This was accomplished by running an annual simulation using weather data for the region. Figure 4 is a plot of the monthly cooling loads that the house would experience throughout the year. It is clear from Figure 4 that April through September are the months that require the most cooling. These months are where energy consumption, water usage and

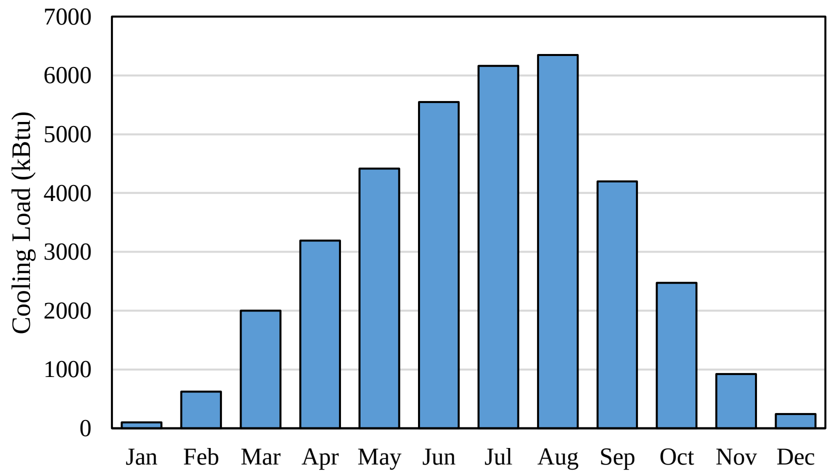

Figure 4. Monthly cooling loads peak during summer hours when maximum temperatures are expected.

harvesting are crucial. Based on load calculations, a 4-ton AC unit was used as a base model for the HVAC system. Unfortunately, DesignBuilder was unable to model evaporative cooling thus an alternate method of analysis was used.

EVAPORATIVE DESIGN

Designs Considered

At the beginning of the design process, pros and cons of both direct and indirect evaporative cooling were considered. Ultimately, neither option was particularly viable exclusively due to the high humidity levels during peak cooling hours. To achieve ASHRAE comfort standards for all cooling hours, a third option, the evaporatively modified condenser, was considered.

Direct Evaporative Cooling

Evaporative cooling is the process of using phase change to absorb energy and lower the temperature of the surroundings. By introducing water into the air, the water absorbs energy in the form of heat from the atmosphere and changes phases into vapor. Direct evaporative cooling is a method of spraying water directly into the air or onto an absorbent media, hence the name. It is an inexpensive method for reducing the temperature of the air, however, the evaporative process drives up the relative humidity. Because of this increase in humidity, it is necessary to carefully analyze the system in terms of its psychrometrics. It is also important to be aware that the cooling effect available via this system is limited by the wet bulb temperature. From **Error! Reference source not found.** it is conveyed that any direct evaporative cooling system will only be able to condition a space to comfort conditions when the ambient wet bulb temperature is below 68 °F. In **Error! Reference source not found.**, there is an example of this cooling process from Point 1, at 94 °F and a relative humidity of 50%, to Point 2, at 82 °F and a relative humidity of 85%. The process assumes an evaporative effectiveness of 80% and follows the wet bulb line for 78 °F. Clearly, at peak conditions there is no hope of achieving comfort conditions.

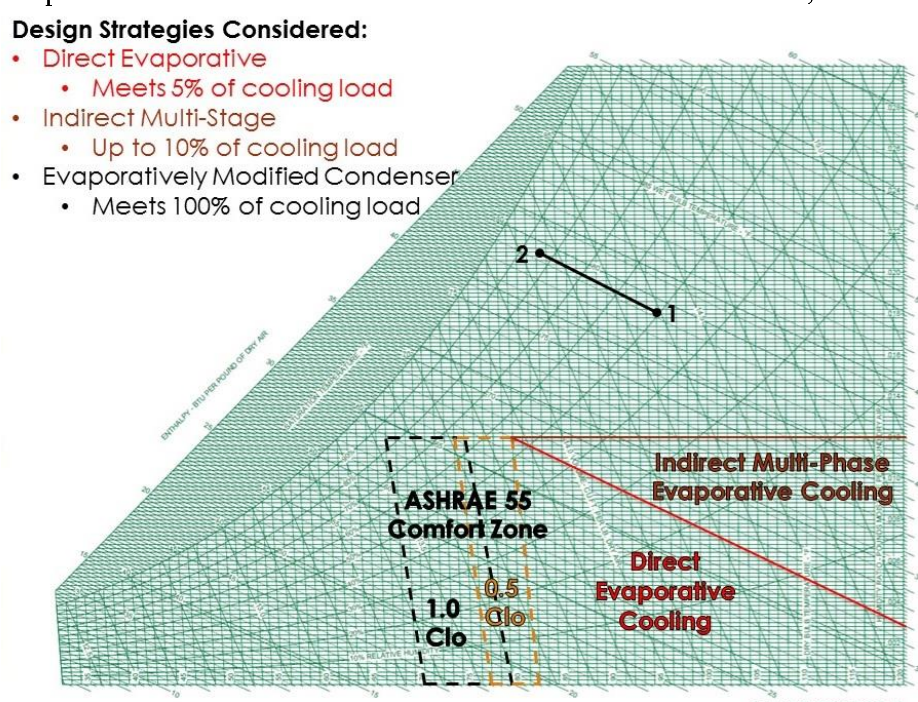

Figure 5. Evaporative cooling, of any type, can only meet ASHRAE Standard 55 comfort levels when the ambient humidity ratio is below $0.012\left[\frac{lb_{water}}{lb_{dryair}}\right]$.

Indirect Evaporative Cooling

An indirect evaporative cooling process would seem more viable than direct evaporative cooling, as it allows for the cooling of air without increasing the humidity of the supply air. It does this by cooling some amount of ambient air and then uses a heat exchanger to reduce the temperature of a smaller amount of supply air without modifying the humidity of that air. The result is air that has been cooled and is at the ambient humidity ratio. Unfortunately, indirect cooling is still limited, this time by the dew point temperature. To achieve comfort conditions using indirect cooling the ambient air conditions cannot exceed a dew point temperature of 62 °F.

Based on the yearly weather data, Atlanta had 2,647 cooling hours in 2013. Of these hours, direct or indirect evaporative cooling only accounts for roughly 170 hours or 6.4% of the load. For any given year, it is unlikely that even a multi-stage system such as a Sub Wet-Bulb Evaporative Chiller (SWEC) or a Maisotsenko system, which maximizes the indirect evaporative benefit, could meet more than 10% of the cooling load.

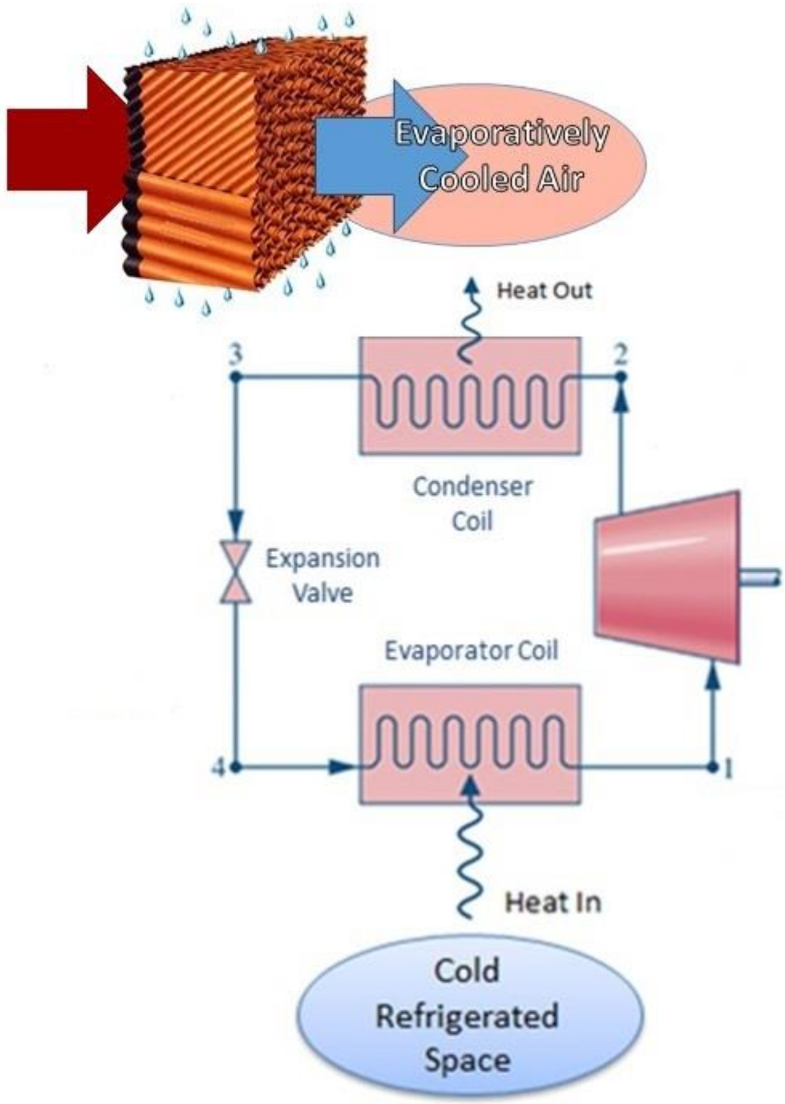

Figure 6. The conventional refrigeration cycle remains almost untouched except for the evaporative cooling of the air which flows across the condenser.

Evaporatively Modified Condenser

Based on the above analysis the high humidity levels during peak cooling periods make Georgia non-ideal for evaporative cooling. To realize the project design goals, the modified condenser represented a more realistic option. The analysis of this system can be found later in this report, but what was found is that by changing the temperature of the air which passes over the condenser it is possible to significantly boost the efficiency of the system. This increase in efficiency can be calculated by assuming a reduced condensing pressure, which is attributed to the reduction in the temperature of the air which passes over the condenser.

Condensers commonly use evaporative cooling in industrial and commercial applications before now—the goal of this design is simply to take the same process and design technology that can produce a similar effect on a smaller scale.

Figure 6 shows the refrigeration cycle supplemented by evaporative cooling.

Note that this process is not the same as a cooling tower. Both systems employ evaporation to produce a larger temperature gap through the condenser, but unlike a cooling tower this process uses air as the medium of heat exchange rather than water. This is almost exclusively to reduce the need for extensive retrofitting, which would allow the condenser to be cooled by water. Ultimately, the boost in efficiency makes the minimal initial investment required by this system worthwhile.

Energy Analysis

Analyzing the modified condenser design began with applying a direct evaporative cooling process to the air that flows through the condenser, before it enters the condenser. The major principle for this process can be summed up by the following equation:

$$T_2 = T_1 + EE * (T_{wb} - T_1) \quad \text{(Eq. 1)}$$

where T_1 is the dry bulb temperature of the air entering the evaporative media, T_2 is the air entering the condenser, EE is the evaporative effectiveness of the media, and T_{wb} is the wet-bulb temperature of the air. Since the wet-bulb temperature does not change during the cooling process and will always be larger than T_1, it becomes simple to predict the temperature drop across the media. Being able to predict this temperature drop makes it possible to create the model found in Figure 7 for the high efficiency 3-ton unit in the Cal Poly HVAC lab. Assuming peak cooling conditions and using manufacturer data and settings (T_1=94 °F) the unit went from a COP of 5.4 to a COP of 7.3. While this model made several assumptions such as perfect heat exchange across the condenser, the potential was apparent enough to continue the analysis based on this early success. The next

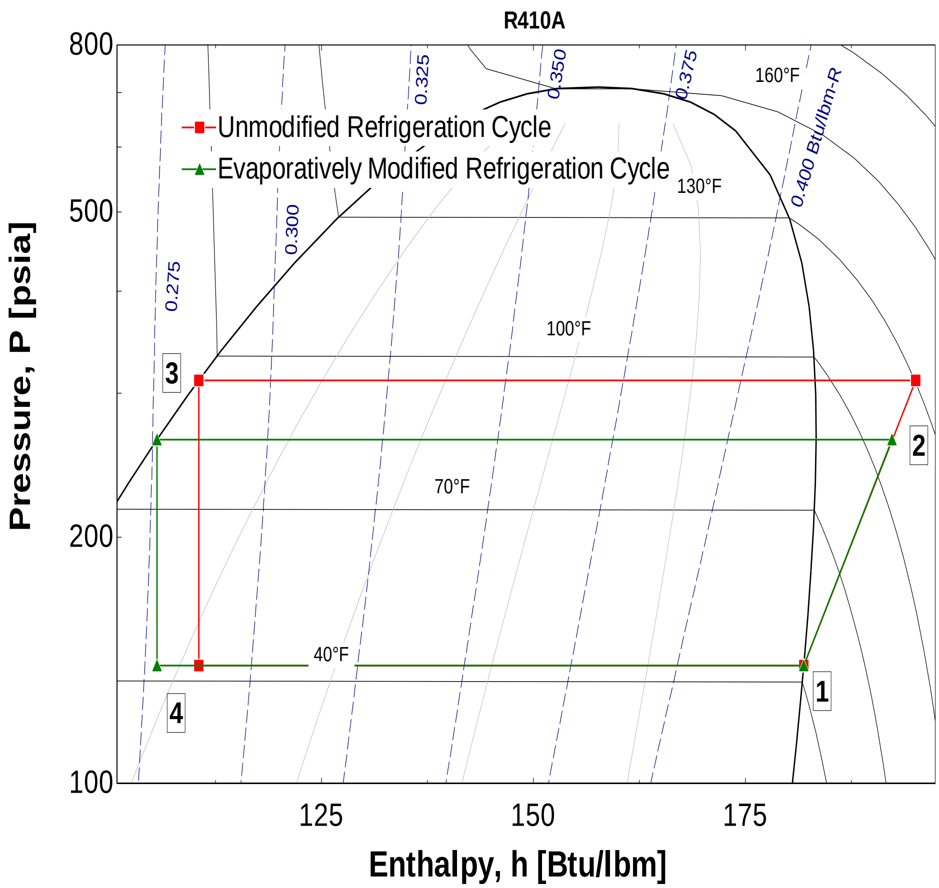

Figure 7. This pressure drop creates an increase in efficiency from an, already large, COP of 5.4 to a COP of 7.3.

process was to use manufacturer's data to produce curve fits for a 4-ton AC unit, which predicts the unit total capacity and compressor consumption based on any outdoor air temperature. These curve fits can be found in Appendix A. Using the 2013 weather data, curve fits, and building energy model cooling loads,

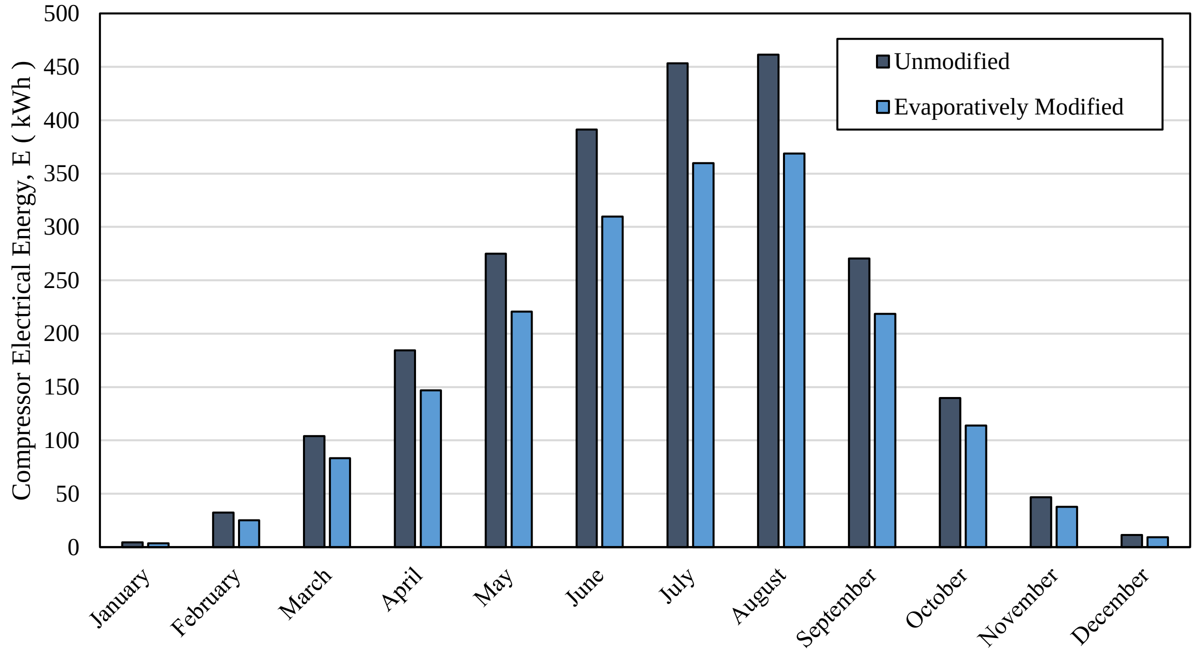

Figure 8. Monthly compressor energy consumption throughout the year.

hourly compressor usage for the entire year was established. For the entire year, we found that the unmodified system consumed 2375 kWh of electricity while the modified system only consumed 1898 kWh. This drop-in consumption represents a 20% reduction in the cost of cooling. Figure 8 shows the energy savings created by the evaporative modification of the condenser.

The manufacturer's data used in this model is for a high efficiency AC-unit with a nominal COP of roughly 5.5. Typically, a lower-income household will be using a much less efficient unit. In order to predict power usage for a less efficient system it is possible to create an inverse relationship between COP and compressor work. The result is that the model predicts a unit with a nominal COP of 2.5 will result in an annual compressor consumption of 5224 kWh for the unmodified condenser and 4175 kWh for the modified condenser. At $0.115 per kilo-watt-hour this represents savings of at least $120.00 per year.

Water Usage Analysis

Once the temperature drop is known for each hourly temperature humidity level it is also possible to predict the flowrate of the water required to cool the air based on Equation 2 below:

$$\dot{m}_2 = \left[\frac{c_p * (T_1 - T_2) + \omega_1\left(h_{g,1} - h_f\right)}{h_{g,2} - h_f} - \omega_1\right]\dot{m}_{air} \qquad \text{(Eq. 2)}$$

where ω is the humidity ratio of the air, h_g is the enthalpy of water vapor, h_f is the enthalpy of liquid water, c_p is the specific heat of air, and $\dot{m}_2$ is the mass flow rate of the water needed to cool the air. What is seen in Equation 2 is that the energy required to evaporate water is taken from the air causing the cooling from T_1 to T_2 and producing some change in the humidity ratio of the air. If the temperature change is known, then it is possible to calculate the amount of water it takes to achieve that temperature drop. Figure 9 shows the weekly water consumption for 2013 based on weather data for Atlanta's Hartfield-Jackson International Airport.

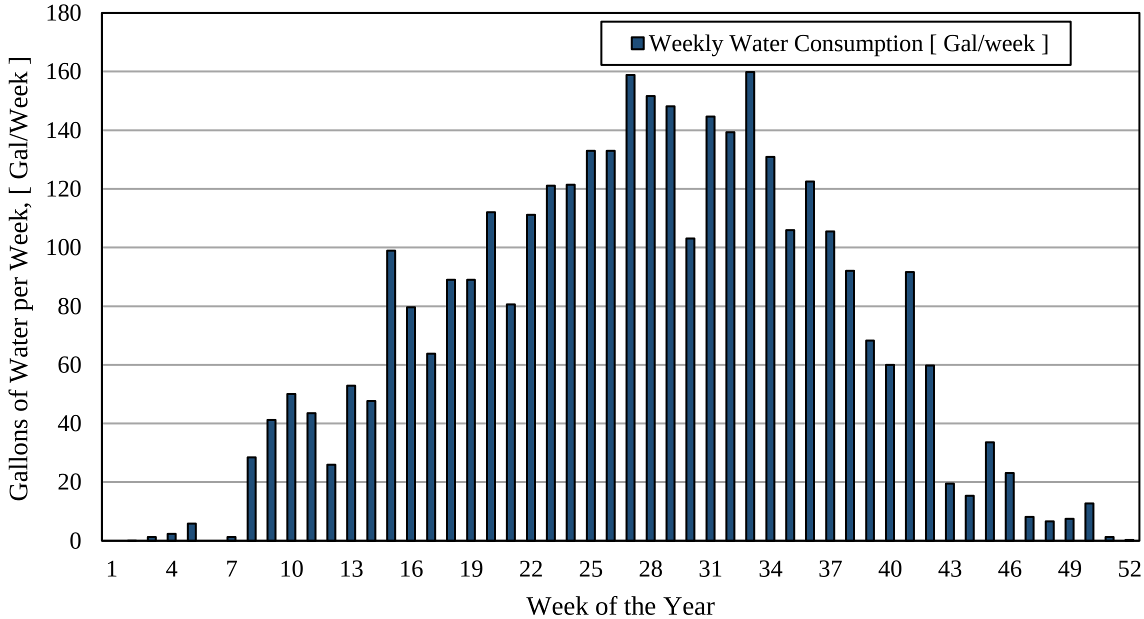

Figure 9. At peak consumption in 2013 the system will consume up to one-hundred sixty gallons of water per week.

EVAPORATIVE SYSTEM

The form to the evaporative design is shown in Figure 10. The evaporative media, in this case CELdek, is sandwiched between two hexagonally patterned layers of polyester to allow airflow through them. Outside of this is a simple frame of pvc tubing to provide support to the structure. The piping to the top of the evaporative system is a rubber hose in the shape of a ring with eight 1/8" holes symmetrically spaced around the ring to provide equal water flow down the entire evaporative media.

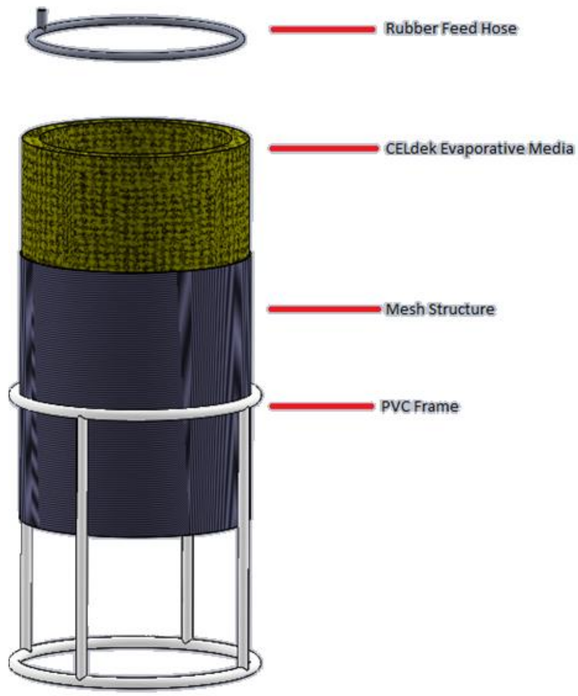

Figure 10. Exploded view of evaporative media with flexible and stationary structure.

In order to design the mesh structure a decision matrix was made based off 5 materials that are easily obtainable and feasible to create a structure for the evaporative media. After weighting each criterion based on importance to the design and the consumer and ranking each material out of 5 being the highest and 1 being the lowest, polyester was deemed the best material. However, after researching costs of polyester, it was determined that the use of a polyester mesh was not feasible due to the high cost. [5] Instead, safety fencing made of polyethylene composite was chosen due to its low cost and durability.

Table 1. Design Matrix for Mesh Material Choice

Item	Cost	Maintenance	Environmental Impact	Absorption	Decision
Weight	5	4	1	2	
Polyester	3	5	5	1	42
Polypropylene	4	2	3	4	39
Rubber	1	3	1	4	26
Polyamide	5	1	2	2	35
Nylon	2	4	4	2	34

To determine the best media of the system, three different options were considered: CELdek® (cellulose), GLASdek® (glass fibers) and ASPENpads®. Initially, the conclusion was that ASPENpads® would be the most ideal due to their ease of use and the cost for the product. However, even with the best maintenance ASPENpads® would have to be replaced every year and the efficiency of the ASPENpads® were lower than the GLASdek® and CELdek® media. The GLASdek® and CELdek® were both roughly 90% efficient, based on depth of the material and saturation level. Alternatively, ASPENpads® had an efficiency of around 70%. Of course, these efficiency values were found to change depending on humidity, location, temperature difference, usage and maintenance. Nevertheless, noting these variables, CELdek® and GLASdek® were superior. [6][7][8]

Per Munters, a supplier of cellulose and glass fiber products for commercial applications, pressure drop tables depending on the type of product shown below were given. From looking at both Figure 11 and Figure 12, the pressure drop of the system is never very large due to low face velocities and therefore is not an obstacle for this design.

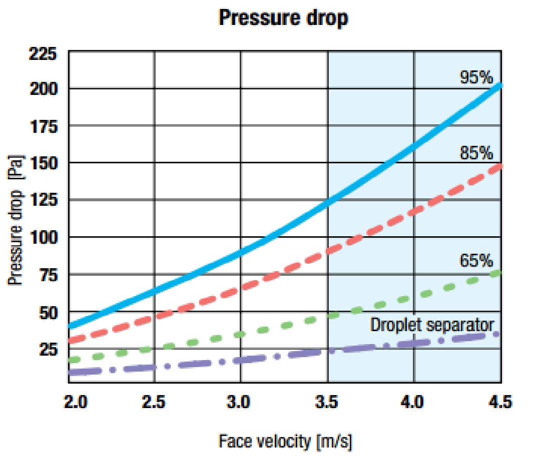

Figure 11. Pressure drop vs face velocity for GLASdek pads; Although not shown, the Blue, Red, Green, and Purple refer to D=300mm, 200mm, 150mm, and 100mm, respectively.

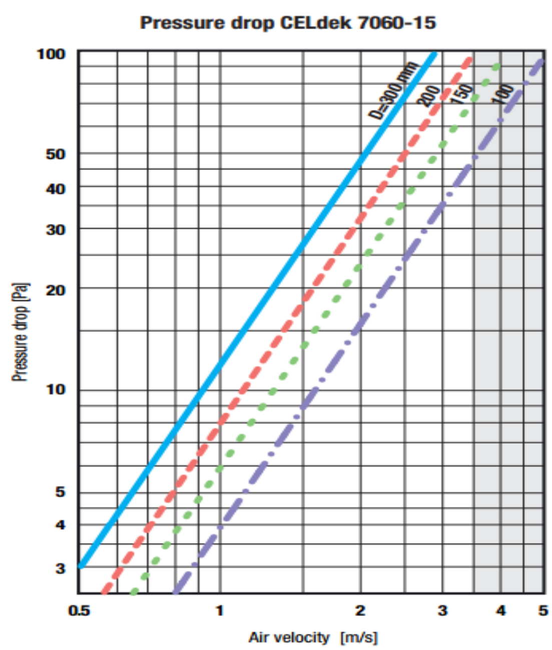

Figure 12. Pressure drop vs. air velocity at various pressures for CELdek (Model Nº 7060-15).

When it came to maintenance of the evaporative media, it was determined that the GLASdek® would be harder to maintain because a constant water bleed off is required to prevent any type of molding or algae growth. However, the CELdek® media is better because it has a protective edge coating that can withstand scrubbing and other methods of cleaning. The CELdek® pads are nonporous and quick drying preventing the growth of mold or algae and will not deteriorate from UV exposure. Also, per Munters, CELdek® has a lifelong durability averaging 4 years for commercial applications meaning that if used in a residential application the lifelong durability of the media would see an increase in durability. [9]

In the end, CELdek® was chosen because although the efficiencies were the same as the GLASdek®, which was only better for commercial applications at higher airflow rates. However, since the challenge is aimed at residential buildings for low income families in Atlanta, GA, the low cost and higher efficiency of CELdek® ultimately led to it being the final choice.

WATER SYSTEM DESIGN

When exploring options for water sources, the two options available are harvested rain water and reclaimed grey water. Grey water is defined as any waste water from a home that does not encounter fecal matter or food. The benefit of using reclaimed or harvested water is to use a resource that would be otherwise wasted and to not increase utility costs of the family.

Potential Availability

To find the potential amount of grey water that could be reclaimed annually, a water use calculator created by the Metropolitan North Georgia Water Planning District was utilized [10]. For a family of five, 13,104 gallons of grey water per year could be reclaimed and implemented in the design. This water comes from showers, baths, bathroom sinks, and washing machines. To find the potential amount of rain water that could be harvested, the following equation was utilized:

$$Roof\ Area\ (ft^2) \times Annual\ Rainfall\ (in.) \times Conversion\ Factor\ (.623) \times Collection\ Efficiency\ (0.90) \quad \text{(Eq. 3)}$$

The annual mean rainfall in Atlanta is 50 inches but a conservative 30 inches was used for this design. A collection efficiency of 0.90 is typically used. [11] For a 1,600 square foot roof in Atlanta, 27,000 gallons of water are available to be harvested annually.

Rain Water vs Grey Water

Rainwater harvesting was ultimately chosen over grey water reclamation, although both methods yield sufficient water for use in this design, because rainwater harvesting is superior in its simplicity and cost effectiveness. The grey water system would require excavating the family's property to install the necessary piping components to properly route the reclaimed water. An appropriate water treatment system would also have to be designed and installed to clean and decontaminate the water to safe and healthy levels, as well as prevent any damage to any pumps or equipment. The grey water system proved to be prohibitively expensive for implementation in a retrofit for low-income homes.

Harvesting

The existing gutter system of the house will be used to redirect rainwater into a (45”x40”x46”) 275-gallon tank. Figure 13 is a plot that illustrates the weekly availability of rain water that can be harvested as well as the weekly water consumption by the system. In the event of drought periods as was seen in the first two weeks of September 2013, the 275-gallon tank has enough capacity to sustain for two weeks. It is recommended that the storage tank be placed as close as possible to the condensing unit, up to within 3 feet. A relief pipe will be added to the tank in order to release excess water when the tank is full. The recommendation is that excess water be routed to a strategic location for irrigation purposes and to prevent any puddling or flooding at the base of the tank. In the case that one is not already in place, a rain gutter filter should be added upstream of the tank to prevent any leaves or other debris from entering the tank.

Water Delivery Methods

Once the water is harvested, it must be delivered from the storage tank to the evaporative media located on the outside of the condensing unit. The two options considered were a closed loop pumping system and a gravity fed system. The following sections include descriptions and analyses of the two systems.

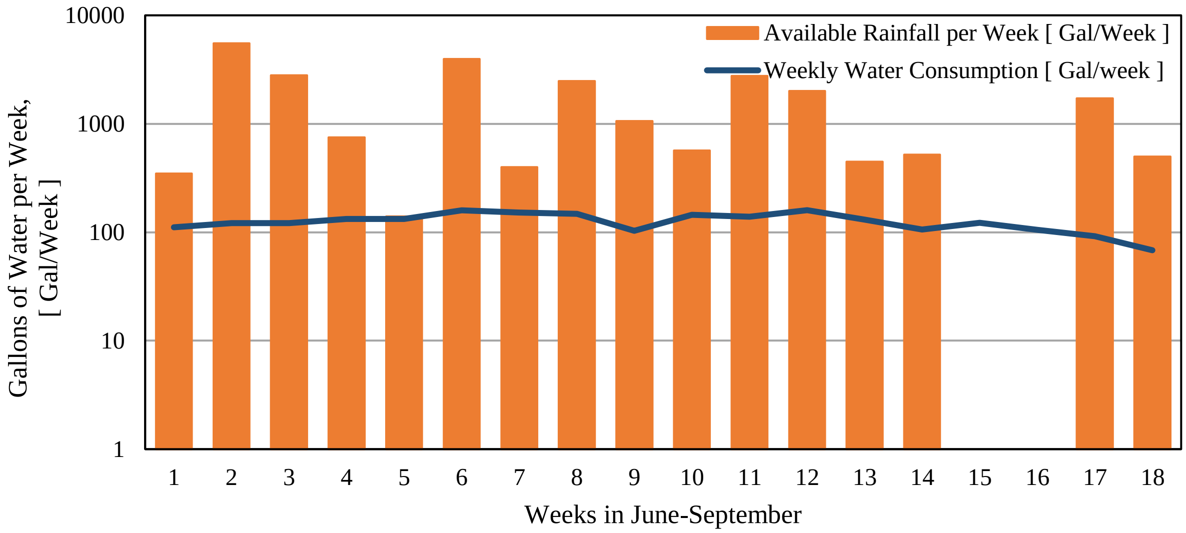

Figure 13. During the design period harvested rainfall will provide sufficient water to run the system.

Option 1: Pumping System

The first design that was explored was a closed-loop pumping system. A 1/6 HP Aquapro Utility pump would be used to pump water from the bottom of the 275-gallon tank to the inlet of the rubber feed hose located on top of the evaporative media.[12] The water that does not exit through any of the eight 1/8" perforations on top of the evaporative media will be recirculated by the pump to the top of the tank. Figure 14 is a layout of the pumping system with the design conditions.

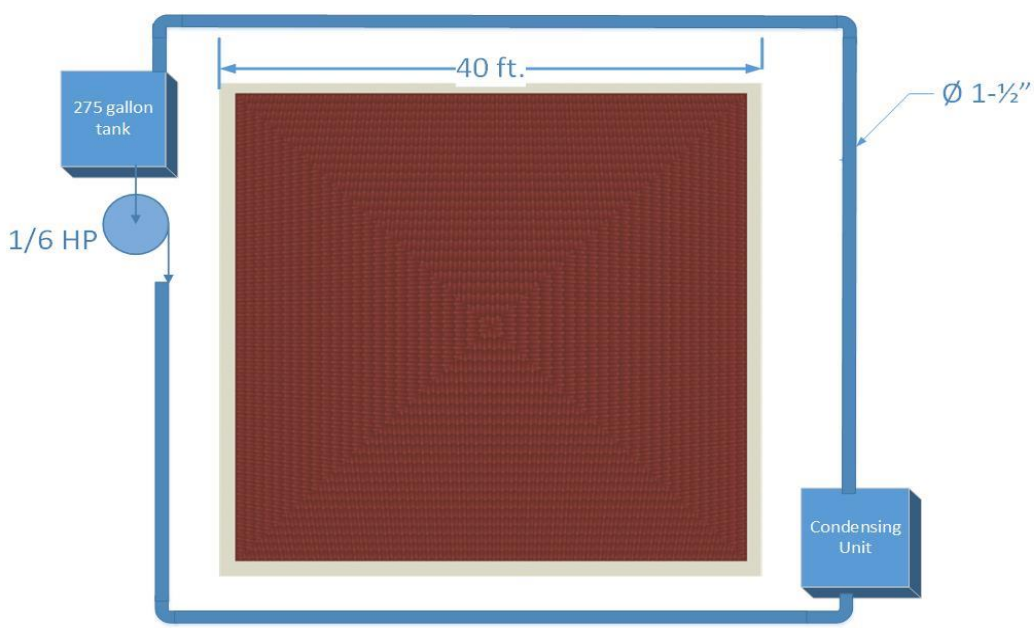

Figure 14. The piping system can be highly adjustable and configurable to the point that we have included worst case calculations and two different designs in the hopes of meeting a diverse set of needs.

The piping for this design is 1-1/2" schedule 40 PVC piping [13]. It is difficult to get an accurate estimate of the number of bends and pipe fittings that would be required as the actual dimensions of the home as well as the location of the condensing unit were not provided.

For design considerations, 160 feet of straight pipe and 20 feet as an equivalent length to model losses due to bends or fittings were used. A value of 10 gallons per minute was selected to begin the pump analysis and was found to have a head of 3.2 feet. Pump performance curves listed a flow rate of approximately 24 gallons per minute at 3.2 feet of head. This indicates the pump is oversized for the given application. An analysis could be done to properly size the pump using pump laws but a cheap, commercially available 1/6 HP pump will work adequately. The pump is estimated to run 2,548 hours annually. At 0.253 kW and with a rate of $0.115 per kWh, the pump will cost $74.13 to operate yearly.

Option 2: Gravity Fed System

The second water delivery method considered is a gravity fed system. Figure 15 is a layout of the system. A Saferstack 5' x 5' x 7' scaffolding set will be used to elevate the water storage tank and provide the necessary head to deliver water to the condenser. [14] The scaffolding has a maximum load of 4,900 lb while the full tank will weigh approximately 2,444 lb. For design considerations, the tank was assumed to be located 1.5 feet above and 5 feet away laterally from the condenser. The total length of PVC flexible piping is 20 feet with a diameter of 1 inch. A full tank provides 3.5 feet of head while the empty tank provides 0.5 feet of head. Both are sufficient to provide the desired 0.06 gallons per minute. When erecting the scaffolding, it is imperative that one must be cautious of any run off from the tank or excess pooling/ flooding from the condensing unit. This could cause the ground beneath the scaffolding to become unstable. It is recommended the homeowner regularly inspect the system in case of flooding.

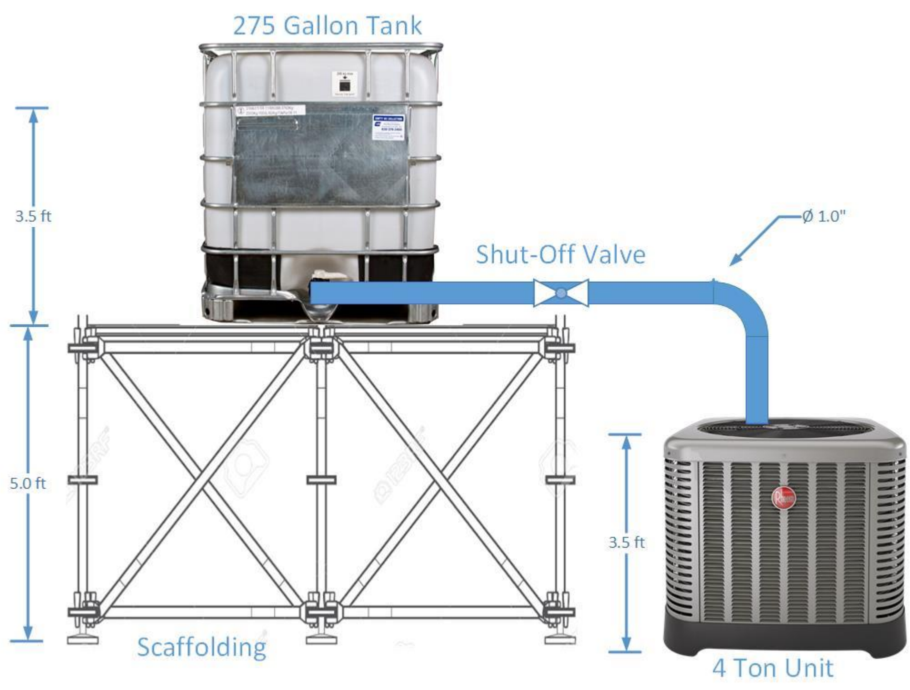

Figure 15. The gravity fed system requires no power input compared to the pump.

System Recommendation
Based on the two options provided, the gravity fed option is superior. Although the scaffolding may not be aesthetically pleasing, the gravity fed option has less equipment that will eventually need replacement, cheaper upfront costs as well as operational costs and a control system that is less prone to failure. A detailed economic analysis can be seen in the Cost Analysis section.

CONTROL SYSTEM DESIGN

Pump Control System
A control system is needed to regulate the pump during operation. An accelerometer will be attached to the condensing unit to detect any vibrations the condensing unit produces when it is providing cooling to the house. The accelerometer will also be connected to the pump's power source and will send an on/off signal. Figure 16 is an illustration of the Pump control system.

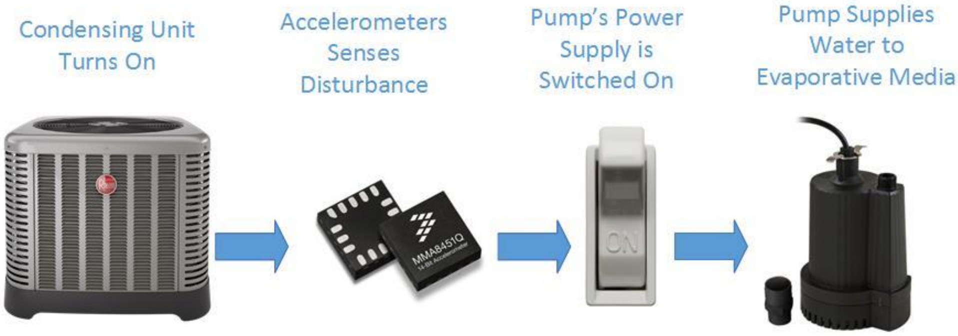

Figure 16. Pump control diagram.

Gravity Fed Control System
As with the pump control system, the gravity fed system will also use an accelerometer to monitor the vibration of the condensing unit. The accelerometer will communicate with a solenoid shut-off valve. When the condensing unit is on (vibrating) the valve will be set to open. When the condensing unit is off, the valve will close. Figure 17 is an illustration of the Gravity Fed control system.

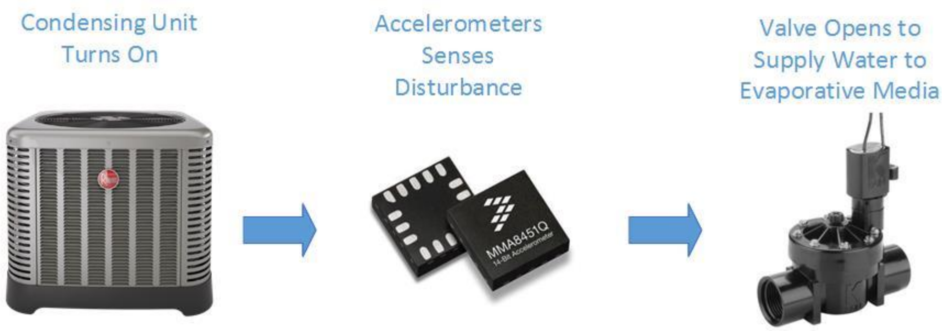

Figure 17. Gravity fed control diagram.

MAINTAINABILITY

Water and Control System

For the 275-gallon tank and PVC piping, there should be little to no maintenance required other than the occasional check for any holes, tears or damage. The Aquapro pump has a limited warranty of 1 year. The pump should be cleaned and checked for any damage or breaks to the housing after every cooling season. The homeowner should do routine inspections of the valve and pumps to ensure that they are operating in-sync with the condensing unit.

Evaporative System

According to Munters, in a commercial application, CELdek will last 4 years, however, with a conservative estimate it can be assumed that in a residential application the evaporative media will last around 5 years. Overall, it was found that the airflow rate going through the media has no effect on the maintainability, rather, it is affected by the saturation of the media. If there is running water on the CELdek® the media requires no maintenance due to its self-cleaning design. It is engineered to be nonporous and clean away dirt with running water by putting the media ridges at an angle for dirt and other unwanted contamination through the media to wash out.

COST ANALYSIS

Table 2. Initial Cost of Mechanical Pumping System [15][16]

Mechanical System	Initial Cost ($)
275 Gallon Tank	$170.00
Pump	$300.00
Evaporative Media	$85.00
Mesh	$32.00
Piping (100 ft)	$109.00
Control System	$50.00
Total Amount Spent	$746.00

Table 3. Initial Cost of Gravitational Pumping System

Gravity System	Initial Cost ($)
275 Gallon Tank	$170.00
Scaffolding	$100.00
Evaporative Media	$85.00
Mesh	$32.00
Piping (100 ft)	$109.00
Control System	$50.00
Total Amount Spent	$546.00

Table 4. Payback Calculations for Mechanical Pumping System

Energy Savings/yr (kWh/yr)	1044.8
Energy Cost in GA ($/kWh)	0.115
Money Saved ($/yr)	$46.02
Payback Duration (Yrs)	16.2

Table 5. Payback Calculation for Gravitational Pumping System

Energy Savings/yr (kWh/yr)	1044.8
Energy Cost in GA ($/kWh)	0.115
Money Saved ($/yr)	$120.15
Payback Duration (Yrs)	4.5

From Table 4 above, it will take about 16.2 years to pay back the initial cost of the system if the pump design is chosen. This is due to the pump's yearly operational cost of $74.13. However, by using the gravity induced system, the payback duration is reduced to 4.5 years. Noting these differences in the payback duration and because the initial cost of the gravity induced system is cheaper than the mechanically induced system, the gravity induced system is better.

CONCLUSION

Due to the high humidity levels present in Georgia the evaporatively modified condenser is the most viable solution. Based on analysis, it can provide energy savings up to 20% on cooling. For a typical low income household this can represent as much as $120 a year. The sustainable impact of this design is most strongly associated with its ability to prolong the life of outdated systems by contemporizing them with current market models. Designed for lower-income families, the gravity induced system has an initial cost of $546 and a payback period of 4.5 years. With a higher budget, improvements can be made to the design that were ultimately ruled out of this one due to the desire to keep initial costs low such as: including a recycling system for water that has run through the evaporative media, adding a control system to monitor the amount of water being used and adjusting for flooding. Ultimately, this is a very feasible design, even more so when applied in more accommodating environments, specifically ones that are not so humid. The lower the relative humidity outside, the more cooling can be provided to the air before it goes into the condensing unit. The same goes for dry bulb temperatures. The higher the outdoor air temperature is the more energy can be saved. It is a simple, robust design that can last years with little maintenance.

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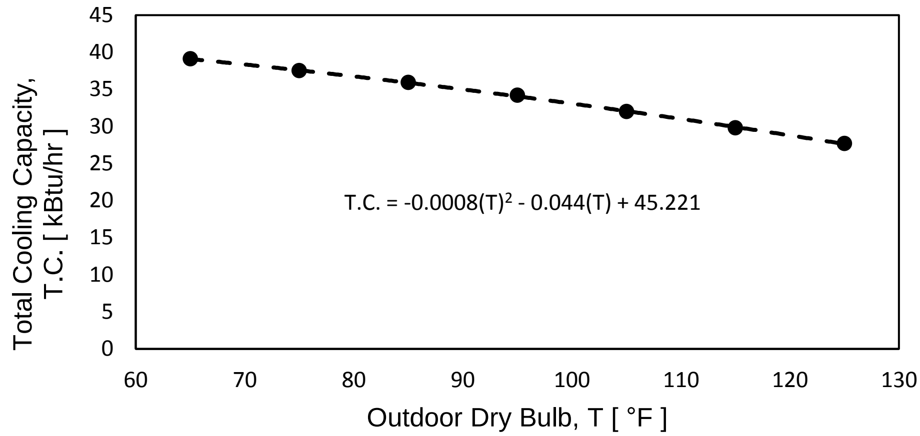
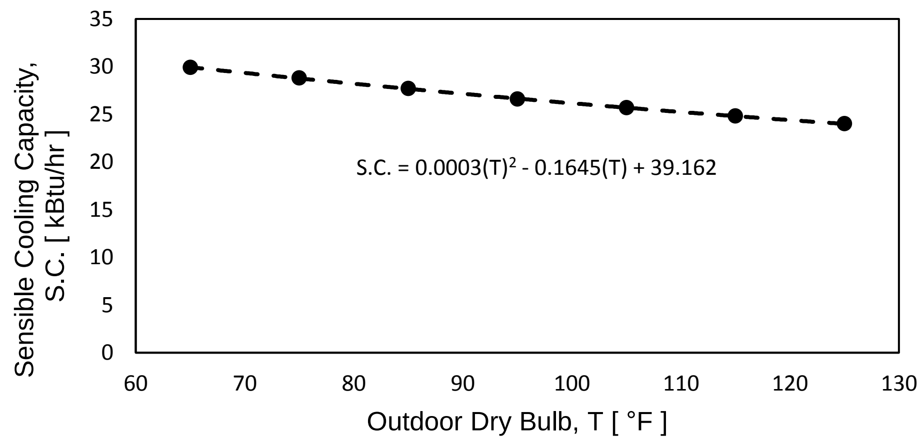
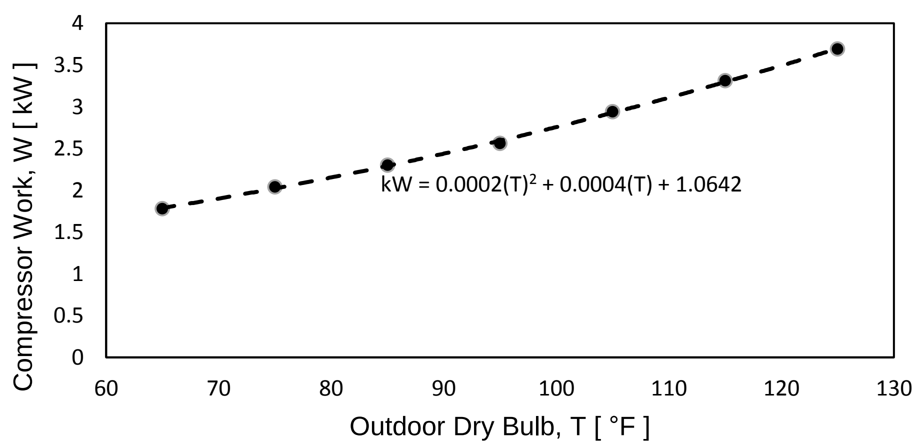
APPENDIX A: CURVE FITS FROM MANUFACTURER'S DATA FOR YORK AFFINITY 8T SERIES







APPENDIX B: TANK CONFIGURATION