Automatic Plant Watering System Optimization

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Introduction

Some of the major problems that humanity is facing today are shortages of food and water. Growing large amounts of food requires vast amounts of fertile land and millions of gallons of water. Approximately 80% of the United States' water consumption is from agriculture [1]. With our present agricultural system, water efficiency is low. States like California typically find themselves in water shortages, while water is wasted in other parts of the country. Likewise, food distribution is also quite inefficient. Since food is typically grown in areas of low population density, it must be transported to areas of high population density and distributed in supermarkets. Through this transportation and distribution, almost 50% of all US produce is thrown out or wasted (nearly $160 Billion worth) [2].

A solution to these problems is the use of large greenhouses. The Netherlands is an example of how greenhouses have successfully addressed these issues by producing the second largest amount of food by value in the world despite being a small country [3]. Greenhouses offer controlled, efficient growing environments for plants. An efficient greenhouse can control water and light to optimize the plant growth. Therefore, it can improve the efficiency of water use. Greenhouses can compact the space used by agriculture. They can be multiple stories to decrease the surface space used by agriculture. This can allow food to be grown closer to, or perhaps in cities. A desired side effect of this would be cleaning the air in metropolitan areas. Greenhouses take in carbon dioxide filled air and output oxygen because of the process of photosynthesis. Unfortunately, providing controlled environments for plants is very costly. Large amounts of energy are required to cool and heat the plant environments. Although technology has been on the works for some time, the United States itself needs much growth to make greenhouse technology widespread.

Typical Agricultural Fields

Large-scale vertical shelving

Project Goals

The Technology Evolutionary Components (TEC) Center at UCR wanted to focus on water efficiency due in part to Riverside's heat and to make the project more manageable. This was broken up into two main objectives over the year:

1) Develop an off-grid, cooling and heating system for a greenhouse.
   a) Design and model our cooling system
   b) Locate a build location
   c) Start building if modeling successful
   d) Collect data on the cooling/heating capabilities

2) Greenhouse movable rack with smart technology
   a) Design and model racks
   b) Build initial rack including smart sensors, pumps, lighting
   c) Control growth rate of crops grown in rack

Materials and Methods

Cooling-Heating System: Standard procedure for the cooling system was to create thermal models on MATLAB, draw it on Solid Works, and explain it through reports. This design is for a small UCR AG OPS greenhouse that will be used to test the concepts and perfect the design. Our model allows us to scale the design to larger greenhouses in the future providing the design and modeling was sufficient.

Heat Transfer Variables/Coefficients

Heat transfer, Q=UA(T2-T1)

q: amount of heat transferred (heat flux), W/m^2

h: heat transfer coefficient, W/(m^2•K)

ΔT: difference in temperature between the solid surface and surrounding fluid area. It is used in calculating the heat transfer, typically by convection or phase transition between a fluid and a solid. The heat transfer coefficient has SI units in watts per square meter kelvin: W/(m^2K).

NuD=h*D/k

ReD=V*D/ν

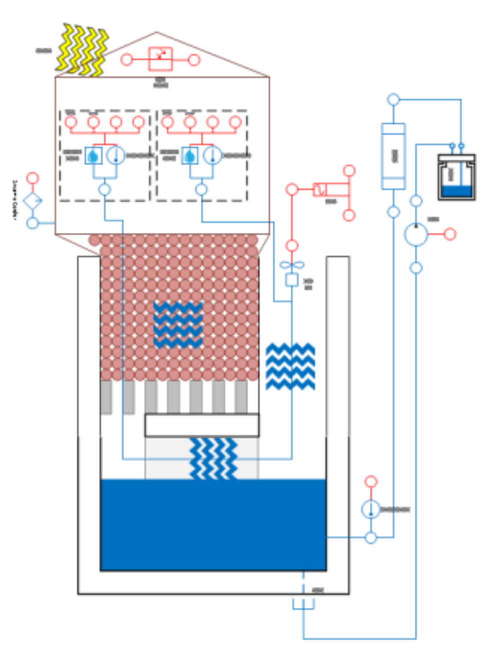
NuD=.023*(ReD^4/5)*(Pr^0.3)

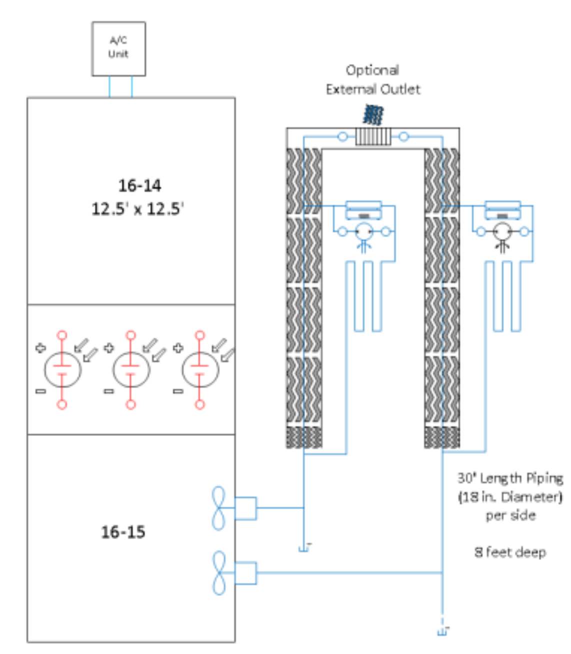
Q=h*A*(Tf-Tw)

Greenhouse Rack: The rack involved design work on Solidworks and mapping out proper materials such as 4 inch PVC pipes, metal signposts, water tanks, pumps, and corresponding hardware. It intends to create a structure with straight pipes spaced evenly. The structure had multiple options choose from such as the 'A' frame that would hypothetically would allow all plants to receive light evenly based on levels to a tub based system to move plants easier to a box frame with a cascading water system.

Results and Outcomes

Cooling-Heating System: A mathematical MATLAB model was used to find the steady state heat transfer from the air to the pipe to the ground. The model takes an input of the length of the pipe design and many predefined design constants and outputs the steady state heat transfer rate and a plot of the time it takes to reach steady state. With these constants and input, it iteratively calculates the change in temperature after each second and eventually finds where the system is in equilibrium. Then it finds the heat transfer rate at equilibrium. We found that a design with an 80 ft section of pipe would bring us close to our desired heat transfer rate of 4500 W as shown in **Figure 1**. We considered using corrugated stainless steel fins to increase our heat transfer surface area. Unfortunately, the model showed that the steel will heat up faster than it can be cooled. As shown in **Figure 2**, the fins reached steady state at a very low heat transfer level. We verified the model with a FEA Solid Works flow simulation. **Figure 3** shows that 3D model with the fluid temperature gradient through the pipe. **Figure 4** shows the flow trajectories of the air that we determined to ensure that the air was flowing at maximum efficiency.





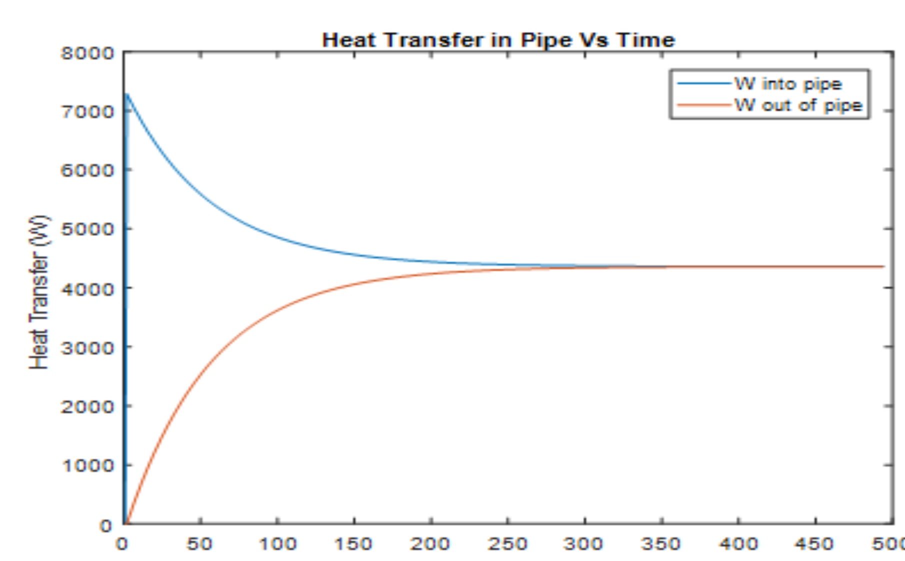


Figure 1

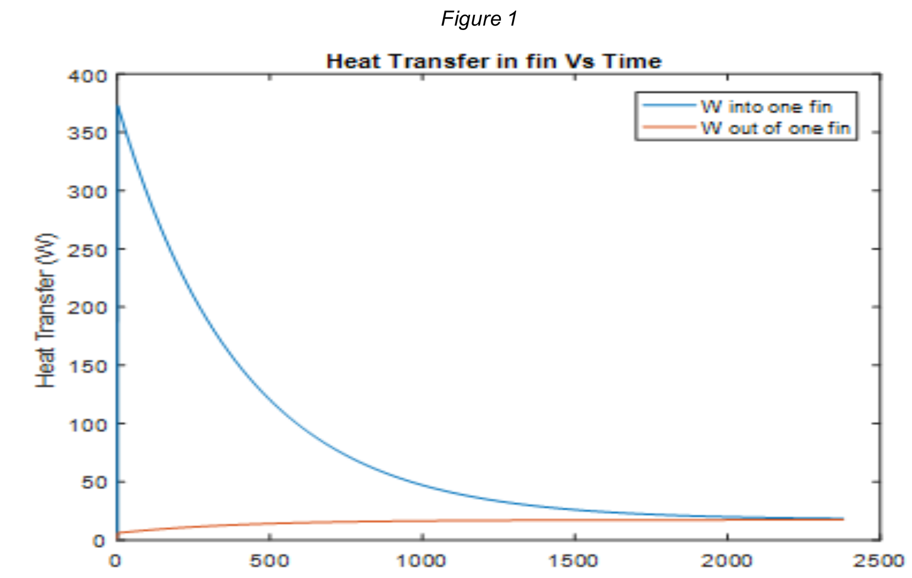


Figure 2

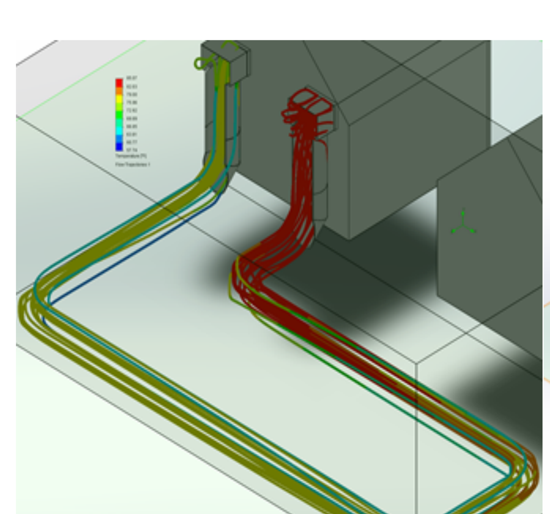


Figure 3

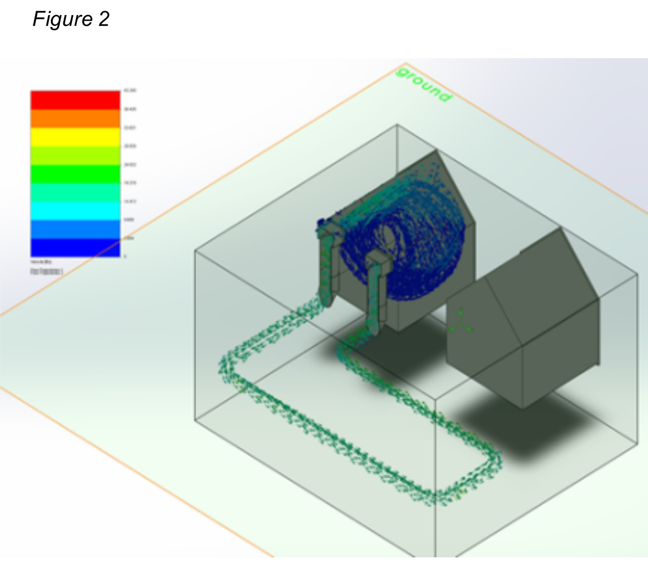
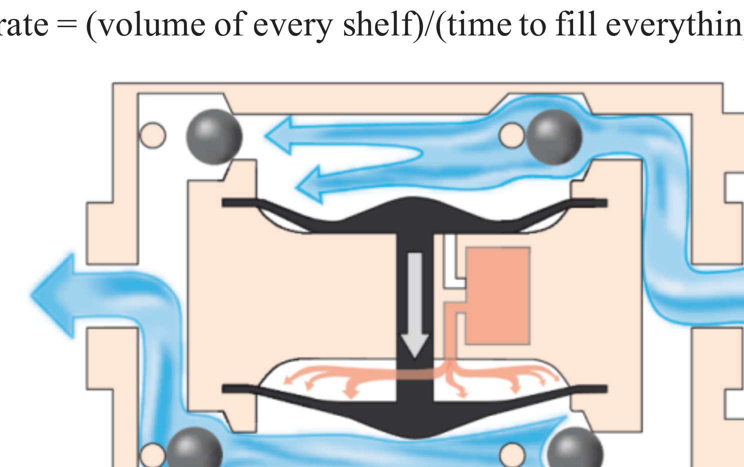


Figure 4

Greenhouse Rack: The vertical farming structure made from PVC has a cascading water system inside to nurture the plants. It consists of a box frame made out of metal signposts. Horizontal PVC pipes make up the shelving with slots for the plant seedlings. Iterations were designed in Solidworks, and materials have been ordered at the time of this poster writing. A more efficient and aesthetically pleasing water/nutrient circulation system is also being designed using pumps, drains, and water tanks.. To sustain the rack size, the estimated water flow rate was calculated as follows:

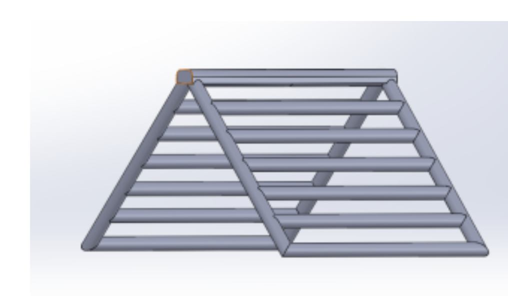
flow rate = (volume of every shelf)/(time to fill everything) = 22gph

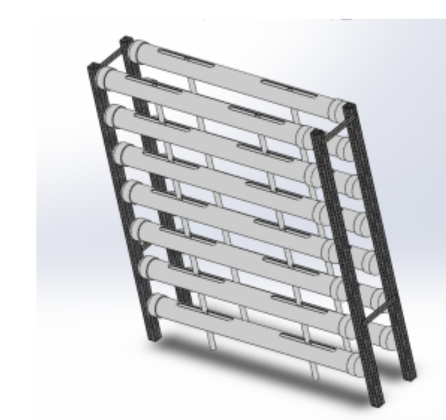


Conclusions

Cooling-Heating System: It was expected to produce a design for a greenhouse that operates off the grid with very little energy and water waste. After assembling the bill of materials and labor expenses, it was found that this design will actually be more expensive than an air conditioner for a 12X12 greenhouse. Although the concept is not efficient for small greenhouses, the heating and cooling system could be designed to be inexpensive relative to typical air conditioners for large-scale applications. No more than $4000 can be spent on the entire system prototype. The finished design maintains the greenhouse temperature between 70-85 degrees Fahrenheit. For future work, we aim to convert UCR greenhouses to use a design that will reduce energy consumption.

Greenhouse Rack: The design moved towards the box frame design due to compactness and water system reasons. Unlike the cooling-heating system, the design efficiency can't be tested through modeling software. Thus, building the actual rack for testing purposes is required. Luckily, Solidworks design was used to determine materials required and costs. The total cost for parts so far was $600, not including pumps and water tanks. The goal remains with proof of concept as cheaper materials can be found in bulk.





Future Goals

Cooling-Heating System: The next step would be to adapt the cooling system for the smaller greenhouses in UCR Agricultural Operations. Once a sufficient system is built, testing using the sensors and data can commence. The hope is to fit the system for the UCR Solar Greenhouse that can deal with the Riverside heat.

Greenhouse Rack: Once the structure is built, a cascading watering system for the plants will be added. Pumps circulate the water with water tanks for storage. Implementing sensors to monitor the plants' growth around the pipes with parameters such as water, nutrients, and sunlight levels would be the next step to prepare for data collection and testing. Calculations on $NPSH_A$(Net Positive Suction Head Available) depend on the system geometry. These would allows us to then choose a pump with an $NPSH_R$ (Net Positive Suction Head Required), such that $NPSH_A$ is greater than $NPSH_R$ (basically meaning a sufficient pump).

Overall, this goal would translate to the greenhouses in the pictures below:

References

[1]https://www.ers.usda.gov/topics/farm-practices-management/irrigation-water-use/

[2]https://www.theatlantic.com/business/archive/2016/07/american-food-waste/491513/

[3] Viviano, Frank. "Feeding The World." National Geographic, Sept. 2017.

[4] Incropera, F.P., and DeWitt, D.P., Fundamentals of Heat and Mass Transfer, 5th edition, John Wiley & Sons, New York, 2000.

Acknowledgements

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