Design and Development of a Mobile Geothermal Laboratory Equipment

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Abstract

As the development and promotion of renewable energy resources advance, the implementation of geothermal energy has been receiving attention, for it is a part of renewable energy source from industry and academia. Geothermal energy (GE) is heat derived below the earth's surface which can be harnessed to generate clean renewable energy. This vital, environment-friendly clean energy resource supplies renewable power around the clock and emits little or no greenhouse gases all while requiring a small environmental footprint to develop. GE related coursework is becoming an important part of the science, engineering, and technology curricula. Hands-on training in GE-related coursework is a major part of engineering technology-related technical coursework. GE courses typically require applied laboratory experiments for the students, unless the course is being taught in programs related to business and education. Laboratory experiments for the related courses require a good laboratory workbook pertaining to what is being taught in the lectures and the related laboratory equipment. There is a variety of laboratory equipment available on the market for GE-related courses. The cost of the equipment varies between \$20,000-\$100,000 or more depending on what is expected and required in the course. Some of the training/laboratory equipment companies offer manuals or workbooks to accompany their equipment. Technical and engineering programs cover specific renewable energy curricula. However, due to excessive cost, some academic programs face budget challenges to buy necessary lab equipment for renewable energy technologies. These funding restrictions mean the programs must seek ways to build their own equipment and prepare related laboratory activities. This research describes design and development of a mobile geothermal energy training/lab unit. The unit is completely designed and built in the design and production laboratories of an engineering technology program by faculty and students, with the help of a local geothermal company.

Introduction

Various technologies have been developed to take benefit of geothermal energy systems, for example, the heat from the earth. There are three major geothermal technolgies are available for our use: (a) the geothermal electricity production from the earth;s heat, (b) direct use of geothermal which produce heat directly from hot water within the earty, and (c) geothermal heat pumps use the shallow ground to heat and cool buildings. Moreover, this energy can be extracted from several sources: hot water or steam reservoirs deep in the earth that are accessed by drilling; geothermal reservoirs located near the earth's surface, and the shallow ground near the Earth's surface that maintains a relatively constant temperature of between fifity – sixty degrees fahrenheit. This variety of geothermal resources allows for development on both large and small scales. For example, a utility can use the hot water and steam from reservoirs to drive generators and produce electricity for its customers. Other applications utilize the heat produced from geothermal directly to various uses in buildings, roads, agriculture, and industrial plants. Still others use the heat exchange between the ground and equipment to provide heating and cooling in homes and buildings -- the geothermal (or ground source) heat pump [1].

According to the latest report prepared by Benjamin Matek from Geothermal Energy Association, the global geothermal energy and operating capacity is at about 13.3GW as of January 2016 [2]. Globally, in 2015, eighteen new geothermal power plants were activated by adding about 313MW capacity to the overall geothermal energy capacity. The Matek report indicates that there was about 3.7 GW of installed capacity and 2.7 GW of net capacity at the end of 2015.

The addition of new geothermal power plants necessite qualified personnel in any phase of geothermal energy installation, production, and distibution. Most importantly, the promotion and awareness of geothermal energy is needed to educate communities about the advantages of the geothermal energy systems. There are a variety of occupations which contribute to geothermal energy fields from building to maintaining. Some of the main occupations are science (environmental, geologist, hydrologist, wildlife biology), engineering (civil, electrical, mechanical, power), drilling, construction (surveyers, estimators, plumpers, electricians) and construction management, plant operations etc. [3].

According to Paul Lester [4], three of the ten important facts of the enhanced geothermal are summarized as part of the *Top Things You Didn't Know about…* series are:

> *(a) Geothermal technologies use the naturally occurring heat located in shallow ground, hot water and rock below the earth's surface to generate electricity. Geothermal is considered a renewable source of energy because the earth's core generates nearly unlimited heat;*
> *(b) The United States generates more electricity through geothermal energy than any other country in the world. The leading state, California, generates 79% of the nation's geothermal electricity;*
> *(c) With current geothermal technologies, electricity can be generated only where three key conditions are met: heat, fluid and natural permeability at depth. Small underground pathways conduct fluids through the hot rocks, carrying energy in the form of heat through wells to Earth's surface, driving turbines and generating electricity* [5].

The report titled *US Geothermal Education and Training Guide* was shared by Geothermal Energy Association (GEA) in 2010 [6]. This guide incorporates lists of (a) geothermal educational opportunities; (b) institutions and academies that offer geothermal related programs and trainings; (c) research centers; (d) potential research and academic related grant resources; (e) industries offering geothermal energy related research and experience; and (f) national and international associations.

The majority of alternative energy educational training units are built and sold by companies that offer custom-made systems according to the customers' needs; this increases the cost of the training units. Alternative energy teaching tools help students to fully comprehend complex concepts with interactive educational training equipment and are very important for the hands-on laboratory sections of energy education. Due to the major costs of educational training units, it becomes a budget concern when purchasing multiple units of training equipment for $50,000 dollars per unit [7-11]. If there are a budget concerns for a program, the only option the instructor has is to teach only the associated theory of the course.

Taking these issues into consideration, building an energy training unit becomes a smart idea for exposing students to alternative energy fields at least for demonstration purposes. The training units need to be designed for use in hands-on activities which can provide students opportunities to engage in experiments that will reinforce the material covered. The construction cost of the training unit should be kept low in order to make the project cost-efficient, esperically for multiple unit projects. In this project, the outcomes enable the project participants to understand and work with the developed systems. The aim is to design and implement an interactive educational training unit covering fundamentals of geothermal energy systems. The unit's mobile nature makes the unit portable so that the unit can be moved between schools for demonstration purposes.

Theory of Operation

The geothermal heat pump (HP) demonstration unit (Figure 1) consists of a small standard geothermal heat pump unit utilizing a water tank as the ground source. Water in the tank is circulated through the HP using a small electric pump with the flow rate being controlled by a globe type valve [12]. The water flow rate is measured using a small electromagnetic flow meter [13]. Imprtant to the operation of this HP unit is the temperature of the water being fed into the HP (i.e. the water tank temperature). The water temperature is measured at two locations—as it leaves the tank and as it leaves the HP unit. The HP is used to condition (change) air temperature. Air temperature is measured entering the HP unit and as it leaves the unit. The unit is controlled using a programmable logic controller (PLC) that acts as a thermostat affected by water temperature. In theory, varying the water flow will change the rate of change in the water tank temperature and affect the change in cooling capacity of the heat pump. In addition to controlling the system, the PLC can be connected to a computer to log the flow and temperature changes taking place. This can be used to analyze the most efficient operating conditions for the heat pump.

Figure 1: Geothermal AC Unit

Industry Colloboration and Design Process

An engineer from Loop Tech, LLC [14] met with the students who would be working on the project to discuss the intent of the unit, outline the criteria for its design, and to brainstorm ways to construct the demonstration unit. A lesson in how ground source heat pumps operate and the different types of units was presented to the students. Initial design criteria defined that the unit:

- must be portable;
- must fit through a 36" wide classroom door;
- must have clear sides to view the internal components of the heat pump;
- and will use a water tank as the ground source.

The water tank [15] will heat up and cool down; this allows trainees to feel the heat exchange taking place; the tank should also be drainable to lighten the weight of the unit for loading/unloading during transport. The unit will work on a thermostat that senses the water entering the unit rather than sensing the air temperature, in order for the unit to automatically switch between cooling to heating modes.

A process diagram (Figure 2) was drawn to identify the components of the heat pump system. It is important to understand and view the temperature transfers taking place, so a control panel was conceived to allow trainees to monitor those temperatures. A team worked on the instrumentation and control system. A programmable logic controller (PLC) [16] was chosen to perform the thermostatic control and monitoring of temperatures.

The heat pump operates on 240VAC; however this power is not available in most classrooms. Since most wall receptacles provide 120VAC at 15 amps, this became a design criterion for the demonstration unit. A power converter (used to convert between European and US power) was evaluated and selected to operate the heat pump [17].

Proper water flow through the heat exchanger is critical to proper operation of the heat pump and tank capacity must be evaluated to allow for a reasonable cycle time for the thermostat function. A team evaluated these parameters and began the process of selecting the appropriate pieces of equipment, pricing, purchasing sources, and delivery time to fulfill the criteria.

It was determined that a wagon capable of supporting the weight of the equipment and a full tank of water would allow the unit to be portable and still fit through a door. Keeping in mind the equipment to be used, a team began creating designs for support, piping, electrical connections, and air ducting of the system.

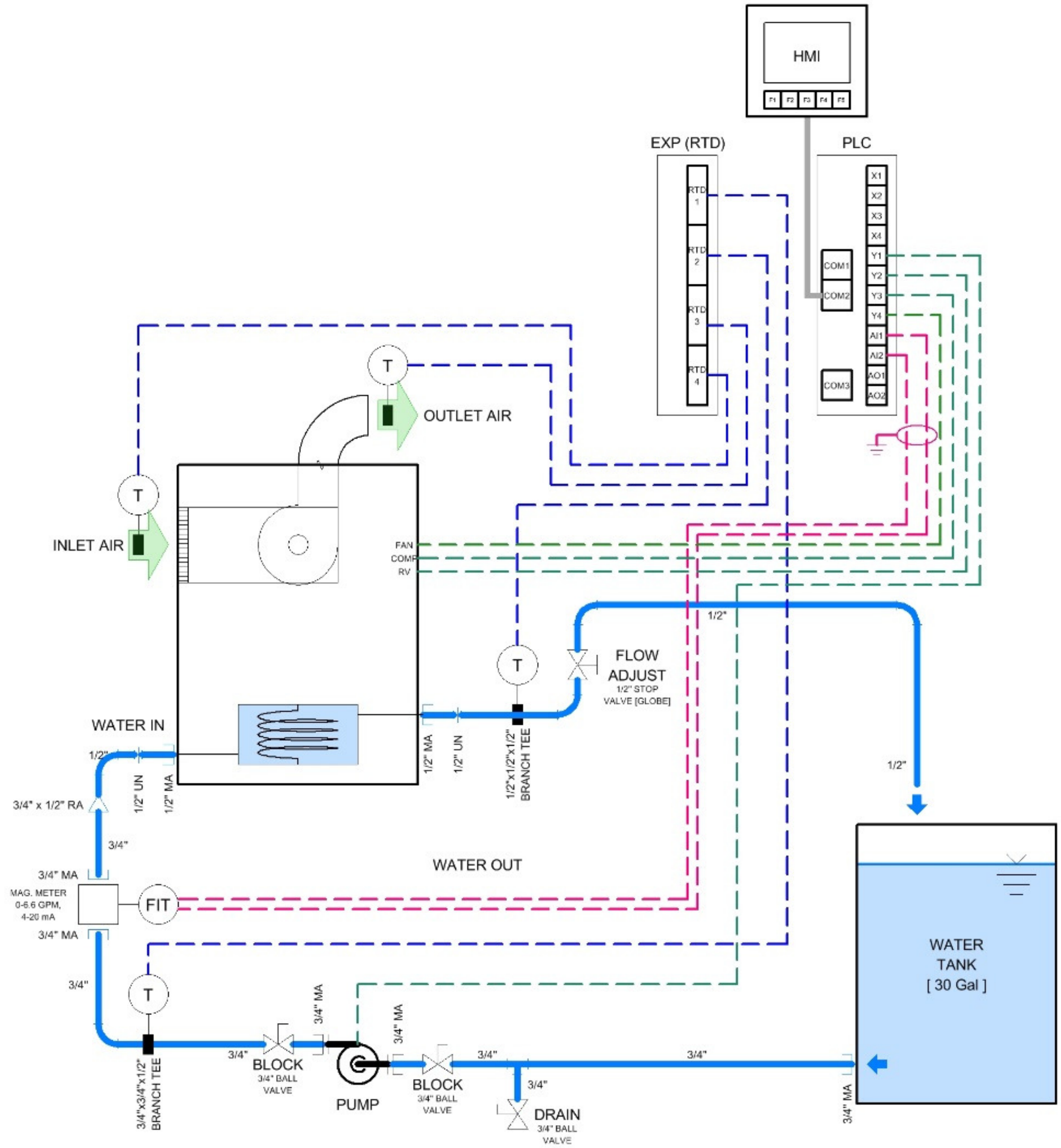


Figure 2: Process Diagram

A major component list is provided in Table 1. The component list provides a complete list of materials purchased from various vendors with the support of departmental funds.

Table 1: Material List

Item	Description	Source	Part Number	Cost
Heat Pump	Water Furnace - Versatec Water Source/Geothermal Heat Pump	LoopTech, LLC	VLV009C000CRT2SSA	2500.00
Tank	RomoTech Poly Storage Tank, 30-Gallon Capacity, # 2390	Northern Tool	48171	109.00
Pump	TACO 009-F5 Pump	Supply House.com	009-F5	231.95

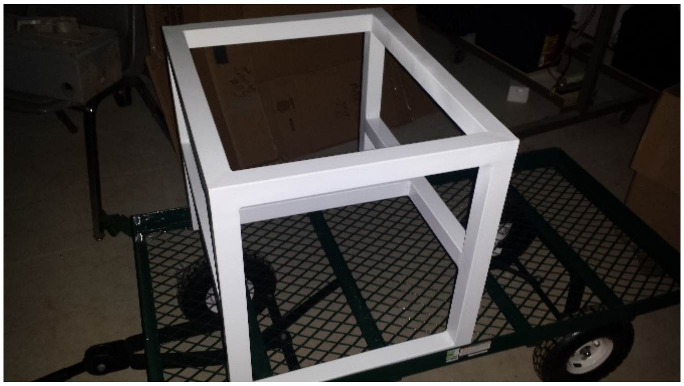
	TACO 110-523BSF 3/4" Bronze Flange Kit	Supply House.com	110-523BSF	27.95
Controls	PLC, RTD Module, Power Supply, Relay Module, HMI, Breakers, Fuse Holders, Terminal Blocks	Automation Direct		479.50
Flow Meter	ProSense Magnetic Flow Meter w/ accessories	Automation Direct		474.25
Float Switch	ProSense float level switch, top-mount	Automation Direct	FLS-VM-100	10.50
RTDs	McMaster Carr #6577T28 (surplus purchase-8pc)	EBAY		86.00
Voltage Converter	120/220VAC, 3000VA, 2000W	WW Grainger	30C522	238.75
Plumbing/Piping	copper piping	Home Depot		160.28
A/C Windows	18 in. x 24 in. x .220 in. Acrylic Sheet, clear (2 reqd.)	Home Depot	SKU# 241929	41.94
Misc wiring	Power cords and hookup wire	Mouser		50.64
Wagon	Mesh Deck Steel Wagon 2'X4', 100# Capacity	Harbor Freight	38137	79.99
Flat free tires	Northern Tool (4 reqd.)	Northern Tool	189386	91.96
Control Box	Aluminum Bare Sheet 6061 O, .063"x 36"x48"	Online Metals		43.74
A/C Outlet	24ga. Steel 24" x 36"	Online Metals		17.70
A/C stand	1.25" Sq Tubing	surplus		35.00
			TOTAL	**4679.15**

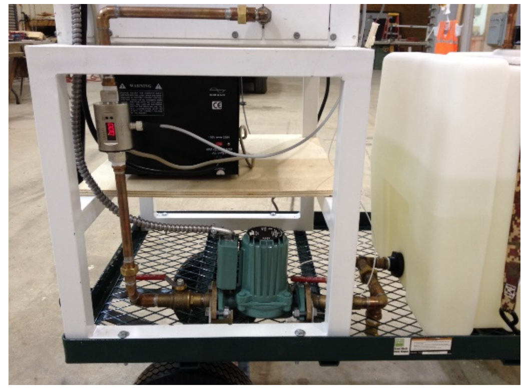
Building Process

The wagon was acquired and the mechanical design team began fabrication of the heat pump support stand, exhaust duct, and control box (Figures 3a, 3b, 3c, 3d). It was determined that since the demonstration unit was heavy and would have a high center of gravity, it could fall over if the pneumatic tires on the wagon went flat. Therefore “no-flat” tires were purchased to minimize this concern.

Copper piping was fabricated to form a ridged and durable piping system. Adapters were fabricated to attach the temperature sensors to the water inlet and outlet copper piping. Temperature sensor brackets were also fabricated for the air inlet and exhaust.

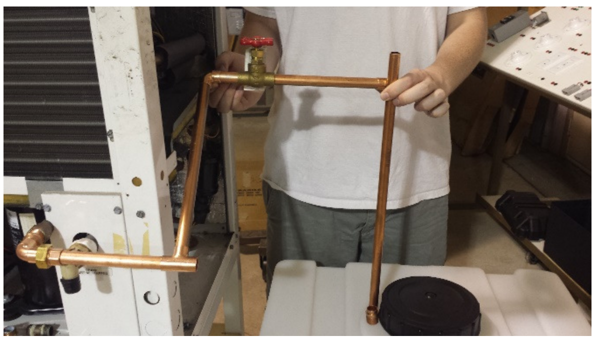
A team fabricated the electrical back panel and prepared the PLC program to monitor and control the system. Bench testing was performed to verify its functionality. Once verified, the back panel was installed and wired to the heat pump, water pump, voltage converter, and sensors.

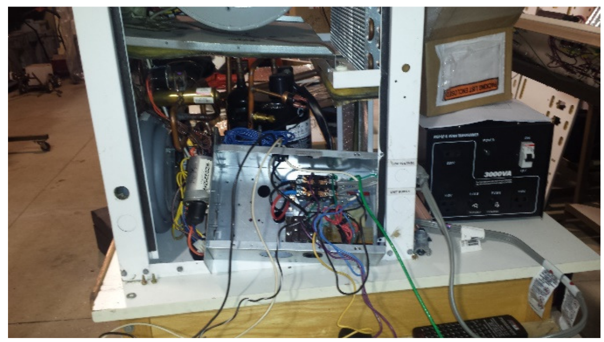




a) Metal Housing for HP

b) Pump and Flow Meter Installation





c) Piping Installation and Testing

d) HP installation and Testing

Figure 3: Fabrication and Assembly Process

Elevation diagram of the complete unit is given in Figure 4. Each component in the diagram is indicated by the leaders. The diagram gives a clear picture of how the major components are laid out on the mobile unit. The unit is portable and easy to transport for demonstration and teaching purposes.

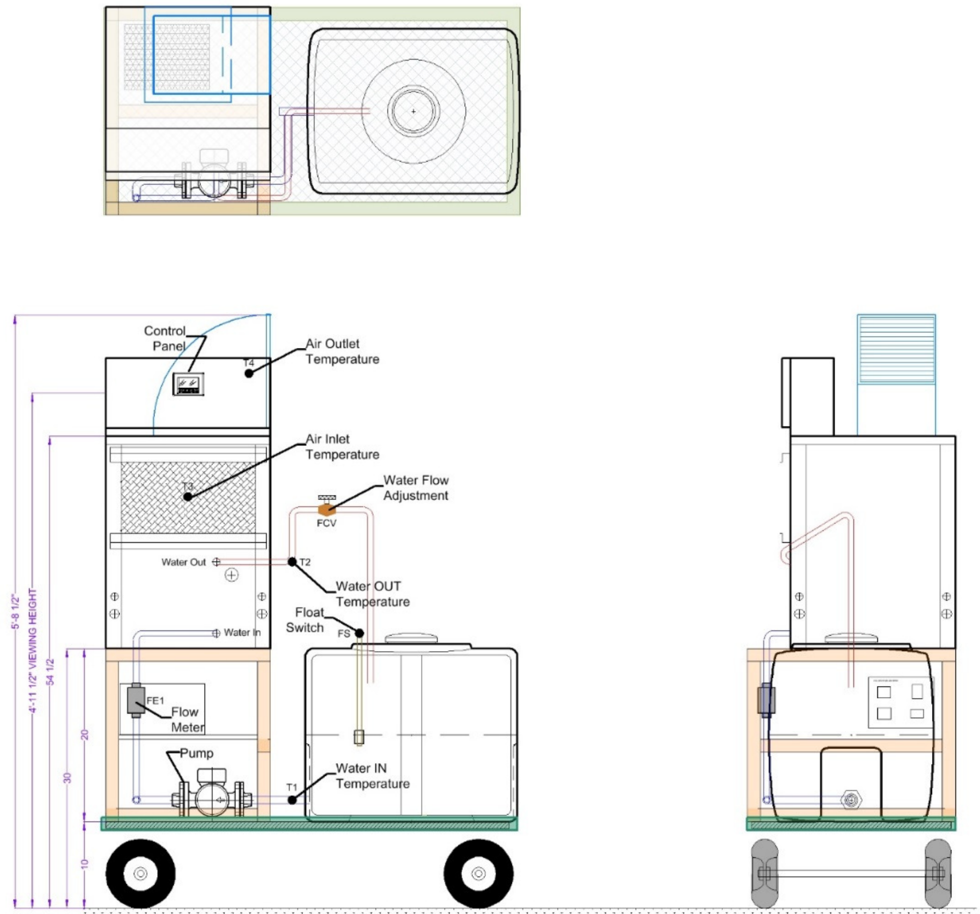


Figure 4: Elevation Diagram

Commissioning

Once the piping was completed, the tank was filled with water to perform a leak test. No leaks were found after the test process. The water pump was used to circulate water and verify that the piping did not leak. The water flow control valve was varied, and the water flow measurement was monitored to verify it was responding properly. All temperature sensors were monitored verify they were responding properly. The voltage converter was activated, and power was applied to the heat pump. The heat pump was placed in the automatic mode, and temperatures were monitored for appropriate response (air was cooling; water was heating). During these operations, the supply voltage and current were monitored to verify neither were overloading the wall receptacle using a “Kill A Watt” power monitor.

The project team held a meeting to discuss which temperature control approach would be best suited for this system. An investigation was made into the operations of a wall thermostat (both electro-mechanical and electronic types), their internal switching, and anticipator circuits. Since the system will work off of the water temperature in the tank rather than operating on ambient air temperature, it was determined that the operating temperature range would work best using high and low temperature set points. A PLC contact and timing arrangement was conceived to emulate the conventional wall thermostat for the heat pump.

During the commissioning stage, the transition between cooling and heating modes of operation did not operate as anticipated. The heat pump controller board monitors operation of the heat pump had fixed delays that confounded the PLC program. The PLC program was designed to have an adjustable delay between transitions of cooling and heating; however the controller board also had such a delay. It was determined that the PLC delay could be removed, which would allow the controller board to perform the delay function.

Control Unit and Logic

For the process control and instrumentation purposes aforementioned, Automation Direct (AD) products were preferred due to cost and easy programming environment. Most of the sensors and meters were also obtained from AD for compatibility reasons. The control and instrumentation unit is shown in Figures 5a, 5b, 5c, 5d, 5e, 5f.


a) PLC Control/Monitoring Box – Internal

b) PLC Monitoring Display

c) System Startup/Welcome Screen

d) HP Control Screen

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e) Temperature Setpoint Control Screen   f) Process Monitoring Screen

Figure 5: Control and Monitoring Unit

The control and monitoring unit is the *brain* of the geothermal unit. This unit is expandable in order to handle more sensors, so that the project can be extended. The enclosure of the control and monitoring unit is a custom-made enclosure designed and built in the engineering technology production laboratories. The PLC selected has 24VDC sourcing discrete and analog I/O. The wiring diagram is shown in Figure 6. The diagram shares all the wiring details with the users. The main purpose of this diagram is to construct other similar units in future energy ralated courses and training workshops.

Conclusion

This study gathered students from a variety of disciplines together, merging their creativity and design knowledge to solve a real world objective by implementing a hands-on experimental project. The project taught the students the value of team cooperation, planning, problem solving, and project management. The outcome of this project was an efficient, easy to build and operate, cost-efficient, portable geothermal energy training unit which works as a stand-alone mini-lab. The results of this type of project demonstrates that other institutions can develop their own systems and acheive simlar success. The project engaged student participation from different disciplines (design and development, electronics and computer engineering technology, and ET- electronics). The team leader (a faculty advisor) set up meetings to organize working schedules, progress reports, construction and commissioning was conducted for the project. This fully functional laboratory training unit will augment applied energy education workshops for local community colleges, secondary/high school science/technology teachers, students, and special interest populations who are not exposed to state-of-the-art renewable energy technologies.

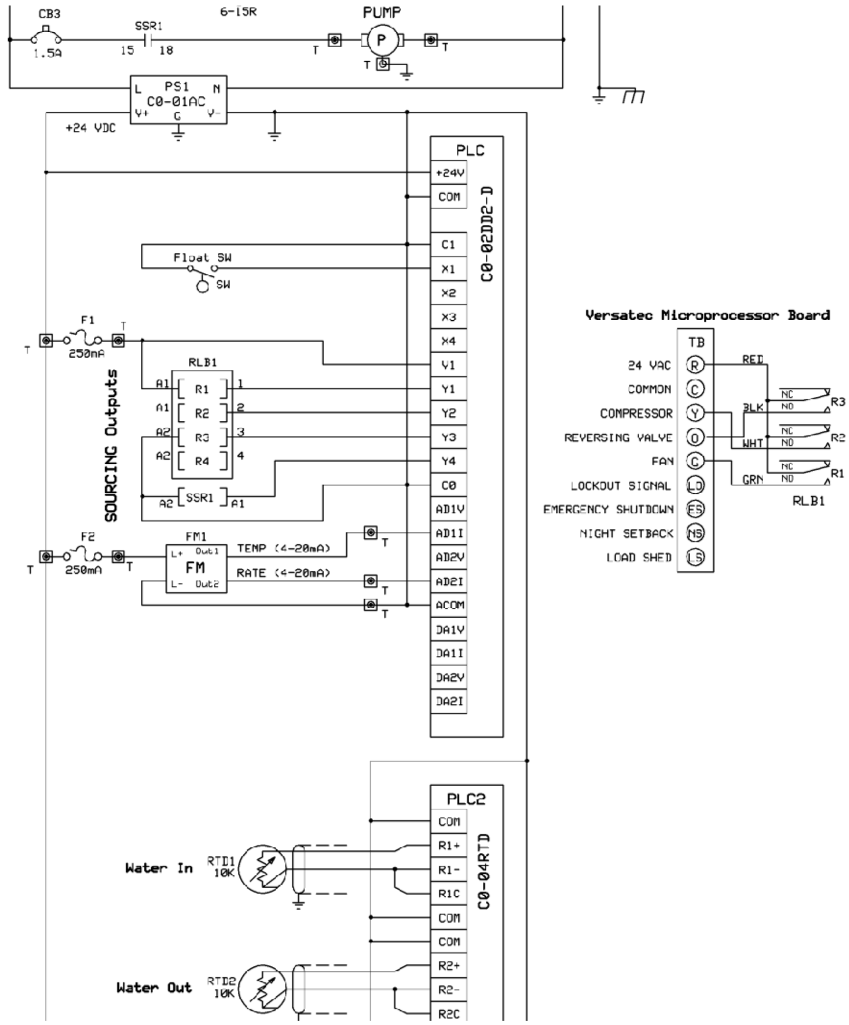

Figure 6: AC and HP Wiring Diagram

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