Energy Management Monitoring of a Geothermal System at Northwest Tennessee Correctional Facility

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Introduction

The Center for Energy Management is located in the College of Engineering and Natural Sciences at the University of Tennessee at Martin. This center was created in the summer of 2000 to provide energy-related services to regional government and industrial organizations. The Center gives faculty members in the Department of Engineering an opportunity to conduct applied research that is supported with undergraduate engineering students. The students are actively involved with projects that tie their coursework to the real world, and the center provides a necessary service to regional government and industrial organizations. The concept for the center began in the summer of 1999 when an Energy Management Administrator with the Department of Finance & Administration [1], contacted the School of Engineering. The Department of Finance & Administration was looking for a resource that would provide the state with independent third-party analysis and verification of new energy management technologies.

To date, five engineering students and three engineering faculty members have been involved with the center and the funding level has reached approximately $150,000. The sources for this funding are the State of Tennessee Department of Finance & Administration and the Tennessee Department of Corrections.

This paper provides a description of a long-term energy monitoring and analysis project undertaken by the Center for the Northwest Tennessee Correctional Facility. In addition to describing the project, it also discusses how undergraduate engineering students obtain real-world experience through their involvement with the project.

Geothermal Energy Monitoring Project

The largest project involving students and faculty from the center is the long-term monitoring and analysis of the geothermal HVAC system at the Northwest Tennessee Correctional Facility

(NWCX). Funding for this project began in May of 2002 and the project is expected to continue for approximately three years.

NWCX is a medium custody correctional facility that houses 2,370 inmates. It consists of two compounds, a Main Compound that was constructed in 1992, and an Annex Compound that was constructed in 1980. The Annex contains sixteen similarly built inmate-housing units, known as guilds, as well as a host of other buildings. The guilds are 4,000 sq ft brick buildings that are similar in construction, and are located side by side along a circular arc. Each guild houses approximately thirty inmates who follow the same daily routine. Figure 1 shows the front view of three guilds.

Figure 1. Guilds 5, 6, and 7 at NWCX. Guild 5 is on the left, 6 is in the middle, and 7 is on the right.

The heating, ventilating, and air conditioning (HVAC) systems for the sixteen guilds use twenty-year old water-to-water heat pumps. The source water for the heat pumps is provided by a "central loop" system that uses a chiller and boiler to maintain the water within a temperature range of 60 to 90 ^{o}F. These cooling towers are shown in Figure 2. The domestic hot water (DHW) system for these guilds is provided by electric resistance hot water heaters. The expense of operating and maintaining the chiller/boiler system and the age of the heat pumps prompted the Department of Corrections working with the Tennessee Energy Management Office to examine alternative methods for providing HVAC and DHW to the guilds. In 1999, a decision was made to run a demonstration project by replacing the heat pumps in one guild with new heat pumps connected to a closed-loop, vertical well, geothermal system. The UT at Martin was contacted during the design of the geothermal conversion to develop a plan to determine the life cycle savings that would be realized by converting all of the guilds to a geothermal system.

Figure 2. Cooling towers used in the existing central loop system.

Cost Analysis Plan Overview

A literature review was conducted to determine if similar geothermal monitoring programs had been conducted elsewhere. While several programs had been completed [2], [3], they each made use of direct digital control systems to collect the data and none of the programs had attempted to

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compare similar buildings with and without geothermal systems. A comparison of the cost effectiveness of meeting HVAC and DHW systems in multiple buildings is difficult because of the differences in thermal load and construction. Although the prison guilds being considered in this demonstration project are of similar construction and are located next to each other, it was felt that differences in demand (e.g. thermostat settings, in-and-out traffic, hot water usage, etc.) would be difficult to control. Therefore, the metric used to compare the cost effectiveness of the geothermal system and the boiler/chiller system has to be normalized to the actual HVAC and DHW load for each guild for the respective guild.

Although several metrics were considered, a normalized cost equation was developed that provides the cost of delivering a unit of energy used in the respective guilds. This metric allows a direct comparison while accommodating differences in load and use patterns in the various guilds. It was also found to minimize the cost and amount of instrumentation required.

Figure 3 shows a control volume of Guild 5, which uses the geothermal water source heat pumps to provide HVAC and domestic hot water. Nomenclature for the terms used in figure 3 and the following equations can be found in the Nomenclature Section following the Summary. The energy load that the geothermal source heat pumps must accommodate is given by the equation

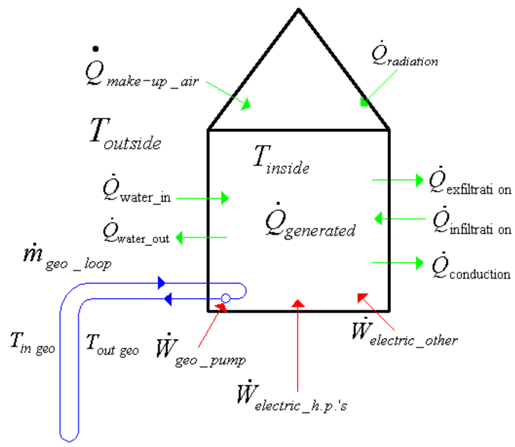

Figure 3. Control volume of Guild 5.

$$\dot{Q}_{load} = \dot{Q}_{generated} + \dot{W}_{electric\_other} + \dot{Q}_{infiltration} - \dot{Q}_{exfiltration} + \dot{Q}_{radiation} + \dot{Q}_{water\_in} - \dot{Q}_{water\_out} + \dot{Q}_{make\text{-}up\_air\_in} - \dot{Q}_{make\text{-}up\_air\_out} - \dot{Q}_{conduction} .$$

In this equation, some of the terms can be measured in a reasonable manner and others cannot. Although a direct measurement of all of quantities is not possible, $\dot{Q}_{load}$ can be found from an energy balance and is given as

$$\dot{Q}_{load} = \dot{W}_{geo\_pump} + \dot{W}_{electric\_hps} + \dot{m}_{geo\_loop}\, c_p\, \Delta T_{geo\_loop} .$$

All terms on the right-hand-side of this equation can be measured in a reasonable manner. The cost of delivering a unit of $\dot{Q}_{load}$ can then be written as

$$\frac{\text{Cost}}{\text{Unit of Load}} = \frac{\int_{t_1}^{t_2} \left(\dot{W}_{geo\_pump} + \dot{W}_{heat\_pumps} \right) dt \left(\frac{\text{cost}}{\text{kW-hr}} \right)}{\int_{t_1}^{t_2} \dot{Q}_{load} \, dt}$$

This metric, modified to account for differences in how the DHW is provided, provides the basis for the measurements being taken and the analyses being performed.

Guild 5 is the housing unit in which the geothermal closed-loop HVAC and DHW system has been installed. The system contains five water-to-water heat pump units for heating and cooling, a water-to-water unit for heating and cooling fresh air brought in from outside through a blower coil, and one water-to-water heat exchanger for heating the domestic hot water.

Guild 6 remains connected to the existing chiller/boiler central loop system. However, modifications were made to minimize other differences between it and Guild 5. Guild 6 had five, 20-year-old heat pumps replaced with new units identical to those in Guild 5. This was done to eliminate the performance issues between new units versus old units in the geothermal versus central loop comparison. An additional water-to-water heat pump unit was added to the existing central loop to condition the fresh air being brought in through a blower coil. The DHW in Guild 6 will continue to be heated with electric resistance elements.

Guild 7 contains 20-year-old heat pumps connected to the central loop system and uses electric resistance to heat the domestic hot water. This guild does not contain a make-up air system and represents the current state of the remaining guilds.

Undergraduate Student Involvement

Upper division undergraduate engineering students have been involved in the geothermal performance-monitoring project from its inception. During the design of the geothermal conversion for guild five, two students, working on a senior research project, were tasked with determining what measurements needed to be made to determine the cost savings that would be realized by converting from the central loop system to the geothermal system. This was an open-ended problem in which the students had to perform research to determine if similar comparisons had been made and what methods had previously been used. They applied knowledge learned in Thermodynamics and Energy System courses to identify the energy sources entering and leaving the guild. They then determined which of the energy sources could be measured directly

Figure 4. Student beside two geothermal water source heat pumps in Guild 5.

or inferred from other measurements. This was not an easy problem and significant discussions and iterations with faculty advisors and personnel from TDOC were required. The normalized cost equation previously described resulted from this activity.

Once the students had developed an approach for comparing the guild containing the geothermal conversion to the other guilds, the variables in the normalized cost equation were used to develop a list of parameters to be measured. The students were actively involved in identifying the measurement methods and the necessary instrumentation. They assembled a spreadsheet that listed all measurements, the required transducers, vendor model numbers, and associated cost. This list was used by the Department of Corrections to purchase the instrumentation.

A second pair of students assisted in the installation, calibration, and commissioning of the monitoring phase of the project. These students prepared detailed drawings that included piping and HVAC duct schematics. The locations of all instrumentation were shown on these drawings which were used by the TDOC to install the devices. The students spent approximately one day per week at the prison facility monitoring progress and making sure that all transducers and wiring were properly installed.

The TDOC used prison labor to perform most of the geothermal conversion and to install the measurement devices. Prisoners were provided training, and installed the geothermal piping, insulation, and instrumentation wiring throughout the effected guilds. The students involved in this project were required to pass through prison security to gain access to the guilds and were in close proximity to the prisoners while doing much of their work. The students were a little anxious and uncertain on their first visit to the prison, but quickly overcame any apprehension and have experienced no difficulties working in the vicinity of the prisoners.

Figure 5. Insulated piping installed by inmate labor at Northwest Tennessee Correctional Facility.

Seeing first hand the steps taken to ensure the safety of the prisoners and prison staff was also an educational experience for the students. All low voltage instrumentation wiring was run in conduit to prevent prisoners from being able gain access to the wire. Rope and wire can be used by inmates to potentially inflict harm to themselves or other inmates. In addition, all of the data loggers were housed in metal boxes with access keys to prevent inmates from gaining access to them. This type of precaution was something to which the students had not been previously exposed and gave them insight into real world situations.

Fresh Air Controller Design

Both guilds 5 (geothermal source heat pumps) and 6 (central loop source heat pumps) contain a make-up air system required to meet ASHRAE fresh air requirements [4] (Figure 6). The engineering drawings for these guilds contain performance specifications for a controller that turns on a heat pump to condition the fresh air via a coil if the outside air temperature drops below 40 ^{o}F or exceeds 90 ^{o}F. Non-conditioned water is circulated continuously through the coil when the outside air temperature is not outside of these temperature limits. The control specifications also require a number of interlocks and alarms to ensure that water does not freeze in the coil.

Figure 6. Fresh air intake coil assembly suspended from ceiling – coil inlet and outlet piping along with the condensate drain is shown.

Students working on this project were given the task of designing, building, and field-testing the controllers. In addition to the performance specifications, the TDOC required that the cost of material for the controllers be kept below $1,000. One of the students had taken a course in Automated Production Systems that included material on ladder logic and programmable logic controllers. This course material was directly applicable to the design of the controllers, and the students gained real world experience on the design of an industrial style controller.

The students first developed a logic diagram for the controller. They next researched and selected thermostats containing both normally open and closed relay outputs that could be used to implement the logic. A detailed Auto-CAD layout was produced that showed the placement of the thermostats, terminal strips, relays, and panel displays. In addition, a detailed wiring diagram was created that showed the electrical connections between all devices. After presenting their design and material estimate to the Department of Corrections, the students built and tested the controllers in a UT Martin lab. After verifying that they were operating correctly, the controllers were installed at the prison and field-tested. Only minor adjustments were necessary during the final installation.

Figure 7. Students machining screw holes and openings in controller panel prior to wiring the controller.

This controller design project provided the students with valuable real-world design experience and provided the TDOC with two lost-cost controllers. One of the students has expressed an interest in studying controls in graduate school based on exposure gained from this task.

Figure 8. Controller wiring in progress.

Figure 9. View inside of control panel after installation in prison facility.

Summary

Faculty and students from the Center for Energy Management are continuing work on the long-term monitoring of the geothermal pilot project at NWCX. At the present time most of the instrumentation has been installed and some data is now being collected. Over the next few months efforts will focus on instrument troubleshooting, calibration, and baseline operations. It is expected that reliable data will be available at the beginning of the cooling season this spring and that data collection and analyses will be performed for at least two years of operation.

The Center for Energy Management at UT Martin provides an effective mechanism for undergraduate students to receive real-world engineering design and analysis experience while providing a needed service to the region. While working with their customer, vendors, and procurement systems, the students are exposed to elements of true design work that are not normally seen within the classroom. Additionally, they frequently must complete spin-off projects, such as the controller design, that are necessary to reach their original goal. Thus, these students are well equipped to enter the professional world upon graduation.

Nomenclature

DHW	Domestic Hot Water
HVAC	Heating, Ventilation and Air Conditioning
NWCX	Northwest Tennessee Correctional Facility
TDOC	Tennessee Department of Corrections
C_p	Constant pressure specific heat
$\dot{m}_{geo\_loop}$	Mass flow rate in closed loop geothermal system
$\dot{Q}_{conduction}$	Energy transfer rate due to conduction through walls, etc.
$\dot{Q}_{exfiltration}$	Energy transfer rate due to loss of air from inside the guild
$\dot{Q}_{generated}$	Energy generated by biological functions
$\dot{Q}_{infiltration}$	Energy transfer rate due to outside air entering the guild from around doors, windows, or door traffic
$\dot{Q}_{make\text{-}up\_air}$	Energy transfer rate associated with fresh air intake into the guild
$\dot{Q}_{radiation}$	Net radiation heating rate
$\dot{Q}_{water}$	Energy transfer rate due to water entering or leaving the guild through inlet pipes, drains, or as moisture
T_{inside}	Inside air temperature
T_{in_geo}	Geothermal loop temperature entering the guild
T_{in_geo}	Geothermal loop temperature leaving the guild
$T_{outside}$	Outside air temperature
$\dot{W}_{electric\_h.p.'s}$	Power required to operate the electric heat pumps
$\dot{W}_{electric\_other}$	Power required to operate all other electrical equipment in the guild
$\dot{W}_{geo\_pump}$	Power required to operate the geothermal loop circulation pump

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