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Geothermal Monitoring Systems Increase Reliability and Drive Market Demand

Final Report

November 2015

Report Number 15-31

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Geothermal Monitoring Systems Increase Reliability and Drive Market Demand

Final Report

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1 Introduction

Geothermal heat pumps are an excellent choice for building owners who want low operating costs because they have the lowest lifecycle cost of any heating, ventilation, and air conditioning (HVAC) system. Geothermal installations are more complex than conventional HVAC systems and require a variety of skills spanning several areas of expertise including electrical, plumbing, refrigeration and control systems. As with the auto industry, the days are gone when technician can get by with a set of gauges and hand tools. Some problems are very difficult to diagnose and there is no simple way to verify that the system is performing efficiently at any given point in time.

1.1 The State of the Service Industry

The current geothermal HVAC service industry is marked by a lack of cost-effective tools to service and maintain geothermal systems. It often requires costly site visits for diagnosing and resolving problems regardless of severity. The need to send a technician out to someone's home, and subsequent travel and labor costs, effectively reduces the area a contractor is often willing to service. Service contracts often include language related to travel time and hours of service such that travel costs often exceed the actual cost of a repair.

Given the relative sophistication and complexity of geothermal heat pump systems, skills and knowledge about geothermal servicing by HVAC field service technicians is limited and experienced service technicians are scarce.

1.2 Obstacles to the Adoption of Ground-Source Heat Pump Technology

Although the sales of ground source heat pumps have increased as breakthroughs are made with heat pump technology offering higher efficiencies, there still remain obstacles to adoption of the technology.

1.2.1 Cost

The purchase price, cost of installation, and maintenance cost of a geothermal system are perhaps the largest impediments to people embracing ground source heat pump technology, hindering the migration away from fossil fuel based HVAC systems. It is not uncommon for a geothermal systems to cost anywhere from two to four times as much as a conventional HVAC system. Additionally, despite this level of capital investment, building owners are uncertain about support and maintenance of these systems. Customers do not know enough about how their system works and consequently feel compelled to lock themselves into pricey service contracts to ensure service. Without the ability to remotely monitor a client's system, the service contracts include disclaimers and provisions that restrict hours of service to normal business hours with mandatory surcharges to cover service on nights and weekends. Without remote monitoring, HVAC suppliers are forced to make site visits to perform on-site troubleshooting at a higher cost to service their clients with geothermal HVAC systems relative to clients with traditional HVAC systems.

1.2.2 Complexity

Geothermal equipment and supporting components are becoming more sophisticated as advanced solid-state controls and processors have been incorporated into the systems to improve efficiencies and manage operations. These improvements in technology require specialized skills and knowledge that is HVAC-domain specific. Equipment manufacturers may require specialized training and certification for service providers before honoring warrantee repairs on their equipment. This training and skills specialization increases cost for skilled labor, which has to be passed on to the building owner. This training and specialization requirement also narrows the field of qualified service technicians that a building owner can rely on. Along with skills, specialized tools may be required to properly analyze system faults. When a system event occurs that merits a service call, it is unlikely that information leading up to the event is available to the service technician without a site visit. Technicians may be required to try to recreate the event spending a substantial period of billable time trying to diagnose the failure. If it is an intermittent failure, the technician may require several field site visits before the root cause can be determined.

CLD addresses these concerns with the development of a cost-effective remote monitoring and diagnostic system for geothermal HVAC systems providing visibility into the operation and performance of their ground source heat pump. Tracking and logging of key performance parameters in a database allows a user and/or service provider to locally and/or remotely view all critical parameters leading up to an event. Providing the system performance history leading up to an event may be sufficient for a qualified technician/engineer to perform a diagnosis and recommend a solution.

It is possible to draw an analogy with the auto industries adoption of onboard diagnostics (ODB). Auto mechanics today rely heavily on being able to attach a computer to a port on the car to read and analyze codes that indicate the source of a problem. Without this ability to diagnose a problem with an OBD appliance, it would be virtually impossible for an auto mechanic to stay in business. Auto manufacturers are compelled to include the diagnostic capability in their cars to enable the service industry to service them. CLD provides a status dashboard, charts, and database enabling local and remote real time monitoring and troubleshooting of geothermal heating and cooling systems to support the building owner and service provider with accurate system performance information. Alerting can be enabled for any sensor and thresholds set to enable notification via visual indication on the Web portal, email, or text messaging.

2 Project Participants - Roles and Responsibilities

Table 1 provides a partial list of individuals who contributed to the successful completion of this project. Their professional and personal involvement is evident in this final report. Their collective contribution, through this project, fills a significant gap in the service industry supporting geothermal systems.

Table 1. List of Supporting Participants

Lloyd Hamilton (Verdae, LLC)	Geothermal Engineer/Subject matter expert, Field Supervisor/Installer, Training and Testing
Andrew Smallridge (Brush Electronics)	Embedded microprocessor Architect, Designer, Developer, Data Acquisition Subject Matter Expert
Pat Courtney Strong (Courtney Strong Inc)	Consultant - Assistance with Submission NYSERDA PON 1294
Greg Pedrick (NYSERDA)	NYSERDA Project Manager

3 Project Objectives

This section describes the three objectives of the project.

3.1 Develop a Real-Time Monitoring System

CLD Industries set out to develop a low-cost, scalable, energy monitoring, and logging system enabling real-time monitoring of geothermal heating and cooling system to support the site owner and service provider with accurate system performance information in real time.

The commercial and industrial sectors have had building automation for many years. Building automation and control (BAC) has matured over the years. However, application of monitoring and control in the small business and residential sectors has remained virtually undeveloped until recently because of the high cost of hardware and software. Advances in computer technology, computing power and miniaturization of embedded microprocessors, Internet access along with advances in sensor technology has made it possible to create a cost-competitive monitoring platform offering the same or greater functionality of a building automation system at a fraction of the cost of an equivalent system costing tens of thousands of dollars.

The affordability of remote monitoring and managing HVAC systems for residential and light industry drives expectations of the consumer as well. Once this technology penetrates the market allowing remote monitoring and diagnostic capability, service contractors and engineers that wish to offer their services at a reasonable cost to the consumer will need to include this technology in their service portfolio.

Appendix C provides a detailed explanation of how CLD addressed this requirement with the development of a microprocessor based data acquisition module. A high-level, cross functional data flow diagram is included showing the flow and data life cycle from data capture to data visualization.

3.2 Transmit Data via Web and Diagnose the Problem

Data will be transmitted via the Web to a central server where it will be analyzed and compared with historical data and manufacturers’ operational data to determine the current operational efficiency and status.

Data capture and retention was accomplished by implementing a combination of features. Once the information is collected and converted into a usable format, it is transmitted to a central server for further processing, storage, and display. One of the prerequisites required for our monitoring system is high-speed access to the Internet.

The dependency on Internet access requires some mention. Additional safeguards were embedded into the system to minimize or prevent data loss in the event of power outages or other issues associated with accessing the Internet. A single board computer (SBC) provides an intermediate set of functions between data capture and the Web server applications and database including the local storage of sensor data. If the Internet connection fails, the SBC continues to store data until a connection is re-established with the host server at which time it will resume uploading the data until all data are uploaded. In the event of a power outage, the system will automatically restart services once power is restored. An additional safeguard was implemented to assist in recovery is an alert function, which is initiated on the Web server. If a system is no longer communicating to the host for more than 30 minutes the alert icon turns red and, if configured, a text message or email may be sent alerting someone about the event. To limit unwanted or unnecessary alerts, the icon and alarm will reset automatically when communications are re-established.

Appendix D includes a detailed explanation of the SBC features.

3.2.1 Display Results Online

Results will be displayed in a dashboard style Web page that the customer can access at any time. The building owner will be able to obtain constant real-time efficiency and operational cost data to go with the status information. The HVAC contractor will be able to act on system changes in a proactive manner.

A Web portal and Web user interface provides the end user a means to visualize system operation and performance in real time and review detailed historical performance data. Various views are used for analyzing system performance and problem diagnosis.

Figure 1 provides a sample of a 4-hour window showing sensor metrics illustrating a normal system cycle of behavior. A service provider with adequate analytical skills would see at a glance that this system is operating within acceptable tolerances. Interesting values to note are the temperature differences for “air in” and “air out” and “water in” and “water out” for the ground loop. To calculate heat of absorption or rejection, these values along with the flow rate are required. This view is often sufficient to ascertain if the system is performing normally.

Figure 1. Sample 4-Hour Performance Graph

If greater detail is required, the user can click on any of the sensor lines on the graph to pull up a detail dashboard snapshot of the moment in time that they wish to know more about.

Figure 2 provides a fine-grained view of the system operation depicted in Figure 1 at 8:00 a.m. on March 5, 2015. It illustrates the drill down capability of the user interface to be able to pin point operational characteristics.

Figure 2. System Status Dashboard

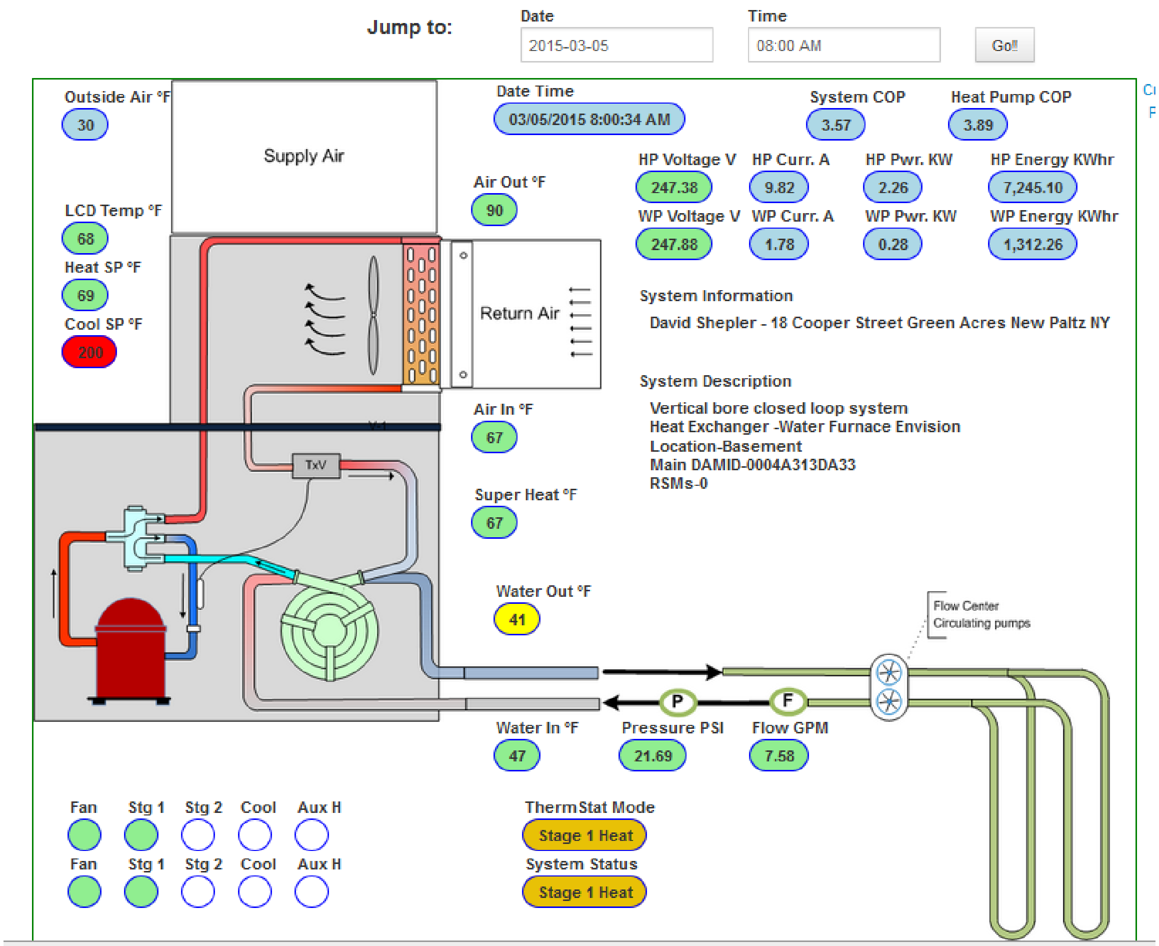


Figure 2 provides additional detail about the performance of the system at a given moment in time. In addition to metrics displayed on the performance graph, thermostat settings, system state, power metrics (voltage, instantaneous power, and current) as well as aggregate power consumption (kilowatt-hours) are provided.

One of the benefits of this system view is that a calculation is performed on operational data used to generate the coefficient of performance (COP), a universally applied metric used to measure operational efficiency.

Two additional views of system performance provide information that may be used to understand system performance in context.

A comparison of different modalities (see Figure E-5 in Appendix E) of heating are provided in a chart that compares the cost for total heat transferred as compared with oil, natural gas, electric heating and propane. The unit cost of fuel for each of the modalities may be adjusted to reflect current prices as well as the efficiency.

3.2.2 Case Studies

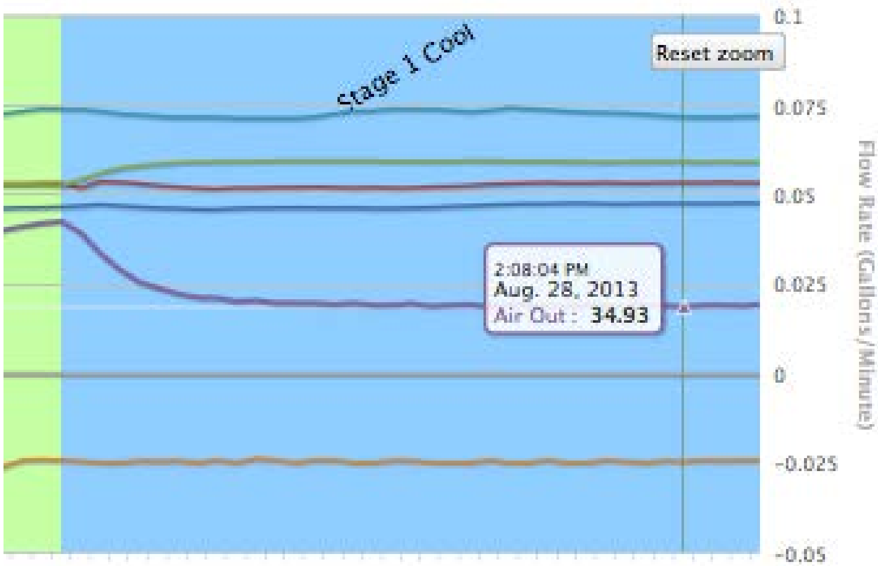
Four case studies of installed pilot systems illustrate the value of real time monitoring and tracking with regard to diagnosing system problems.

3.2.2.1 Case Study 1: System Is Not Cooling and Requires Manual Reset

As a safety feature designed to protect damage to the compressor, this failure requires a manual reset of the geothermal HVAC system.

A CLD monitoring system was installed. Within hours of observing the system behavior, a subject matter expert analyzed the data online, identified the issue, and made a recommendation to remediate the problem. The low supply air temperature (34.9 °F) is clearly a problem that may have caused the compressor safety lock out and is an indication of root cause for the event (Figure 3). In addition to the lock out condition, excessive condensation due to the cold plenum was leaking onto the floor. An increase in air volume prevented a reoccurrence.

Figure 3. Supply Air Temperature Issue



Intermittent failures are among the most difficult and costly to diagnose and resolve. Without a monitoring system, a field engineer must attempt to re-create the problem to verify that it is indeed the cause of a failure. The Field Engineer often has to make several trips to the client’s home to correct a problem. Repeat visit drive up costs and customer dissatisfaction. The ability to remotely view and analyze system history leading up to an event is a core value of CLD's remote monitoring system.

3.2.2.2 Case Study 2: Navigating Complexity to Assess System Performance and Make Recommendations

Removing ambiguity and complexity of the system by visualizing system operation is another core value of using CLD Industries’ monitoring system. A field engineer with adequate expertise in geothermal systems operations can use a system operations chart to rapidly analyze and identify abnormal system behavior. Having the chart can also assist a field engineer explain system behavior to a building owner. Having a visualization of this historical data makes it easier to understand the system behavior and justify corrective remediation measures to the building owner.

Figure 4 illustrates the performance of a system over a two-hour period. The system is a Water Furnace Synergy 3-D 5 zone heating and cooling heat pump that is both a water-to-air and water-to-water heating and cooling system. Figure 4 raises some questions about operation for a field engineer. For example, why would the system call for cooling when the outside ambient temperature is 43 °F?

The shaded blue area indicates it is in cooling mode. The operation shaded in yellow indicates heating mode. The green shaded area is fan only mode. Additionally, the gray line on the right side of the chart indicates a water flow rate of approximately 14 gallons per minute (GPM) in the ground loop with no corresponding air handler activity. System operation is complex, but the problem is that the flow rate without air handler activity is indicative of heat pump operation in water-to-water mode for radiant floor heating.

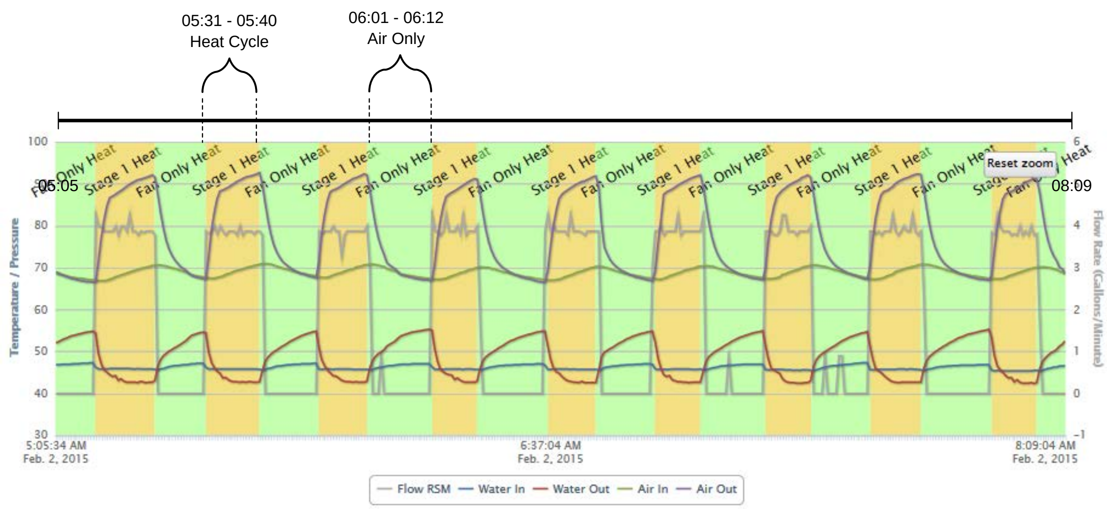
Figure 4. Complex Performance Graph

An HVAC field engineer with adequate expertise in geothermal systems operations can draw several conclusions from analyzing this snapshot, which will assist them in explaining system behavior to the building owner. Without the visualization of this historical data, it would be very difficult to analyze the system behavior and justify corrective remediation measures to the building owner.

3.2.2.3 Case Study 3: Verifying Proper Installation of Heat Pump and System Components

Another benefit of observing system performance over time is the ability to reveal problems related to improper system configuration or installation. Figure 5 shows short cycling of the heat pump in both heating and cooling mode. The heat-pump cycles on for 8-12 minutes or less and then cycles off for approximately the same amount of time. Although the system is operating within expected tolerances, short cycling may lead to excessive wear of mechanical components such as valves and motors, resulting eventually in premature system failure. Although the observation of system performance characteristics and behavior may not lead to a recommendation for a correctly installed and configured system, it is critical to understanding system operation. Action taken based on observing improperly installed or configured systems differentiates the reactive servicing from proactive monitoring.

Figure 5. System Short Cycling



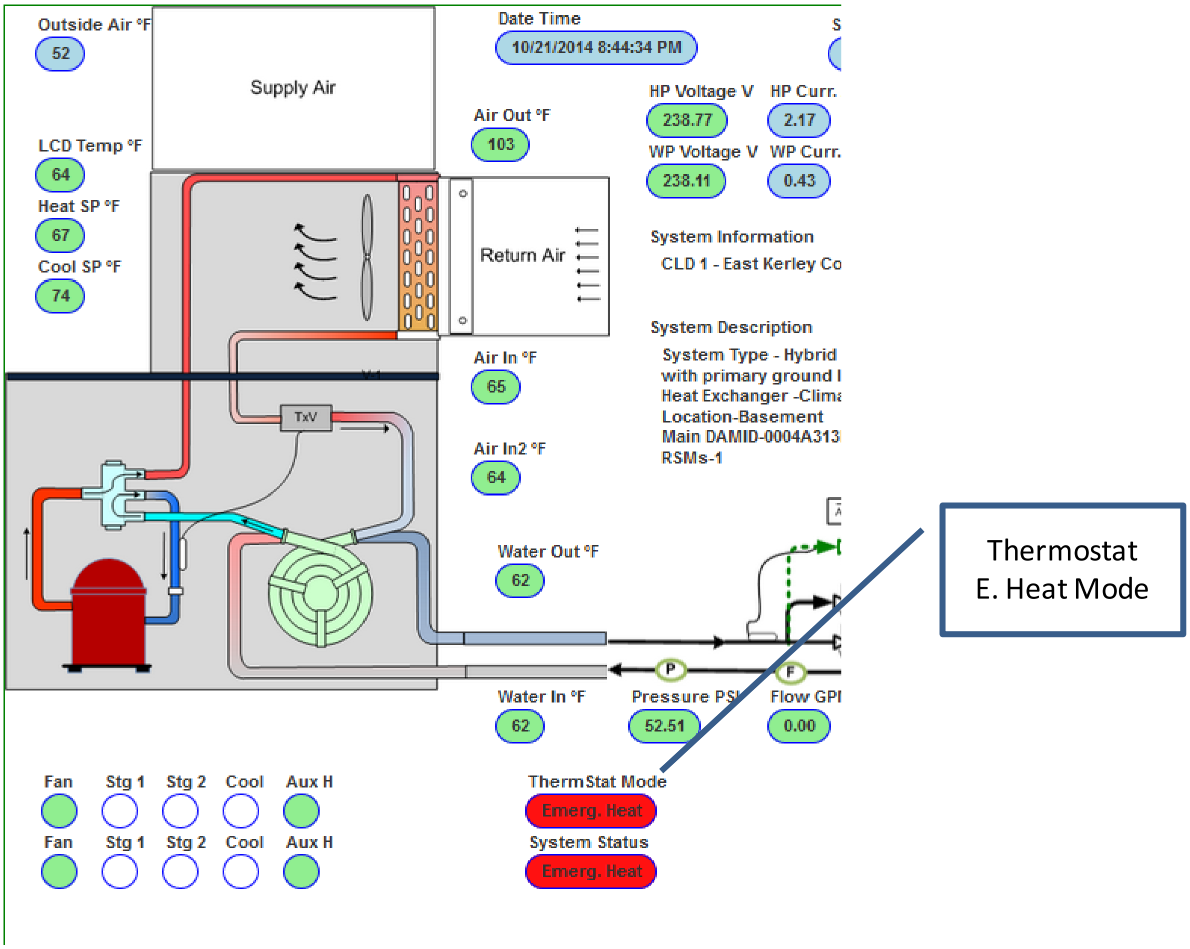
The root cause for the problem in the system shown in Figure 5 is the result of the thermostat being located directly in the air stream of the supply register in the room. The thermostat temperature set point is satisfied before the rest of the room is satisfied. Once identified, this type of problem can be resolved by redirecting the air flow (depending on the register design) or alternatively moving the thermostat to another location in the room away from the direct air flow from the register.

3.2.2.4 Case Study 4: Monitoring Can Save Money

The previous case studies illustrate the value of monitoring used for system fault diagnosis. Another value of remote monitoring is cost avoidance. During routine examination of the system performance of one of the pilot systems, Figure 6 showed that the system was set to operate in Emergency Heat mode. The thermostat mode setting is one of the parameters monitored by the CLD monitoring system.

In this case, the building owner had inadvertently set the system to emergency heat. It was an easy mistake to select “e. heat” instead of “heat.” Although nothing was wrong with the system, if the setting went unnoticed for an extended time, it is possible that building owner would not realize what had happened until they investigated the cause of an exceptionally high electric or fuel bill depending on the type of heating back up.

Figure 6. Status in Emergency Heat Mode



3.2.3 Example of How Not Monitoring Can Create Problems

People are leery of claims that geothermal heat pump technology is more economical or reliable than fossil fuel. This perception is exacerbated by the lack of adequate practitioners, field engineers, and an equally important lack of good diagnostic tools.

For example, a builder asked CLD to review two quotes for repair, and or replacement of a nine-year-old Water Furnace water-to-water heat pump installed in a home that he had built for a customer 10 years earlier. The system worked but the building owner complained that it was excessively noisy and appeared to be short cycling. The building owner wanted someone to diagnose and rectify the problem so that the system wouldn't fail in the middle of the heating season. The building owner received two estimates for the cost of repairing the system. One estimate was $16,000 for the repair or $18,000 for the replacement of the system. A service charge of $800 was billed to the customer for sending someone to diagnose the problem. The contractor reasoned that, with incentives, it was more cost-effective to replace the system with a new heat pump than making the repair. The second estimate for the repair was $12,000. Both estimates included a bill of materials list of replacement parts. The client was unable to determine the correct course of action to either repair or replace the system and contacted the original builder of the house for a recommendation.

The builder was aware of CLD's work on the NYSERDA project and asked if CLD would monitor the building owner's system to identify the root cause of the problem. At this stage, CLD had been deployed all of its monitoring to the eight pilot sites.

CLD examined the estimates and found that neither had provided a diagnosis of what was wrong other than to say the system was not installed correctly. CLD also did a site visit to better understand the issues. The site inspection showed that the load side plumbing was incorrectly installed. Without a system performance history to review, CLD recommended that, as a general first step, a plumber re-plumb the loop according to the manufacturer's specification.

The building owner hired a local plumber with some geothermal experience. The plumber discovered that the circulating pump was air-bound and the system loop had lost pressure over time. The final cost to the building owner was approximately $2,000 for both parts and labor. If this system had been monitored, the erratic flow rate and pressure drop would have immediately indicated the source of the problem, saving the building owner considerable time, effort, and money. As a result of this incident, the building owner remains adamant about wanting to install the monitoring system as soon as it becomes commercially available.

3.3 Rationale for Pilot Project

CLD installed the early release version of the data acquisition system at eight locations as part of a pilot to test the viability of the technology and better understand what modifications to the monitoring system might be necessary for commercialization of the product. Appendix A contains a table with the locations, dates of installation of the monitoring equipment, and additional heat pump information including the type of heat pump installation being monitored.

Another objective is to generate reliable data to support decisions related to overall energy management for zero energy architecture and design in both residential and commercial construction. The data gathered and disseminated can have a profound effect on heat pump manufacturing because actual data can be used to verify advertised performance expectations. Data can also support defect analysis by mining historical information that has been tracked and stored in the database.

As indicated in Section 1.1, issues continue that need to be overcome for broader adoption of geothermal technology. The service industry needs to mature considerably. CLD is addressing development and creation of a cost-effective data acquisition and monitoring system and Web service that captures the key performance parameters of a geothermal heating/cooling system. The system uploads the information near real time to a cloud-based database and application server providing building owners and service providers access to critical operational information. Historical performance data is available to the end user in chart and report format. A status Dashboard provides current detailed information and, via a date entry field, allows of viewing detail at a specified historical reference point.

As remote monitoring becomes more prevalent, contractors will adopt the technology or risk losing market share to competitors willing to invest in the monitoring technology CLD is providing. Remote monitoring of HVAC systems is aligned with the "Internet of Things" paradigm and will improve the HVAC practice for the entire service industry.

The contractor using remote monitoring will be able to reduce costs by remotely determining the “probable cause” of symptoms and avoiding costly site visits. With remote monitoring capabilities, the contractor can offer differentiated services, such as 24 x 7 support and a higher quality response. Depending on the analysis of an event an informed decision can be made if and when a service technician should be dispatched to resolve a system problem.

The availability of historical performance data can be contrasted with current data to alert service technicians of any degradation in performance so remediation steps can be taken to restore a system to optimum performance.

Data is sent over the Internet to a central server where it can be analyzed and compared with historical data and manufacturers' operational data to determine the current operational efficiency and status. This will then be displayed in a dashboard style web page that the customer can access at any time. The building owner will be able to obtain constant real time efficiency and operational cost data to go with the status information. The HVAC contractor will be able to act on system changes in a proactive manner rather than waiting for something to break down.

With the information gathered, analyzed and disseminated, building owners will be confident that their system is working at optimum efficiency at all times, assuring that long term life cycle costs will be stable. This will likely mean that more geothermal systems will be installed because building owners will be confident enough in projected operational cost savings to make the significant capital expenditure for geothermal heat pumps. HVAC contractors will have more income from more geothermal heat pump installations and will have a reliable method of remote monitoring of installed systems, resulting in reduced service costs and improved system reliability along with increased profitability.

4 Product Development and Scope

4.1 Selecting Parameters to Measure and Monitor

One of CLD's challenges at the outset was deciding what key performance indicators would need to be monitored and measured. A committee of subject matter experts in geothermal systems, data analysts, and engineers determined the selection of sensors that are critical to analyzing performance. Appendix B contains the names of the committee members and their credentials and the outcome of the meeting. The list of sensors in Section 4.1.1 resulted from a consensus of the participants.

4.1.1 Core Sensors

Temperature sensors:

- Ground loop : water temperature in and out of heat pump heat exchanger
- Conditioned space : Supply and return Air or Water temperature -
- Inside air temperature
- Outside air temperature

Flow sensor:

- Measures ground loop liquid line flow rate GPM

Pressure sensor:

- Measures ground loop pressure PSI

Digital Input Output (I/O) - Status of Heat Pump system:

- Heating and cooling stages;
- Fan
- Identifies stage of heating and cooling
- Each stage of auxiliary (emergency) heating
- Additional valve actuators or contactors (optional) - monitoring open-loop valve operation (TACO**™)**

Power:

- Instantaneous power (kilowatts)

4.1.2 Additional Sensors

In addition to the core sensors in Section 4.1.1, a thermostat and power meter utilizing industry standard serial communications protocol (Modbus) has been integrated. The advantages of using a standard protocol (Modbus) is that other off-the-shelf devices/sensors can be integrated into the monitoring system while reducing one-off development costs. Integration instead of development removes dependencies on single-source suppliers and potentially keeping costs lower by taking advantage of market-based competitive pricing.

The Modbus thermostat captures thermostat program and status information, providing insight to what the building owner is doing. The captured parameters include:

- The current thermostat set point.
- The current heating/cooling mode.
- The current temperature as displayed on the thermostat.
- The stage of operation (1st, 2nd, E Heat, fan only etc.)

The Modbus Power meter provides additional metrics that are useful in diagnosing electrical energy related issues and total energy use. The information captured includes:

- Voltage.
- Current (Amps).
- Instantaneous power (kilowatts).
- Aggregate power (kilowatt-hours).

4.2 Hardware and Firmware –Data Acquisition Module (DAM)

A three-tiered architecture supports remote monitoring of geothermal systems. The logical separation into these tiers provided for independent and parallel development of the functions. The integration testing and refinement of the product development has been ongoing and will continue into the next phase of refining the hardware and software to meet commercialization objectives.

The following appendices include technical details for each of the three tiers summarized here:

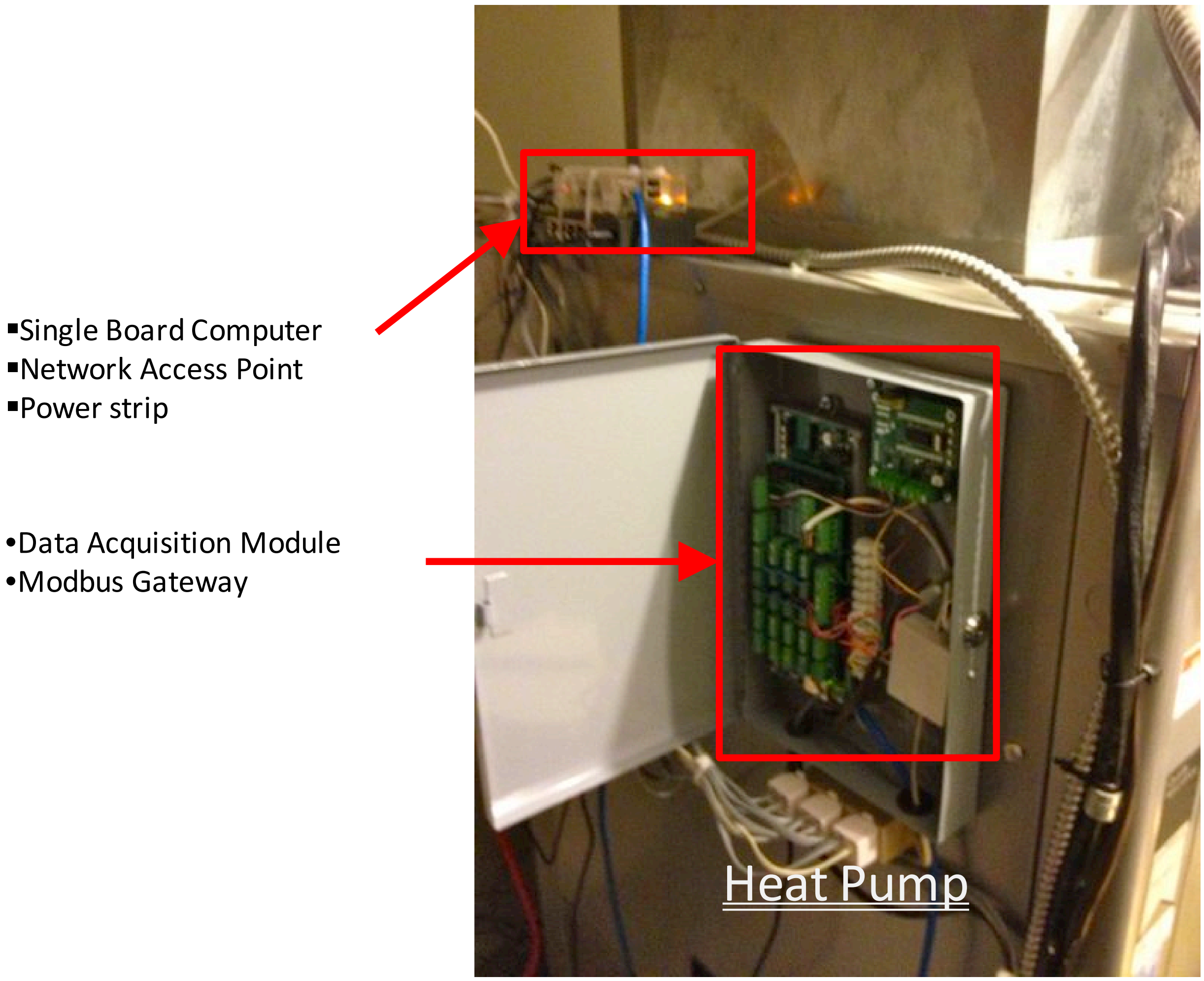
- Appendix C - Tier I - data acquisition / collection.
- Appendix D - Tier II - local data management and communications.
- Appendix E - Tier III - Web portal and hosting environment.

CLD took a modular approach for system development of each tier, which enabled development of working prototypes relatively quickly and attainment of certain milestones with limited resources.

Hardware Component Location

The hardware installed at the client's location includes the Data Acquisition Module (DAM), a single board computer, a network access point, and the various sensors attached to the heat pump making up the data collection, formatting and data transmission functions of the system. Figure 7 shows a typical installation in the mechanical room at one of the pilot test sites.

Figure 7. Typical Field Installation of a Data Acquisition Module (DAM)



Tier I components installed on site include:

- Data Acquisition Module (DAM)
- Remote Sensor Module (RSM)
- Modbus Gateway Module (MGM)
- Network – wired and wireless
- Sensors

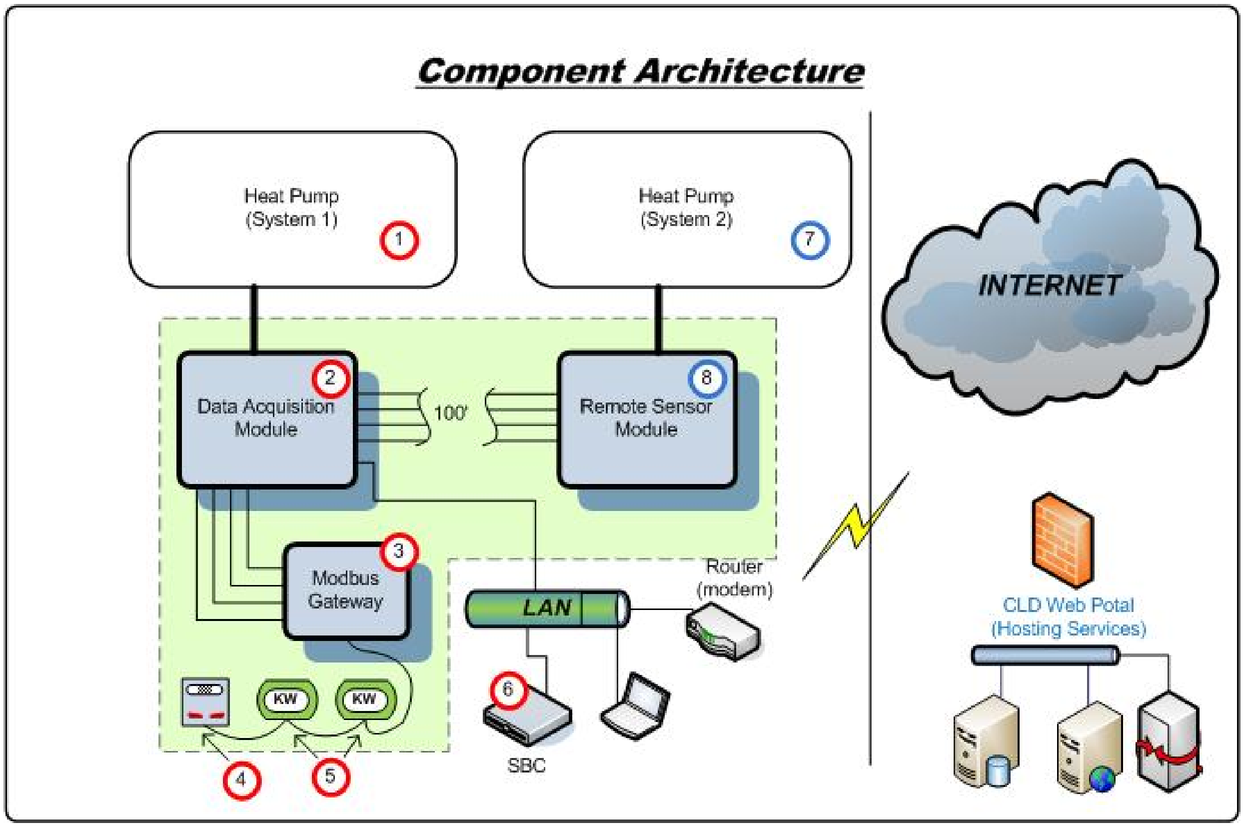
Tier II components installed on site include:

- Single board computer system (SBC)
- Network
- Router

Tier III components are the Web Portal, database, and applications hosting the User Interface.

Figure 8 provides a diagram of the components making up the monitoring system. It shows the data communications path between components of the monitoring system, the system that is being monitored, and how data will flow to the Internet hosting environment. Elements 2, 3, 4, and 5 belong to Tier I and Element 6 and the router belong to Tier II. Tier I and Tier II elements form the core monitoring system components installed at the site location. Remote sensor module (RSM) 8 is an optional Tier I element if a second heat pump is being monitored. A RSM is implemented at one of the pilot sites (CLD-1).

Figure 8. Component Architecture Diagram



5 Conclusions

The old service paradigm of dispatching a technician to the site, potentially spending hours attaching sensors, probes, and gauges to a system, attempting to diagnose a problem or to capture and analyze critical metrics defining system behavior, is no longer a viable service model. Remotely analyzing system behavior and visualizing system performance and only dispatching a service technician after the operational data has been analyzed will drive down costs for both the service provider and, ultimately, the building owner.

CLD Industries will develop a low cost, scalable, energy monitoring and logging system enabling real-time monitoring of geothermal heating and cooling system to support the site owner and service provider with accurate system performance information in real time. Data will be sent over the web to a central server where it will be analyzed and compared with historical data and manufacturers' operational data to determine the current operational efficiency and status. Results will then be displayed in a dashboard-style Web page that the customer can access at any time. The building owner will be able to obtain constant real-time efficiency and operational cost data to go with the status information. An HVAC contractor will be able to act on system changes in a proactive manner.

The CLD real time monitoring systems looks at the HVAC system as an integral part of a larger ecosystem collecting system and environmental metrics that can be analyzed and used to improve building owner's comfort and optimize system operation. This system addresses the needs of the one million plus geothermal system installations that are not equipped with any monitoring technology and are currently left to a service industry lacking in adequate tools to properly analyze and support these systems. The paradox is that ineffective service providers, ill-equipped to cost effectively maintain the current install base serve to reinforce the negative experience and perceptions of heat pump owners. The improvements in technology and heat pump efficiencies are marginalized in the face of negative perception associated with the high cost of servicing.

5.1 Current Status of Residential Monitoring Equipment

Until recently, monitoring, real-time diagnostics, and data analytics were only available on an industrial scale. Building automation and control (BAC) for commercial buildings will not scale down to the residential HVAC market. BAC software costs are high, typically in the tens of thousands of dollars. Software applications are highly customized to support individual building physical plant architectures and skilled resources available to modify software are scarce and expensive.

However, recent advances in information technology and communications has changed the service paradigm for residential energy management and, in particular, the HVAC industry making it affordable and necessary. Fifteen years ago, it might have been a rare to go to someone's home and discover that they had broadband Internet access. Today, it is assumed that high-speed internet access is available everywhere. Smart phones and other mobile devices are ubiquitous.

The convergence of lower cost computing power, Internet access, cloud computing, and reduced cost of hardware allows affordable high-quality real-time remote energy monitoring and management for residential and light commercial HVAC applications.

Remote real-time monitoring and real-time visualization of system operation will lower the cost of servicing and improve system owner satisfaction. It will provide valuable field data that can be used to improve heat pump performance and technology as well as offering critical data leading to the improvement of the implementing/installing of new HVAC systems to achieve optimum efficiency. Based on the historical performance data gathered from these monitoring systems, HVAC heat pump vendors will refine best-practice system installation guidelines, which in turn will benefit the industry as a whole.

CLD’s product and service is technology-agnostic. It can be applied on any heat pump system and adapt quickly to changes in technology. The product and service are aimed at filling the gap for servicing the install base of the one million plus ground source heat exchange systems already installed in the U.S.

Regardless of who captures the market share, the trend toward incorporating remote monitoring as a core feature of the sale or service is a given. Service engineers incapable of diagnosing problems quickly and accurately will disappear. Building owners, once aware of the remote monitoring capabilities, will demand that service providers include remote monitoring, diagnostics, and alerting capability in their service contracts.

6 Next Steps

CLD is committed to hardening the hardware and software with the objective of lowering costs of the system components. A redesign of the DAM is expected to be complete within the next six months. A first run of manufacturing the DAM integrated with the SBC is planned as the first product for sale. The temperature sensors will be included as part of an entry-level package along with the ability to monitor eight to 12 digital channels and a minimum of four analog channels. Modbus communications connections are integrated into the DAM.

Optional sensors that will plug into the DAM will be priced separately and include:

- Grundfos flow meter.
- Grundfos pressure sensor.
- Modbus thermostat.
- Modbus power meter.

The costing for the initial Web service hosting has not yet been determined. Additionally, support for setting up an independent Web hosting environment will be offered that will be capable of supporting multiple clients.

The integration of state-of-the-art servicing practices using remote monitoring and data analytics will enhance the acceptance of clean renewable energy alternatives.

Appendix A: Pilot Projects

Eight pilot installations were deployed in accordance with the statement of work. They were deployed in two phases and are currently logging data that can be accessed through the Web portal. Candidates for the pilot were evaluated on a number of factors including a diversity of heat pump configurations. Two installations were open loop, five of the systems are closed loop water-to-air, and one is a combined water-to-water and water-to-air system (Water Furnace 3-D).

Table A-1. List of the Eight Sites and the Geothermal Equipment Comprising the Pilot Study

The case studies in the final report were results taken from the pilot systems in the table highlighted in yellow.

Client Information				System Information			
ID	**Name**	**Location**	**Customer ID**	**Configuration**		**Manufacturer Model**	**Install Date**
C-1	Collet	Tivoli	0004A313DA30	Open Loop	Standing column	Climate Master - Tranquility 27	11/28/12
C-2	Olson	Rhinebeck	0004A313DA2A	Open Loop	Standing column	Climate Master - Tranquility 27	11/28/12
C-3	Hamilton	Rhinebeck	0004A313DA2E	Closed Loop	Vertical Bore	Water Furnace Series 7	01/20/13
C-4	Shepler	New Paltz	0004A313DA33	Closed Loop	Vertical Bore	Water Furnace Envision	02/27/13
C-5	Redfield	Stormville	0004A313DA2C	Closed Loop	Vertical Bore	Water Furnace Synergy 3-D	08/27/13
C-6	Lawrence	New Paltz	0004A313DA37	Closed Loop	Vertical Bore	Water Furnace Envision	12/09/13
C-7	Danneman	New Paltz	0004A313DA36	Closed Loop	Vertical Bore	Water Furnace Envision	02/28/14
C-8	Landrum	New Paltz	0004A313DA40	Closed Loop	Vertical Bore	Water Furnace Envision	03/02/14

Appendix B: Technical Review Committee

The Technical Review Committee consists of five members: Lloyd Hamilton (CLD) as committee chair with Denis Collet (CLD), John Manning (Phoenix Energy Supply), Steve Davies (Ecologix), and Benoit Maneckjee (TermAtlantic) as reviewers.

Related experience:

- **Lloyd Hamilton** – 30 years experience in HVAC – International Ground Source Heat Pump Association (IGSHPA) certified geothermal designer
- **Denis Collet** – 20 years experience systems engineer – IGSHPA certified geothermal installer.
- **John Manning, PE**
  Owner of Phoenix Energy and a geothermal consultant/designer. He has extensive experience in air conditioning and heat pump manufacturing, wholesaling and retaining. He spent years in R&D at Carrier prior to venturing into geothermal near the beginning of its commercialization. He is a self-described geo junky.
- **Steve Davies, PE,** president of Ecologix Manufacturing. He represents the manufacturing interest. Ecologix is interested in embedding the hardware for this monitoring system in their geothermal products.
- **Benoit Maneckjee,** director of product development for ThermAtlantic Energy Products Inc. He is an HVAC contractor who has been working on his own Internet based monitoring system for air source heat pumps.

The above practitioners and subject matter experts volunteered to consult and offer their expertise and opinion on the parameters and metrics that CLD is proposing to monitor and record. The members were asked to participate on the review committee and to share with CLD the depth and breadth of their experience in the geothermal industry. Their insight has proven to be very valuable in narrowing down and prioritizing the parameters that are critical to success in measuring, monitoring, and tracking system performance.

Moving forward, this committee will assemble from time to time for acceptability testing of the user interface, the services, and validate that the service performs as intended.

Committee Report July 30, 2010:

The technical review committee met by phone July 30, 2010 for two hours and discussed what we needed to monitor.

B.1 Agenda

CLD Monitoring Measurement Points and Topics for Discussion

The purpose of this review committee is to determine what we need to measure for the following:

- An entry level system that will provide some meaningful value, key performance indicators. Is the system working? Is the system going to fail? Is the energy use appropriate?
- An expanded system that will provide fault detection and diagnosis. Why is the system not working correctly?
- Extras that have perceived value for a top of the line system.

We have identified the following points. This list has to be expanded and then broken into the tasks identified above.

Temperature

- Ground source loop - In
- Ground source loop - Out
- Load side supply - air/water in
- Load side return – air/water out
- Outside Air
- Inside Air

Flow

- Ground source loop
- Load side – water or air

Power Consumption in watts

- Heat Pump Package
- Auxiliary components
- Back up heat (if electric)

On/Off conditions

- Fan
- Each stage of heating or cooling
- Auxiliary switched devices
- Valve actuators
- End switches
- Circulators

Discussion

It was agreed that we do not need to insert pressure sensors into the refrigeration circuit in order to measure superheat and sub-cool. Instead we can attach temperature sensors to evaporator and condenser points to measure the saturation temperature on each and use the refrigerant pressure temperature table to determine pressure. We will then be able to calculate superheat and sub-cooling by measuring the temperature of the vapor and liquid lines.

Conclusion

The types of sensors that will be deployed include both analog and digital sensors capable of monitoring temperature (degrees Fahrenheit), liquid flow (Gallons P/M), electrical energy (Kilowatt-hours), Pressure (PSI), and binary (On/Off) variations as a function of time.

Geothermal Parameters we will measure include:

Key performance indicators on the Heat Pump, Temperature of liquid medium in and out of the ground loop and ancillary components including; temperature, power, flow, state condition (binary/on-off), and pressure will be measured, interpreted and analyzed in order to:

- Monitor system operating efficiency
- Assess energy use
- Provide near real-time event monitoring and alerting of system component failure
- Provide an historical record used in problem determination and for root cause analysis
- Verify system performance against pre-established performance projections

    - Flow in the ground loop *
    - Pressure in the ground loop
    - Temperature difference between inlet and outlet in the ground loop. *
    - Saturated temperature of the condenser
    - Saturated temperature of the evaporator
    - Temperature of the vapor line
    - Temperature of the liquid line
    - Real power consumption of the system. *
    - Pressure differential across the house side air or water coil and filter.
    - Temperature differential across the house side air or water coil.
    - Outside and inside air temperature
    - System state - stage of cooling or heating, emergency heating, fan only

The above measurement points identified with an asterisk are the key to providing COP and EER calculations. The additional measurements are included to monitor general system health and be used for fault diagnosis and root cause analysis during problem determination.

Appendix C: Tier I - Data Acquisition / Collection

Tier I is responsible for the acquisition all the geothermal monitoring system sensor inputs including:

- Multipoint temperature measurement.
- Ground loop fluid flow rate.
- Ground loop fluid pressure.
- Thermostat state.
- Geothermal / heat pump state.
- Power consumption.

The integration of thermostat state, power monitoring, water flow monitoring, and multipoint temperature measurement provides the necessary data points for the analytical engine to calculate the overall system efficiency in real time. This information, combined with historical data and reference data will enable the fine tuning of the overall system to achieve optimum efficiency and to identify any elements of the system that are not performing to specifications.

Perhaps the most critical components of a data acquisition system are the sensors. In this case, CLD has opted to employ sensors offering high reliability and accuracy.

For temperature sensing, a programmable resolution 1Wire© digital thermometer - Maxim DS18B20 digital thermometer was used. Unlike thermistors, the DS18B20 is a discrete integrated circuit with programmable features for setting high and low temperature alarms as well as configuring the device for 9-bit to 12-bit Celsius temperature measurement resolution. Each temperature sensor has a unique ID and shares a single three-terminal connection on the connector board. Although CLD currently supports eight temperature sensors in its current software release of the DAM, it can easily expand the number of temperature sensors to 12-16 without making hardware changes. The selection of components was intended to ensure accuracy with relatively low cost components. Prior to deploying the temperature sensors in the field, they were lab-tested as a group verifying their accuracy prior to installation. Given the method, the sensors were attached to make bone-to-bone contact with piping it is possible that variations in temperature will be recorded and care needs to be taken in the installation and commissioning phase to seat the sensors correctly thereby minimizing errors.

Flow meter

Figure C-1. Grundfos VFS 5-100 flow meter

Pressure sensor

Figure C-2. Grundfos RFS 0-4 pressure sensor

Modbus Thermostat

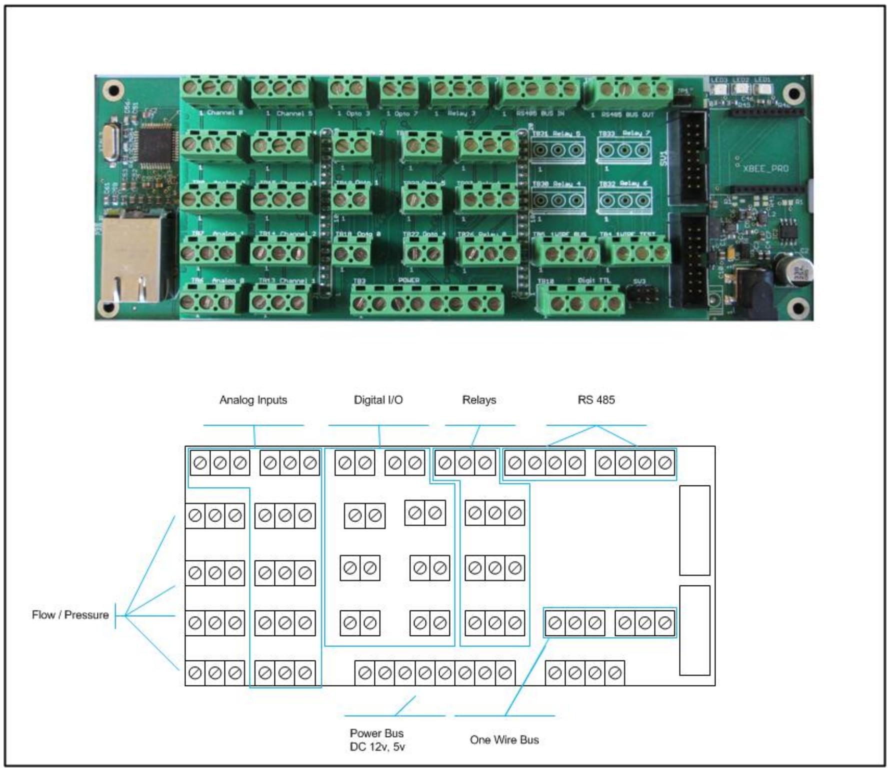
Figure C-3. Modbus thermostat

System state (digital)

Data acquisition is comprised of collecting digital and analog information from a variety of sensors or key performance indicators. CLD made a conscious decision to develop the data acquisition modules to optimize price and performance offering a base set of sensors that are critical to understanding system performance. While not in scope for the current project, CLD designed the monitoring system to accept additional analog and digital inputs maturing the energy analysis and management system. Although not critical to determining system performance, humidity and wind direction and speed may explain the effects on system operation. The open architecture in the design lends itself to incorporating other sensors without redesigning the hardware. This cost-effective way helps to expand system capabilities and improve service offers to contractors and building owners.

The following is a brief description of the primary printed circuit boards that have been developed as part of this project for tier 1. Figure C-4 shows the Connector Board plugged into (sitting on top of) the DAM board.

Figure C-4. DAM and Connector Board layout



- Data Acquisition Module (DAM)
- The DAM attached sensors
  - Sensors
    - Flow meter
    - Pressure sensor
    - Temperature sensors (One Wire Bus)
    - Digital on/off state
    - Auxiliary analog sensors
- Modbus GateWay
  - Power Sensor (s)
  - Thermostat (s)
- Remote Sensor Module
  - Sensors
    - Flow meter
    - Pressure sensor
    - Temperature sensors (One Wire Bus)
    - Digital on/off state
    - Auxiliary analog sensors

C-1. Data Acquisition Module (DAM)

The Data Acquisition Module (DAM) forms the core of the geothermal monitoring system. Connected to the DAM are a plurality of sensors used to monitor system and environmental key performance metrics to provide a user of the system critical system information.

The information captured with various sensors that measure system state, electrical energy usage, outside and conditioned space temperature, system absolute and differential temperature of liquid used to transfer heat (ground loop), and through the heat exchanger and ground-loop pressure. The design of the DAM provides an expansion capability allowing monitoring of multiple systems without the cost of replicating the entire system.

The Data Acquisition Module is the central data acquisition and data logging module for the geothermal monitoring system equipment installed at the customer’s premises. As well as performing the signal conditioning and processing of sensors connected directly to the DAM, the DAM is responsible for the acquisition and logging of data from multiple distributed remote sensor modules (RSMs) and Modbus Gateway boards (MGW). The DAM interfaces to the RSMs and MGWs via a shared RS485 half duplex serial bus and optionally via a wireless network.

The DAM exchanges commands, data, and configuration information with RSMs and MGWs using a messaging construct. Messages are exchanged between the DAM and the RSM and between the RSM and the DAM over the RS485 bus. The RSM performs basic signal conditioning and, where applicable, sensor integrity checking but does not perform any subsequent data processing.

The DAM performs the following key functions:

- Interfaces via TCP/IP to the Single Board Computer (SBC) via a 10/100BaseT Ethernet interface.
- Implements a half duplex RS485 serial BUS master interface for communication to RSMs and MGWs.
- Optionally interfaces to RSMs via a shared wireless network.
- Implements a battery backed real time clock for time stamping logged data.
- Provides system synchronization for data acquisition and communications.
- Implements on-board regulated power supply circuitry for powering the DAM electronics, DAM attached sensors and supplying power to the Remote Sensor Modules that are connected via the RS485 serial bus.
- Exchanging control and configuration information with the SBC.
- Exchanging control and configuration information with the RSMs and MGWs.
- Instructs RSMs and MGWs to perform sensor scans.
- Implements a File System on the SD/MMC media.
- Logs data acquired from the RSMs to the SD/MMC media.
- Provides File management of the SD/MMC media under control of the SBC.
- Implements a bootloader to enable the remote upgrade of DAM, RSM, and MGW firmware.

The version of the data acquisition module that we have developed comprises of two printed circuit board (PCB) assemblies, the DAM board and the Connector board. When combined together, this combination is referred to as the DAM. The DAM board contains the system logic. The Connector board contains the terminal blocks for connection to sensors, power supply, and RS485 communications bus. The connector boards mounts on top of the DAM board via the Connector Board header or optionally via the Expansion headers.

The DAM board contains the following components:

- DAM microcontroller.
- Ethernet controller.
- Power Supply.
- Analog Conditioning Logic.
- Connector Board header.
- Expansion headers.
- SD/MMC card connector.
- Status LEDs.

The Connector Board contains the flowing components:

- Opt-couplers for digital inputs.
- Relays for voltage free contact outputs (digital outputs).
- Terminal blocks for sensor connections, power supply connection, RS485 bus connections.
- Expansion Headers.
- DAM connector header.

Although our current software provides read-only capability of the sensors, the DAM has been designed with spare analog inputs and digital outputs. The DAM system software, with minor software modification, will be able to provide control of system components without hardware redesign. This decision to build rather than to buy was based on quality, cost, flexibility, and expandability of the system. CLD’s plan is to incrementally enhance the data acquisition capability.

DAM Software

The DAM software has been developed in the C programming language. The DAM software comprises the following key functions.

Supervisory

There are five main tasks performed by the Supervisory function.

System Initialization including:

- I/O subsystem.
- File System.
- Real Time Clock.
- Supervisory Timer.
- Reading system parameters from EEPROM nonvolatile memory.

The system parameters read from the EEPROM include the averaging interval, the analog channel sensor mask, the temperature sensor ID and associated mapping in the data packet to the SBC. The number and ID of the RSMs connected to the DAM. The Supervisory Timer drives the data acquisition state machine.

User Interface

The DAM supports a Telnet Server function. Contractors can telnet to the DAM to perform initial system setup, modify the system configuration, enable or disable logging, perform file system maintenance, and perform system diagnostics. The contractor, via the telnet session, can connect to an RSM or MGW module to perform the system setup and modify the configuration of the connected RSM or MGW.

Sensor Scan

The Supervisor function initiate scanning of the sensors directly connected to the DAM and broadcasts a SYNC message to all RSMs to initiate the scanning of their own directly attached sensors. At the end of the sensor scan period, the Supervisor then logs the current scan data from the DAM sensors to the SD/MMC card, telemeters the data to the SBC, sequentially instructs each RSM and MGM to transmit their scanned data to the DAM and then logs the data from each module to the SD/MMC card and telemeters the data to the SBC. The DAM also adds the current scan data for directly attached sensors to their associated *averaging accumulator* and increments the *averaging accumulator sample count*. Once the current scan cycle is complete the Supervisor then determines if the average data interval period has elapsed.

If it has elapsed then the *averaging accumulator* for each sensor is divided by the *averaging accumulator sample count* to derive the average value for the sensor over the averaging period. The DAM records the data to the SD/MMC card, telemeters the data to the SBC and clears the accumulation counters. The DAM instructs all RSMs to send their averaged data, which the DAM subsequently records to the SD/MMC card and telemeters the data to the SBC.

Data Logging

Provided the DAM is enabled for logging, the DAM logs the data to the SD/MMC card as previously described. In the event of a date rollover (a new day), the currently data files are closed and new data files, incorporating the current date in the filename.

DAM Bus Communications

The DAM bus is RS485 half duplex serial bus connection the DAM to the RSM and MGW modules. The DAM is the bus master. This bus is used for configuration and sensor data.

TCP/IP Stack

The DAM implements a TCP/IP stack for communications between the DAM and the SBC. Averaged and Instantaneous data records are transmitted from the DAM using user programming device (UPD) packets and a destination multicast IP address. The use of multicast addressing means the DAM can operate autonomously, it does not need to know the IP address of the SBC. It also enables multiple devices to receive and process data from the DAM. The DAM does not need to know or care if any devices are receiving the data.

The DAM implements an FTP server that allows files to be transferred between the SBC and the DAM. The DAM implements a telnet server as previously discussed. The DAM additionally supports direct manipulation of some configuration data from the SBC via UPD.

File System

The file system is used for logging averaged and current sample interval data from the DAM and RSMs to the SD/MMC card. Logging data on the DAM if enabled, is for DAMs that are:

- Operating headless – i.e., in deployments that comprise ONLY of Tier I infrastructure.
- Redundancy purposes – note that data is logged at Tier II and Tier III

Bootloader

The bootloader enables the DAM firmware and/or the firmware on the RSMs and MGW modules to be upgraded via the Ethernet interfaced on the DAM.

C-2. Remote Sensor Module (RSM)

The RSM is a microcontroller-based sensor interface module acting as an extension to the DAM. A DAM exchanges commands, data, and configuration information with RSMs using a messaging construct. Messages are exchanged between the DAM and the RSM and between the RSM and the DAM over the RS485 DAM bus and via the optional wireless network interface. The RSM performs basic signal conditioning, averaging and, where applicable, sensor integrity checking but does not perform any subsequent data processing. RSMs are optional and a single system may contain from 0 to 4 RSMs. CLD chose to limit expansion to four additional systems.

The Remote Sensor Module performs the following key functions:

- Implements a half duplex RS485 serial bus slave interface for communication to the Data Acquisition Module (DAM).
- Optionally interfaces to Data Acquisition Module (DAM) via a shared wireless network.
- Implements on-board regulated power supply circuitry for powering the RSM electronics and RSM attached sensors.
- Exchanging control and configuration information with the DAM.
- Performs sensor scans in response to commands from the DAM.
- Implements a bootloader to enable the remote upgrade of RSM firmware.

RSM Software

The RSM software was developed in the C programming language. The RSM software comprises the following key functions:

- **Supervisory**: There are four main tasks performed by the Supervisory function:
  - o System Initialization including:
    - I/O subsystem
    - Supervisory Timer
    - Reading system parameters from EEPROM nonvolatile memory

The system parameters read from the EEPROM include the analog channel sensor mask, the temperature sensor ID, and associated mapping in the data packet to the DAM and the ID of the RSM. The Supervisory Timer drives the data acquisition state machine.

User Interface

The contractor, via a telnet session to the DAM, can connect to the RSM via the RS485 DAM bus to perform initial system setup, modify the system configuration and to perform system diagnostics.

Sensor Scan

The Supervisor, on reception of a SYNC packet from the DAM, will initiate the scanning of the RSM's directly attached sensors. At the end of the sensor scan period, the Supervisor then stores the scan data from the sensors in their associated current scan sensor buffer. On reception of a SEND_DATA command from the DAM, the current scan data from the RSM sensors is sent to the DAM over the RS485 DAM bus. The RSM also adds the current scan data for directly attached sensors to their associated *averaging accumulator* and increments the *averaging accumulator sample count*.

On reception of a SEND_AVERAGE_DATA command from the DAM, the *averaging accumulator* for each sensor is divided by the *averaging accumulator sample count* to derive the average value for the sensor over the averaging period. The averaged data from the RSM sensors is sent to the DAM over the RS485 DAM bus.

DAM Bus Communications

The DAM bus is RS485 half duplex serial bus connection from the RSM to the DAM. The DAM is the bus master. This bus is used for configuration and sensor data. The Supervisor parses and executes commands from the DAM that are received on this bus.

Bootloader

The Bootloader enables the DAM firmware and/or the firmware on the RSM module to be upgraded via the Ethernet interfaced on the DAM.

C-4. Modbus Gate Way (MGW)

Early on into the project, CLD was confronted with the dilemma of whether or not to build or buy a power sensor. Many power sensors on the market today employ different protocols for transferring operational information. Costs and firmware required to process and capture that information very a great deal across the industry. Methods employed by other data acquisition systems include the use of low cost current transformers (CTs) combined with simple signal conditioning and subsequent analog to digital conversion. Accuracy of the collected power data utilizing this simple approach may be sufficient for a gross estimate of power usage, however CLD was interested in capturing real-time quality snapshots of energy consumed at a level of precision required to calculate instantaneous coefficient of performance (COP). CLD opted to use an intelligent, revenue grade, power meter to obtain a higher quality assessment of system performance. Additionally, the benefit of monitoring and recording fluctuations in voltage or frequency can offer insight into potential problems with premature equipment failure. Researching available technologies revealed a company in China that manufactured revenue grade meters CE certified and distributed in Europe and Asia and the Pacific Rim. These power meters are monitored and configured via a half duplex RS485 serial bus utilizing the MODBUS protocol.

Although not in scope as part of the original statement of work, it became clear that diagnosing problems that can plague a geothermal system would not be possible without thermostat state information. For example, if someone changes the temperature setting on the thermostat, CLD would have no way of knowing if the system state is responding to change or if the system state was changing as a result of some other factor. It is therefore necessary to determine the user configured set point and comparing it to the actual temperature in the room. It became clear that CLD needed to be able to monitor the thermostat setting and output states. There are a number of Modbus thermostats available. CLD made a design decision to include off-the-shelf sensors and devices that used a common Modbus protocol. CLD can serially communicate with different devices on the same bus, which allows expansion of this number of sensors and the type of sensors without adding additional terminals on the DAM or RSM.

CLD incorporated a Modbus thermostat into our final design and has taken the same approach to monitoring electrical energy use. CLD designed and implemented the Modbus Gateway Module board to support the Modbus RTU protocol thus enabling us to select other sensors supporting Modbus protocol to communicate with the DAM without redesigning hardware.

The MGW performs the following key functions:

- Implements a half duplex RS485 serial slave interface for communication to the Data Acquisition Module (DAM) and emulates and RSM.
- Implements a half duplex RS485 serial BUS master interface for communication to the Modbus sensors.
- Optionally interfaces to Data Acquisition Module (DAM) via a shared wireless network.
- Implements on-board regulated power supply circuitry for powering the MGW electronics and Modbus attached sensors.
- Exchanging control and configuration information with the DAM.
- Sends data to the DAM in response to commands from the DAM.
- Implements a bootloader to enable the remote upgrade of MGW firmware.

MGW Software

The RSM software has been developed in the C programming language. From the DAMs perspective, the MGW emulates an RSM. This simplifies the integration of the MGW with the DAM. The MGW software comprises the following key functions:

Supervisory

There are four main tasks performed by the Supervisory function:

System Initialization including:

- I/O subsystem.
- Supervisory Timer.
- Reading system parameters from an emulated EEPROM nonvolatile memory.

The system parameters read from the emulated EEPROM include the Thermostat and Power sensor type, Modbus addresses and associated mapping in the data packet to the DAM and the ID of the MGW. The Supervisory Timer drives the data acquisition state machine.

User Interface

The contractor, via a telnet session to the DAM, can connect to the MGW via the RS485 DAM bus to perform initial system setup, modify the system configuration and to perform system diagnostics.

Sensor Scan

The Supervisor of the MGW does not process the SYNC packet from the DAM. This is because the MGW continuously cycles though scanning of the Modbus attached sensors. At the end of the Modbus sensor scan cycle, the Supervisor then stores the scan data from the sensors in their associated current scan sensor buffer. On reception of a SEND_DATA command from the DAM, the current scan data from the MGW sensors is sent to the DAM over the RS485 DAM bus.

DAM Bus Communications

The DAM bus is RS485 half duplex serial bus connection from the MGW to the DAM. The DAM is the bus master. This bus is used for configuration and sensor data. The Supervisor parses and executes commands from the DAM that are received on this bus.

Bootloader

The bootloader enables the DAM firmware and/or the firmware on the MGW module to be upgraded via the Ethernet interfaced on the DAM.

Appendix D: Tier II - Local Data Management and Communications - Single Board Computer

The Single Board Computer (SBC) was originally intended to be a commodity-based x86 computing platform providing the interface between the Data Acquisition System and the remote CLD Hosting facility. Selection of the SBC was based on price, performance and availability. The opportunity to use a low cost SBC was not available initially. Initial development of the SBC in 2010 was based on a more expensive hardware platform.

With the advent of low cost LINUX based full featured microcomputers, CLD has been testing and utilizing the Raspberry Pi © as the SBC. The Raspberry Pi is a credit card-sized single-board computer developed in the UK by the Raspberry Pi Foundation with the intention of promoting the teaching of basic computer science in schools, and has been well suited to this application.

In 2014, the Raspberry Pi Foundation launched the Compute Module, which packaged a Raspberry Pi Model B into a SODIMM 200-pin module. This design encouraged its use in embedded systems. The operating system software we have chosen to use is included in a Debian Linux package (distribution). Debian Linux is "Open Source Software" and is free.

The SBC operates in "headless" mode. Headless mode effectively means that there is no display keyboard or mouse attached to the microprocessor. Communication with the microcomputer is accomplished by remotely logging into the operating system from another network-attached computer. Adding remote control software (VNC©) allows access to the SBC from another computer. In the field, remotely logging into the SBC is required for the installer to configure and commission the system. Remotely logging into a data acquisition module via the SBC allows the installer to configure and map the sensors. The installation section describes in greater detail how the SBC is configured in the field.

Software development effort provided for this project includes applications that initialize a scheduler to listen for transmitted packets from the DAM. Additional scripts and programs are provided to parse the packets received from the data acquisition module stores the information locally and initiate communication to the host. Additional error checking software logs errors with a date and time stamp when the error occurred. In a further feature provided just to account for an interruption in Internet access.

Should a communication error occur, an application will continue to buffer collected data until communications with the host is re-established, at which time, the buffered packets will be uploaded to the host.

An important feature of CLD's system is data redundancy. A micro-SD card on the DAM PC board provides a configurable storage location for raw data. A snapshot of the data may be taken and stored at different time intervals ranging from 3 seconds to 15 min.

The Single Board Computer performs the following key functions:

- Pre-processing of the real time data from the Data Acquisition Module.
- Provides a centralized interface for configuring and troubleshooting the data acquisition system via the Data Acquisition Module.
- Interfaces via TCP/IP to the central CLD Hosting Facility.
- Forwards pre-processed data via TCP to the central CLD Hosting Facility.
- Processes alerts/alarms from the Data Acquisition Module performing filtering, consolidating and forwarding of alerts/alarms to the CLD Hosting Facility.
- Provides transient (temporary) storage of the raw data from the Data Acquisition Module.

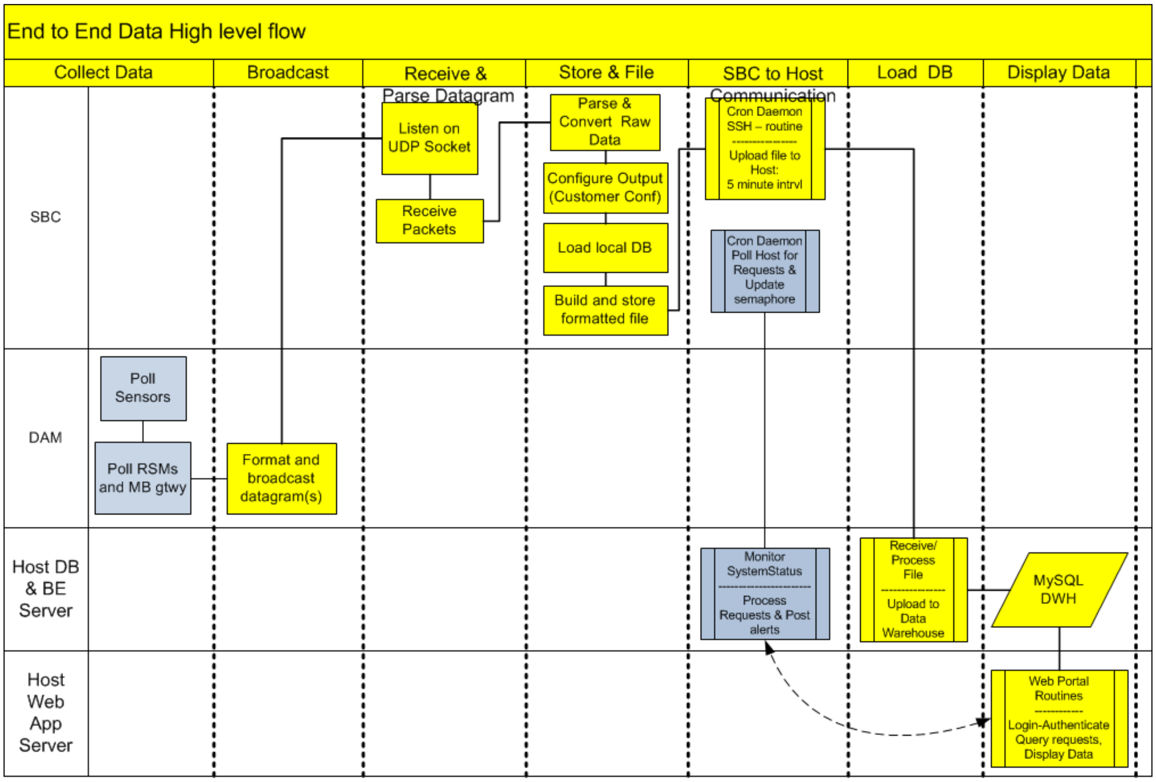
The SBC interfaces to the Data Acquisition Module and the central CLD Hosting Facility via a 100BaseT Ethernet interface or via an optional Wireless Ethernet interface.

The Single Board Computer:

- Receives packets from DAM.
- Stores data locally.
- Initiates secure communication with host.
- Uploads data to host.
- Is automatically initialized on power restore after power outage.

Figure D-1 shows the inter-relationships between each of the tiers and their respective roles in data transmission and transformation.

Figure D-1. Data Flow Diagram



Appendix E: Tier III - Web Portal and Hosting Environment

User interface and the data repository make up the third tier. The user interface provides the contractor and building owner with a rich set of metrics available on a web portal that can be used to view the operation of the geothermal system in near real-time from anywhere in the world.

E.1 Data Storage

Data is stored locally on the single board computer and stored on the MySQL database on the host. This redundant storage is designed to allow for an interruption in communications between each client and the host without losing data. Code written for the SBC senses the lost connection with the host and continues to buffer the data files until such time that communications with the host is restored. It will then resume uploading from the time communications was interrupted. A design objective includes extending the ability to collect and retain data without direct communications with the host for a month. This feature provides adequate time to recover from an interruption in Internet service without affecting the integrity of the data collection and preservation.

The benefit of collecting and viewing system performance history can be clearly demonstrated on multiple levels and from different perspectives.

The contractor experienced with the remote monitoring system with sufficient geothermal analytic skills can quickly diagnose a system that is not performing without going to the customer's location. Although a site visit may become necessary, it is likely that a review of the history will provide valuable information as to the cause of a system failure.

Access to the web portal is password protected to maintain data privacy.

Data Visualization - data loading and processing is handled as follows:

- Application on host server receives files from client.
- An application parses data and converts raw data into human readable information.
- Records are inserted into the MySQL database.
- Errors are logged.

Data is stored in a MySQL database:

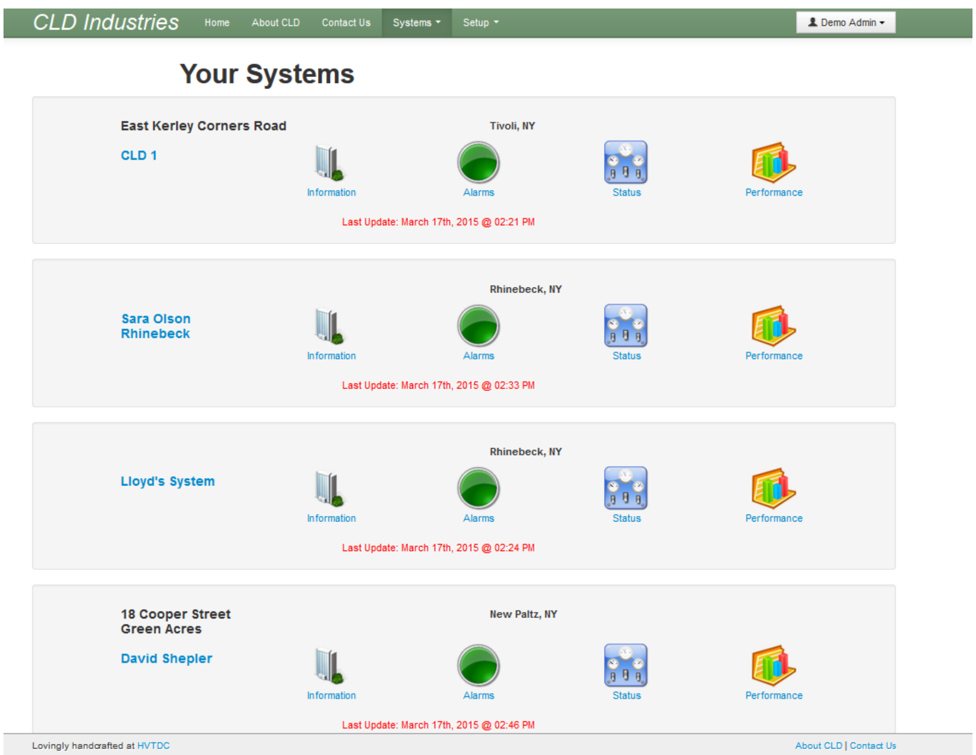
- Data integrity.
- Error Handling.
- Analytics.
- Event handling.

E.2 Web User Interface

Access to a client's information is provided through a password protected Web user interface.

A System Administrator with access privileges to multiple clients systems will be able to see the current status at a glance. Figure E-1 shows the systems selection screen for a user having privileges to view multiple systems.

Figure E-1. Systems List



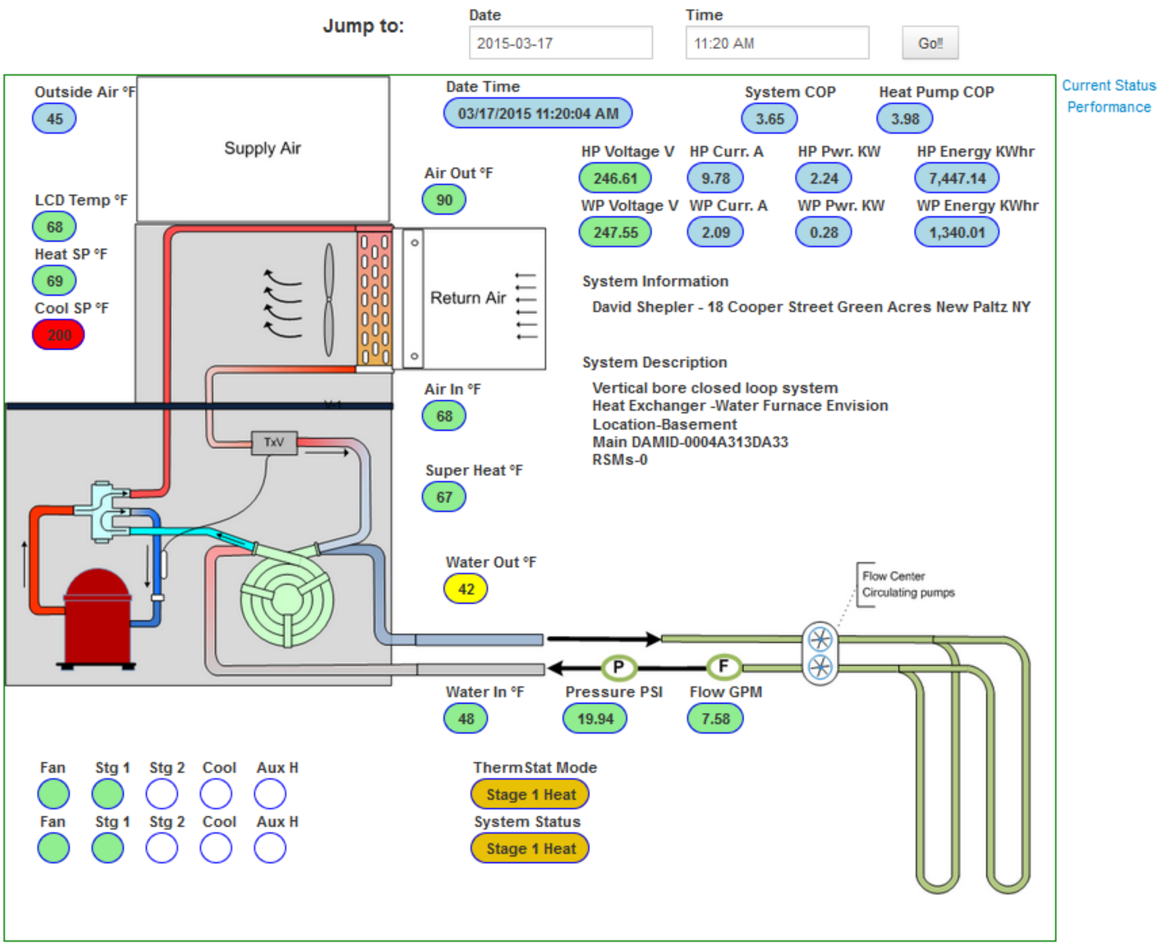
Two Web pages are interrelated to provide the user with a drill down capability.

A ***Performance Chart*** in Figure E-2 provides a timeline showing temperature, flow, and pressure changes with system state. The time interval shown is adjustable up to 24 hours.

Figure E-2. Performance Chart 12 Hr.

The ***Status Chart*** in Figure E-3 provides a detailed view including greater detail at given point in time.

Figure E-3. Status Dashboard



Additional charts have been provided to show operation relative to outside temperature and to other modalities of heating and cooling.

Figure E-4 provides runtime information broken down by system stage of operation as a percentage of a 24 hour period. The chart includes an additional drill down capability to view the same information broken down by hour of a given day.

Figure E-4. System Stages (Run time)

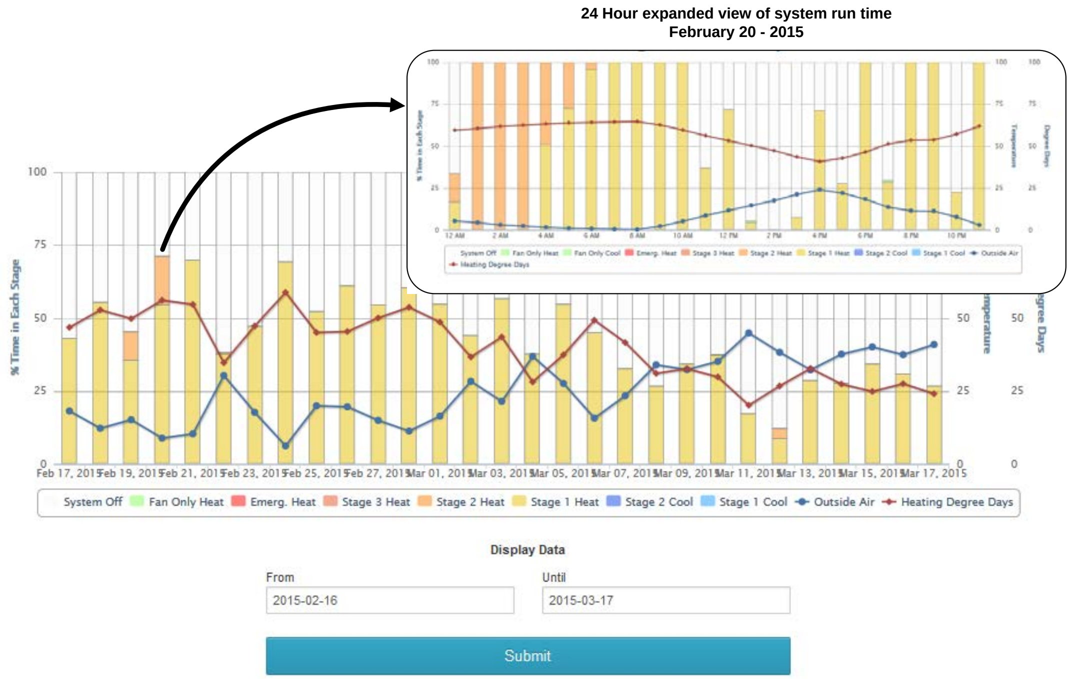
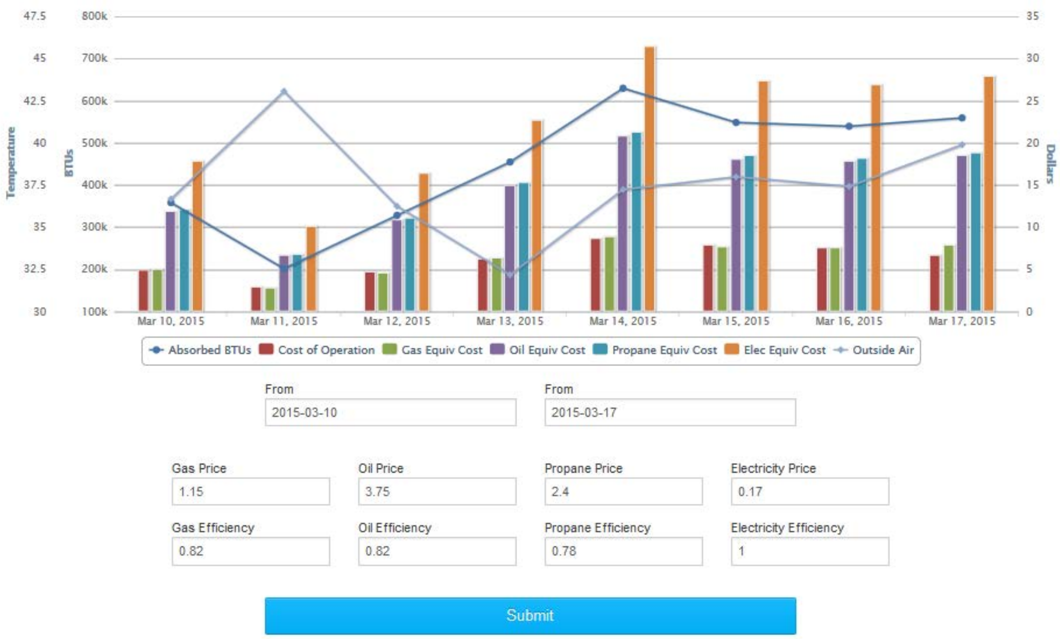


Figure E-5 provides an energy use comparison between different modalities of heating to show comparative costs.

Figure E-5. Energy Comparison Graph



Setup and configuring a new client on the Web portal consists of a set of administrative tasks including:

- Selecting appropriate sensor objects and mapping that incoming data to align with a client's system configuration.
- Setting of alert thresholds for critical performance parameters.
- Setup of contact information for alerting.
- Adding customer information to the database.

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