AHFC Building Monitoring System Project, Phase III: Design Guidelines

Prepared for: Alaska Housing Finance Corporation

A Task 3 Report

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Prepared By:

Alan Mitchell, Analysis North

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1. Introduction and Overall System Architecture

The purpose of this report is to provide guidelines for designing and installing a building monitoring system similar to ones installed for the AHFC Building Monitoring Project. General system architecture, sources for equipment, and installation guidelines are provided. The diagram below shows the monitoring system architecture used for the AHFC project.

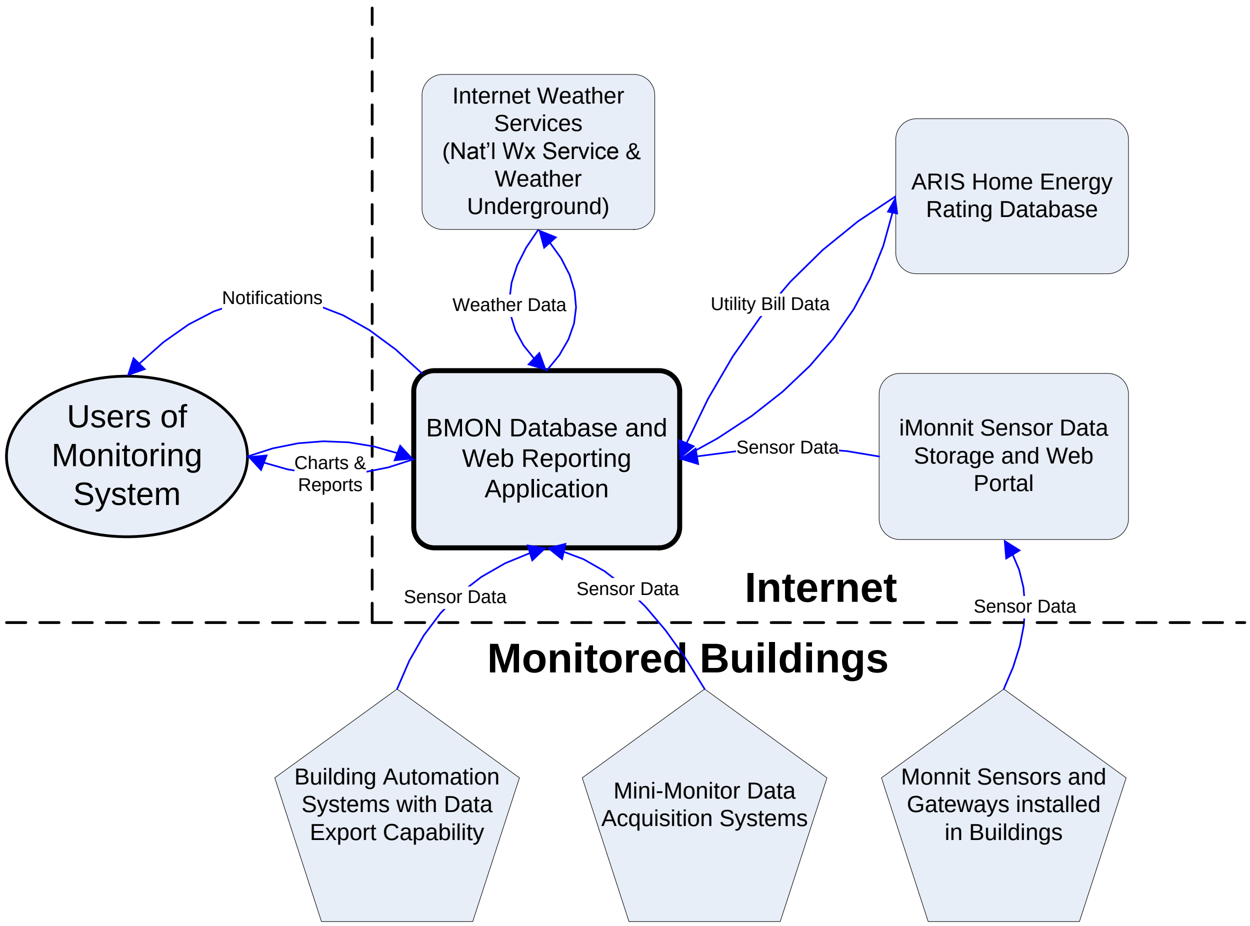

Figure 1: General Structure of the AHFC Building Monitoring System.

The monitoring system stores the collected data on an Internet-accessible server, and the data is accessible to users of the data in near real-time. The core of the system is the "BMON Database and Web Reporting Application". This custom web application consists of a database for storing sensor data and a web-based application for viewing charts and reports that display the data to users. BMON is an open-source application that can be used and modified by others.[1] The BMON installation for the AHFC monitoring system is available online at https://bms.ahfc.us. Complete documentation for the BMON system is available online at:

https://git.ahfc.us/energy/bmon/wiki

The BMON database can receive sensor data from multiple different sources. The BMON documentation explains how to configure the BMON software to utilize the different data sources described in the remainder of this section.

1.1 Data Source: Monnit Wireless Sensors

One possible source of data for the building monitoring system are wireless sensors from Monnit, Inc. (http://www.monnit.com), which are used to sense temperatures, light levels, occupancy, and various other parameters within the buildings. In the Figure 1 diagram, the Monnit sensors and gateways are represented by the pentagon in the lower right of the figure.

The Monnit gateway forwards sensor readings to the iMonnit Web Portal, which is the database and portal maintained by Monnit Inc. to configure Monnit sensors, store sensor readings, and view the stored data. This web portal is accessible at https://www.imonnit.com. When new sensors are added to the monitoring system, they must be added and configured through this web site. This web application also provides the ability to establish text message and/or e-mail Notifications that are sent out when sensor values move outside of user-defined ranges; however, the BMON application also provides this functionality. Monnit notifications can also be sent when sensor battery capacity is low, and this notification feature could be useful as it is not provided on the BMON site.

The iMonnit portal allows for some very simple reporting and charting of the collected sensor data. However, the breadth of reporting and charting tools is limited, and there are no energy-specific or building-specific reports available on the system. The Monnit system has been developed for use in a wide variety of applications, not just building monitoring. To remedy this shortfall and to allow for the inclusion of data other than that collected by Monnit sensors, we built the separate BMON Database and Web Reporting Application. To incorporate the Monnit sensor data into the BMON Database, we used the “Push incoming data to 3rd party” feature of the iMonnit system. That feature allows the Monnit sensor data to be forwarded to another server on the Internet. More detail is provided about the Monnit wireless sensor system in Section 4 of this report.

[1] The charting library used by BMON is not open source. See the BMON documentation for further information about licensing for that component.

1.2 Data Source: Mini-Monitor Data Acquisition System

The "Mini-Monitor" data acquisition system was designed for the AHFC project in order to provide a cost-effective means of collecting data from small boiler rooms serving 3- to 8-plex multi-family buildings. The Mini-Monitor systems are represented by the middle pentagon at the bottom of Figure 1. These data acquisition systems feed their data directly to the BMON system. The Mini-Monitor system utilizes hard-wired sensors and also has the ability to extract data directly from certain boiler models, effectively collecting data from the boiler's native sensor network. Additional information about the Mini-Monitor system is provided in Section 5 of this report.

1.3 Data Source: Building Automation Systems

Building Automation Systems can also supply data to the BMON system. Only one such system has been configured to date, that being the system controlling the HVAC system in the AHFC Headquarters building. This is a highly sophisticated Direct Digital Control system that communicates with many sensors throughout the building, in the boiler plant, and in the Rooftop HVAC unit. The control system was installed with the renovation of the HVAC system in 2012. The control system uses the Tridium Niagara AX software framework. Gordon Timmerman of MacDonald-Miller, the controls contractor for the building, identified a 3rd party software module that allows real-time export of data from a Niagara AX system, the Kors HTTP Poster module.[2] This software module was purchased, installed and configured to export a number of sensor values from the building automation system. Those sensor values are posted directly to the AHFC BMON database, allowing those sensor values to be reported, charted and viewed along with the other sources of data feeding the BMON database.

The process of exporting data in real-time from a building control system will be different for each brand of control system. The solution that we discovered for the Niagara AX system was very economical ($100 for the software module, ignoring research and system configuration time) but will not be applicable to other system types.

1.4 Data Source: Internet Weather Services

Weather services that have Internet-accessible data are an additional source of data for the BMON database. We built retrieval features into the BMON database that allow for acquisition of data from the National Weather Service (NWS) data and the Weather Underground service. Using these services eliminates the cost of installing and maintaining

[2] The software module is the HTTP Poster by Kors Engineering, http://www.korsengineering.com/products/http-poster-for-niagara-ax/.

outdoor weather sensors. Also, these weather sources generally have high quality data, a quality level that is difficult to achieve at a reasonable price with site-specific sensors. For example, acquiring accurate site outdoor temperature data requires placement of the sensor away from the building and providing solar shielding for that sensor. Use of the NWS and Weather Underground sites is generally the way to go.

The Weather Underground service allows access to a wide variety of weather stations; however, free access to the service is limited to 500 retrievals per day (the BMON system retrieves values every half hour). So, we utilize data direct from the National Weather Service where possible (no limit on free access). We did need to utilize the Weather Underground service for the AHFC Headquarters building, since the Alaska Science Center weather station located on the Alaska Pacific University campus is much more appropriate than the nearest NWS site.

1.5 Data Source: Alaska Retrofit Information System (ARIS)

Finally, the BMON system has the ability to acquire utility bill data from the AHFC Alaska Retrofit Information System (ARIS) database. This feature will not be usable directly in other monitoring systems, but the programming code used to develop this feature and the Internet weather service feature provides a pattern for other efforts to extract data from databases accessible across the Internet.

For purposes of adding and configuring sensors and reports for the AHFC Building Monitoring System, a system administrator needs to interact with both the iMonnit web portal to configure Monnit wireless sensors and interact with the BMON Database and Reporting Application to configure sensor, report, and notification settings for that application. The administrative interface for the BMON Database and Reporting Application is available at https://bms.ahfc.us/admin/ through a password-protected log in, and use of that interface is described in the System Administrator section of the BMON documentation.

2. Comparison of In-Building Data Collection Systems

The prior section described three different data collection systems located within the buildings to be monitored. These are shown in Figure 1 as pentagons and include:

- Export of Data from a Building Automation System
- Mini-Monitor Data Acquisition System
- Monnit Wireless Sensors

In this section, we discuss the relative merits of these three methods for acquiring data from within a building. It is important to understand that these methods are *not* mutually exclusive. A building may utilize any or all of these methods, if desired.

Here are a list of considerations relevant to selecting the best data collection methods:

- Monnit wireless sensors can measure a very wide range of quantities, including relative humidity, light, occupancy, temperature, pulse counts, switch closures, etc. For the full list, see http://www.monnit.com/.

3. Providing an Internet Connection to a Building Monitoring System

The data collection equipment located in the buildings requires a connection to the Internet in order to transfer data to the BMON web site. The cost and reliability of the Internet connection are important considerations. Here are three options, in order of preference.

3.1 Existing Ethernet Internet Connection in Building

If there is an existing wired Ethernet Internet connection available for use by the monitoring system, it is generally the least expensive and the most reliable to use. Both the basic Monnit Wireless Gateway (discussed later) and the Mini-Monitor have a standard RJ45 Ethernet port available toternet9(b)691i ost an1 085(d)-4(ar)8(d)Mini

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Monnit does not sell a gateway that can directly connect to a WiFi network. However, you can use the standard Monnit Ethernet gateway and add a WiFi-to-Ethernet adapter (a WiFi Bridge) to convert the WiFi connection into an Ethernet format. This configuration has not yet been used in the AHFC monitoring system, so it is difficult to recommend a reliable WiFi-to-Ethernet adapter. Limited testing was done on the Netgear WNCE2001 model; however situations occurred where the adapter locked up and needed to be power-cycled. If a totally reliable WiFi-to-Ethernet adapter cannot be found, you can always use a clock timer switch to automatically power-cycle the device on a daily basis. One suitable timer is the Woods 50007, http://www.amazon.com/Woods-50007-Indoor-Digital-Settings/dp/B005WQIDHY.

One WiFi-to-Ethernet adapter to investigate would be the Dovado Tiny AC router (http://www.dovado.com/en/products) as that router can support Internet connections from multiple sources, including Internet from the mobile cellular network, and other Dovado products are successfully being used in the AHFC building monitoring system.

3.3 Cellular Internet Connection

Modern mobile wireless networks can provide exceptionally capable Internet connections. It is possible to utilize this system as an Internet connection for a building monitoring system. The advantage of a cellular Internet connection is that it is easy to install, since no building wiring is required. If you must install a new Internet connection in the building because no existing connection is available (or corporate IT policies forbid use of the building Internet network), cellular Internet often will have the lowest ongoing operating costs. Low volume data plans are available from most carriers for $10 per month or less, whereas a new cable modem or DSL connection will generally cost $40 per month. However, as mentioned above, use of an existing Internet connection in the building will always be the least expensive route (and a more reliable connection), as adding the monitoring system to an existing network will cause no additional operating expenses.

There are multiple possible approaches to using a cellular Internet connection. Monnit sells a gateway that has built-in capability for connecting with certain cellular networks. Their primary cellular partner has been Verizon Wireless, and the Monnit gateway uses the 3G Verizon Wireless network. Verizon recently entered the Alaskan market, but their Alaskan network only support 4G data, so the Monnit gateway is not compatible. Monnit is in the process of releasing additional sensor gateways that should work with Alaskan cellular networks, and it would worthwhile to keep up to date with new Monnit offerings, as a

Monnit sensor gateway with direct support for cellular Internet is a desirable and simple solution to Internet connectivity.

In the meantime, use of the cellular Internet network can be accomplished through use of a cellular router. The router provides Ethernet ports that the Monnit gateway or the Mini-Monitor can be connected to. Two different cellular routers have been used successfully with the AHFC monitoring system. They are:

Option Cloudgate Router (http://www.option.com/#firstPage): This has been the most reliable cellular router utilized in the AHFC monitoring system. To date, it has not locked up and required a power-cycle to restore operation. It is the cellular router certified by the General Communication Inc. (GCI) wireless network, and it has been also used by the Alaska Native Tribal Health Consortium for Alaskan village monitoring installations. It is important to use the "Connection Watchdog" and "Timed Reset" features of the gateway to ensure a reliable connection. The 3G/2G version of the router costs about $380 and the model that supports 2G, 3G, and 4G costs $540. We have discovered some sites (1142 Ptarmigan, and some locations within the Chugach Manor and Chugach View) that do not have sufficient 2G/3G signal strength and require a 4G connection.

Figure 2: Cloudgate Cellular Router

Dovado Tiny Router (http://www.dovado.com/en/products): This router is substantially less expensive than the Option Cloudgate, but may be less reliable. Equipment cost is $130 (2G/3G) to $165 (2G/3G/4G). Router operation requires two components—the Dovado Tiny router and a compatible USB cellular modem. Dovado claims to support dozens of compatible cellular modems. Some are 2G/3G modems and others are 2G/3G/4G modems. The Dovado routers have a "Connection Tracker" feature that supposedly watches over the Internet connection and power-cycles the attached USB modem if connectivity is lost. If implemented properly, this is an exceptionally valuable feature for maintaining Internet connectivity without requiring human intervention. Unfortunately, the Connection Tracker watchdog code in the router does always consistently run with certain router firmware / modem combinations. After extensive communication with Dovado, we have found the following router firmware / modem combinations to be reliable:

- Dovado Tiny Firmware 7.3.4 combined with a Huawei 173u-6 3G/2G modem operating on the GCI wireless network. This combination has worked without lockup for multiple months across three Mini-Monitor sites.
- Dovado Tiny Firmware 7.3.4 combined with a Sierra Wireless 313U 4G LTE/3G/2G modem operating on the GCI wireless network. After experiencing lock-ups with a Huawei E3276s-505 4G LTE/3G/2G modem, we changed one site to the Sierra Wireless 313U modem. The Sierra Wireless modem has performed reliably for three weeks, but more data is needed before deeming this combination fully reliable. Again, the only reason to utilize this router/modem combination is in situations where 4G LTE provides sufficient signal strength and 3G/2G does not. Mobile phone apps such as the Android KAIBITS Network Signal Info can provide the signal strength information required to make this determination.

Figure 3: Dovado Cellular Router with USB Modem. Power and Ethernet cables connect at bottom.

It should be noted that Cradlepoint MBR95 routers combined with Huawei E220 modems were initially used in the monitoring system but were not found to be reliable.

Finally, the Mini-Monitor software was designed to directly utilize USB cellular modems such as the Huawei and Sierra Wireless models mentioned above, without the use of a separate cellular router. The modem can be directly plugged into the Raspberry Pi computer in the Mini-Monitor. Watchdog features were built into the Mini-Monitor software to restart cellular connections if needed, but it is physically impossible for the Raspberry Pi to power-cycle the modem. This configuration is economical, as it eliminates the need for a cellular router—only a USB cellular modem is required. There is one Mini-Monitor installation (1142 Ptarmigan Park) that utilizes this hardware configuration with a Huawei E3276s-505 modem, and that installation has been operating reliably without human intervention for almost one year. While this is encouraging, this installation has a high 4G LTE signal strength (although the 3G/2G signal strength was low, thus requiring the 4G LTE modem). Low reliability generally occurs in situations with low signal strength, and this hardware configuration has not been tested under those conditions.

4. Monnit Wireless Sensor System

Monnit Wireless Sensors (http://www.monnit.com/) are the key data collection technology used in the larger AHFC buildings that participated in the monitoring project. As mentioned before, wireless sensors allow for easy installation, without the need for adding long runs of sensor cable. Figure 4 below shows the key components that are used to build a Monnit wireless sensor system.

Figure 4: Key Components of a Monnit Wireless Sensor System.

4.1 Monnit Sensor Gateway

The Monnit Sensor Gateway is the centralized hub that communicates with the wireless sensors in the building and delivers that data back to the iMonnit Internet cloud server, which was depicted in Figure 1. The Monnit Gateway requires AC power or a special model can be powered over an Ethernet connection. The Gateway must also have an Internet connection, as was discussed in the prior section. Each Gateway can support up to 100 sensors; the sensors must be within radio range of the Gateway.

There are no switches and controls on the Gateway; it is configured through the iMonnit cloud server. Configuration of sensors also occurs through the iMonnit Internet server. If the Gateway loses its Internet connection, it has local memory for storing up to 16,000 readings for later posting to the Internet when communication is restored. We have not found this feature to work at all times, so Internet outages should be resolved quickly to ensure complete data collection.

Monnit frequently upgrades the firmware that runs on the Gateway, and these new firmware releases can be installed remotely through commands on the iMonnit server. However, we have not found all new firmware releases to be reliable. We are currently running Gateway **firmware version 3.1.0.1,** and this firmware release *has* proven to be reliable.

We use a surge protector when powering the Gateway, and the **Tripp Lite ISOBAR 2-6** has worked well. The two pictures below show two different Gateway installs. The picture on the left couples the Monnit Ethernet Gateway with an Option Cloudgate cellular gateway for Internet connectivity. There is also a Mini-Monitor install shown to the right of the Cloudgate; this Mini-Monitor is being used to extract data from an AERCO boiler. All components are mounted on an MDF backboard and a piece of 0.093" polycarbonate sheet

of each sensor link, so it is easy to determine whether a sensor is having difficulty communicating with the Gateway.

The first solution to a sensor link with poor signal strength is to add a Monnit Range Extender / Repeater between the sensor and the gateway. This device is shown in Figure 4; it plugs into a AC wall socket and relays transmissions from distant sensors to the gateway. Figure 5 shows a Repeater installed in a Laundry room at the Chugach Manor.

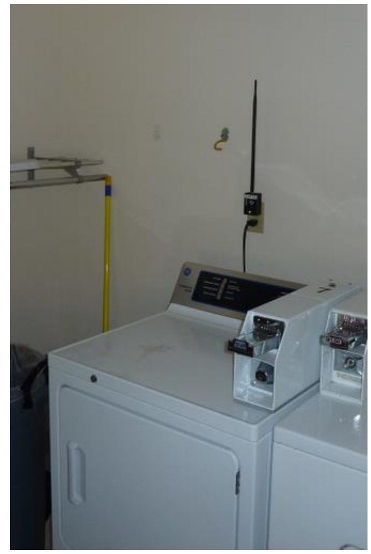

Figure 5: Monnit Repeater in Laundry Room

Although Monnit made software modifications that allow chaining of repeaters (Sensor -> Repeater 1 -> Repeater 2 -> Gateway), this feature is not reliable, and you should only utilize one repeater between a weak sensor and a Gateway. If that configuration is insufficient to make the link useable, then you need to install an additional Gateway and the Internet connection required by that Gateway.

To give you some sense for coverage of Gateways and repeaters, here are the number of Gateways and Repeaters utilized in some AHFC buildings:

- AHFC Headquarters (78,000 square feet): 3 Gateways, but only 2 are needed, and 2 Repeaters. The repeaters are needed to reach the Gas Meter and the Electric Meter, which are located outside of the building. The Gateways are positioned in the core of the building.
- Chugach Manor multi-family housing (114,000 square feet): 2 Gateways and 2 Repeaters.
- Chugach View multi-family housing (97,000 square feet): 2 Gateways and 1 Repeater.
- Glacier View multi-family housing (28,000 square feet): 1 Gateway and no Repeaters. The wireless sensors are all located in the mechanical room, so link distances are short.

4.3 Monnit Wireless Sensors

Monnit wireless sensors come in four model lineups—Commercial Coin Cell, Commercial AA, Industrial, and WiFi. The WiFi sensors do not use a Gateway and communicate directly to a WiFi network; however, cost is higher and battery life is shorter than those sensors utilizing a Monnit Gateway. We strongly recommend the **Commercial AA** sensors, which use a pair of AA batteries to power the sensor. The Commercial Coin Cell sensor uses a very small Lithium coin cell, but the battery life is substantially reduced relative to the AA sensor, thus increasing maintenance costs. The Industrial sensor carries a substantial price premium and only adds a weatherproof case and a lithium battery instead of conventional AA batteries. For installations needing weather protection, we instead opt to install the Commercial AA sensor in a weatherproof enclosure such as the **BUD Industries PN-1324-DGMB**.

Monnit states a 4 year battery life for the Commercial AA unit with Alkaline AA batteries. We choose to use **Energizer Ultimate Lithium AA batteries** with the unit for two reasons:

- The Lithium batteries can operate in cold Anchorage outdoor temperatures.
- The Lithium batteries have very low self-discharge and somewhat more capacity than Alkaline batteries.

Our own measurements of the current draw of the Monnit temperature sensor indicate that the Lithium AA batteries may last over 10 years, which will keep maintenance costs to a minimum.

To mount the Monnit Commercial AA sensors, we have successfully used both 3M Command Brand Medium Picture Hanging strips and Velcro Extreme. The newest model of Commercial AA sensor has added mounting feet with holes. So, screws or zip ties are now an additional mounting option.

4.4 Notes on Specific Monnit Sensor Applications

In the following sections, we provide product selection and installation notes on specific applications where we have used Monnit Wireless Sensors for building monitoring.

4.4.1 Natural Gas Consumption

The whole-building natural gas usage can be measured by installing a device that produces a dry switch pulse (no voltage) every time a fixed quantity (typically 0.1 ccf) of natural gas flows through the meter. For the meters used by Enstar Natural Gas company in Anchorage, the proper pulse output device is the **Miners and Pisani MVP-10** unit. The unit costs approximately $225 (available from Ferguson Enterprises in Anchorage) and Enstar charges $150 to install the unit. To count and transmit the pulses we use a Monnit Pulse Count sensor, model MNS-9-PC-W2-SI. Figure 6 shows a completed installation at the AHFC Headquarters building. The weatherproof enclosure for the Monnit sensor was mounted to a ¼" polycarbonate base plate that was then clamped to a pipe with U-bolts. Through use of the wireless sensor, no building penetrations were required. A Monnit repeater was needed to allow this sensor to reach the Monnit Gateway located in core of this building.

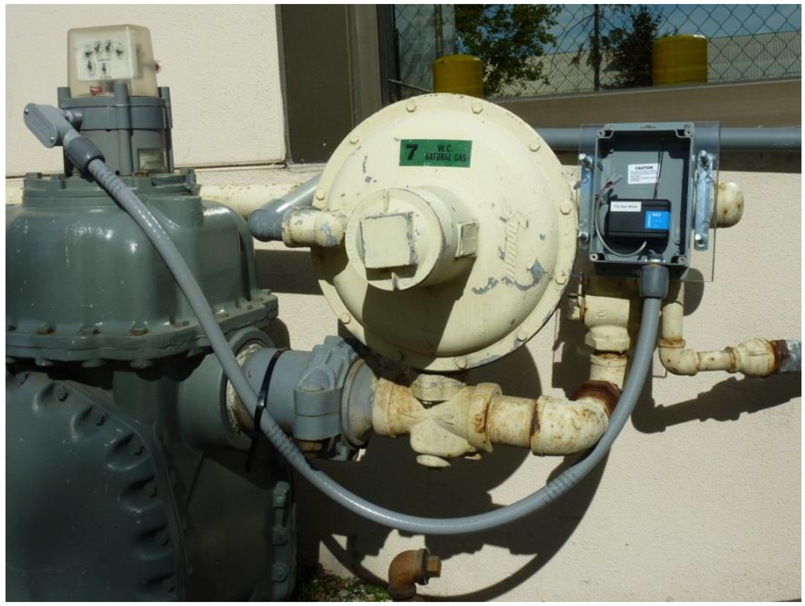

Figure 6: AHFC Headquarters Pulse Output attachment to the Natural Gas meter (upper left) and associated wireless pulse counting sensor (upper right). The cover has been removed from the enclosure holding the wireless sensor. Flexible conduit protects the cable connecting the gas meter pulser unit to the wireless sensor.

4.4.2 Fuel Oil Consumption

Fuel oil consumption can be measured by installing a fuel flow meter inline to the heating equipment. Because some fuel delivery systems involve a circulation loop to remove air from the oil, fuel meter placement is critical so that the actual consumption of the heating system is measured and not the circulation flow. Sometimes, a separate meter for each heating appliance will be required.

We have successfully used Elster 4P fuel oil meters with a Reed Pulser option (10 pulses per US Gallon) and purchased those meters from Arctic Controls, Inc. in Anchorage ($484 per meter). The fuel oil meter is connected to a Monnit Pulse Counter, model

MNS-9-PC-W2-SI. We initially experienced interference from the boiler oil burner that affected the proper operation of the Monnit pulse counter. That interference problem was resolved by mounting the Monnit pulse counter at least 10 feet away from the burner. The figure to the right shows an installation at the Glacier View public housing facility in Seward, Alaska.

Figure 7: Fuel Oil Meter installation at the Glacier View building. The translucent plastic box at the top of the picture is the fuel oil meter. The wireless pulse counter sensor is attached to the Unistrut at the left side of the picture.

4.4.3 Electricity Consumption

Measurement of whole building electricity use is possible through a couple different methods. In the AHFC project, only one method has been used to date, and it has been applied to three different buildings. We chose to have the electric utility, Anchorage Municipal Light and Power, install a pulse output unit ("KYZ relay") on their building electric meter ($1700 per meter). We then connected a Monnit wireless pulse count sensor (model MNS-9-PC-W2-SI) to that pulse output unit. Figure 8 shows the installation at the Chugach Manor building.

Figure 8: Chugach Manor Electric Meter measurement system. The utility's pulse output unit is shown in the lower right. The wireless pulse count sensor is upper right.

Another option for measuring building electricity use is installation by an electrician of a separate electric power transducer that utilizes its own voltage taps and current transformers to measure electricity power consumption directly. This technique can also be used to measure individual circuits or pieces of equipment within the building. The Dent Instruments PowerScout (http://www.dentinstruments.com/power_meters_demand_response_branch_circuit_monitoring.html) is one such product. Another product, which has been used by the Alaska Native Tribal Health Consortium for measuring pump power consumption, is the Continental Control Systems (CCS) WattNode Pulse transducer (http://www.ccontrolsys.com/w/WattNode_Pulse). For smaller buildings, this approach may be less expensive than paying the electric utility for installation of a pulse output unit on their meter. Although, the amount charged to install a pulse output device on the electric meter can vary substantially across utilities. The charge at Anchorage ML&P is $1700, but the charge by Golden Valley Electric in Fairbanks is only $480.

Electric power transducers such as the Dent and CCS models mentioned above can be provide pulse outputs, but also can be purchased with analog 4-20 mA or Voltage outputs. The pulse output versions produce more accurate results, because every digital pulse, representing a certain number of kilowatt-hours, is accurately read by the Monnit pulse counter. With an analog output, two issues diminish the accuracy when used with a Monnit analog sensor (e.g. the 0-20 mA Monnit current sensor). First, the Monnit analog sensors without user calibration are only accurate to within 3% of the full-scale reading, which is a much higher percentage error of a part-load reading. Second, the Monnit analog sensors only read the power transducer every 10 minutes at most. This reading is an instantaneous electric power reading and provides no information about variation in power consumption during the time period since the last read. In contrast, with the pulse output power transducer, the power transducer is continually reading power usage and accumulating energy use. Power consumptions at all points in time are accumulated into the pulse output stream.

4.4.4 Temperature

Temperature is the most prevalent parameter measured in building monitoring systems that are used for energy management and maintenance purposes. The remainder of the section addresses techniques for measuring room air temperatures, fluid temperatures in pipes, and air temperatures in ducts with Monnit wireless sensors.

Room air temperatures are the easiest to measure and can simply utilize the MNS-9-TS-W2-ST Monnit Temperature Sensor. The temperature sensing element protrudes slightly from the sensor case.

Measuring fluid temperatures in pipes requires more care. Unless an empty thermowell is available, the fluid temperature in a pipe will generally be measured by attaching a temperature probe to the outside surface of the pipe. The Monnit MNS-9-TS-W2-LD is suitable for this purpose and comes with a temperature probe attached to three feet of cable. The key to making an accurate temperature measurement of the fluid in the pipe is to make very good thermal contact with the fluid and very poor thermal contact with the ambient air surrounding the pipe. As an example, consider a fluid temperature of 170 degrees Fahrenheit and an air temperature surrounding the pipe of 70 degrees F. If the heat transfer coefficient (heat transfer strength) from the sensor to the fluid is only 10 times greater than the heat transfer coefficient to the air, a significant measurement error will occur. Under these conditions, the temperature of the sensor will fall at point in between the fluid temperature and the air temperature such that the delta-temperature to the fluid is 1/10th as large as the delta-temperature to the air. That temperature in this scenario is 79.1 degrees F, so the error in measuring the fluid temperature is a very significant 9.1 degrees F.

To eliminate this attachment error, two important things must be done:

- Strap the temperature probe tightly to the pipe with cable ties and use thermal heatsink compound to increase the heat transfer from the probe to the pipe. We have used compound similar to:
  - Banggood Thermal Grease (http://www.amazon.com/Banggood-Thermal-Compound-Silicone-Heatsink/dp/B008MIMB0E/)
  - but, the Super Lube 98003 Silicone Heat Sink Compound should also work (http://www.amazon.com/Super-Lube-98003-Silicone-White/dp/B0044NI2M2/)
- Insulate over top of the sensor to minimize heat loss to the surrounding air.

The figure below shows an installation of the Monnit temperature probe on a pipe. The picture is taken before the critical re-installation of the pipe insulation over the sensor.

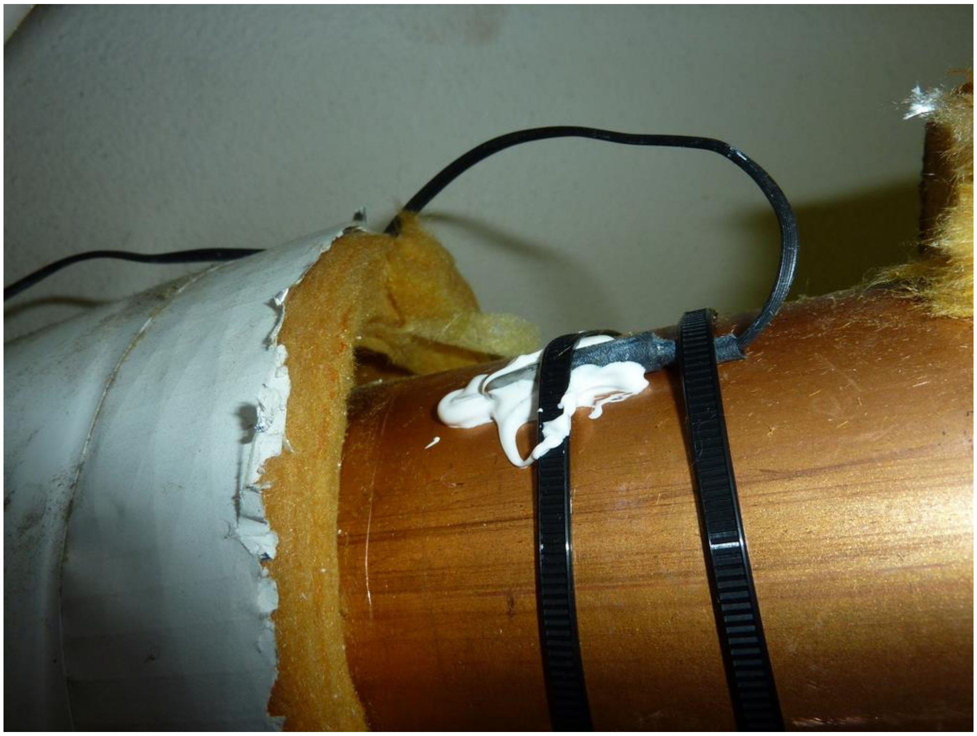

Figure 9: Typical Mounting Configuration for a Temperature Probe on a Heating System Pipe. Two black cable ties are shown in the picture holding the sensor against the pipe. The white paste is thermal grease (heat sink compound), which ensures good thermal contact between the pipe and the sensor. The pipe insulation *must* be reinstalled over the temperature sensor in order to achieve accurate measurements (not shown in this picture).

To measure the air temperature in duct work, Monnit has a special Duct Temperature Sensor, model MNS-9-DT-W2-LD. We have not used this product, but it appears to be the correct solution for duct air temperature measurement.

Monnit states the accuracy of their temperature measurement sensors to be +/- 1.8 degrees Fahrenheit. We did limited testing on the product and believe it performs somewhat better than that specification. For many building monitoring tasks, this accuracy is sufficient. However, when you are trying to measure the temperature difference between two fluids, generally for measuring the energy used in a fluid loop, accuracy needs are higher. As an example, consider a heating distribution loop, where the supply and return temperatures are measured. The energy consumption of that loop is proportional to the temperature difference between the supply and return temperatures. If the supply temperature has an error of +1.5 degrees F and the return temperature has an error of -1.5 degrees F, the temperature difference measurement will be 3 degrees F incorrect. If the overall loop temperature difference is actually 8 degrees F, this 3 degree F error is a 37.5% error in delta-T measurement.

To alleviate this problem, you can either buy a Monnit Temperature Sensor with a calibration certificate or do calibration of the sensor yourself using a water bath of an appropriate temperature and an accurate temperature sensor as a standard. Once you have a calibration value, you can enter that into either the iMonnit configuration system or into the BMON system as a "Transform Function" (see BMON documentation).

4.4.5 Motor/Pump On/Off Sensing

It is useful to know when pumps, motors, fans, burners, etc. turn On and turn Off. This information can be used to estimate energy use, determine whether operating schedules are proper, and to determine cycle lengths of equipment. There are a number of different approaches to this task using Monnit sensors:

Relay Across Device: Install a relay with the coil connected across the power leads of the device you are trying to measure. Functional Devices RIB models are well suited for this purpose. Then, the dry relay contacts can be connected to a Monnit Dry Contact sensor (model MNS-9-CF-W2-LD). The Dry Contact sensor will report when the target device turned On and turned Off. The BMON software also has a special calculated field function that will convert these On/Off events into a half-hour runtime percentages, which are useful for estimating energy use.

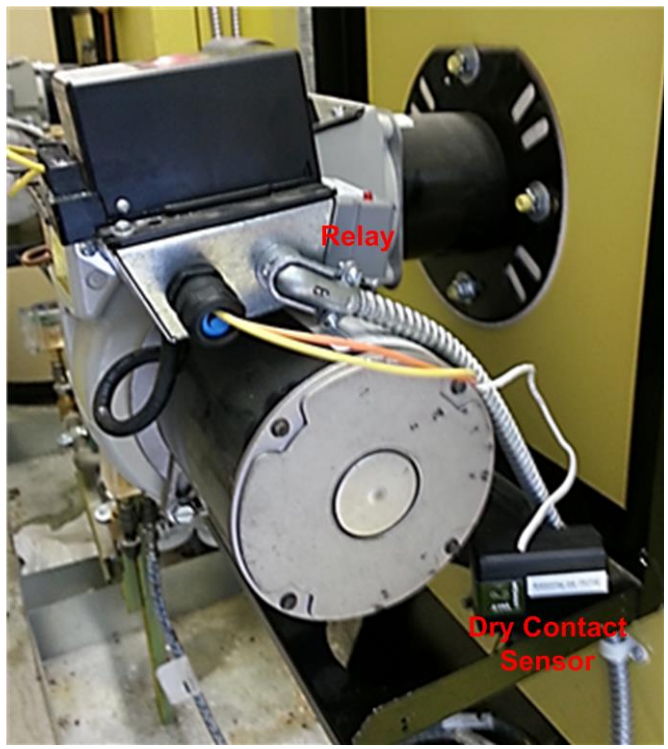

Figure 10: Sensing Boiler On/Off Cycles using a Relay and Dry Contact Sensor. The Orange and Yellow wires are from the contact side of the Relay and connect to the Monnit Dry Contact Sensor. Contrary to what is shown here, the Monnit Dry Contact sensor should be mounted at least 10 feet away from a burner assembly to eliminate noise interference.

Figure 10 shows a picture of this technique being used to measure the On/Off cycles of an oil burner by connecting the relay across the fuel solenoid of the burner. Contrary to what is shown in the picture, the Monnit Dry Contact sensor should be mounted at least 10 feet away from the burner assembly to eliminate noise interference. Also, ensure that the Monnit Dry Contact Sensor has an internal low pass filter installed to reduce noise impacts (this was a special order from Monnit but now may be incorporated in the standard product. Contact Monnit to verify.)

Analysis North Motor Sensor: Use an Analysis North Motor Sensor coupled with a Monnit Dry Contact Sensor to determine On and Off events of the device. This Motor Sensor requires no wiring to the device but is instead attached with high-temperature Velcro to a location on the device having a strong AC electromagnetic field. The sensor works with motors, zone valves, gas valves, solenoids, and other AC devices emitting an electromagnetic field. Figure 11 shows a Motor Sensor being used to sense the On/Off cycles of a pump.

Figure 11: Analysis North Motor Sensor

Current Switch: Veris, Honeywell, Dwyer, and others manufacture current switches that fit around an electrical conductor and close a switch when sufficient current is flowing through the conductor. The switch can once again be connected to a Monnit Dry Contact sensor to record On/Off events. The current switch does occupy space in the electrical junction box where the conductor is located, and sufficient space may not be available.

Auxiliary Contacts on Zone Valve: Some devices such as certain models of zone valves have an extra set of contacts that close when the device is On. If so, those contacts can be directly wired to a Monnit Dry Contact sensor.

AC Voltage Detection Sensor: Monnit sells an AC Voltage Detection Sensor (model MNS-9-VD-W2-LD) that can be wired across the power leads to a device that operates at 24 – 500 VAC. When the device is powered or unpowered, the Monnit Sensor will report the event. This eliminates the need for a relay, as described in the first approach above. However, the Monnit AC Voltage Detection Sensor is not UL approved.

Monnit also sells an Activity Timer sensor that relies on a vibration detector to determine when a device is being used. We don't recommend this approach as it does not report precise On and Off events (it only reports accumulated run time), and the vibration sensor may not work in a number of HVAC applications.

4.4.6 Equipment Alarm Contacts

Some boilers and other types of equipment have special dry contacts that close when a failure occurs in the equipment. The Energy Kinetics System 2000 boilers at the Glacier View public housing facility in Seward are an example of this type of equipment. By attaching a Monnit Dry Contact sensor (model MNS-9-CF-W2-LD), the monitoring system can detect when this equipment alarms occur. A BMON alert notification can be created so that appropriate maintenance staff are notified when the alarm happens.

4.4.7 Fluid Flow

Fluid flow rates are expensive to monitor but can provide useful data. More economical installations of flow monitoring could be achieved by installing flow meters at times of HVAC renovation or equipment replacement, as much of the expense is the labor required to install the actual flow meter. Here are some different approaches to measuring flow:

Ultrasonic Flow Meters: We have used non-intrusive ultrasonic flow meters in two places in the AHFC monitoring system. In addition, the Alaska Native Tribal Health Consortium has made numerous installations of these meters. No plumbing work is required to install the ultrasonic sensors, as shown in Figure 12 below. The flow meter used is the model TUF-2000M, a transit-time ultrasonic model available for about $250 from a number of Chinese-based sellers through E-Bay. The pipe should be cleaned before installation and Dow Corning 111 valve lubricant is used to improve acoustic coupling to the pipe. After installing the sensor, accuracy when measuring low flow rates can be improved substantially by "zeroing" the meter. The zeroing process involves shutting off flow in the pipe and executing the zeroing command on the meter (Menu 42).

Figure 12: Ultrasonic Flow Sensors installed on the Space Heating Distribution loop at Glacier View. Important installation details include the use of Dow Corning 111 valve lubricant and sealant as acoustical coupling between the sensor and the pipe. The pipe should be sanded and cleaned before installing the sensor.

The flow meter has multiple output options. We have used the pulse output option and connected the meter to a Monnit Pulse Counter (model MNS-9-PC-W2-SI) for incorporation into the Monnit wireless sensor system. The meter also can provide a 4-20 mA output, which can be used with a Monnit 0-20 mA current sensor, although accuracy will be reduced relative to the pulse counter approach.

The advantage of the ultrasonic flow meter approach is that no plumbing work is required, as the sensor does not need to be inserted into the fluid stream. A disadvantage of the approach is that the meter does not work in certain situations where the fluid flow is disturbed, for example near a pump. Without actually trying the install, it is difficult to predict whether the flow meter will work properly. Also, configuration of the flow meter requires some skill as there are dozens of meter settings available. Finally, stated accuracy of the flow meter is 1%, but we believe the flow meter is substantially less accurate than this.

Water Meters: There are numerous water meters that are primarily meant for measuring and billing water usage. The meters can generally be ordered with a dry contact pulse output that can be connected to the Monnit Pulse Counter (model MNS-9-PC-W2-SI). As one source of these meters, see http://esubmeter.com/index.php?cPath=22. They are inexpensive and accurate but do require plumbing work to install. The meters can be used in some HVAC applications, but here are some considerations:

- The Cold Water versions of these meter typically can only handle water temperatures up to 105 – 120 degrees F, depending on the model. This temperature range will certainly work for measuring flows involving unheated domestic water but will not be suitable for most heated water applications. There are also Hot Water versions of water meters, and these typically can handle temperatures up to 160 degrees F, which may work in some heated water situations.
- These meters may not be compatible with glycol solutions. Check with the manufacturer to answer that question.
- The standard pulse output setting is 1 pulse per 10 gallons of flow. This low pulse rate may not give very good resolution when measuring low flows. For example, if you are measuring a 3 gallon per minute flow and hoping to record flow rates every 10 minutes, 30 gallons will pass in that 10 minute period generating three pulses. The measurement resolution is 33%, which may not be acceptable. With some special ordering, it is possible to acquire some of these meters with a pulse output of 1 pulse per 1 gallon of flow. We acquired the Master Meter Flexible Axis Meter in this format.

Conventional HVAC Flow Meters: Other more conventional HVAC flow meters can be used. The Cold Climate Housing Research Center has used meters made by Grundfos in a number of projects, (http://www.grundfos.com/directsensors/products/flow_temperature.html). The flow accuracy is good. These come with a built-in temperature sensor that has relatively poor accuracy, so is not suitable for measuring temperature differences unless calibrated. Omega also sells a number of flow meters, and we have used their turbine models (FP-5600) for measuring flow in a sidewalk snowmelt system. With that particular model, the output is a relatively high frequency pulse stream; you need to make sure that it does not exceed the 20 Hz frequency limit of the Monnit Pulse Counter.

4.4.8 Light Level

Measurements of lighting levels can be used to determine when lights are operating and determine whether daylight could provide assistance in meeting lighting needs. Monnit sells two different types of light sensors—their Light Detection Sensor and their Light Meter. The Light Detection sensor only reports whether light is present or not present. It does have a calibration feature to improve its accuracy in determining when artificial lights are on. The Light Meter sensor (model MNS-9-LU-W2-ST) reports the lighting level in Lux. Although this sensor is slightly more expensive than the Detection sensor, it provides substantially more information, and we recommend its use over the Detection sensor. The accuracy of the Light Meter sensor is relatively poor, +/- 30%, but some simple calibration with a quality light meter can correct for this if needed.

4.4.9 Occupancy

Occupancy sensing can help set accurate operating schedules and provide data to determine the savings from occupancy-based control strategies. Monnit sells an Infrared Motion Detection sensor (model MNS-9-MS-W2-ST) that has a detection range of about 16 feet. We have successfully used it for detecting the occupancy patterns in hallways and lounge spaces that might benefit from occupancy-based control strategies.

The Motion sensor reports the times when a space becomes occupied and also unoccupied. The BMON software has a function for converting this information into the occupied percentage for each half-hour interval; this format is the most useful for determining energy savings from alternative control strategies.

4.4.10 Sidewalk Snowmelt Energy Use

An out-of-control sidewalk snowmelt system can use over $2 of energy per year per square foot of sidewalk melted (natural gas), and can account for as much as 40% of the a building's heating fuel consumption. So, a 5,000 square foot sidewalk will cost over $10,000 per year of energy. Proper control of the system can reduce this energy cost in half.

A relatively simple energy monitoring approach for sidewalk snowmelt systems is the following:

- Make an estimate of the flow rate of glycol to the sidewalk when the circulation pump is On. When the pump is on, the flow rate is relatively constant under normal operation, as the circulation pump is usually a fixed flow rate pump. You can make the flow estimate by:
    - Doing a one-time measurement of the flow rate using a portable ultrasonic flow meter.
    - Examining design documents for the system and hoping that the engineer's calculations were accurate.
    - Waiting until some data is collected from the monitoring system and performing a statistical analysis of how heating fuel usage is affected by snowmelt temperature differences and pump runtime parameters. The

statistical analysis can produce an estimate the flow rate of the circulation pump.

- Install a sensor to detect when the circulation pump is On. Section 4.4.5, Motor/Pump On/Off Sensing, describes a number of techniques for accomplishing this.
- Install a Monnit temperature sensor on the warm supply pipe to the sidewalk and another temperature sensor on the cool return pipe from the sidewalk.

These sensors allow the determination of the energy use of the system, by assuming the flow rate to the sidewalk is fixed at the value determined in the first bullet above. The BMON Calculated Field function, “fluidHeatFlow”, can be used to combine the monitored values into a Btu/hour heat flow or fuel usage figure.

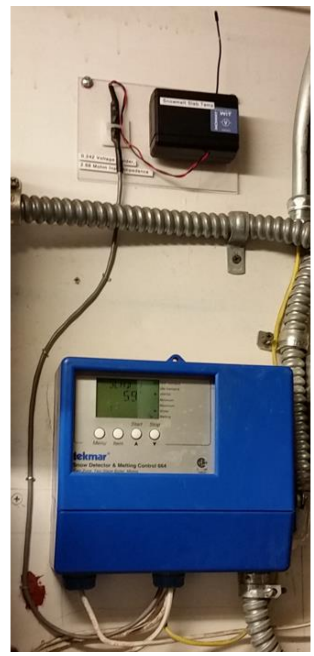

Figure 13: Measuring Sidewalk Temperature

An additional parameter that is very useful to monitor in a sidewalk snowmelt system is the temperature of the sidewalk, as this will allow you to determine the “idle” temperature of the system, which greatly affects energy use. Snowmelt control systems generally have a sensor that provides this temperature. At the Chugach View building, a Tekmar 664 snowmelt controller is being used. We determined how to read the sidewalk slab temperature sensor utilized by this controller through use of a voltage divider circuit and a Monnit model MNS-9-AN-W2-LD 0 – 1.2 VDC Voltage Meter. We wired the voltage divider across the Sidewalk Temperature sensor connections. The output of the divider went to the Monnit Voltage sensor. The voltage divider had a 0.242 divider ratio and consisted of a 2 MOhm resistor and a 680 KOhm resistor. A 0.1 micro-Farad capacitor was added across the output of the divider to provide low-pass filtering. Because the voltage divider has a very high input impedance of about 2.7 MOhm, it does not distort the temperature sensor reading on the Tekmar controller. Figure 13 shows the installation with the Monnit sensor and voltage divider located at the top of the picture and the Tekmar controller at the bottom.

The Monnit sensor reads the voltage across the Tekmar sidewalk temperature sensor. In order to convert this voltage into a temperature in degrees Fahrenheit, we analyzed the controller and temperature sensor characteristics to determine the following expression to use as a Transform Function in the BMON software:

```
117.6 - 104.85*val - 15.95*val**2
```

If you attempt to perform a similar installation, contact this report's author for help, if needed.

5. Mini-Monitor Data Acquisition System

The Mini-Monitor data acquisition system was designed for the AHFC monitoring project in order to provide a cost-effective means of collecting data from small boiler rooms serving 3- to 8-plex multi-family buildings. These data acquisition systems feed their data directly to the BMON system. The Mini-Monitor system utilizes hard-wired sensors and also has the ability to extract data directly from the control systems used by certain boiler models, effectively collecting data from the boiler's native sensor network.

Currently, the Mini-Monitor system has the following data acquisition capabilities:

- The ability to read twenty values from the Sage Boiler Control used by Burnham Alpine Boilers, including Firing Rate, Supply and Return Temperatures, and Site Outdoor Air Temperature. The Sage controller is actually manufactured by Honeywell under the model name "SOLA", so it is possible that the same controller is used in other boilers.
- The ability to read thirteen values from the AERCO BMS II Boiler Management System, the controller that can be used with an installation of multiple AERCO boilers.
- The ability to read 1-Wire Temperature Sensors, model DS18B20, and 1-Wire Analysis North Motor Sensors, which attaches via high-temperature Velcro to an AC motor, an AC valve, or most any device that emits an AC electromagnetic field. "1-Wire" is a sensor network technology that really uses three wires in a daisy-chain wiring scheme to connect a series of sensors; star wiring back to the Mini-Monitor is *not* required. For more information on 1-Wire sensor networks, see https://en.wikipedia.org/wiki/1-Wire.
- The ability to read very low building air pressures from an Energy Conservatory DG-700 pressure gauge.
- The ability to read thermistor temperature sensors connected to a Labjack U3 Data Acquisition device.

The Mini-Monitor system is an open source project, and software code can be added to extend its data acquisition capabilities. Many HVAC devices have computer interfaces and are potential candidates for data extraction by the Mini-Monitor system.

All of the documentation for the Mini-Monitor project is online in a project Wiki. Instructions on how to build and configure the Mini-Monitor are present there, as well as guidance for software developers who wish to enhance or modify the code. Here is the link to that Wiki:

https://git.ahfc.us/energy/mini-monitor/wiki