DAVIS ENERGY GROUP

Springer Residence
(Winters, CA)
Monitoring Plan
AEC PIER Project

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1 BACKGROUND & OBJECTIVES

The goal of this monitoring project is to provide detailed monitoring data to Architectural Energy Corporation (AEC) and Oak Ridge National Laboratory (ORNL) on the heating and cooling system performance of an advanced house located in Winters, California (approximately 40 miles west of Sacramento). AEC and ORNL are interested in gathering data on the HVAC distribution efficiency and indoor comfort characteristics of advanced HVAC systems and distribution technologies. The Winters house, owned by Davis Energy Group president David Springer, includes both radiant and forced air heating and cooling delivery, as well as night ventilation cooling, and therefore provides an excellent opportunity to evaluate these features individually and in combination for their energy savings and peak load shifting benefits.

The HVAC system includes the following:

- Forced air heating distribution to all major rooms
- Radiant heating distribution to all first floor rooms
- Radiant cooling distribution to the main living areas only (Great Room, Dining Room, Kitchen, Entry, Laundry, ½ Bath).
- A high-capacity condensing water heater for heating domestic hot water and for space heating (radiant and/or forced air distribution).
- A hot/chilled water air handler with variable speed (GE ECM-powered) fan.
- A split-system cooling system with the condensing unit supplying a refrigerant-to-water heat exchanger capable of delivering chilled water to radiant floor tubing or to the hydronic fan coil.
- A "NightBreeze" control system and damper which provides summer ventilation cooling using the air handler fan and winter fresh air ventilation.

The specific monitoring objectives are to gather detailed monitoring data to allow ORNL to assess comfort, energy, and demand characteristics of various HVAC system operating modes. The collected data will allow energy use and peak demand comparisons; for ASHRAE-defined comfort calculations using indoor air, air velocity, and mean radiant temperatures; and radiant vs. forced air distribution efficiency comparisons using ASHRAE 152P. The monitoring will continue for one year with a projected start date of June 15, 2002.

The system will be operated in three modes during the cooling season, each lasting for approximately one-month. The three modes are as follows:

1. Conventional cooling mode: Uses the condensing unit, air handler, and forced-air distribution to meet cooling loads in response to an 80°F thermostat setting (upstairs thermostat location).
2. Slab pre-cooling: Applies conventional cooling, plus chilled water cooling of the living area concrete floor for the purpose of shifting peak air conditioning load. Floor

cooling will operate between 4 AM and 8 AM. The floor cooling air temperature setpoint will be 70°F during this period. Conventional cooling will operate to maintain second floor temperatures at an 80°F setpoint.

3. Slab pre-cooling and night ventilation cooling: The existing NightBreeze controls will operate the air handler fan and outside air damper to ventilate the house with cooler outside air when conditions permit. If the ventilation system fails to lower the indoor air temperature to 70°F by 4 AM, the condensing unit will operate to cool the floor as in Mode 2.

The owners may use natural ventilation (open windows) during any of these test periods, and will maintain a log of which windows are operated and on what schedule.

The system will be operated in two modes during the heating season to assess the relative distribution efficiencies of radiant floor heating and forced air hydronic heating. A minimum six weeks of monitoring will occur in each mode, centered around the middle of winter (January 7th). Radiant heating will be operated initially so that the slab temperature will not need to be raised significantly at the mid-winter mode change[1].

The Winters house is currently being monitored on a reduced scale to gather data on the performance of the NightBreeze system. The proposed monitoring will require the existing DT-50 datalogger to be replaced by a DT-500 logger which has more input channels.

2 MONITORING STRATEGY

2.1 Key Monitoring Parameters

Key parameters required for evaluating impacts and verifying operation include:

- Total house space conditioning load (heating and cooling)
- Ventilation system cooling output
- Air conditioning system cooling output
- Fan and pump electrical energy use
- Condensing unit energy use
- Outdoor and indoor temperatures and relative humidity
- System status

Specific monitoring data points necessary to define the key parameters include:

[1] In the analysis of the data, the first week or more of forced air heating data should be discarded so that residual slab heat is not credited to forced air system heat delivery or reduced envelope load.

Temperature: Supply and return air; indoor and outdoor air; immersion temperatures on hydronic supply and return lines

Relative humidity: Outdoor, indoor, and supply/return RH on the fan coil unit

Insolation: Solar insolation measured by a pyranometer.

System Status: The status of the relief dampers and hydronic heating pumps

Airflow: An airflow vs. power curve will be generated for the variable speed air delivery system. A powered flow hood or True Flow airflow measuring grid will measure airflow coincident with blower power measurements.

Water Flow: supply or return flow into the hydronic delivery system will be measured.

Electrical Energy: Condensing unit, fan coil blower motor, pump power (or one-time measurement of hydronic pump power and status monitoring)

Gas Use: Gas consumption for instantaneous water heater

Fan RPM: Motor RPM will be used to calculate airflow rates from fan test data provided by the equipment manufacturer

2.2 Data Acquisition Approach

Individual monitoring systems will be installed to obtain, store, and transfer data. Monitoring systems will consist of dataloggers, multiple sensors, and a modem for communicating data via phone lines. Other test equipment will be used for one-time measurements. Monitoring and test equipment in general include:

- Dataloggers for temperature, power, water flow and insolation measurement
- Solid state or RTD temperature sensors for indoor, outdoor, and duct temperatures
- Immersion thermocouples for water temperatures
- 24V relays for status monitoring of pumps and damper position
- True RMS power monitors for blower fan, pumps, and condenser energy use
- Powered flow hood or True Flow grid for airflow vs. power and RPM calibration measurement

All datalogger sensors will be scanned every 15 seconds, and data will be summed or averaged (as appropriate) and stored in datalogger memory every 15 minutes. The dataloggers will also compute energy transfers at 15 second intervals by multiplying flow rates by temperature differences.

Datalogger memory will be sufficient to store at least four days of data, so that loss of communications will not interrupt the stream of data. Dataloggers will be powered by low voltage power supplies with battery backup to protect against data loss during power outages.

Data, in comma-delimited ASCII format, will be regularly downloaded to a central computer and screened using software to review data ranges. Out-of-range data will be reported and investigated to determine whether a sensor or monitoring error exists or equipment has failed. Data will be transferred to ORNL and AEC on a monthly basis in comma-delimited ASCII format.

2.3 Monitoring Period

The project schedule provides for installation of monitoring equipment by June 15, 2002. Formal monitoring will commence when the monitoring system has been commissioned and calibrated, and will continue for at least twelve months, terminating not later than July 2003. Dates for monitoring the various operating modes are as follows:

Operating Mode	**Schedule**
Standard Air Conditioning	June 15 – July 15
Air Conditioning with Slab Pre-cooling	July 16 – August 15
A/C, Slab Pre-cooling & Night Ventilation	August 16 – September 15

3 MONITORING SYSTEM DESIGN

3.1 Datapoints

Datapoints are defined in detail in the attachments. Dataloggers will be used to calculate certain values from inputs. Calculated values related to the HVAC system including space heating and cooling energy, ventilation cooling energy (including economizer cycle[2]), and fresh air vent winter heating load. Since both heating and cooling energy are measured using a water flow meter and supply-return temperature sensors, total (sensible and latent) cooling loads will be captured.

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3.2 Datalogger Specifications

Table 1 lists datalogger channel requirements, and channel specifications for the Data Electronics DT-500 proposed to be used for this project. Analog inputs are single-ended (referenced to ground). Digital channels will be used for power monitors and signal states; high-speed counter inputs will be used with fluid flow meters and to determine fan speed on the variable speed blower units. Detailed datalogger specifications are provided in the attachments.

Table 1: Datalogger Channel Requirements and Input Specifications

	Analog	**Digital**	**Counter**
Channels Required	21	4	2

[2] If outdoor air is cooler than indoor air and the air conditioner is operating, the outside air damper will open.

Datataker 500	30	4	3

3.3 Sensor Types and Specifications

Table 2 lists the types of sensors to be used for the various monitoring points and their performance specifications. Sensor selection was based on functionality, accuracy, cost, reliability, and durability. Specific model numbers are listed as examples; similar models by other manufacturers may be used based on price and availability. Signal ranges for temperature sensors correspond approximately to listed spans. Detailed manufacturers' specifications are provided in the attachments.

Table 2: Sensor Specifications

Type	Application	Mfg/Model	Signal	Span	Accuracy
LM34	indoor temp.	Basys TS 1100	~0-2 V	.01V per °F	±1% (70°F)
RTD	outdoor temp.	RM Young 41342LF	4-20 mA	-30 - 130°F	±1.6%
RTD	duct temp.	ACI TTM 100-7-D	4-20 mA	40 - 130°F	±1.5%
Flow meter	water flow	Onicon F1300	0-15Vpulse	~800 pulse/gal	±2%
Gas meter	WH gas use	Equimeter S-275P	pulse	1 pulse/ft^3	±2%
Type T	water temp.	Gordon 20CTOUH	~0-3 mV	~0-160°F	±0.4%
Type T	Globe temp*	Thermocouple wire	~0-3 mV	~0-160°F	±0.4%
power monitor	elect. energy	CSS-WNA-1P-240-P	pulse	4 pulse/Wh	±0.5%
24V Relay	signal state		digital		

"*" the thermocouple will be located within a flat-black painted ping pong ball

3.4. Equipment Panel

Dataloggers with batteries, terminal strips, and electrical power strips will be mounted in a locking metal enclosure. The enclosure will also contain pre-wired terminals for connection to powered sensors and for 4-20 mA signal inputs. Shunt resistors for converting 4-20mA to 0.4 to 2.0 VDC will be pre-wired.

3.5. Wiring

Wiring shall be Belden 22 gauge shielded communications cable or equal, #8761 single pair, #8771 3-conductor, and #8723 two pair. Thermocouple wire shall be Gordon T20-5-510 or equal.

4 MONITORING SYSTEM INSTALLATION

4.1 Documentation

Monitoring documentation, included in the attachments, includes the following:

- Datapoint list
- Drawings showing sensor locations

- Datalogger and sensor wiring diagrams and cable schedules

Any changes to the monitoring plan made in the field will be noted in the documentation. Calibration data such as flowmeter meter calibration factors will be recorded, as well as datalogger serial numbers.

4.2 Datalogger Installation

The monitoring panel containing the dataloggers and other equipment will be installed in the attic mechanical area. Power connections will be secured and/or labeled to prevent inadvertent disconnection. Equipment panel covers will be marked with a contact name and phone number.

4.3 Sensor and Wiring Installation

Sensors and wiring will be securely installed, but in a manner as to minimize damage to existing surfaces/materials and reduce repairs needed during decommissioning. Wiring will be labeled at both ends using abbreviations listed in the cable list. Except for equipment located in close proximity to the monitoring panel, wiring will be installed in walls and attic prior to drywall application.

The following procedures will be followed for installation of the various sensor types:

Indoor Temperature Sensor. If a thermostat is installed in that room, the indoor sensor will be installed in close proximity.

Floor Surface Sensor. Surface mount thermocouples will be installed in uncarpeted locations to measure hard surface floor temperature. Sensor locations will be in an area not subject to traffic or disturbance.

Globe Temperature Sensor. Thermocouples will be inserted into ping pong balls (painted flat black) and suspended from the ceiling or wall, as appropriate.

Outdoor Temperature and Relative Humidity Sensor. Install in shielded enclosure (Gill radiation shield) with no direct solar exposure.

Supply and Return Air Temperature and Relative Humidity Sensors. Sensors will be mounted in supply and return plenums of the indoor unit. Supply sensors will be located as far from heating/cooling coils as possible, but prior to any duct branches. Sensor boxes will be secured using sheet metal screws.

Power Monitors. Verify that power is disconnected during power monitor installation. Install current transformers (CTs) with proper orientation to line and load, and connect to power monitors in accordance with manufacturers instructions. Locate power monitors close to CTs, preferably inside equipment. If exposed, mount power monitor boxes using sheet metal screws or double-stick tape. Observe that CTs and power monitors do not present an electrical hazard.

Flow meters. In-line flow meters will be installed into copper pipe in the locations shown on the sensor plan. Where possible, the will be installed no closer than 10 pipe diameters from the nearest upstream elbow.

Air Velocity Sensors. Locate in room where the sensor is not obstructed from typical airflow circulation. Avoid placing behind plants or in a corner.

Wiring. Wiring will be routed as inconspicuously as possible between the datalogger and sensors. Wiring will be labeled at both ends with the sensor abbreviation. Wiring in framing and attic will be secured with staples and routed so as to minimize risk of damage during construction. Wiring exposed to view will be run in conduit or neatly bundled and secured to the wall using plastic wire tie anchors. Strain relief will be provided at points of connection, including the monitoring panel.

4.4 Commissioning and Calibration

A commissioning log will be completed to record sensor calibrations, one-time measurements, and other data. On completion of equipment installation, a laptop computer will be connected to the datalogger for reading real time data, and the following calibrations and verifications will be completed:

Air Temperature. Using calibrated temperature sensor, record monitored and calibrated temperatures for each sensor. Duct sensors may be removed, or calibrated prior to mounting in ducts.

Relative Humidity. Using calibrated handheld RH sensor, record monitored and calibrated temperatures for each RH sensor.

Power. Activate monitored system and verify power measurement. Reverse polarity of CT, voltage, and datalogger connections as needed to correct for lack of readings.

Airflow. Set up the datalogger to record fan RPM and use a TrueFlow (Energy Conservancy) air handler flow meter to measure system airflow. Record airflow rates and RPM at control settings of 200-1600 CFM in increments of 200. A fit of these data will be used to program the datalogger to compute airflow from RPM.

Water Flow. The Onicon flow meters are of high accuracy and come factory calibrated. Each flow meter will be checked to verify the datalogger is recording flow.

Water Temperature Sensors. Operate the system pumps or otherwise initiate flow with the furnace fan off. Immersion thermocouples should indicate comparable supply and return temperatures. Note temperature readings of each sensor and apply an offset, if necessary.

Communications. Dial the datalogger modem from a remote computer and verify communications to both dataloggers.

Permanent Programming. Enter offsets and other program variables determined during commissioning into the site datalogger program, and upload the program. After one day of operation, download and verify all readings.

On completion of commissioning, the site monitoring plan will be updated to document equipment installed, serial numbers, and calibration values.

5 DATALOGGER PROGRAMMING

Dataloggers will be configured with monitoring programs specific to the monitored datapoints. Programs will scan individual channels at 15 second intervals and will store these data in temporary buffers and sum or average the values over a 15 minute logging interval. The 15-second scanning interval provides high data resolution on parameters which may change during the logging interval and allows for more accurate calculation of energy transfers. In addition, the 15-second interval allows for filtering of temperature data to provide representative supply and return water/air temperatures only during system operation.

5.1 Air Side Equations

Equations for calculating energy transfers are very similar, with the exception of the temperatures used. Space heating (or cooling) energy delivered by the hydronic coil will be computed by the datalogger on 15-second intervals, using Equation 1.

Equation 1: Qair = CFM * (Tsupply - Treturn)*1.08

where: CFM = measured airflow for 15-second interval (cubic feet per 15-seconds)
Tsupply = supply air temperature (°F)
Treturn = return air temperature (°F)

If the damper opens to provide fresh air while the heating system is operating, the following equation will be used to calculate space heating energy:

Equation 2: Qair = CFM * (Tsupply - To)*1.08

where: To = outside air

The fresh air vent load will also be calculated for periods when the damper is open to admit fresh air during winter (heating mode) operation, using Equation 3:

Equation 3: Qfavl = CFM * (Trelief - To)*1.08

where, Trelief = relief air temperature (°F)

Equations 4 and 5 will be used for calculating sensible cooling load:

For normal air conditioning operation (damper closed, outside air warmer than inside air):

Equation 4: Qacn = CFM * (Treturn – Tsupply)*1.08

For air conditioning with economizer (damper open, outside air cooler than inside air):

Equation 5: Qace = CFM * (To – Tsupply)*1.08

Equation 6 will be used to calculate the cooling benefit contributed by the economizer (during economizer cycle operation only):

Equation 6: Qacel = CFM * (To – Trelief)*1.08

The following equation will be used to calculate the cooling capacity of the night ventilation cooling system:

Equation 7: Qvc = CFM * (Trelief – To)*1.08

Latent mechanical cooling will be calculated using enthalpy equations from supply and return air temperatures and relative humidity. Depending on datalogger memory available, these calculations will either be completed by the datalogger, or after the data is downloaded.

5.2 Water Side Equations

Heating or cooling delivered from the water heater to the air handler will be computed using Equation 8:

Equation 8: Qhyd = FLH * (TSUP – TRET) * 8.33

Where:	FLH	= hydronic loop flow (gallons)
	TSUP	= supply water temperature to hydronic system (°F)
	TRET	= return water temperature to hydronic system (°F)

Since heat delivered by the air handler is also calculated (Equations 1 & 2), an energy balance can be performed between air and water side heat flows. The sign convention for Equation 8 is "+" for heating and "-" for cooling.

6.0. DATA ACQUISITION

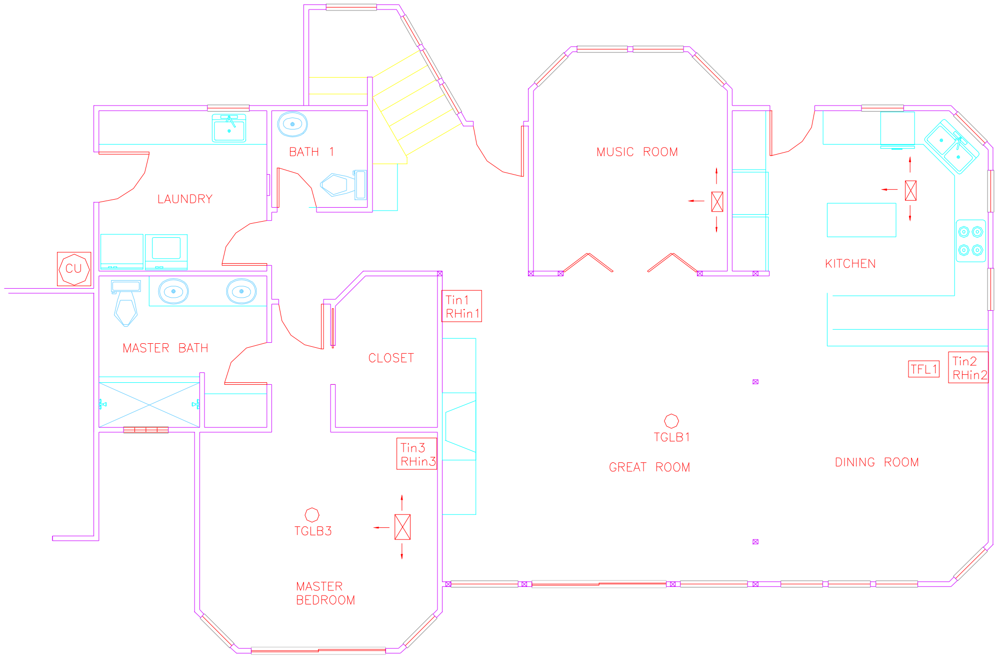
Data will be transferred from the monitoring site to DEG offices using PCMCIA data cards. Data will be transferred at least twice a week. Software will be developed to read in the "raw" data and verify that all readings are within expected values (e.g. indoor air temperature is between 40 and 90°F). An automated screening program scans the data and reports measurements that are out of range. If data are out of range, the suspect data will be visually examined to determine whether a sensor is defective. If the review indicates sensor error a service call will be scheduled to repair or replace sensors. On a weekly basis, data will be graphed in time-series format to further insure the data are physically consistent. For example, if the system is operating in heating mode, supply air temperature and pump energy consumption should both reflect heating operation.

Data will be stored in comma-delimited ASCII format in files named by site and date in the format S#MMYY (where S# is the site number). For example, the July 2002 file for Site 1 would be named "S1010702.DAT". A header list will be developed for use in identifying columnar data for each site. All files will be stored on a DEG computer and files will be archived on a monthly basis and transmitted to both AEC and ORNL.

ATTACHMENTS

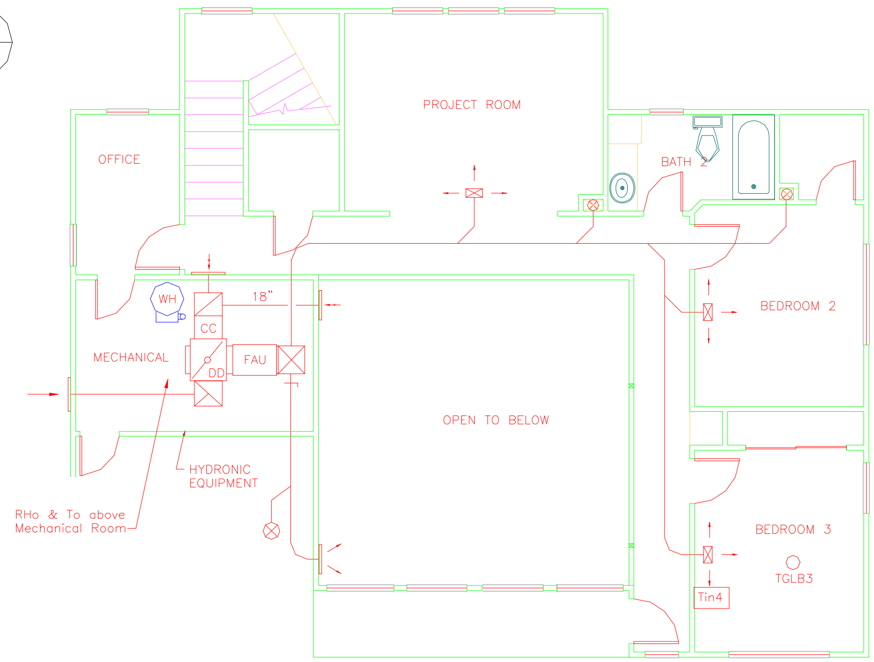
1. Cable List
2. Monitoring Points Plan
3. Mechanical System Monitoring Points

Site:	Z1									
Logger1:	DT-500 Serial No.									
Phone:										
Point		Sensor			Cable				Logger	Logger
No.	Abbrev.	Description	Location	Signal	# Conduct	Color/#	Label	Pair	Channel	Wire
LOGGER #1 (DT-500)										
1	TO	Outdoor temperature	Shielded	RTD, 4-20mA	4	1 (+)	TOUT	b/r	+24V	red
					.	2 (-)			1+	black
2	RHO	Outdoor relative humidity	Shielded	4-20mA	.	1 (+)	TOUT	g/w	+24V	green
					.	2 (-)			1-	white
3	TAS1	Supply air temperature (Unit 1)	FAU	RTD, 4-20mA	4	1 (+)	TAS1/RHS1	b/r	+24V	red
					.	2 (-)			1*	black
4	RHS1	Supply air RH (Unit 1)	FAU	4-20mA	.	1 (+)	TAS1/RHS1	g/w	+24V	green
					.	2 (-)			2+	white
5	TAR1	Relief/Return air temp. (1)	FAU	RTD, 4-20mA	4	1 (+)	TAR1/RHR1	b/r	+24V	red
					.	2 (-)			2-	black
6	RHR1	Relief/Return air RH (1)	FAU	4-20mA	.	1 (+)	TAR1/RHR1	g/w	+24V	green
					.	2 (-)			2*	white
7	TIN1	Indoor temp (great room)		RTD, 4-20mA	4	1 (+)	TIN1/RH1	b/r	+24V	red
					.	2 (-)			3+	black
8	RHIN1	Great room RH		4-20mA	.	1 (+)	TIN1/RH1	g/w	+24V	green
					.	2 (-)			3-	white
9	TIN2	Indoor temp (mstr bedroom)		RTD, 4-20mA	4	1 (+)	TIN2/RH2	b/r	+24V	red
					.	2 (-)			3*	black
10	RHIN2	Master bedroom RH		4-20mA	.	1 (+)	TIN2/RH2	g/w	+24V	green
					.	2 (-)			4+	white
11	TIN3	Indoor temp (dining room)		LM34	3	1 (COM)	TIN3	b/w/r	GND	black
					.	2 (OUT)			4-	white
					.	3 (+7.5)			+24V	red
12	TIN4	Indoor temp (bedroom 3)		LM34	3	1 (COM)	TIN4	b/w/r	GND	black
.					.	2 (OUT)			4*	white
					.	3 (+7.5)			+24V	red
13	TGLB1	Globe temp (great room)		Type T TC	2	1 (+)	TGLB1	blue/red	5+	blue
					.	2 (-)			R	red
						shield			GND	shield
14	TGLB2	Globe temp (mstr bedroom)		Type T TC	2	1 (+)	TGLB2	blue/red	5-	blue
					.	2 (-)			R	red
						shield			GND	shield
15	TGLB4	Globe temp (bedroom 3)		Type T TC	2	1 (+)	TGLB4	blue/red	6+	blue
					.	2 (-)			R	red
						shield			GND	shield
16	THYDS	Hydronic supply water temp		Type T TC	2	1 (+)	THYDS	blue/red	7+	blue
					.	2 (-)			R	red
						shield			GND	shield
17	THYDR	Hydronic return water temp		Type T TC	2	1 (+)	THYDS	blue/red	7-	blue
					.	2 (-)			R	red
						shield			GND	shield
18	DMPS	Damper status	FAU		2	1(+)	DMPS	b/r	7*	red
					.	2(-)			7R	black
19	GAS	Water heater gas use	FAU	Pulse	2	(+)	GAS	b/r	D1	red
					.	(-)			GND	black
20	EAC	Condenser energy		Pulse	2	(+)	EAC	b/r	D2	red
					.	(-)			GND	black
21	EFAN	FAU fan energy	FAU	Pulse	2	(+)	EFAN	b/r	D3	red
					.	(-)			GND	black
22	EPMP	Pump energy		Pulse	.	(+)	EPUMP	b/r	D4	red
					.	(-)			GND	black
23	FLHYD	Hydronic flow		0-15VDC puls	3	(+)	FLHYD	b/w/r	+24V	red
					.	(-)			GND	black
					.	Signal			C1	white
24	FNSPD	Fan speed	FAU	Pulse		(+)	FNSPD	g/w	C2	green
					.	(-)			GND	white



FIRST FLOOR SENSOR PLAN

2
M1



SECOND FLOOR SENSOR PLAN

1
M1