Critical Measurements to Verify Operation of Biomass Boiler Heating Systems

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Energy Efficiency & Sustainability | Optimization | Modeling
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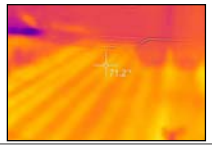
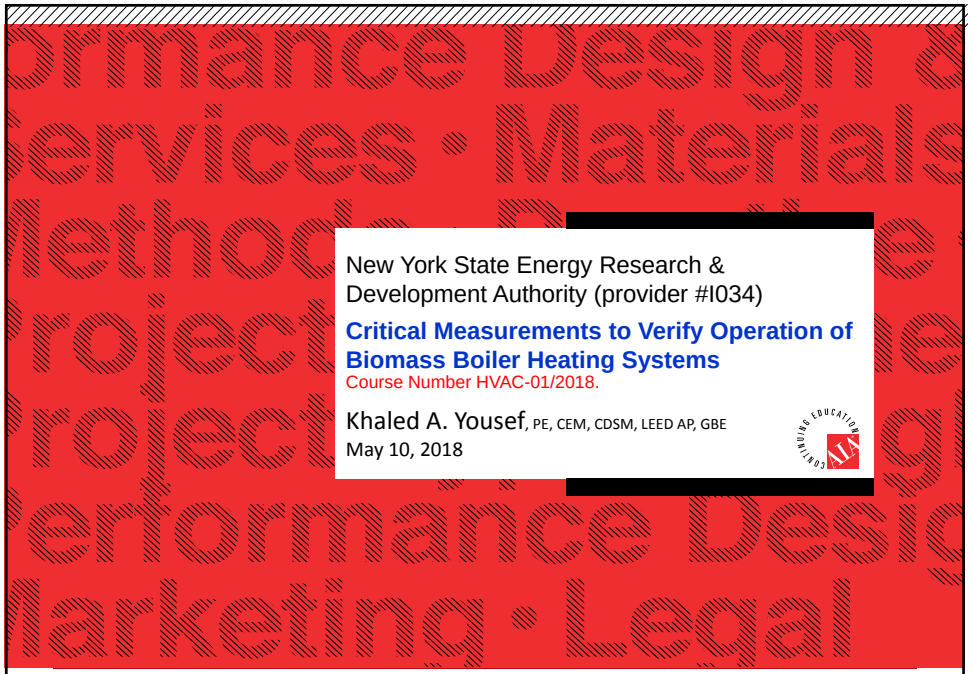
Presented: May 10, 2018
NYSERDA RHNY Seminar &
Training Series from Albany, NY.





New York State Energy Research & Development Authority (provider #I034)

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Course Description

This webinar discusses instrumentation and measurement techniques to verify proper operation of biomass boilers. It also includes lessons learned from measurement and verification work on a wide range of biomass heating systems

Learning Objectives

1. Introduction to the four (4) International Performance Measurement and Verification Protocols (IPMVP) M&V options.
2. Establishing an energy baseline, procedures and benefits.
3. Examples of critical measurements required to assess the performance of biomass heating systems.
4. Lessons learned from the trenches, M&V data collection and analyses for enhancing system operation.

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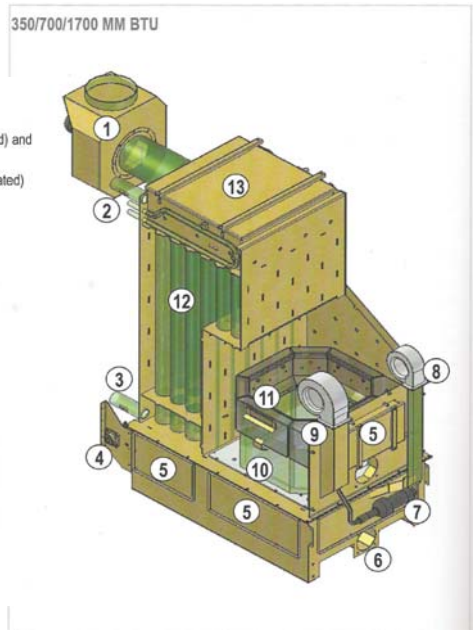
Identify High-Efficiency Wood Pellet Boiler **Components**

Photo Courtesy of *EvoWorld, Troy, NY (Subsidiary of TBW (Troy Boiler Works)) - Taken at RHNY Launch 9/29/2014*

Answers



1. Fully modulating EXHAUST FAN
2. Water connection: FLOW (with temperature sensor integrated) and THERMAL VALVE (heat exchanger)
3. Water connection: RETURN (with temperature sensor integrated)
4. CLEANING SHAFT
5. SERVICE DOORS to maintain the unit
6. ASH DISCHARGE
7. HOT AIR GUN
8. Fully modulating PRIMARY FAN
9. Fully modulating SECONDARY FAN
10. STEP-GRATE combustion system
11. AFTERBURNING with secondary air
12. Self-cleaning 3-PASS HEAT EXCHANGER
13. TOP CAP

Illustrations Courtesy of *EvoWorld*

Introduction to M&V

This section offers an introduction to the four (4) IPMVP M&V Options. It then discusses establishing an energy baseline, billing analysis, M&V Plans, and M&V Execution.

What does M&V stand for?

1. Measurement and Verification?
2. Measurement and Validation?
3. Metering and Verification?
4. Metering and Validation?
5. Monitoring and Verification?
6. Monitoring and Validation?

I do not care what you call it, but it needs to be done correctly!

Why M&V?

- *Verifies fuel displacement and financial savings.*
- *Verifies system performance.*
- *Protection of system components.*
- *Ongoing commissioning.*
- *System troubleshooting.*
- *Others?*

"You cannot manage what you do not measure"

"You cannot expect what you do not inspect"

"~~Trust me - you saved and did well!~~ - NO, it has to be "independently" measured and verified"

What M&V Resources do we have?

- **ASHRAE Guideline 14P**, Measurement of Energy and Demand Savings.
- **FEMP** (Federal Energy Management Programs) M&V Guidelines for Federal Energy Projects.
- **NEMVP** (North American Energy M&V Protocol) DOE.

- **IPMVP** (International Performance Measurement & Verification Protocol):
  - Concepts and Options for Determining Energy and Water Savings - Volume I.
  - Concepts and Practices for Improved Indoor Environmental Quality - Volume II.
  - Concepts and Practices in Renewable Energy Technologies Applications - Volume III.
  - Concepts and Options for Determining Energy Savings in New Construction - Volume III.

What are the "Famous Four" M&V Options and what is most appropriate for biomass heating projects?

- **Option A - Stipulated Savings (with some measurements)**: This will be used with extreme caution and if the analysis is conservative and the savings are well supported and can be trusted without M&V.
- ***Option B*** **- Metered Savings of Equipment and Systems**: ***This is the most appropriate for many energy projects***.
- ***Option C*** **- Whole Building Utility Billing Analysis**. This can be acceptable in very rare occasions at certain sites. For example, if there is a metered electrical feeder or panel that is solely serving "major" equipment that is directly impacted by an EEM. (pumping station or entire CHWP) or for *fuel displacement measures* after adjusting for HDD & occupancy.
- **Option D - Calibrated Computer Simulation Models**: Ideal for new construction and can be used with caution in existing facilities. Nicely captures interactive effects, if the model is done correctly.
- **Option E** - Use an appropriate ***hybrid (e.g. B + C)*** of the above in projects with multiple EEMs and as appropriate.

The previous resources included a lot of M&V material, However, you may ***focus*** on NYSERDA's ***M&V Plan Template***.

It explains how to plan and implement successful M&V to verify the development of well-designed, well-operated, and well-maintained HELE biomass heating systems.

Suggested an M&V Plan Outline

An M&V Plan may include, but is not limited to:

1. Project Description.
2. Selected M&V Options, and why, per EEM.
3. M&V Activities.
4. List of data points.
5. Savings Equations, Calculations, Regressions.
6. Tables.
7. Engineering units must be clear.
8. Schedule & Duration.
9. QC & Corrective Actions.
10. Ensure it is clear and straightforward with no ambiguity.
11. Define Roles and Responsibilities, etc.

Establishing a multi-year Energy & Economic Baseline

Pre and post heating and electrical normalized figures of merit.

What is the ideal duration for a reliable energy baseline and why?

- Baseline billing ranges from one year to three years. Three years is preferred to account for weather variations and changes in schedules, facility use, or recent rehabilitation projects.
- Note - Be cautious of missing bills and erroneous bills as certain billing correction opportunities may identify themselves easily ($$$ saving possible).

Obtain energy usage information

- Obtain hardcopies of some energy bills.
- Electronic billing records.
- Hourly interval meter data.
- Water and Sewer Bills.
- EMCS Points Lists.
- EMCS Trend Logged Data.
- Chiller/Boiler Logs.
- Process Logs.
- Utility Tariffs.
- Request deploying energy loggers on major energy consuming equipment that has no available baseline data or logs.
- *Fuel tank level readings, especially with biomass projects*.

What general building benchmarks are appropriate for northeast climates (pre and post) and what to do with the energy usage Info?

Process and analyze the data. This includes, but is not limited to:

- Normalize energy figures per square foot: Calculate $/ft^2/year, kBtu/ft^2/year, Btu/h/ft^2, *Peak Btu/h/sqft (for the building vs. the heating plant)*, Watts/ft^2, EFLH (elec and fuel), ft^2/ton, $/occupant, $/product, etc.
- Normalize energy use, using other indices such as number of students, number of inmates, number of hospital beds, number of manufactured products, etc.
- Identify seasonal patterns, unusual spikes, consistency and accuracy of the data.
- Compute EUI (Energy Utilization Index) in kBtu/ft^2/year using clearly defined conversion factors.
- Compare EUI to published benchmarks, if available.
- Compare EUI to similar facilities owned by the same customers or other customers, if available, for a campus or district settings, or multiple sites.
- Other computations, as appropriate, for specialty facilities.

What to do with the energy usage info? Cont.

- Rank and order facilities based on their importance and determine level of effort based on their rank.
- Identify obvious problems such as demand spikes, irregular demand profile, ratchets, *abnormal EFLHs*, and high energy usage intensities in general, etc.
- Identify certain HVAC equipment abnormalities depending on the level of end use breakout of the baseline data.
- An advanced version of the billing analysis attempts to provide a baseline end use breakout/allocation for where the energy is consumed. This can be a very difficult task before conducting an energy audit*; however is a doable task after concluding the audit. A good end use breakout is part of a good baseline development.

* Experienced energy professionals can put place holders early enough based on past experience with similar facilities.

Heating Load Calculations from Available Plant Logs

- BTU Meters for GPM Delta T measurements.
- Fuel Oil Tank Level Readings (hardcopy printouts or electronic).
- Boiler Plant Logs (hardcopy and/or electronic).
- Smaller intervals preferred if possible: 15 min to 1 hour is ideal, 4 hour is okay, 8 to 24 hr is long but can be dealt with, 1-week you start to lose peaks, 1-month presents some analytical challenges.
- Regression against OAT, DD, and other independent variables such as bldg. schedules, setpoints and setbacks (like occ and unocc), other multi-variable regressions in industrial and process sites, etc.

A1 Bldg Fuel Oil #2 Baseline Example

Fuel Oil #2 Bills for 2008-2013

A1 Bldg

Area (sqft) = 23,729

Yr Varies	Year	Dates From-To	Building Sqft	Annual HDD B 65	Quantity (Gallons/year)	Cost ($)	Cost ($/Gallon)	Gallons per HDD	Gallons per HDD per 1000 sqft	Exact Year
1	2005		23,729	8,143						
2	2006		23,729	7,237						
3	2007		23,729	8,072						
4	2008		23,729	8,003	6,997.8	$15,070.88	$2.15	0.87	0.0368	2008/2009
5	2009		23,729	7,980	6,819.9	$19,028.05	$2.79	0.85	0.0360	2009/2010
6	2010		23,729	7,128	7,463.1	$22,217.52	$2.98	1.05	0.0441	2010/2011
7	2011		23,729	7,302	6,786.7	$23,958.68	$3.53	0.93	0.0392	2011/2012
8	2012		23,729	6,963	5,863.0	$21,078.47	$3.60	0.84	0.0355	2012/2013
9	2013		23,729	8,100	8,543.0	$28,226.74	$3.30	1.05	0.0444	2013/2014
10	2014									
11	2015									
Total				68,928	42,473.5	$129,580.34	$3.05		0.23609	
Average				7,579	7,078.9	$24,421.30	$3.48	0.934	0.03935	

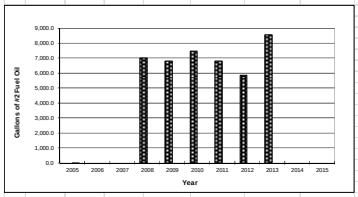
To Convert Gallons of #2 Fuel Oil to Btu, Multiply by 138,690

kBtu/year 981,775

kBtu/sqft/year 41.37

$/sqft/year (using 6 year average) $0.910

$/sqft/year (using most recent 3 year average) $1.029



Boiler IBR =	11.80	Gallons of Oil per Hour
Boiler Input Btu/hr =	1,636,542	Btu/hr
Boiler Output Capacity =	1,358,000	Btu/hr
Boiler Full Load Eff with Oil =	83.0%	
Boiler Normalized Output Capacity / sqft =	**57.23**	**Btu/sqft**
Boiler Output EFLH =	723.0	EFLH Per Year
ssumed Peak Building Load Factor of Boiler Capacity =	0.50	
Assumed Peak Building Load =	679,000	Btu/hr
Assumed Peak Building Load =	**28.6**	**Btu/sqft**
Assumed Building EFLH =	1,445.9	EFLH Per Year

A1 Baseline Electric Bills

Figure 2013

Electric Utility Bills for 2013

A1 Bldg

Area (sqft) = 23,729

Month	Date From	Date To	Days Per Month	On Peak kWh	Off Peak kWh	Monthly Electricity Use kWh	Charge ($)	Charge ($/kWh)	On Peak Demand kW	Off Peak Demand kW	Electric Demand kW	Ratchet kW	Electric Demand W/sqft	Charge ($)	Charge ($/kW)	Other ($)	Other ($/kWh)	Tot Elec Cost ($)	Aggregate ($/kWh)	EFLH	Load Factor
1 Jan	01/03/13	02/01/13	29			16,400		$0.000			40.8	NA	1.72		$0.00		$0.000	$1,813.69	$0.111	402	0.58
2 Feb	02/01/13	03/04/13	31			17,200		$0.000			42.4	NA	1.79		$0.00		$0.000	$1,227.52	$0.071	406	0.55
3 Mar	03/04/13	04/02/13	29			15,280		$0.000			38.4	NA	1.62		$0.00		$0.000	$1,473.01	$0.096	398	**0.57**
4 Apr	04/02/13	05/03/13	31			15,680		$0.000			37.6	NA	1.58		$0.00		$0.000	$1,383.94	$0.088	417	**0.56**
5 May	05/03/13	06/04/13	32			15,920		$0.000			69.6	NA	2.93		$0.00		$0.000	$1,854.62	$0.116	229	0.30
6 Jun	06/04/13	07/02/13	28			17,200		$0.000			65.6	NA	2.76		$0.00		$0.000	$1,911.29	$0.111	262	0.39
7 Jul	07/02/13	08/02/13	31			20,800		$0.000			66.4	NA	2.80		$0.00		$0.000	$2,406.67	$0.116	313	0.42
8 Aug	08/02/13	09/04/13	33			19,120		$0.000			52.5	NA	2.21		$0.00		$0.000	$2,017.87	$0.106	364	0.46
9 Sep	09/04/13	10/02/13	28			15,040		$0.000			59.2	NA	2.49		$0.00		$0.000	$1,690.34	$0.112	254	0.38
10 Oct	10/02/13	10/31/13	29			14,240		$0.000			50.4	NA	2.12		$0.00		$0.000	$1,391.94	$0.098	283	**0.41**
11 Nov	10/31/13	12/03/13	33			15,280		$0.000			37.6	NA	1.58		$0.00		$0.000	$1,318.93	$0.086	406	**0.51**
12 Dec	12/03/13	01/03/14	31			16,960		$0.000			52.5	NA	2.21		$0.00		$0.000	$1,835.62	$0.108	323	0.43
Total			365			**199,120**	$0	$0.000			613.0		25.84	$0	$0.00	$0	$0.000	**$20,325.44**	**$0.102**	4,057	0.46
										Max kW =	69.6	W/sqft =	**2.93**					Compare to maximum kW =		2,861	0.33
Percent of Total Electric Bill							0.0%							0.0%		0.0%		0.0%			

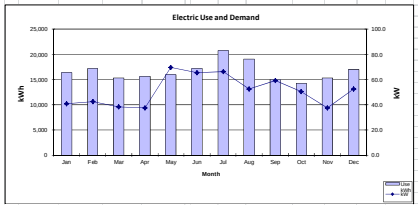
To convert kWh to Btu, multiply by 3,413

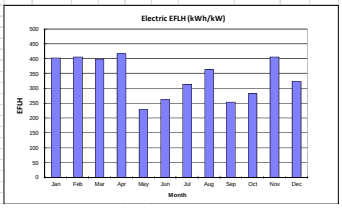
kBtu/year 679,597

kBtu/sqft/year 28.6

kWh/sqft/year **8.39**

$/sqft/year $0.00 $0.00 $0.00 **$0.857**





Question - Provide a Sizing Summary for General Commercial Buildings in terms of Btu/h/ft^2 at three different levels!

- Boilers Normalized or Installed Output Capacity = **40 to 80 Btu/h/ft^2**
- Estimated Peak Building Heating Load = **20 to 40 Btu/h/ft^2** Normalized
- Recommended Biomass Boiler Capacity = **10 to 20 Btu/h/ft^2**
  < Carefully select between single or tandem biomass boilers >
- Let us average and call it the **60 / 30 / 15 Btu/h/ft^2** rule!

Important Note - There is no one size that fits all, those are just general ball park normalized ranges from past experience in New York State projects with *existing* building vintage anywhere from 30 to 100 years with varying system types, potential retrofits/rehabs over the years, varying insulation levels, infiltration rates, outdoor air flow rates, and added wings and extensions, etc.

Other Important Figures of Merit:

- **EFLH** simplified guidelines of **1,000**, **2,000** and **3,000** support the **60 / 30 /15 Btu/h/ft^2** discussed earlier.
- Put it all together so both peak sizing and operation are coordinated well to avoid oversizing; however, remember that there is no one size that fits all; those figures provide simplified, but valuable guidelines.

Data Collection

Discussion of the data collection process, trend logging, setting up Range and Relational (R&R) Checks, Regressions, and other data analysis and practices required for a successful M&V process and system troubleshooting.

Data Sources

- Data Loggers.
- Trend logging using BMS (& w/ remote access preferred).
- Using the boiler's built in memory or thumb drive.
- Handwritten logs?
- A combination of the above.

Other Topics:

- Setting up Range and Relational (R&R) Checks.
- Regressions, why? Ans. Weather & occupancy.
- Data analysis supports M&V, Cx and troubleshooting.
- Use sketches, PIDs and flow diagrams.
- Hand-held spot measurements vs. long term metering.

RHNY M&V Guidance Doc for Large Commercial Pellet Boilers

"M&V Plan may specify some or all of following measurements* and/or data collection requirements depending on system arrangement":

1. Fuel and pellet delivery logs (dates and amounts), periodic tank level measurements or metering to track use over the M&V period.
2. Runtime and cycle rate/count data for all the boilers collected at regular intervals over the monitoring period.
3. Supply and return temperatures for the individual boilers and overall system as appropriate.
4. Hot water flow readings at regular intervals over the monitoring period (to calculate thermal output and efficiency).
5. Wood pellet auger runtime or speed denoting fuel supply to the boiler.

*NYSERDA encourages the installation of *M&V-enabled control systems* to collect this data.

Question - Identify Suggested Sensor locations for M&V on the diagram below (Warning - may include more than RHNY Min requirements)

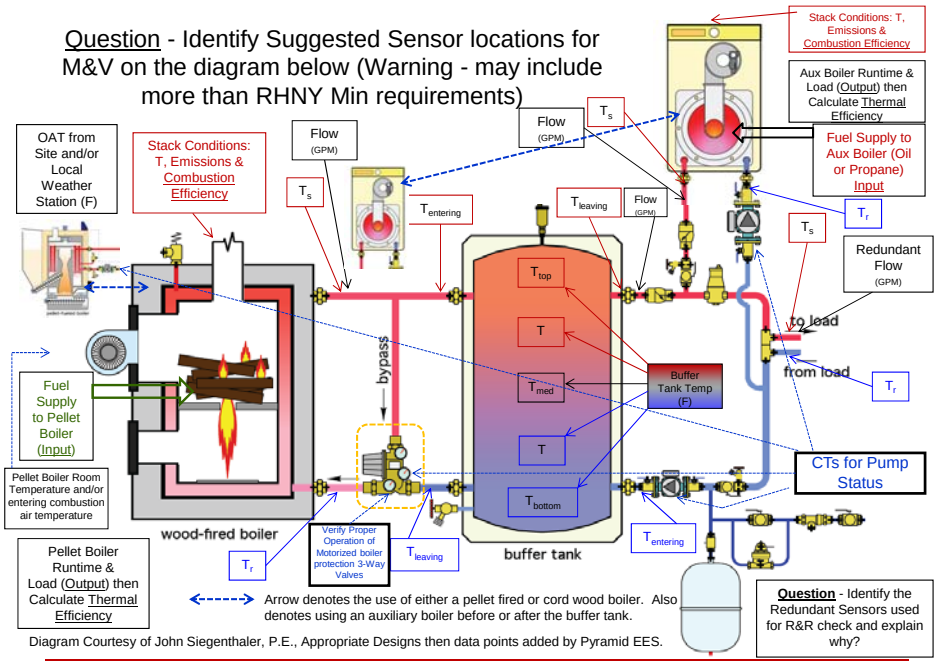


Diagram Courtesy of John Siegenthaler, P.E., Appropriate Designs then data points added by Pyramid EES.

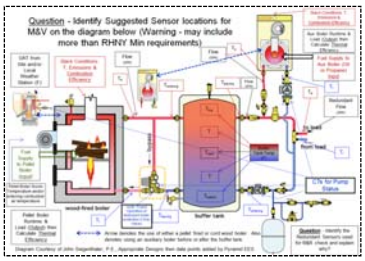
M&V Guidance & Examples

Attaining and verifying the performance of advanced biomass heating systems

Additional M&V & Emissions Plan Data Points:

1. OAT DBT (Deg F) local preferred over weather station, or collect both and compare, ensure sensor calibration. WBT not needed but can be collected for overall data QC,
2. Stack Temperature,
3. Combustion Efficiency Monitoring (different from the calculated Overall thermal Efficiency),
4. Stack Gas Monitors or Emissions Analyzers (not required with RHNY as selected boilers have been pre-qualified already), can include but not limited to O_2, CO, CO_2, NO, NO_2, NO_x, (and PM2.5), all using proper engineering units,
5. CO Monitoring and Alarms where necessary.

M&V Data QC & Cx



- Verify sensor location.
- Sensor installed/inserted properly.
- Sensor calibration & data quality.
- Sensor communication and download capabilities.
- Sensor and logger protection (power outage, water).
- Data archival, retrieval, backup, and remote access.
- EMCS or SCADA Programing for both system controls and data acquisition and verify integration.
- Automatic and manual Range and Relational (R&R) Checks for optimal data QC.
- Speedy intervention when data issues are identified.

Overview of Data Loggers and Sensors for Flow and Temperature Measurements

- Temperature measurement - Easy.
- Flows? More difficult……
  - Non-Intrusive - Ultrasonic or Electromagnetic.
  - Intrusive - Insertion Type.

Courtesy of NMCP, Onicon and KRAL.

Considerations……

- Pipe Diameter/type.
- Fluid type, Conductivity.
- Density, viscosity, corrosiveness.
- Required accuracy level.
- Flow level and/or speed.
- Maintenance considerations.
- Budget.
- Etc.

Courtesy of Rosemont and Krohne.

Highlights of Existing Building and Boiler Plant Controls, Future Controls Integration, Pneumatic vs. DDC, etc.

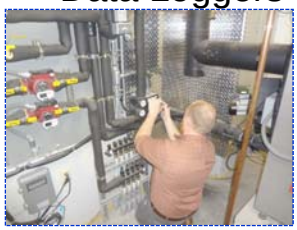
Controls - Old Pneumatics



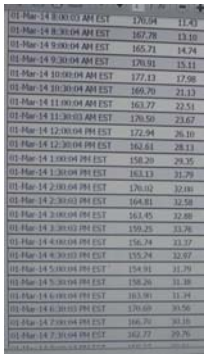


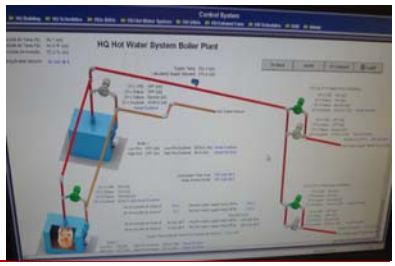
Data Logging Highlights for M&V using a Combination of Dedicated Data Collection Systems, Sensors & External Data Loggers

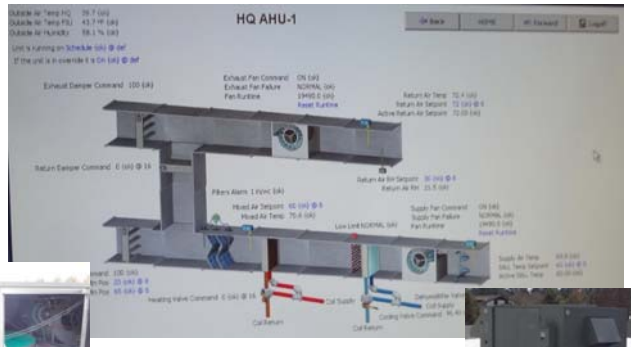


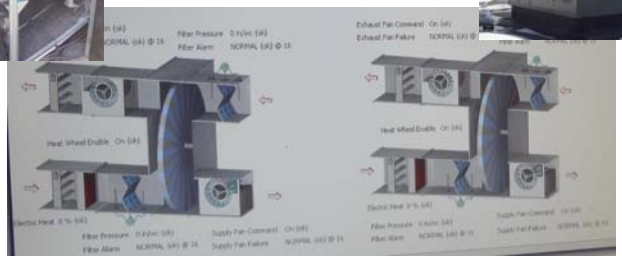


Controls - Newer DDC









Sample M&V Calculations

- Load = 500 x GPM x Delta T.
- Overall Thermal Efficiency = Output / Input.
- Combustion Efficiency calculated from stack temperature, O_2 and other readings.
- EMCS Monitor data to determine savings, efficiencies, displacement, controls feedback, etc.
- Regressions for weather and/or occupancy.
- See NYSERDA's M&V Guidance Doc for additional calcs.

Note 500 = 1.0 Btu/lb/F x 8.34 lb/Gal x 60 Min/hr (okay for Water, but use lower C_p & density for Glycol-water mix, water density also varies with Temp)

Another Example

What else you should do, besides M&V, to attain successful HELE biomass project's multiple benefits including but not limited to efficiency, emissions, longevity and good economics, and why?

Besides M&V, you should also

1. Complete an energy study before recommending biomass.
2. Proper boiler sizing (deliberate undersizing) and include thermal energy storage.
3. ***Commissioning (Cx)*** throughout all project stages for proper systems integration.
4. Finally, implement M&V of heating system and component performance.

Q/A

Thank you for Attendance and Participation

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