Portable Hands-On Instrument Training for Energy Engineers

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ABSTRACT

The use of simple instruments to help read and record physical aspects of an energy consuming system has expanded the way energy assessments are conducted. As simple as these instruments are, ignorance about them leads to their underuse – both by auditors and plant personnel. It is hard to overstate the lost opportunities resulting from insufficient use of measuring equipment. This has led to an effort to develop hands-on instrumentation training as part of an overall energy management curriculum.

While the best place to learn about best practices in terms of measurements is in the plant, many training programs take place in gentler environments – often a hotel conference room. Presentations with pictures of measuring devices or holding up a Pitot tube or thermocouple does not give the student the experience necessary to overcome worries that they are too complicated or difficult to use. To address this, in conjunction with the U. S. Department of Energy, The Center for Advanced Energy System from Rutgers University has in development five portable laboratories to train personnel on the use of monitoring and recording equipment. The labs utilize equipment frequently used by professionals in the field which include; thermocouples, flue gas analyzers, pressure transducers, ultra-sonic leak detectors, data loggers, light meters, current transducer and multi-meters. In addition, the lab demonstrations were designed to model important energy consuming systems illustrating important concepts.

This paper will discuss these portable laboratories in detail and their impact in different training settings.

Introduction

Periodic reviews of energy practices within a plant or facility are quite common and normally prove worthwhile. General estimates of operating cost savings range from 20-30% (Abdelaziz, EA, et. al, 2011) with additional implicit savings in terms of equipment life and reduced maintenance and repair costs. However, with the increasing complexity of energy systems and energy procurement, the classic "walk-through" audit with an engineer pointing out things needing improvement is of marginal benefit. Quantification both of the energy being wasted and the costs to correct are essential to generate informed decisions on potential energy improvement projects (Bunse, K. et al, 2011). Also, studies have shown that after financial barriers, it is the lack of information which causes most good energy efficiency projects to remain undone (Anderson and Newell, 2004).

The phrase of note is that "you cannot control what you cannot measure." There is also usefulness of being able to show the facility owner something they have not already seen. Data and other "pictures" of what is going on can generate credibility for the assessment team and interest and motivation for the plant personnel. Historically measuring systems have been expensive and difficult to use but this has changed dramatically in recent past. A host of easily used instruments are available to the energy manager to allow both instantaneous and long term data. Penetration of these measuring techniques has not matched the increase in ease of their use. In addition, attempts to provide pictures or descriptions or even holding up devices during training sessions has not been as effective as was first anticipated. Recognizing this disconnect, a series of portable laboratories has been developed with significant success. These laboratories were designed to simulate the common energy systems used in industry and showcasing devices frequently used by other energy professionals. Apart from getting familiarity with the measurement tools, a point was made to help participants understand and interpret the data received.

The Center for Advanced Energy Systems from Rutgers University, in conjunction with the U.S. Department of Energy, has been involved in energy management training for 25 years. During a recent training series focused on utilities and their technical support personnel these laboratories were first deployed. Lessons learned and the general success of the hands on exercises led to several iterations and improvements which have created a set of laboratories which seem wise to replicate. These and some operational issues are described in detail in the remainder of this paper.

Basic Laboratory Structures

The decision on what laboratories to develop were predicted by three primary drivers:

1. **Utilization of important measuring instrumentation.** Assessment teams which operate out of CAES bring with them an array of instruments to allow quantification of energy consumption or waste. It was desired to find a use for each and every critical instrument in our laboratory packages and to space them out if possible.
2. **Demonstration of important concepts or common energy using equipment.** The opportunity exists to show interesting but not intuitive features of certain energy systems as the same time as demonstrating the use of measuring equipment. This is a good motivator for seeing the potential of energy savings in everyday systems.
3. **Ease of setup, portability, and use.** The laboratories need to be robust – almost indestructible. They need to fit on top of small table and use easily available energy systems (single phase electrical power). They also need to be light weight and portable.

Of the five laboratories which were proposed, operational success has varied. The first three have been highly effective:

Compressed Air Laboratory

Rationale	Compressed air is one of the most common and most misunderstood energy consumers in both industrial and commercial applications
General Setup	A small, portable air compressor running off single phase AC with instrumentation attached
Concepts demonstrated	Dramatic temperature changes involved with compressed air, vibration implications of soft and hard footings, air leak detection
Instrumentation used	Pressure transducer, vibration meter, digital thermometer, dataloggers, ultrasonic leak detector

Basic Hardware

The lab consists of a portable air compressor with associated instrumentation. Key here is portability and a reasonably sized air storage tank.

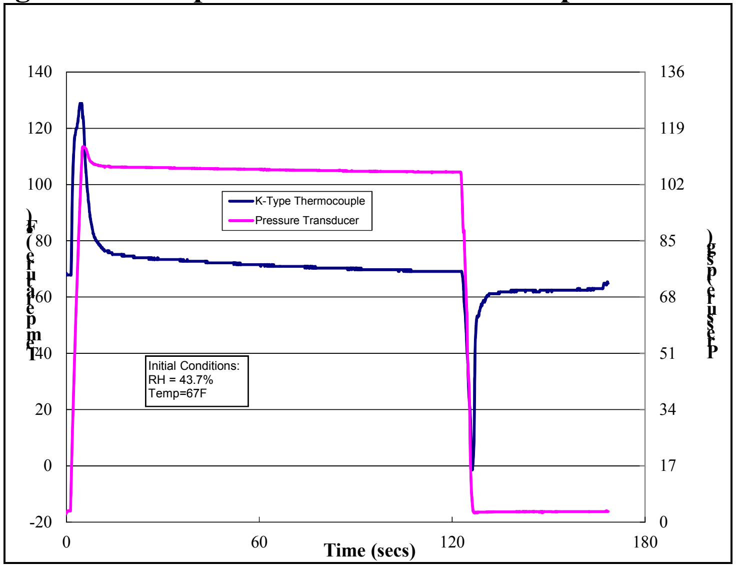
Figure 1. Air Compressor Setup

Demonstration sequence

- **Vibration study.** At the beginning, the compressor is operated with a vibration meter magnetically attached to the steel shell. Two cases are considered – one with the compressor on a hard surface and one with the compressor on a foam pad[1]. Data on vibration amplitudes will be much higher when the soft footing is used showing that the vibrations pass easily through the foam and that firm footings are important for the best use of motorized equipment.
- **Temperature/pressure relations.** In most large scale air compressors, the temperature of the incoming air increases dramatically as it is compressed. The effect is muted in smaller machines as there are plenty of fins for cooling installed on the intake. Therefore to demonstrate temperature changes with sudden and significant changes in pressure, the compressor is charged up to full pressure, allowed to settle for a few minutes, is then turned off and a discharge value is abruptly fully opened. Attached thermocouples in the air compressor tank will show a dramatic drop in temperature (in our case often -10 °F). Example data is shown in Figure 2. Such low temperatures are responsible for much of the water condensation in compressed air systems and this demonstration shows this in a pretty dramatic fashion. If dataloggers are being used, the plot of both pressure and temperature as a function of time can be displayed and printed out.

[1] Foam pads are normally part of the shipping boxes and are in plentiful supply

Figure 2.   Sample T-P Plot from Air Compressor Demo

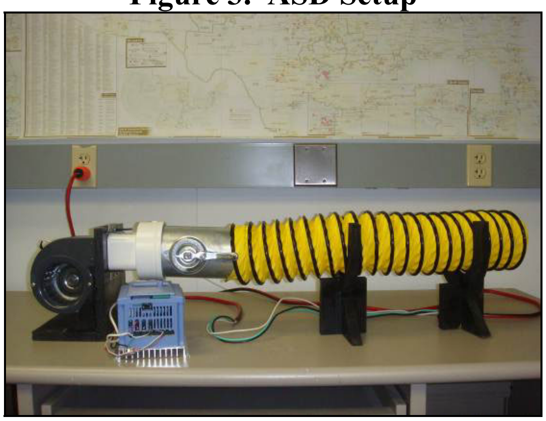


- **Leak Detection.** The compressor is recharged again and then turned off with air stored in the surge tank. Some natural leakage occurs and can be increased by cracking a valve on the compressor slightly. An ultrasonic leak detector can then be used to determine exactly where the air is leaking. Additional experiments can be done using headphones and focusing devices.

Adjustable Speed Drive Laboratory

Rationale	Using adjustable speed drives instead of dampers to control air flow is more effective. Measurements should be taken with proper devices
General Setup	An adjustable speed drive connected to a blower with a damper attached.
Concepts demonstrated	Use of different measure tools and methods to measure air flow, effectiveness of implementing adjustable speed drives
Instrumentation used	Anemometer, Pitot tube, Digital Pressure Indicator, Adjustable Speed Drive

Figure 3. ASD Setup



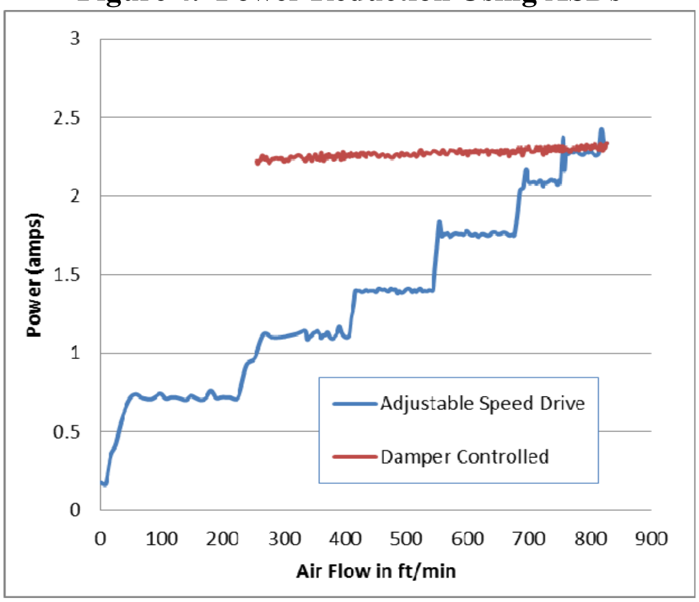
Basic Hardware

The lab consists of a three phase blower connected to an adjustable speed drive. The blower exhaust is attached to a flexible hose which contains a damper. The key here is the small size of the adjustable speed drive; its ability to use single phase electricity as an input, and an induction Ampere meter which can measure low Amperage levels.

Demonstration Sequence

The blower can be first used to demonstrate two types of anemometers – the vane type and the Pitot tube. The vane type flow measuring devices are both easy and accurate, but are normally unable to handle any temperatures above about 300 °F[2]. While old fashioned, the Pitot tube can handle high temperatures which is why it needs to be included in this lab. The pressure difference from the Pitot tube (which can be translated directly into velocity) is measured both with a simple manometer and a digital pressure indicator.

Figure 4. Power Reduction Using ASDs



Turning to the blower end of the experiment, an induction type amp meter can now be used to determine the load on the blower. Using a low wattage instrument makes things easier, but if a higher amp reading is needed, the wire from the wall socket can be looped several times multiplying the sensed amperage.

The remainder of the experiment involves changing the flow rate from the blower with either the internal damper in the flexible hose or with changing the output from the adjustable speed drive. Flow rates and corresponding power draw readings are taken using the anemometer

[2] We bring with us an old vane-type anemometer which was used accidentally in a hot steam of fluid and melted into a blob – a good visual aid!

and ammeter at different speeds. The results are striking showing a dramatic reduction of energy consumed with the ASD compared to little or no change for the damped system. Typical results are shown in Figure 4.

Office Environment Laboratory

Rationale	Through the use of simple measurements, energy losses in an office space can become apparent.
General Setup	An assortment of various handheld instruments.
Concepts demonstrated	Light intensity standards, CO_2 standards, magnetic vs. electronic ballasts, inefficient HVAC systems, standby power consumption of devices, distance measurements.
Instrumentation used	Light Meter, Light Discriminator, Infrared Thermometer, Draft Detector, Ammeter Clamp, CO_2 Detector, Laser Distance Meter

Basic Hardware

The normal audit equipment list includes several devices which are used primarily in office environments and others which are generally useful but were not easy to include in other experiments. A tabletop is used to hold the instruments in a display.

Figure 5. General Instrument Display

Demonstration Sequence

In no particular order,

- Lighting Meters: light level and light/ballast discriminators[3]. Color evaluators are not currently priced low enough for common use and therefore were not included in this lab.
- Infrared Thermometer: this very useful device is good for many uses – in this case to determine if there is significant stratification in the room.

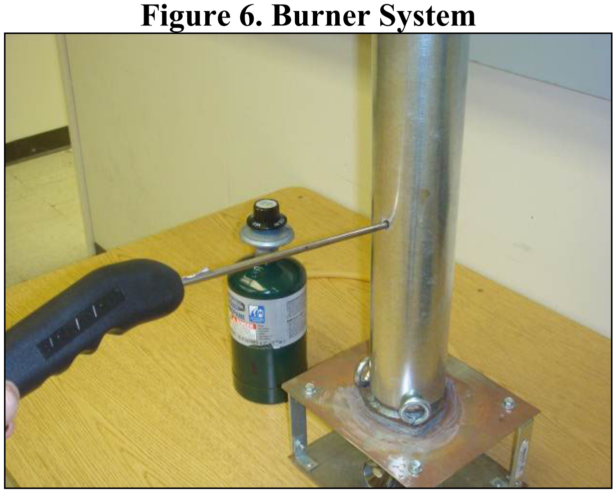
[3] a simple device that when held under a fluorescent light source will indicate an electronic ballast or conversely, a magnetic ballast.

- Draft Detector: two types are shown – one making steam from a tiny electric heat source and the other being a smoke stick. It is common to need information on air drift patterns when the actual flow velocities are too low to use an anemometer.
- Save-A-Watt energy consumption device: a cheap and easy to use in-line power meter which plugs into standard single phase outlets. It can be used to demonstrate the standby energy consumption can be saved by simply shutting down a device or unplugging it when it is not being used.
- CO_2 Detector: Used to measure the effectiveness of ventilation in occupied spaces.
- Laser Distance Meter
- Sound Meter: Used to determine sound levels from equipment,

Combustion Laboratory

Rationale	Plants commonly do not regulate oxygen and fuel inputs economically and lose efficiency from wasted heat or fuel.
General Setup	A stack is attached to a Bunsen burner and fuel is provided by a connected propane tank.
Concepts demonstrated	There is an optimal point at which the oxygen and fuel in the air will react to yield maximum combustion efficiency. Increasing air flow in the system will show an increase in efficiency (indicated by a drop in carbon monoxide levels) up to a certain point, after which heat is lost which lowers the amount of energy that can be transferred from fuel to steam in boiler systems.
Instrumentation used	A flue gas analyzer and thermocouple are used to gather flue gas composition and temperature readings respectively.

Figure 6. Burner System



There are good reasons to demonstrate combustion monitoring equipment as part of the mobile lab package, but it comes with its share of headaches. Clearly permanent combustion systems come with ventilation systems designed to carry combustion products safely out of a building. However, temporarily, flames are used without such ventilation – examples include plumbers using torches to sweat pipes and with Sterno based heating systems on chafing dishes. It was decided to use a small propane tank with a Bunsen burner as the combustion source.

Operation of the flame is discontinuous – used only when measurements are being taken, thus limiting any environmental problems.

It is also desired to measure flow rates as well as the properties from inside the combustion stack. As temperatures are quite high in the stack, the laboratory was designed so that the incoming air mass flow rate (at ambient temperature) can be measured.

Demonstration Sequence

The primary goals are to demonstrate the use of a flue gas analyzer and show the benefits of controlling excess oxygen in fired equipment. After starting up the system (see Figure 6) oxygen content, CO, temperature and flow rate are measured for an open flame and then in steps are the amount of air provided to the propane becomes more limited.

Steam Laboratory

Rationale	A common method for space heating, producing power in industry as well as used in industrial processes. Important to understand the production of steam.
General Setup	A 2 liter electric boiler with a 25 psi pressure release valve. Attached to the boiler is a pressure transducer and thermocouple and data loggers.
Concepts demonstrated	Temperature and pressure relationships, latent vs. sensible heat, the use of data loggers to measure and record physical aspects of an energy system.
Instrumentation used	Data loggers, pressure transducer, thermocouple

The importance of steam in industrial energy systems and some of the mysteries and myths surrounding it makes some kind of steam demonstration laboratory in this set very desirable. Several different setups were tried – and needed to fit the following requirements

1. Steam needs to be generated quickly from an electrical heating source
2. Leakage must be limited so that pressures established can be maintained
3. During the demonstration, no "spitting" of steam can occur when valves or connectors are adjusted

To date, none of the assemblies that have been built meet these requirements. Current efforts are abandoning making steam by heating (just takes too long) and will attempt to create flash steam by vacuum. This should resolve both the time and spitting issues, but adds the complexity of a vacuum pump.

Operational Issues

When constructing these mobile lab demonstrations, many surrounding factors affected the overall design. Factors included the robustness of the set-up, the overall weight of the demonstration, ease of set-up and performing the demonstration in a group setting.

One unforeseen issue was that for any particular training, not all of the laboratories are needed. This changed the packing approach to creating as few packing boxes as necessary to putting each lab in its own box.[4]

Other issues that have occurred and are still being addressed are time management during training sessions. Always at a premium, sufficient time to observe and explore the labs creates a dilemma between how many labs to offer. There are always tradeoffs. It was also the intention to use data loggers on the majority of the laboratories. This continues to be an operational issue because launching and then downloading data is time consuming and not visually very exciting. Current thinking involves launching data loggers in a classroom at the start of a day – perhaps measuring CO_2 concentrations, and then presenting that data at the first part of the afternoon session. In this way the value of data over time can be illustrated with minimal impact on time.

Figure 7: Packed Air Compressor Lab

Conclusions

The experience to date has shown that adding mobile laboratories with classroom instruction in energy efficiency workshops is enormously effective in both removing the mystery surrounding many of the "toys" used in estimating energy consumption and on motivation attendees.

It is expected that continued development of these packages will refine both the experience and the use of time with a training program.

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[4] In fact, design of the packing system for each experiment required significant thought and experimentation!

References

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