Instructions for Use of the Laboratory Emissions Monitoring System (LEMS)

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1. Purpose of the LEMS

The purpose of the LEMS is to quantify reductions in health-harming emissions from cooking stoves by collecting, measuring, and analyzing emissions of CO_2, CO, and PM. Additional add-ons can be made to measure other gases. Collecting emissions is important for quantifying the total amount of pollution released without the effects of ventilation and dilution within the air of a kitchen. The combustion efficiency of the stove can be understood by investigating the reported measures such as emissions per task completed (specific emissions) and emissions per kilo of fuel burned (emission factors).

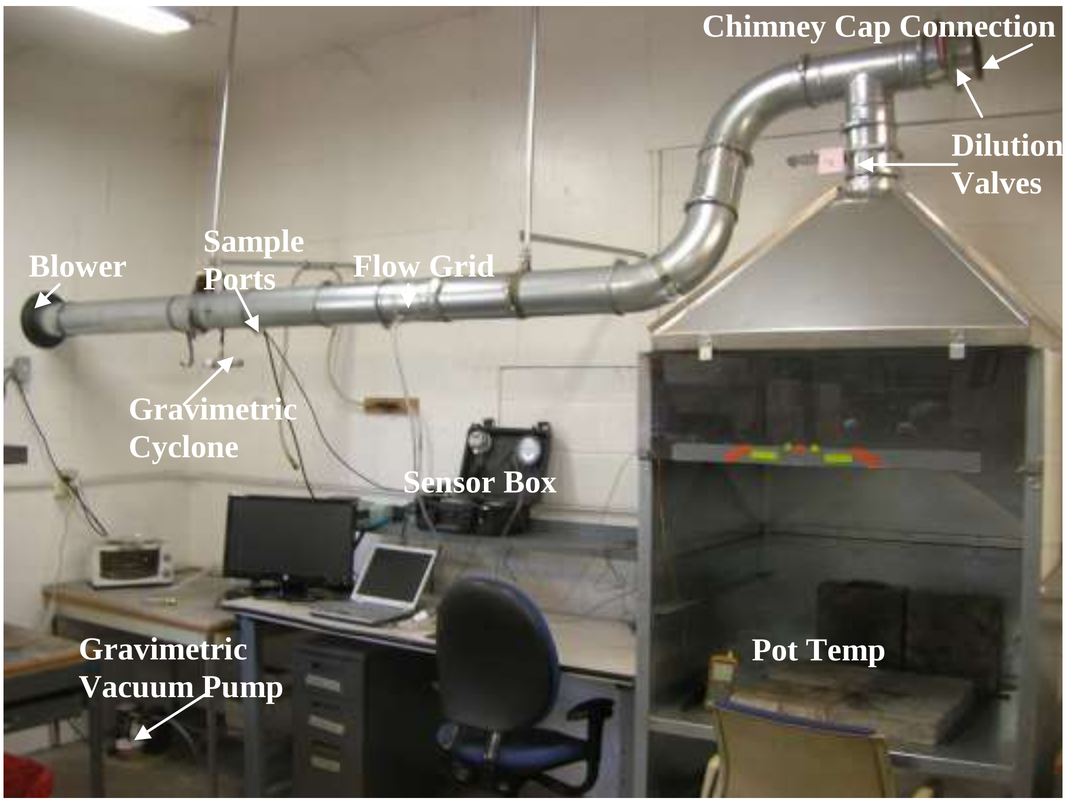


Figure 1: LEMS Hood, Ducting, and Gravimetric Assembly

Figure 2: Livegraph Sensor Box Output

Figure 3: Gravimetric Assembly

2. Uses of the System

2.1 Lab-Based WBT

The WBT is used to test stoves in the laboratory. The same fuel, pot, and tending practices are used in every test to eliminate variables in order to focus on the stove alone. It is suggested to complete at least three tests of each design so that differences in performance of differing models can be evaluated. Download the WBT protocol at community.cleancookstoves.org/files

2.2 Lab-Based CCT

This test is used to compare two stoves (often traditional vs. improved) using local cooks to prepare an identified local dish. The CCT is typically performed in the community or area that the stove is designed to be used. The CCT may be done under the LEMS if your lab is in an area where local cooks are available to perform the test. Your lab must weigh the pros and cons of completing the test under the LEMS vs. in the cook's home. If the cook's home is preferred, a portable hood is available. Read more about the CCT here: www.aprovecho.org/lab/pubs/testing

2.3 Teaching & Design

The real-time emissions display of the LEMS gives immediate feedback to the tester. Designers may make modifications to their stove and witness changes in emissions, using this process to fine-tune the stove design. The real-time display can be a great teaching tool for cooks and users who come to the lab as well.

2.4 Quality Control

Some PEMS/LEMS users have reported using their system for Quality Control of stoves made in their factories. Samples of stoves are routinely tested to ensure each batch performs up to specifications.

3. How the LEMS Works

The LEMS measures the total emissions produced during stove combustion. The stove is placed under a hood which collects the emissions and air from the laboratory. The flow rate and exhaust temperature are measured in the exhaust tube. A fraction of the flow through the system is drawn by a suction pump through a sample line to the sensors. Separately, a thermocouple measurement is logged of the (water) pot temperature. A computer displays and records the temperatures, flow and concentrations in real-time (see

Figure 2). The tester then processes the recorded data (.csv file) using provided software to report the performance of the stove based on the mass of emissions measured.

Sensors

- The carbon monoxide (CO) sensor is an electrochemical cell. Conductivity between two electrodes in the cell is proportional to the concentration of CO present. This cell has a reference terminal as well and requires a potentiostatic controller.
- The carbon dioxide (CO_2) sensor uses non-dispersive infrared (NDIR) to measure CO_2 concentration and outputs voltage. It is self calibrating, with pure Nitrogen gas used for a zero reference.
- The LEMS has two particulate matter (PM) sensors:
    - The scattering photometer has both a laser and a light receiver. When smoke enters the sensing chamber, particles of smoke scatter the laser light into the receiver. More light reaching the receiver indicates more smoke in the chamber. The amount of scattered light is calibrated with a laboratory-standard nephelometer. A constant is applied to the output to estimate the mass concentration of smoke particles. This is integrated into the data processing spreadsheets.
    - The gravimetric system gives a direct measurement of total PM using filter-based sampling. A vacuum pump pulls a sample through the sample line and the critical orifice, which holds the flow at a steady 16.7 L/min. A cyclone particle separator is used so that all $PM_{2.5}$ is collected on a glass fiber filter while the pump is on. The filter is pre- and post-weighed to calculate the total $PM_{2.5}$ mass.
- The flow is measured by a pressure transducer which outputs a signal based on the pressure drop measured across the flow grid. The flow grid is an amplified pitot tube that provides a low pressure drop through the system and a strong differential pressure signal, averaged across the entire duct cross-section. Exhaust gas velocity, volume, and mass flow rate within the duct, are calculated based on pressure drop recorded using the Magnesense® pressure transducer
- Analogue pressure measurement is provided by the Magnehelic® sensor. Measuring in parallel to the pressure transducer mentioned above, the Magnehelic sensor provides a calibration to the Magnesense for each test. The Magnehelic sensor can also be used to balance the pressure from calibration tanks with the suction pressure of the sensor box pump. Lastly, higher flows within the duct are represented by higher values on the Magnehelic, reported in inches of water.
- The temperature of the exhaust gas is measured by the sensor in real-time. The data are required to calculate the density of exhaust air in order to calculate the mass flow of emissions. Do not put this temperature sensor in water.
- The thermocouple (TC) temperature sensor is used to record the water temperature of the pot. The thermocouple temperature output is linear and the thermocouple probe provided with the LEMS is rated for temperatures up to 250°C.

4. Setting Up the System

4.1 Choosing a Location

The LEMS has a rigid metal hood and metal ducting that is used to direct the exhaust out through the blower and out of the building. The permanent, non-portable nature of the LEMS means that more ducting can be incorporated in order to achieve a better mixing profile than the portable hood system. Mixing and sampling are also improved by utilization of a variable-speed fan downstream of sample ports. The LEMS needs a space of at least 5.33 m x 1m x 2.75 m tall (17.5 ft x 3 ft x 9ft). This space should be indoors to avoid breezes. The space should be located near an exterior wall so that the blower assembly can be mounted to exhaust outside the building either through the wall or a chimney. If the ducting is installed so that the blower exits through the wall, than the centerline of the hole in the wall must be located at a minimum of 92 in (2.26 m) from the ground, or a maximum of 132 in (3.35 m). If a height in between the maximum and minimum are used than the ducting will align to a different plane by up to 20 in (50 cm) (from centerline to centerline) owing to the size of the right angle bends.

4.2 Setting-up the Hood and Sampling Duct

Below is a set-up diagram of the system:

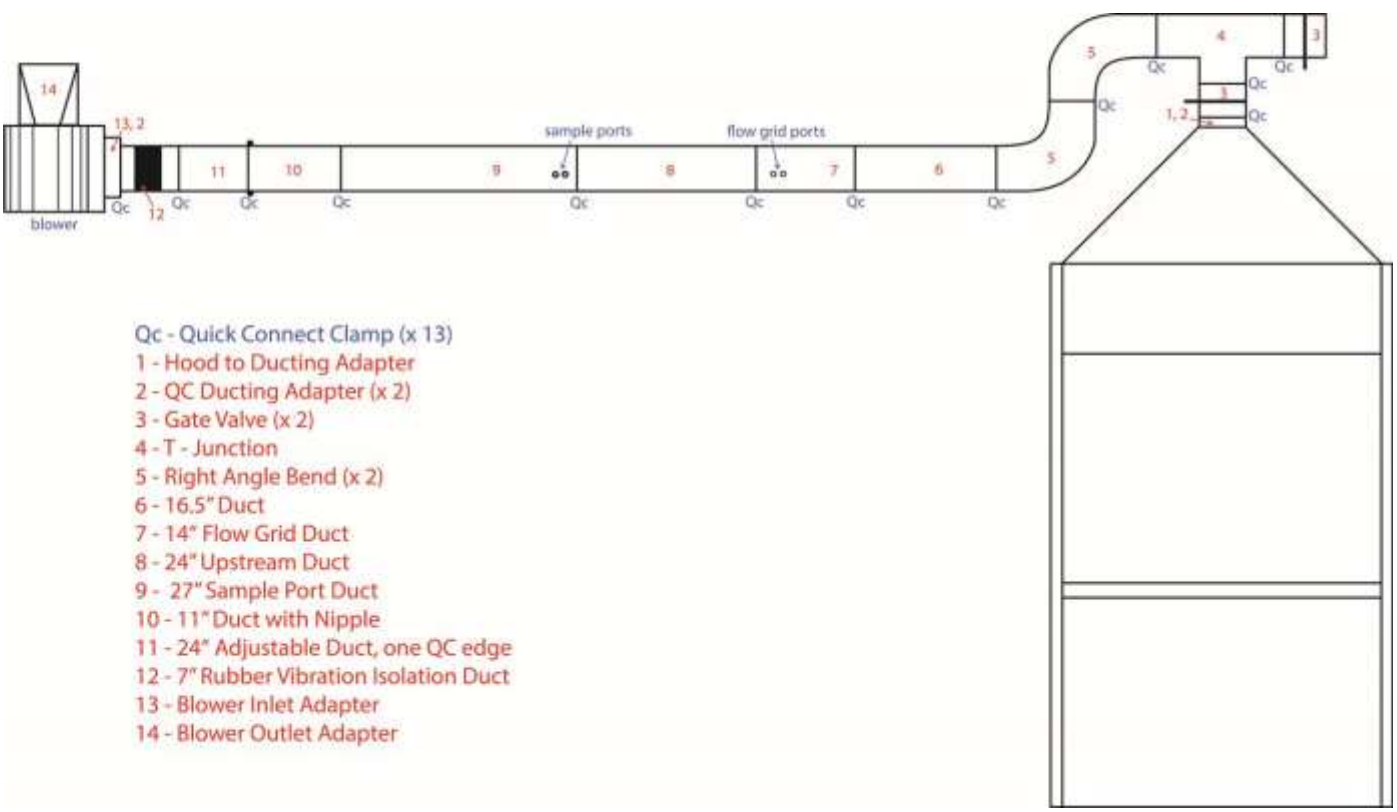


Figure 4: Hood and Ducting Assembly Diagram

List of parts shipped with the LEMS system:

Ducting

- 1 – Hood to ducting adapter
- 1- 2” duct extension, 6” QF
- 2- Flow Gate, 6” QF flow gate
- 1- T Junction, 6” QF
- 2- 90^0 Elbows, 6” QF 1.5CLR
- 1- Extension duct, upstream, 6” QF x 16.5” duct
- 1- Flow Grid duct, 6" QF x 14” with Flow Grid tubing
- 1 – Extension duct, 6” QF x 24”
- 1- Sample port duct, 6" QF x 27” includes:
    - 1/4" sample port, 0.12" ID x 0.25" OD 304 Stainless round seamless
- 1- 5/16” Gravimetric sample port
- 1- Nipple, 6” QF x 12” ducting
- 1- Extendable duct – 6” QF x 24”, unrolled edges
- 1- Blower Inlet, 7” to 6” reducer
- 1- Blower Outlet, 8” to rectangular reducer
- 13- Clamps, 6” QF
- 1 – 7” Rubber vibration isolation duct

Blower assembly

- 1- Dayton 1TDU2 Blower
- 1- Mounting Hardware
- 2- Mounting plates for 1TDU2

Gravimetric Assembly

(see section 4.5)

Sensor Box Assembly

(see section 4.4)

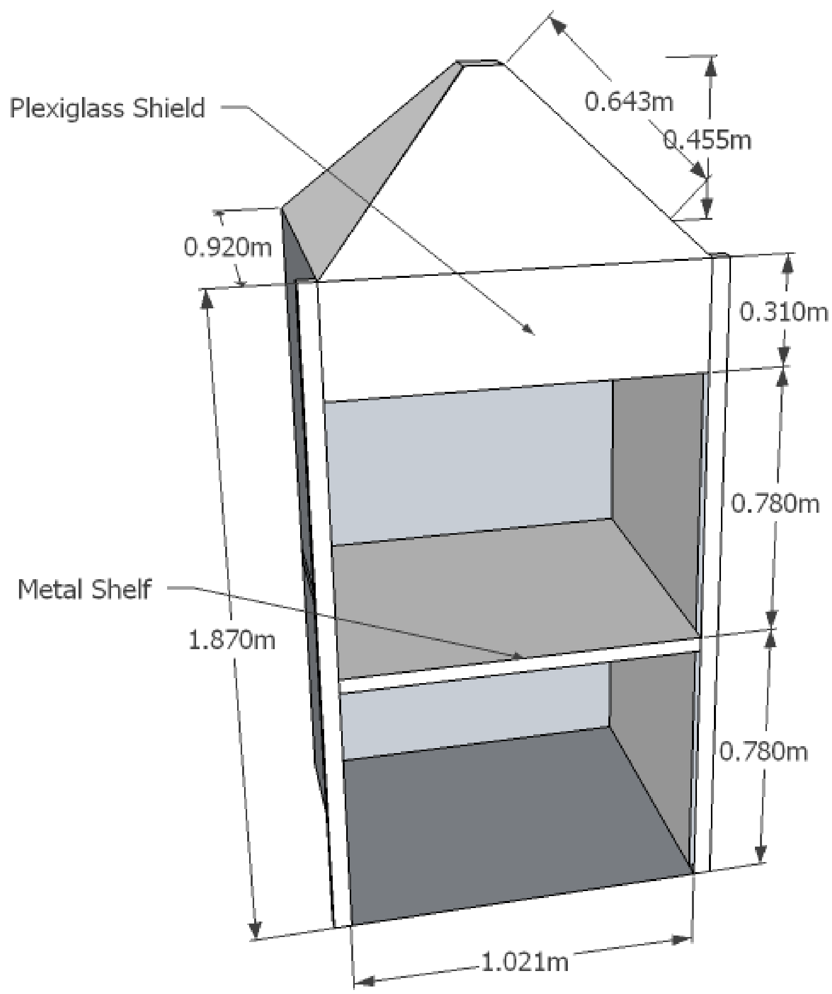


Figure 5: Hood Assembly with Dimensions

The hood is not generally shipped with the LEMS package as it is bulky and easily manufactured in most countries. The following are tips for constructing the hood:

- The hood should be made from 1 mm (or similar to this thickness) galvanized sheet metal according to the dimensions above. It should be tall enough so that small chimney stoves can fit when sitting on the ground.
- It is important that the exhaust from the stove flow out of the stove at its natural velocity. Therefore, the velocity in the hood should not exceed 0.25 m/s as to not induce an artificial draft. If using a chimney stove, the top of the chimney should not exceed the height of the square part of the hood or about 1.87 meters (6 ft.) from the ground. For taller chimney stoves, please see section:
- The lower portion of the hood must have three sides and the upper 25-30% of the hood should be closed on all four sides (see figure 5) in order to guide emissions into the ducting and prevent any cross winds from the room.
- Secure a movable shelf at a height comfortable for the tester that can be removed for testing chimney stoves. This shelf should be strong enough to support a large amount of weight without bending or flexing.

Figure 6: Two gate valves and "T" pipe

Attach the gate valves (see section "4.2.2 Dilution Valves") and right angle tubes to the hood according to the diagram in Figure 4. The bottom gate valve must be installed in this orientation relative to the two elbow bends to ensure proper flow profile. Use "quick-connect clamps" ("Qc" in Figure 4) where tubes come together making sure a tight seal is made. Follow the assembly diagram to complete the ducting layout, attaching ducting to the wall or ceiling for support. Provide a table for the sensor box and computer within reach of the flow grid and sample ports.

The blower should be mounted on the wall either inside, or outside under an enclosure, with the exhaust exiting the building through a wall or chimney (see Figure 8 for an example). The blower system ships with a square to round outlet adapter to convert the blower outlet to 8" pipe diameter. An inlet adapter is provided to convert the 8" inlet to 6" pipe. See section 4.2.3 for complete instructions on assembling the blower.

Figure 7: Sampling tubes for Gravimetric and LEMS sensor box. The tapered end of the 90° angle tube points into the flow, parallel to the axis of the duct. The flow grid is shown in the background, upstream of the sampling

Figure 8: Blower and chimney

A set of mounting brackets is included so that the blower can be mounted on rails which are attached to the wall. A chimney should be attached to the blower to direct exhaust away from the building. A minimal chimney is best, to avoid unnecessary reductions in flow. A cap is placed on the ducting and if needed, a protective structure should be built to protect the blower, and allow access for cleaning (see Figure 8).

Figure 9: Blower switch inside building

4.2.2 Dilution Valves

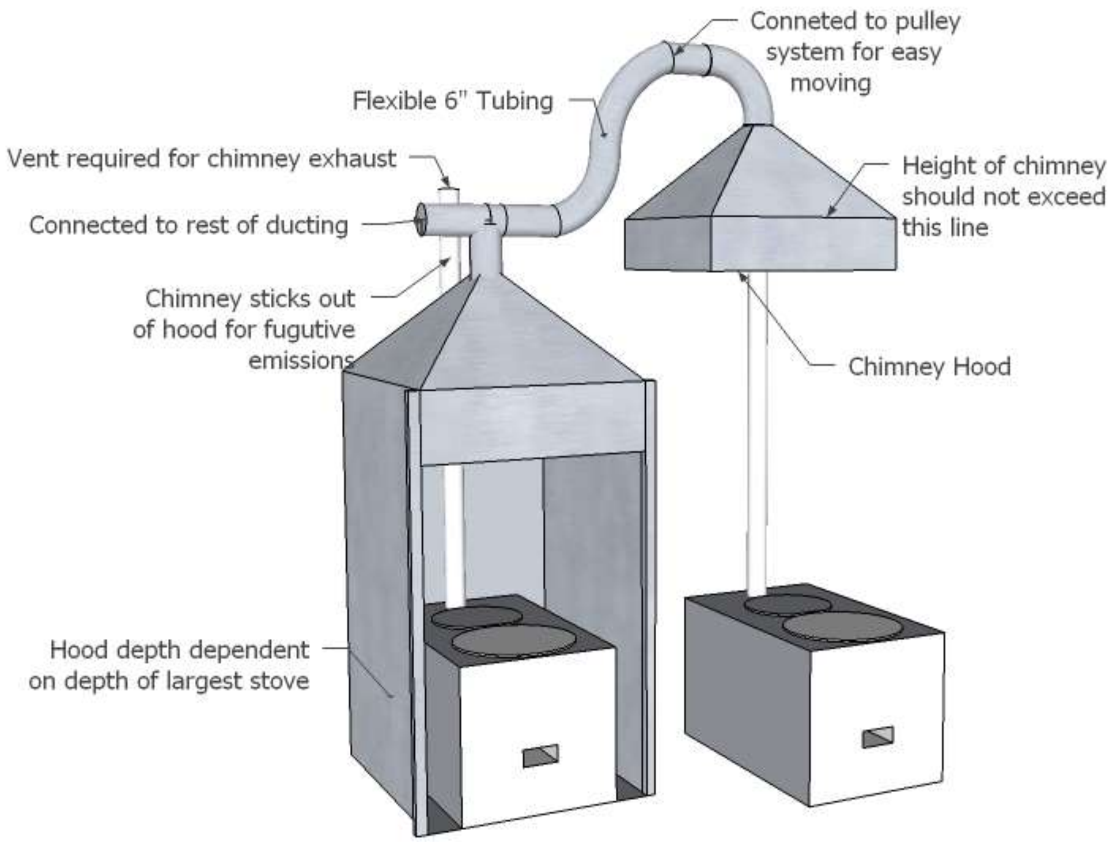
Two gate valves are shown in Figure 6, one connected to the hood and one open to clean air. They are both shown in a partially open position. In this configuration the system will produce an intermediate flow rate and dilution ratio. The Magnehelic pressure gauge will vary depending on the position of the dilution valves. Typically very clean burning stoves can be tested with lower flow while smoky stoves need a higher flow.

4.2.3 The Blower

The LEMS comes with a Dayton 1TDU2 squirrel cage blower. It has an open rate of 1200 cubic feet per minute (CFM), and at 0.5" w.c. (1/2 water column differential pressure) it develops 1100 CFM. The blower must be removable so that the metal impellor blades can be cleaned. The flow rate can be controlled using only the gate valves when the blower is at full power. Thus, a variable speed controller is not required. For practical purposes, the gate valve alone can be used to control the flow from 0.10” w.c. to 0.80” w.c, as displayed on the Magnehelic gauge in the Sensor Box.

4.3 Setting-up the System for Chimney Stoves

Below is an example of how to set up the LEMS for testing chimney stoves:



In addition to the LEMS hood you will need to construct a floating metal hood that connects to the gate valve by flexible 6” ducting. It is suspended from a pulley so it can easily be moved up and down. For chimney stoves with a high amount of fugitive emissions (smoke exiting around the pots), you will need to do separate tests for fugitive emissions. For testing fugitive emissions a hole can be cut in the full hood for the stove’s chimney. If your stoves are too big for the specified hood you will need to make the hood deeper to accommodate the largest stove you will be testing.

4.4 Setting-up the Sensor Box

Below is a complete list of everything included with the LEMS Sensor Box:

1- Sensor Box Assembly (black box)
1- 12V wall adapter
1- Thermocouple, Bead probe -40 to 500F, Type K miniature 1
1- Completed exhaust temperature cord
1- Serial Cable
1 – DIN
1- RS-232 Optical Bridge Hexin 1
1- RS-232/USB Adapter FTDI
1- Conductive Tubing, Black, 6’

Complete the following steps to connect your sensor box:

1. Connect the exhaust temperature cord to from the sensor box to the exhaust duct. Use a 3/32” hex key to tighten the screw. If the fit is too tight, you may file the hole so that the probe will more easily enter. See figure 11 below.

2. Plug in the yellow/orange thermocouple probe to the sensor box. This will be used to measure water temperature in the cooking pot during tests. Ensure that the cable is securely held away from the flames.

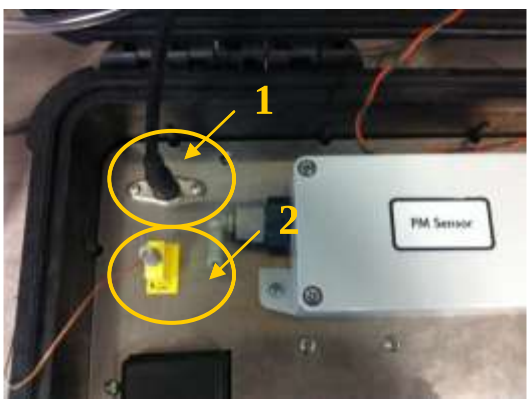


Figure 10: Black exhaust temp cord (1) and yellow/orange thermocouple cord (2)

Figure 11: Exhaust temperature probe (1)

3. Slip the black sample line onto the sample port on the exhaust duct. Slip the other end on the sensor box at spot labeled PM filter. See Figure 12 below. This tube directs exhaust through the sensor box in the following order:

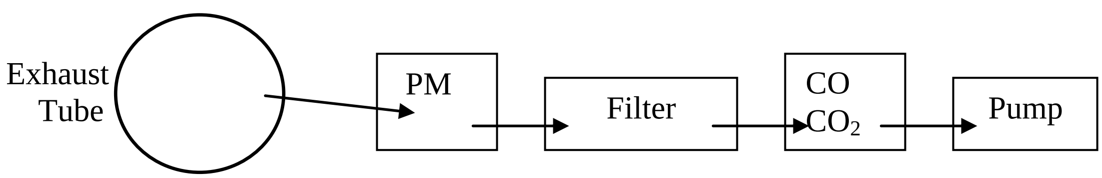


Figure 12: Gas sample tube

Figure 13: Gas sample tube entering duct

3. Connect a ground wire by sticking the bare end of the wire into the base or top of the green "panel ground" (Figure 14). Plug the other end into the ground of a properly grounded outlet, or create your own ground connection. Failure to ground the sensor box properly will result in unusable data or prevent proper communication between the sensor box and computer.

4. Set up the pressure measurement device (Magnehelic) by first ensuring the sensor box is set in a stable, level position and the lid is all the way open. The Magnehelic pressure gauge should be vertical (Figure 15). Once vertical, gently adjust the zeroing screw of the pressure gauge to zero the dial. Do not change the angle of the lid during a test because the pressure reading is affected by the vertical orientation of the sensor.

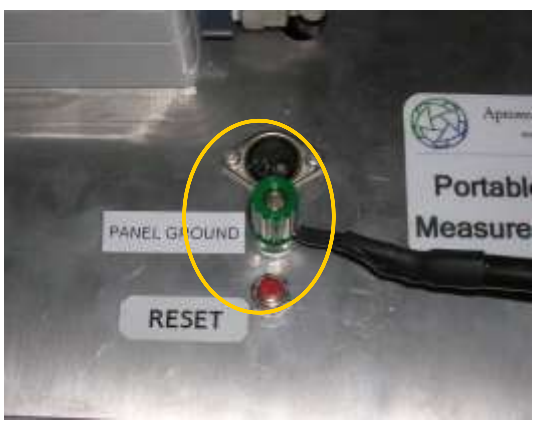


Figure 14: Green ground wire

Figure 15: Magnehelic Zeroing screw

5. Connect the two "high" and "low" pressure tubes to the flow grid on the ducting. Make sure the "high" pressure tube is upstream and the "low" pressure downstream.

Figure 16: Flow grid sample tubes

6. Connect the power cord (#1 in Figure 17) and TTL output cord (#2 in Figure 17) to the sensor box. See section 4.6.1 for details on power, and section 4.7.1 for details on connecting the Sensor Box to your computer.

Figure 17: Sensor Box power cord (1) and TTL data output cord (2)

4.5 The Gravimetric System

The gravimetric system is included as part of the LEMS to get a more complete measurement of PM emissions during a cooking task. It was designed to measure $PM_{2.5}$, particulate matter less than 2.5 microns in diameter. The system was designed, with some simplifications, following the United States Federal Code of Regulations *Title 40: Protection of the Environment, Part 60, Appendix A-3, Method* 5. The methodology is consistent with the testing standards being developing the ISO standard for cook stove testing.

Below is a complete list of items included with the LEMS Gravimetric System:

<u>Vacuum Pump</u>

1- Vacuum Pump Assembly (see section 4.5.1 for assembly instructions)

<u>Flow Control System</u>

1- Critical orifice

1- Sample nozzle

1- Vacuum gauge assembly
10 ft- 3/8" braided PVC tubing

Particle Separator

1- Cyclone type particle separator (see section 4.5.1 for assembly instructions)

Filter Housing and Filters (see section 4.5.5)

1- Filter housing, metal screw case that holds the filter
1- Filter housing bracket
3- Quick connectors, 3/8" female
3- Quick connectors, 3/8" male
1- Filters

Balance and Desiccator

1- Semi-micro balance, for obtaining mass on filter (see section 4.5.2 for assembly instructions)
1- Desiccant, material that pulls water out of the air
1- Forceps (tweezers), used to handle the filters

4.5.1 Setting Up the Gravimetric System

The Gravimetric system requires some minor assembling.

1. Screw muffler on Gravimetric pump. Tighten with wrench.

Figure 21: Gravimetric pump muffler

2. Attach sample line to gravimetric pump. Tighten hose clamp.

Figure 22: Sample line attached to pump with hose clamp

3. Assemble cyclone by attaching the inlet and outlet to cyclone body.

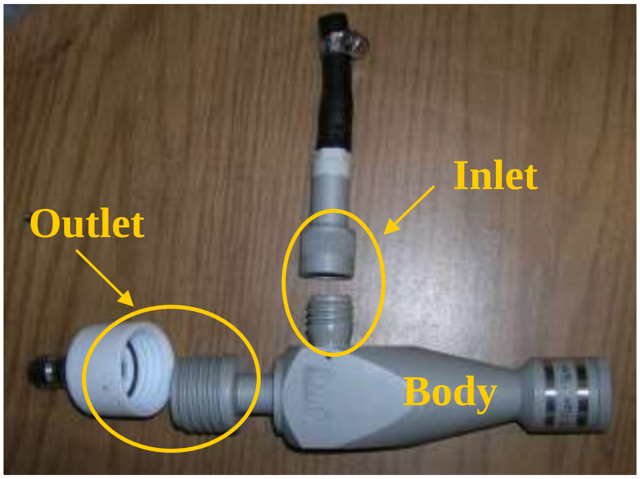


Figure 23: Cyclone assembly

4. Attach cyclone to sample port on ducting by inlet line. Tighten hose clamp.


Figure 24: Cyclone particle separator attached to ducting

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5. Attach filter housing bracket to ducting using screw provided. This bracket will hold the filter housing with filter during the test.


Figure 25: Gravimetric system as connected to LEMS ducting

4.5.2 Assembling the Balance

When shipped, the balance comes in tight packaging. The balance is disassembled so that it can ship safely. It is reassembled as follows:

Figure 26: Screw the posts into the base plate with the large flat head screws.

Figure 27: Insert the base plate

Figure 28: Affix the base plate with the six screws.

Figure 29: With a second person put glass in place

Figure 30: Screw the back tab in place.

Figure 31: Screw the top piece onto the posts, and the front piece of glass. Slide the top piece of glass in place.

Figure 32: Vacuum sucking pump

4.5.3 The Vacuum Pump

The vacuum pump is a rocking piston type. It does not require maintenance oil, and it is rated for continuous operation. It is wired to a switch and a capacitor, and its vibration absorbing mounts are screwed to a baseplate. A muffler is screwed into the outlet port. It is sized to maintain 16" of hg pressure at 16.7 lpm (liters per minute). The motor is an AC induction type.

4.5.4 The Critical Orifice

The critical orifice limits the flow to 16.7 Liters per minute as needed to calculate PM concentration. The orifice is screwed into an inline adapter. The orifice must be oriented upstream of the adapter, or else the flow will increase. The unit must be screwed into the tubing, not jammed, or else the o-ring will not seat, and the flow will increase. The flow rate through the orifice is dependent on changes in temperature, although for the range found in stove testing the change has been shown to be negligible (*Critical Orifice Theory, Design, and Implementation*, JW Stockham). This piece comes assembled as a part of the LEMS package.

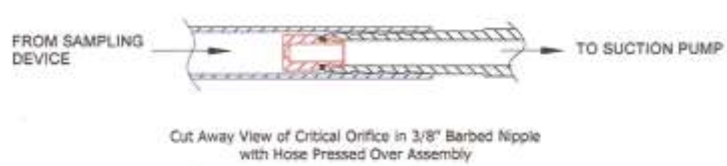


Figure 33: Correct orientation of critical orifice.

The vacuum gauge is used to see if the vacuum pump is maintaining the proper flow rate. Any reading above 16" of hg indicates that the flow is 16.7 lpm, while any reading below 16" indicates that either the pump is failing, or the pump is receiving inadequate power.

4.5.5 Particle Separator (Cyclone)

The particle separator must be operated at a flow rate of 16.7 lpm in order for the desired particle distribution to pass through. Figure 35 shows the particle penetration rates at 16.7 lpm for the particle separator used in the system. From the diagram, one can see that all of the particles less than 1 µm are able to pass, while only 10% of the particles greater than 5 µm may pass. Of the particles that are 2.5 µm, 50% may pass. The diameter where 50% of the particles pass is called the cut-point. Figure 34 below shows how the cut point varies with flow rate. The particle separator may be installed horizontally or vertically. If one wishes to measure TSP the particle separator may be removed from the system.

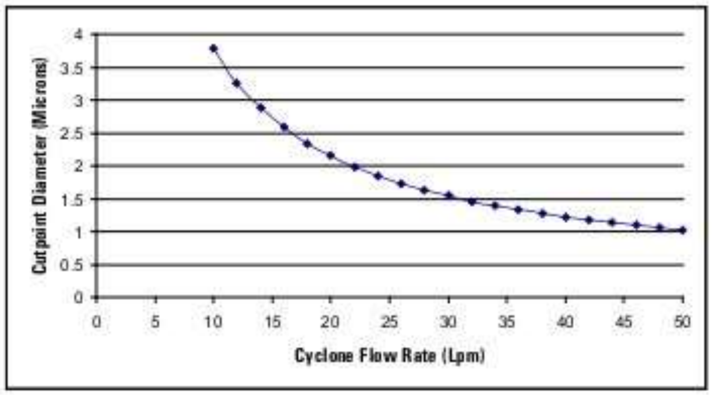


Figure 34: Cut points for the particle separator for various flow rates (taken from product brochure).

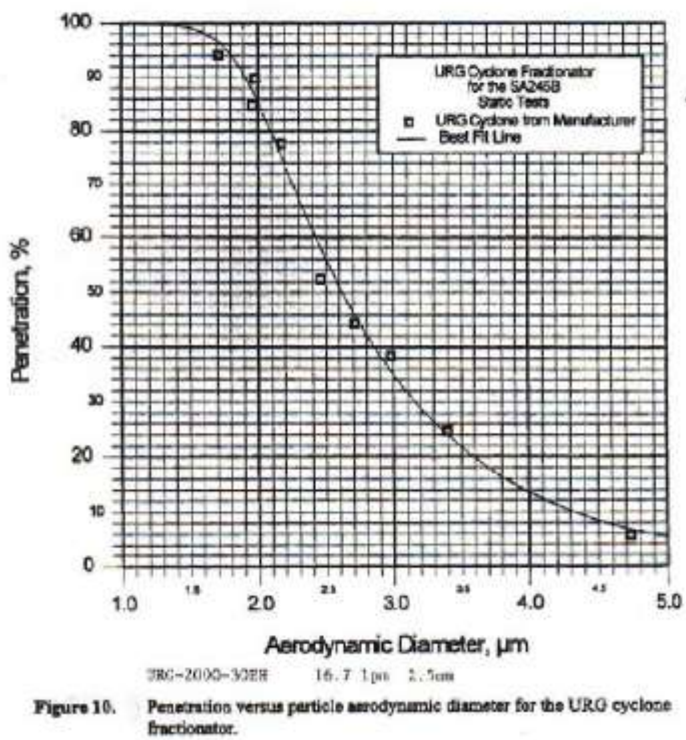


Figure 35: Particle penetration rates for the particle separator (taken from product brochure).

4.5.6 The Sample Nozzle

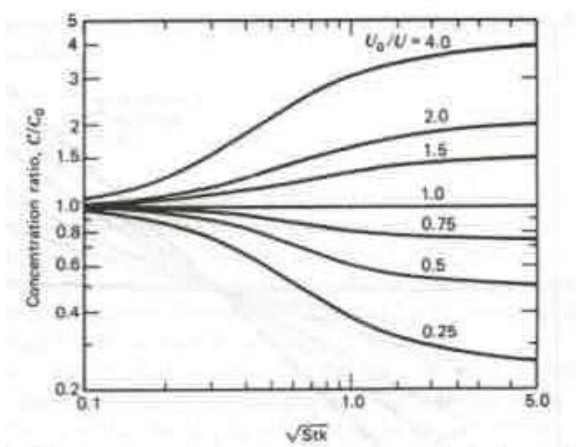


Figure 36: The ratio of the sampling concentration to the duct concentration vs. the square root of the Stokes number for different ratios of duct to sampling velocity. Taken from Aerosol Technology, by William C. Hinds.

The sample nozzle is sized to sample iso-kinetically when the Magnehelic reads 0.45 inches of water, at other flow rates it will not sample iso-kinetically. Iso-kinetic sampling is not of the greatest concern for stove measurements because the particles tend to be small enough to follow the stream lines leading to the sample nozzle. The square root of the Stokes number is between 0.15 and 0.31 (U/U0 = 1.8,0.7)for the LEMS flow conditions, Figure 36 shows that aniso-kinetic sampling introduces an error of about +-5% in the worse case. When the particle size distribution is assumed to be less than 1um, the error is negligible.

4.5.7 Handling the Filters

Figure 37: Carefully separating new filters

When handling the filters with the forceps one must grab the filter on the very edge. When moving the filter around it will droop. One must be careful that is does not hit surrounding obstacles or else mass will be lost. One may grab the filters in the middle area if they are clean (white). The filter is sized to hold up to 30 mg of mass without significantly slowing down the flow. It is difficult to get the filters out of the box. They come stacked in a group of 100 and they stick together. One must carefully slide the forceps under the top filter (figure 37). The edge of the filter may tear. The torn bits can be crunched back onto the filter body with the forceps. One should not attempt to tear off the hanging bits, more will come off than is desired. The filter housing is hooked into the sampling system using “flow-through quick connectors”. The connectors are slid over the ball bearings with the thumb and the forefinger. The filter is placed with the rough side facing the upstream towards the flow of exhaust. The filter housing comes apart by unscrewing the ring. Now place the filter in the desiccator.

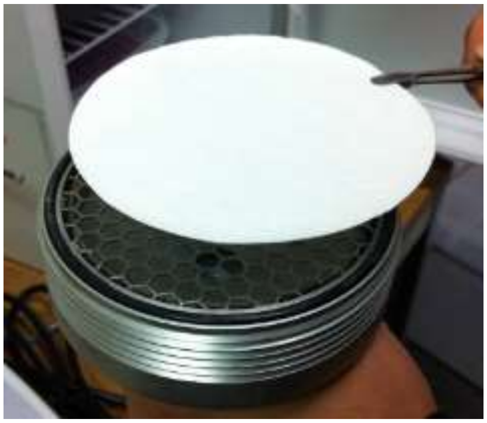


Figure 38: Clean filter placed rough side up in filter housing

Figure 39: Quick Connectors used to secure filter housing to tubing

4.5.8 Desiccating the Filters

The desiccator is a sealed vessel that contains a desiccant (see next paragraph). The sealed vessel is not included with the LEMS, your lab must provide one. The desiccant works by pulling moisture out of the air within the vessel. As the air becomes dry, moisture evaporates off of the filter. After 24 hours, the filter becomes sufficiently dry. If the filter is weighed directly after the stove test, without being desiccated, its weight will include moisture from the test. We recommend waiting for the filter to desiccate for at least 24 hours before weighing it.

The desiccant is beads of silica gel beads that attract and holds moisture. The beads are orange when dry and turn green when the gel is wet. When the indicator turns green, the desiccant must be dried by placing it in an oven over night at 105^0 C.

4.5.9 Weighing the Filters

Figure 40: Used filters must be held on the edge as pictured here

The semi-micro balance measures mass with a resolution of 0.01 mg. The linearity, as measured by the manufacturer, is 0.04 mg, which is essentially the accuracy of the balance when repeated measurements are taken. The balance must be operated on a level surface. A heavy table should be used as it will damp out vibrations from the room, but it must not be leaned on while measurements are being made. The room must be kept within +- 0.5 deg C during measurements, or the balance must be recalibrated. The balance has internal calibration weights, and can be set to automatically recalibrate based on temperature changes. The balance manual should be consulted for further details of operation.Multiple measurements must be taken of each filter. The standard deviation of 5-10 measurements is about 0.05 mg. A set of measurements of a single filter can take up to 10 minutes. The lab technician may need a distraction to allow the balance enough time to stabilize, and to resist the urge to report a reading before a good average has been obtained.

4.5.10 Relationship to the Scattering Photometer

The gravimetric system directly measures the average concentration of $PM_{2.5}$over the time the pump is running. The scattering photometer (in the sensor box) measures the scattering coefficient of the particles it is exposed to second by second (real-time). To obtain the mass concentration from the scattering coefficient, one must know the mass scattering cross section of the particle distribution (see Roden, et al. *Emission Factors and Real-Time Optical Properties of Particles Emitted from Traditional Wood Burning Cookstoves.* Environ. Sci. Technol. 2006 for examples of the mass scattering cross section for wood stoves). The mass scattering cross section for the scattering photometer is derived after every test by relating the average concentration measured with the filter to the average scattering coefficient measured by the scattering photometer. For particles less than 1 um in diameter it is well known to be 3 m2/g (Malm, W.C., et al. *Spatial and seasonal trends in particle concentration and optical extinction in the United States.* J. Geophys. Res. 1994). For other particle distributions it varies drastically. With Aprovecho's scattering photometer, it has ranged from 0.01 m2/g to 2 m2/g. It appears that for very low concentrations, as are seen for Tier 4 stoves, the scattering photometer detects disproportionately low.

4.6 Powering the System

The LEMS requires power for four parts: The Sensor Box, the exhaust blower, the gravimetric suction pump, and the PC (or laptop).

4.6.1 Mains 110v 60 Hz Operation

All four systems can be plugged into grounded outlets. Minimum surge protection: Surge protector installed for the Sensor Box and PC. It is recommended that a Uninterruptable Power Supply (UPS) is used both for the added protection provided, and to prevent the data logging from terminating when there is a brief power outage. There is no need for surge protection for the blower or pump.
Ensure that the blower is wired correctly for 110V 60 hz operation (see wiring diagram on blower)

4.6.2 Mains 220v 50 Hz Operation

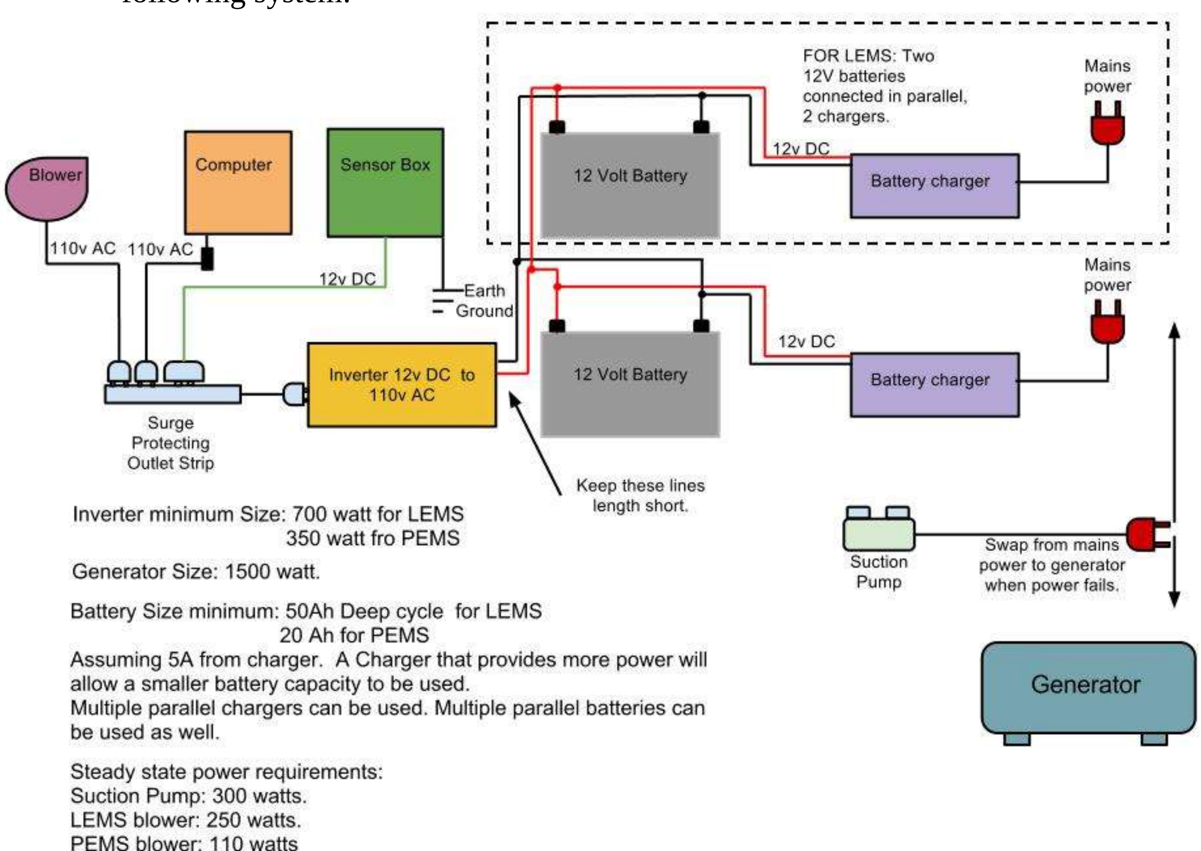
The Sensor Box wall power supply can be plugged into a surge protector connected to a 220v outlet. The wall power supply is more easily damaged by power surges when running at 220v, so do not forget the surge protector.
The blower can run on 220v or 110v depending on the wiring configuration. Ensure that the blower is wired for the correct voltage rating (see wiring diagram on blower).
At 50 hz The blower's rated flow will be reduced by 17%.
For 50hz operation please use the appropriate gravimetric pump. The 110v 60hz pump does not have enough capacity when run on 50hz.

4.6.3 Off-Grid Operation

Here are some guidelines for operating the LEMS when unreliable or no mains power is available:

- When setting up an off-grid LEMS, always observe baseline sensor noise, and make sure the digital signal from the Sensor box to the PC is reliable.
- Additional grounding to an earth ground rod may be required.
- Run a practice test to be sure that the power sources are adequate for the duration, and try to avoid damaging batteries by over-discharging.
- The Sensor Box can be run while the battery is being charged from an external source, such as a car, but the electrical noise from this source should be observed in the baseline readings from the sensors.
- The suction pump requires a sine wave AC power at rated frequency (pump motor labeled 50 or 60 hz) Options for powering it are a gas or diesel generator, or a pure sine wave inverter, and a large capacity battery.

To run the LEMS in a location with frequent power outages, we suggest the following system:



4.7 Installing the Software and Connecting the LEMS Sensor Box to the computer

4.7.1 Installing the LEMS Software

The following steps explain how to install the software for the LEMS sensor box:

- Check your computer to determine whether you have a 32bit or 64bit operating system. To do this, go to the Start Menu→Control Panel→System, and check your System Type, highlighted below: If you are running Windows XP or older and cannot find what system is used, it is most likely 32bit.

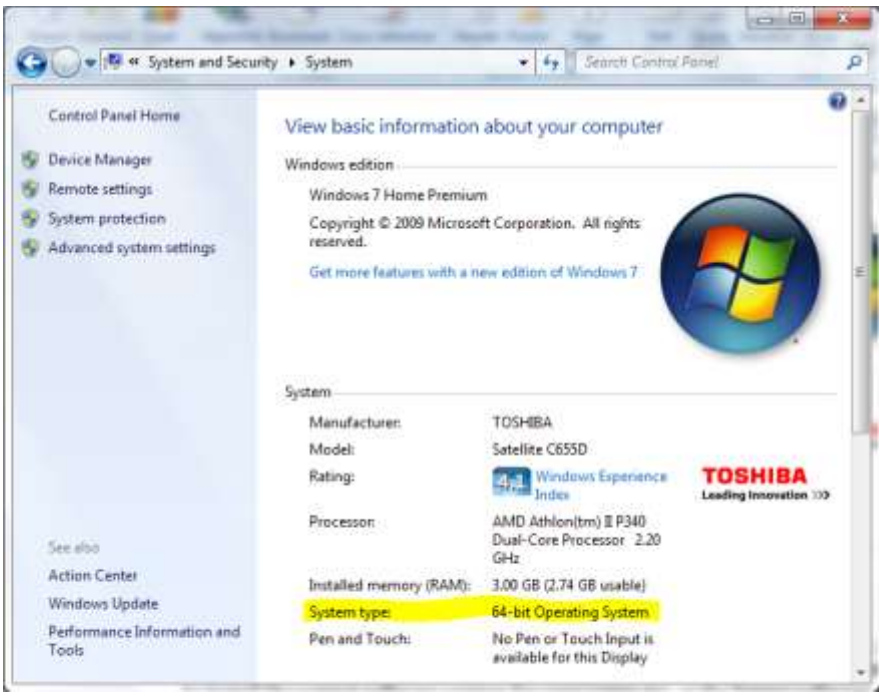


Figure 42: How to Determine your Operating System Type

- Insert the installation CD or USB stick that was provided with the LEMS and run the correct Software Installer. It is important to install the correct software version for your computer, or the logger software will not work. For a 32bit system, install the file labeled “Emissions Software Installer - 32bit”, and for a 64bit system, install the file labeled “Emissions Software Installer - 64bit”. The installer creates the folders C:\Emissions-Output, and either C:\Program Files\Emissions (32bit operating system), or C:\Program Files (x86)\Emissions (64bit operating system). The installer also adds desktop shortcuts for the Logger program, TeraTerm, Livegraph, and your system’s Device Manager.
- Java is required to use Livegraph. Java may already be installed on your computer. If it is not, once the installation is complete, go to the C:\Program Files\Emissions folder and run the Java installer. If this does not work, go to www.java.com to download the newest Java installer for your computer.
- Obtain the appropriate processing sheet (Excel file) for your test (WBT or CCT). These files are located on the CD or USB data stick included with your Sensor

Box. However, they are updated regularly. Please check www.aprovecho.org weekly for the most recent version.

- Ensure that your computer is not set to hibernate as this will freeze the data logging. Right click the desktop and select Properties, then the Screen Saver tab, then Power. In the Power Schemes tab, ensure that “turn off hard disks”, “system standby”, and “system hibernate” are all set to “never.

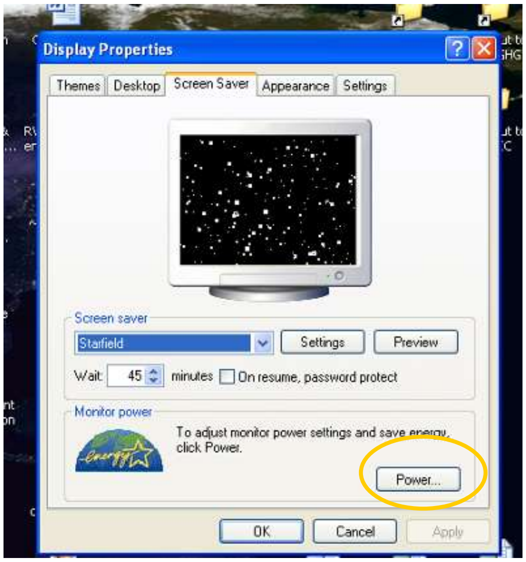


Figure 43: Windows screen saver menu

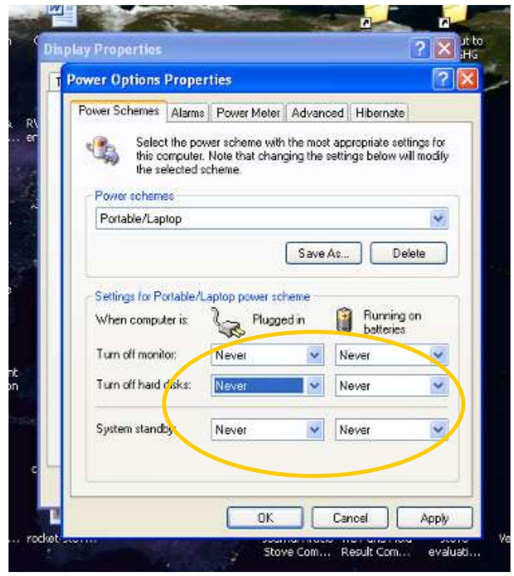


Figure 44: Windows power saver menu

- Also ensure that Macros are enabled in Excel so that the automatic processing can take place. This can be done by choosing menus (in Excel) Tools/Options/ Security/Macro Security. It is best to choose “Medium” security within these options. Then whenever you open a file with a Macro, it will ask if you want to Enable or Disable the macros.

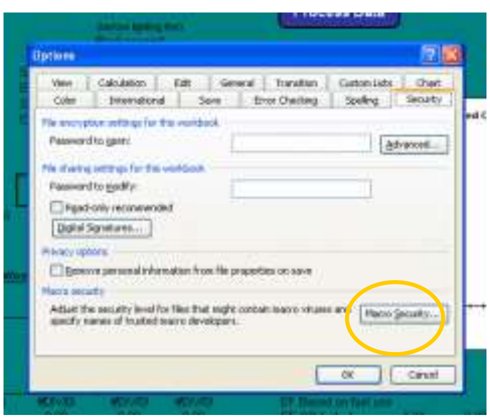


Figure 45: Microsoft Excel Options

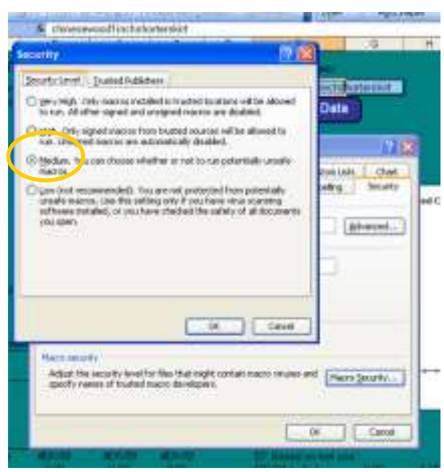


Figure 46: Set Macro security to medium

4.7.2 Establishing a Connection Between the Sensor Box and Computer

The LEMS sensor box outputs data through an RS-232 serial port. The most reliable way to connect the sensor box to the computer is to plug the 9 pin connector of the LEMS sensor box cord directly into an RS-232 port on the computer. Given that most modern computers use USB connections only, the LEMS is sold with an RS-232 extension cord and an RS-232 to USB adapter. This adapter needs drivers installed on your computer in order to function properly.

To install these adapters, copy the appropriate driver folder for your computer to your C:\ drive. This folder is located on your software CD. It is labeled “FTDI Chip - USB Serial Adapter” – make sure to copy the appropriate 32-bit or 64-bit folder for your system. Plug the RS-232 to USB adapter into a USB port on the computer. A window should pop up, asking you to install the driver software for the UC232R device. If it does not, then go to the Device Manager found in the “Control Panels” in the system folder, or click on the Device Manager icon installed on your desktop. In the Device Manager you will find and may need to open Ports:(COM & LPT) to see the recognized ports. If there is a yellow exclamation point next to the port name, the driver was not successfully installed, in which case you should try downloading the latest driver for your operating system:

http://www.waltech.com/software-win/ or at:
http:/www.ftdichip.com/FTDrivers.htm

Once the USB adapter driver is successfully installed, and the USB adapter is plugged into your computer, go to Device Manager and note the COM number that the USB adapter is using (e.g. COM1). This COM number must match the Logger software.

Check the port settings in the Logger software by going to the C:\Program Files\Emissions folder and open the file logger.ttl with a text editor. Line 4 of the code defines the COM port number. This COM number must be the same as the COM number found in the Device manager of your computer. Edit the logger.ttl file as necessary.

Note that in Windows 7, this logger.ttl file cannot be edited in the folder where it is installed. Instead, this folder must be copied to another folder (e.g. the Desktop), then edited before being re-copied (returned) to replace the old file at C:\Program Files\Emissions folder.

5. Running a Test

5.1 Powering Up

1. Ensure that the power supplied to the sensor box is 110 VAC (or 220 VAC with a surge protector or UPS power supply).
2. Plug the LEMS sensor box cord into the computer, using the USB adapter and optical isolator.
3. For USB adapters, wait a few moments for the device to register. Go to Control Panel, then System, then the Hardware tab, then Device Manager to check the port number. As mentioned in the section titled, "4.7 Installing the Software and Connecting the LEMS Sensor Box," the port number must be the same as that which is listed in the Logger software (The logger.ttl file is located at C:\Program Files\Emissions folder).
4. Open the "Logger" icon on the desktop and follow the on-screen steps. Remember to use the suffix ".csv" in your file name.
5. When the message says "Power up," turn on the LEMS sensor box. When it is on, you will hear the suction pump running inside the black carrying case.
6. Click "okay" and the Tera Term window will display the incoming Sensor Box data:

```
# type cal (in 5 seconds)
# 'log' command starts logging >log
#logging
##,##
# ,.087,.263,13.6, ,.00381,.1
seconds,CO,TC,PM,flow,gas temp,CO2, PM_RH
1.00,70,1249,219,65536,4830,586
2.00,67,1504,217,65536,4830,586
3.00,65,1605,219,65536,4835,586
4.00,62,1693,215,65536,4834,586
5.00,67,3564,216,65536,4834,586
6.00,67,2986,219,65536,4834,586
```

7. Line 5 displays the calibration constants for each column of data.
8. Line 6 displays the name of each column of data.
9. Open LiveGraph from the desktop.
10. In LiveGraph, open the .csv file you just created in C:/Emissions-Output. Ensure that the file manager is set for the "C:/Emissions-Output" folder in order to find the correct file. Click "Open" and the data will be displayed.

5.2 Using LiveGraph

There are 4 LiveGraph windows, each with several features.

1. Data file settings window
    - Select "open" to open the desired file.
    - Move the bar to change the update frequency.

    - Large files will flash when updated if the “Do not cache data” box is checked
2. Graph settings window
    - change the axis range
    - add gridlines
3. Data series settings window
    - check and un-check the series that you want displayed
    - click color bars to change color
    - click “Actual value” in Transformation column and scroll down to “scale by specific”, then double-click and change the scaling factor in the next column. You can apply a scaling factor of 0.00381 to the gas temp to see the output in °C. You can apply a scaling factor of 0.1 to the thermocouple reading to see the output in °C.
4. Plot window
    - move cursor over a point to see the coordinates and to verify data you are pointed at (e.g. CO_2)

5.3 Checking the Readings

- Take a quick look at the readings with the blower off. Scroll over each line on the graph in the LiveGraph Plot window to see the current reading. In the bottom left corner, numbers will appear in the format (XXX.X,YYY.Y). The X readings show the number of seconds since logging began. The Y readings shows the value in logunits multiplied by the scaling factor.

5.4 Zeroing Period

- First, let the system run for at least 1 minute with the blower off in order to capture a zero flow reading. Level and adjust the Magnehelic using the small screw to ensure it is reading 0 (Photo 21).
- The background period starts 4 minutes after the LEMS begins logging to allow time for the sensors to warm up. The blower fan must be on during the background period to capture a full flow pressure reading. Therefore turn the blower on 1 to 4 minutes after the start of data logging. On the test data sheet, record the ***full flow calibration reading*** of the Magnehelic pressure gauge. This will be required to calibrate the flow in the data processing sheet.
- Take a background reading by letting the system run for at least ten minutes with the blower ON with clean (no source of dust or smoke) background air in the room.
- During this time, the other test materials such as fuel can be prepared.

5.5 Running the Test

- Begin the WBT or CCT. **Use the computer clock** to record times on the testing sheets in **24-hour time** format. After the start of the fire, check to see a response of the sensors on the screen.
- Periodically observe the levels.

5.6 Ending a Test

- When the test is completed, remove the stove and charcoal from under the hood and allow the system to run for another 10 minutes. This will clear the gases out of the sensor boxes so that they are stored with clean air.
- Exit the Logger and LiveGraph programs.

6. Processing Data

- The data was saved automatically within the C:/Emissions-Output folder.
- Data is processed in software written in Microsoft Excel.
- Open the data processing file. Click "Enable Macros" when the box appears to warn you that you are about to open a Macro file.

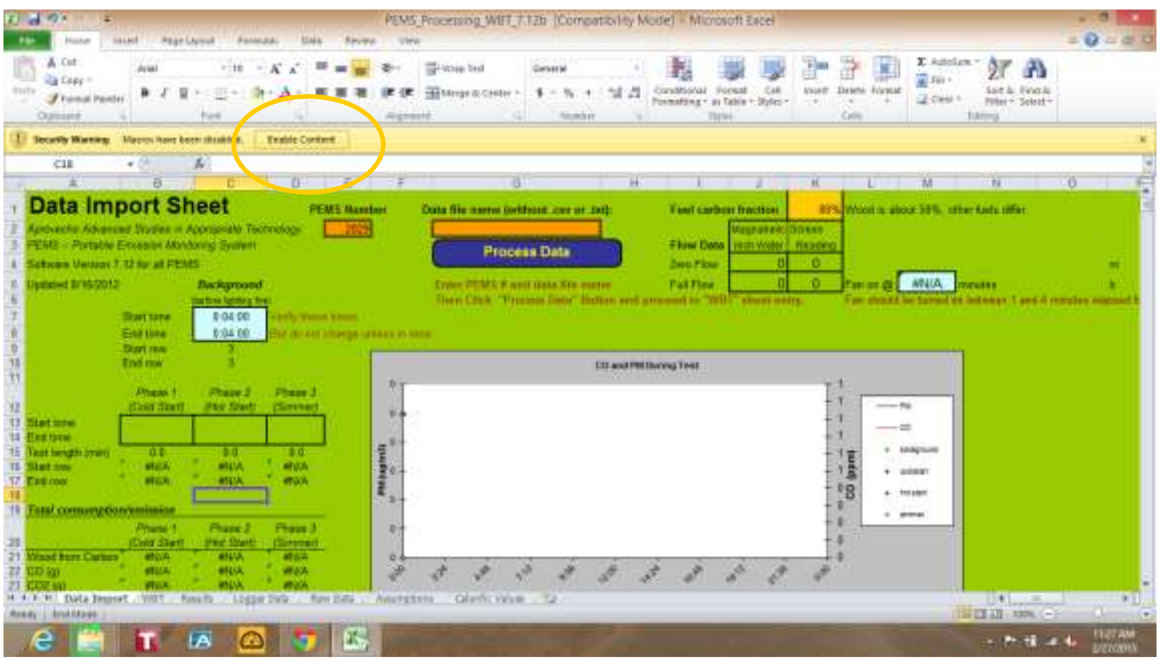


Figure 47: Microsoft Excel 2010 macro security warning pop-up window

- Select the Data Import sheet. Enter the LEMS Sensor Box serial number (located at the upper right-hand corner of the inside of the aluminum board). Then enter the file name in the orange cells, and verify the carbon content of the fuel. The serial number identifies the data file format for the spreadsheet.

- Click the “Process Data” button. Wait while the data is processed.
  If nothing happens when the button is clicked, Macros are disabled by security and should be enabled per the instructions in the previous section.
- The software will prompt you to save the completed file. The original processing file itself should not be saved with any changes.
- Enter all the WBT of CCT info into the WBT or CCT sheet. Time MUST be entered in **24-hour HH:MM:SS** format, such as 15:34:12. Click *only once* on the cell and simply type this number.
- Once the data is entered on the WBT or CCT sheet, go back to the Data Import sheet to check that the background times are correct. They should automatically be four minutes after recording was started, and two minutes before the start of the test. Also check the start and end times of the test phases and ensure that row numbers are listed, not #N/A.
- If additional gases were measured, on the Data Import sheet there is space to enter the name, molecular weight, and concentrations of these gases. Data will be calculated automatically, even after the “Process Data” button has been clicked.
- Look at the Results sheet to see the final data.

7. Using Data

Results of the test are presented in the Results tab sheet.

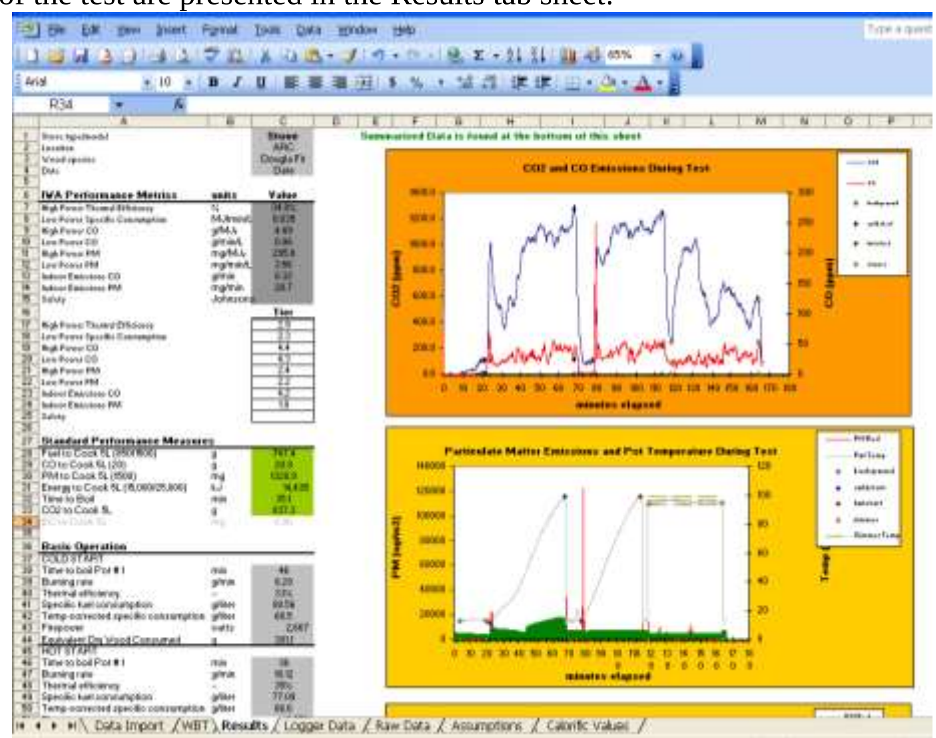


Figure 48: Data Processing Sheet results page

Data in this sheet is designed to easily copy into another spreadsheet for comparison of a series of tests. The column of numbers can be copied and pasted along side results from other tests, allowing for easy averaging, comparison, and graphing.

Scrolling from the top down, information appears in the following order:

- IWA Performance Metrics:
    1. High Power Thermal Efficiency
    2. Low Power Specific Consumption
    3. High Power CO
    4. Low Power CO
    5. High Power PM
    6. Low Power PM
    7. Indoor Emissions CO
    8. Indoor Emissions PM
    9. Safety
- IWA Performance Tiers, each of the above metrics ranked 1-4, 4 being highest
- Standard Performance Measures (highlighted in green):
    1. Fuel to Cook 5L
    2. CO to Cook 5L
    3. Energy to Cook 5L
    4. Time to Boil
    5. CO2 to Cook 5L
- Basic Operation separated into Cold Start, Hot Start, and Simmer
- Energy Consumption separated into Cold Start, Hot Start, and Simmer
- Total Emissions
- Specific emissions (per liter of water, corrected for starting temperature, moisture content, and unburned charcoal)
- Emission Factors (mass of emission per mass or energy of fuel burned)
- If additional gas sampling was done, the results of these follow.

8. Changing Parameters in Setup Mode

Setup mode allows you to:

1. Change calibration constants displayed in the header of the data file
2. Change channel names displayed in the header of the data file
3. Change zero offsets of each channel
4. Communicate with and change parameters stored in the CO_2 sensor

To enter setup mode, connect to the LEMS Sensor Box with a serial port terminal software program such as Tera Term (go to the C:\Program Files\Emissions folder and open the program called ttermpro.exe). Select the "serial" connection, then select the port in the dropdown menu (COM1 for RS-232 connection and COM4 for USB adapter). Then select the setup tab and click "Serial Port" to make sure the settings are baud: 9600, data: 8 bit, parity: none, stop: 1 bit, then click "okay". Turn on the Sensor Box and the screen will display:

```
# type cal (in 5 seconds)
```

When you see this, you have 5 seconds to type the word “cal” and press <enter>. If you miss your chance to enter the word, or if you type something other than “cal”, then the Sensor Box will continue on to log mode and ask for the “log” command.

Once you have entered setup mode, you will see the main menu:

```
1: Names, 2: Cal vals, 3: offsets, 4: CO2 com
 enter number >
```

To exit setup mode turn off the Sensor Box.

8.1 Change Channel Names

Enter “1” to change a channel name and the display will show:

```
Name Entry Menu (15 letters max)

channel:  name
0: CO
1: CO2
2: PM
3: flow
4: gas temp
5: pot temp

enter channel number to change >
```

Enter the channel number that you would like to change the name of and the display will be:

```
you entered: 0
enter new name >
```

Once you enter the new name for the channel the prompt will return to the main menu. Enter “1” again to check that the name was stored correctly.

8.2 Change Calibration Constants

Enter “2” from the main menu and the display will show:

```
Cal Val Entry Menu (15 digit max)

channel:  name, Cal Val
99: time
0: CO .087
1: CO2 .263
```

2: PM 13.6
3: flow
4: gas temp .00381
5: pot temp .1

enter channel number to change >

Enter the channel number that you would like to change the constant for and the display will be:

you entered: 2
enter new calval >

Once you enter the new cal constant the prompt will return to the main menu. Enter “2” again to check that the cal constant was stored correctly.

To be compatible with the Sensor Box data processing spreadsheets, the calibration constants are in units of:

CO: ppm / logunit
CO2: ppm
PM: (ug/m3) / logunit
Gas temp: deg C / logunit
Pot temp: deg C / logunit

9. Adding Additional Channels

The Sensor Box is equipped with a Waltech Model 32 programmable DAQ. It can be configured to log additional inputs, or to change how existing inputs are treated. To configure the DAQ, open a serial port terminal software program such as Tera Term, connect to the Sensor Box port and turn on the Sensor Box while holding down the reset button. The prompt will display:

ADVANCED INPUT SETUP MODE
current value: 35
enter input mask decimal #0>

If you have reached this prompt in error, simply turn off the Sensor Box. For more information about which channels are available and how to configure new channels, contact Aprovecho for the Waltech Configurable DAQ Manual.

10. Special Notes

- Never run a stove without a pot of water under the hood. The pot cools the flames enough so that the hood and blower do not overheat. If the blower shuts off, it is likely it has overheated.
- It is important your computer does not enter a power-saving mode during a test. This could freeze the data logger and require a restart. All data may be lost. Ensure that the power-saving properties (accessed by right-clicking on the desktop) are set accordingly.
- The same USB port on the computer must be used each time in order for the logger to be recognized where it was installed.
- Avoid turning the sensor power supply on and off unnecessarily. It is best to leave it on for all tests of the day. It should, however, be turned off at night.
- Emissions from the chimney (for stoves with chimneys) with can be measured by placing the hood about 40 cm above the top of the chimney.
- The Data Processing files should not be saved with changes. Once used to incorporate raw data for each test, the file should be renamed to one specific to the stove test. This is done automatically when the "Process Data" button is clicked.
- The system was designed for small household stove tests only. There is a limit to the size of fire the system can handle. The blower can only collect a certain volumetric flow of emissions. Reducing the head loss in the exhaust duct and cleaning the blower will allow the LEMS to handle higher concentrations of emissions.

11. Care and Maintenance

11.1 Cleaning

The LEMS should be cleaned on a regular basis: once every 30 tests for clean-burning stoves, and once every 10 tests (or more often) for smoky stoves. It is important to record a history of the PM baseline and the full flow Magnehelic pressure reading for every test. It is time to clean the LEMS when the PM baseline increases and the full flow pressure reading decreases. It is a good idea to clean the PM sensor, flow grid, blower, and sample line all at the same time.

11.1.1 PM Sensor

A build up of particles inside the sensor can cause false readings. Access the smoke chamber by opening the white case in the sensor box labeled 'PM Sensor'. The round smoke chamber is opened by gently lifting up the top. Be gentle with the laser. It is attached to the smoke chamber with adhesive, and if it breaks loose the PM sensor must be recalibrated.

Using a Q-tip soaked in rubbing (isopropyl) alcohol, thoroughly clean the inside of the smoke chamber. This includes all the walls, lid, and the notch where the laser light shines through. **The mirror chamber should be cleaned with**

distilled (purified) water only. Gently run the wet Q-tip down into the mirror tube, keeping it as straight as possible. Twist gently to clean the receiver. Ensure no fibers are left from the Q-tip by turning on the laser and carefully looking for fibers; the laser should not be shined directly at your eyes. The walls of the Pelican case may also be cleaned with Q-tips after a rag is used for the large areas. After cleaning, replace the smoke chamber lid and close the Pelican case.

Figure 49: Cleaning PM chamber

Figure 50: Cleaning laser

11.1.2 Flow Grid

The flow grid, located in the ducting, may become clogged with soot, signified by a drop in the pressure reading. Before cleaning, remove the flow grid by releasing the quick-connect clamps. There are four holes facing upstream that need to be cleaned. The soot can be cleaned out by using a toothbrush, other soft-bristled brush, or compressed air. Also, while the exhaust vent is apart, use a rag to wipe off the soot that has built up on the inside of the tubing.

11.1.3 Blower

When the flow rate in the duct slows down, it is likely the blower needs to be cleaned. This can be done by opening the protective housing for the blower and removing the five screws holding the plastic blower housing together. The interior of the blower can be cleaned with a soft bristled paintbrush. Or, if very dirty, the squirrel cage and plastic housing can be removed and washed in warm soapy water. After reassembling the squirrel cage and housing, be sure that the squirrel cage spins freely and is not pushed too far onto the shaft.

11.1.4 Sample Line

The sample line includes the metal portion of the sampling tube, the black sample hose, and the sample hose that connects the smoke chamber and the filter. Clean the metal portion of the sampling tube by removing the black hose and inserting a flexible cylinder of smaller diameter, such as a pipe cleaner, into the metal tube. Clean the inside of the rubber tube with compressed air. **Important**: ensure the tube is disconnected from the sensor and/or filter first, as blowing compressed air through the sensors will harm the seals and the sensors themselves.

11.1.5 Sensor Box Filter Replacement

The large white filter underneath the sensor panel (HEPA filter) will need to be replaced occasionally (less than once per year), depending on use. To see if it is clogged, blow through one end to determine if there is much resistance to flow. If it is difficult to blow through and the filter has turned a dark color, replace it. Replacement filters are available by contacting Aprovecho or another source by referencing the part number, listed on the filter.

11.2 Calibration

Calibration of the PM, CO and CO_2 sensors in the LEMS Sensor Box takes place after construction in the ARC lab. The PM sensor does not need to be recalibrated, provided that the cleaning instructions detailed above are followed carefully. If the PM sensor is damaged in anyway, it must be sent back to ARC for repair and recalibration. The CO sensor needs recalibration once every year, using calibration gasses, detailed below. The CO2 sensor is self-calibrating, however ARC recommends zeroing the sensor in a neutral gas on a similar schedule to the CO sensor calibration. Calibration gases are available throughout the world and ARC will work with your lab to locate the correct gases for calibration. Calibration is also offered by the ARC lab for a small fee. However, sending the Sensor Box can be time consuming and expensive. Investing in calibration gases and the necessary regulators and fittings is recommended. Detailed gas calibration instructions are included in the LEMS software CD.

The calibration constants are stored in the data logger and are output in the header of each CSV file. Enter setup mode (see Section 8) to change the calibration constants.

11.3 Travel

The LEMS is not intended for use as a portable testing system. If a portable system is required, contact ARC for more information about the PEMS system. If the LEMS system needs to be relocated, proper care is essential to ensure the equipment is not damaged. When packing the LEMS for movement, there are a few important considerations. Be sure to wrap foam around the motor of the blower so that any rough travel will not damage the motor, or force the motor cover too far onto the blower, thus preventing it from spinning. Pack the metal tubes so that the sample and flow ports are protected.

The sensor box and gravimetric scale ideally should be carried by hand.

12. Troubleshooting

12.1 Software

12.1.1 Tera Term

- Logger COM(x) Error: The communication software could not find the USB serial adapter on COM(x). The serial adapter may not be assigned to COM(x). This can be corrected in the Device manager.
  - For FTDI adapters: the adapter's firmware may have been corrupted by electrical noise. Reset the adapter by unplugging it from the USB port on the PC.

- Logger does not start upon initial installation:
  - Occasionally communication port software becomes corrupted. Re-download and re-install.

- Logger stops intermittently:
  - Electrical noise can interrupt the USB communication.
  - The best solution is not use a USB converter and connect the Sensor Box data cord directly to an RS232 port on your computer (COM1). Tell the logger software to communicate through COM1 by going to C:\Program Files\Emissions and open the file logger.ttl with a text editor. Line 4 of the code defines the COM port number. Set port = 1 and save the changes.
  - If you do not have a RS232 port, and the USB connection is still bad, try, try installing the two black snap-on ferrite beads. Snap one around the cord coming out of the PEMS sensor box, and one around the USB adapter cord.
  - If the ferrite beads do not fix the problem, try connecting the HEXIN optical isolator in between the USB adapter and RS232 extension cord.

12.1.2 LiveGraph

- LiveGraph displays scrambled data:
  - Toggle "do not cache data".

- LiveGraph flashes every refresh:
  - Unselect “do not cache data”. Using "do not cache data" forces reload of all data on each refresh.

- LiveGraph has skewed axis:
  - When "show tail data" is selected x-axis must be set to "auto" in the "graph settings window".

12.1.3 Data Processing Spreadsheet

- Spreadsheet adds ".xls" extension to whatever string is supplied to the save window prompt.
  - Don't provide the extension.

12.2 If the Blower is Not Working

- Ensure it is receiving the appropriate voltage power from the power transformer supplied.
- Ensure that the blower is wired for the correct mains voltage.
- Open the blower and ensure there is nothing inside the housing and that the parts are not caked in soot and spin freely.

12.3 If the Sensors are Not Working

- If the readings are near zero for all of the sensors, this is likely a problem with the power supply. With the unit plugged in and ON, use a voltmeter to measure the voltage at the DC spring terminals. There should be a voltage close to 12v. Verify power at the cord, and make sure it is seated. If the power supply still doesn't provide 12v, the input section may be damaged, and must be sent back for repair. As a temporary solution: provide 12v, 1A to the DC terminal. ***Observe polarity:*** Red is positive(+), black negative(-).
- If there is 12v at the DC terminal, and the sensors still fail to function, open the power supply case using a screwdriver, and check the internal fuse. Replace the fuse if blown.
- Check to see that all wiring connections under the panel of the sensor box are securely connected.
- If the temperature output says “over”, make sure the thermocouple is plugged in.

12.4 If the Gas Concentrations are Too Low

- Ensure that there are no leaks in the sampling system from the exhaust tube, through the sensor box, to the pump. This can be done by plugging the end of the sample line with your thumb and see if the pump pulls a vacuum. If not, then find the leak. Ensure the sensor boxes are closed tightly. Ensure the tubing is tightly connected. Check the silicone and grommets around the wires, and add silicone as necessary.
- Ensure the filter under the panel has not become clogged. Remove it from the tubing, and blow into one end. Air should move with little resistance. If it does not, contact Aprovecho for a replacement. The filter should not need to be changed very often, unless extremely smoky stoves are tested. When you replace the filter, ensure the flow arrows point towards the CO/CO2 sensors.

12.5 If the Sensor Box Pump is Making Loud Straining Noises

- Check to make sure there are no kinks in the tubing anywhere. First check the black tube from the exhaust to the sensor box. Then lift up the panel to ensure there are no kinks underneath.
- Also check to make sure the filter has not become clogged. This can be done by removing the filter (located under the panel) and blowing through it. There should not be much resistance. Ensure when the filter is replaced the flow arrows point towards the CO/CO2 sensors.

12.6 If the CO_2 Sensor is Giving Strange Readings

- Always ensure that when the sensors are turned on, the air in the CO/CO2 box is clean. It is best to let the sensors run at the end of a test until clean/ambient air is inside. Otherwise, you can open the sensor box to provide fresh air. However, take care not to breathe toward this box or a high level of CO2 will be there.
- If the pump is working too hard due to a kink or a clog, it may affect the power supplied to the CO2 sensor. Ensure this has not happened.
- Rezero the CO2 sensor using calibration gas or ambient air. Contact Aprovecho for appropriate documents.

13. Technical Support

Technical specifications and up-to-date information can be found at www.aprovecho.org. Please contact Alex Seidel at Aprovecho Research Center for technical support:
alex@aprovecho.org.
+1-541-767-0287 (USA Pacific Standard Time Zone)