Instructions for Use of the Portable Emissions Monitoring System (PEMS)

For PEMS #2015 and Newer

Aprovecho Research Center

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1. Purpose of the PEMS

The purpose of the PEMS is to quantify reductions in health-harming emissions from cooking stoves by collecting, measuring, and analyzing emissions of CO2, CO, and PM. Collecting emissions is essential 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).

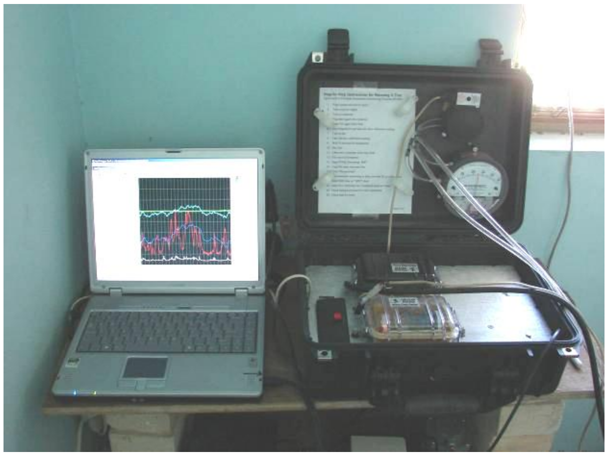


Photo 1: PEMS sensor box and computer

Photo 2: PEMS hood in use

Photo 3: PEMS sensor box, laptop, and hood in cases

Photo 4: Live graphical readout

2. Uses of the System

2.1 Lab-Based WBT

The WBT is used to optimize stoves in the laboratory. The same fuel, pot, and tending practices are used in every test to eliminate those variables in order to focus on the stove alone. When at least three tests per design are completed, differences in performance of differing models can be evaluated.

2.2 Field-Based CCT

Field studies are necessary to see what happens when the stove is used with local fuel, local pots, and local cooking practice. The Controlled Cooking Test (CCT) is great for this. In the CCT, a woman will cook the same meal three times on the improved stove and three times on the traditional stove. When the PEMS is used to measure emissions, the CCT can help to predict real-world fuel, time and emissions savings when the stove is used by local women. Several cooks should be used to provide statistically significant data.

2.3 Teaching

The real-time emissions display of the PEMS can show things like what happens when too much wood is added, or when only charcoal is burning, and how much pollution is emitted at start-up. Changes in emissions when variables such as air supply are adjusted can help to fine-tune a design. This display can be a great teaching tool.

2.4 Global Warming Potential

When fitted with two additional systems that can be purchased separately, the PEMS can also collect all of the data necessary to get a full picture of the Global Warming Potential of the stoves as used in the field. The additional systems include a bag sampling system for gases such as methane and nitrous oxide, and a particle collection system for black and white (ECOC) particle analysis. These samples will require analysis by a capable laboratory.

2.5 Quality Control

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

3. How the PEMS Works

The hood and fan collect the emissions from the stove. The flow rate and exhaust temperature are measured in the exhaust tube. The suction pump draws a sample of emissions through the sample line to the sensors. The thermocouple measures the pot temperature. The computer displays and records the flow and concentrations in real-time. The software processes the recorded data to report the performance of the stove based on the mass of emissions measured.

Sensors

- The CO sensor is an electrochemical cell. It is a potentiostatic circuit which requires a controller. The conductivity between two electrodes in the cell is proportional to the concentration of CO present. It is calibrated using zero and 100 ppm span gas.

- The CO_2 sensor uses NDIR (non-dispersive infrared) to measure CO_2 concentration and outputs voltage. It can be calibrated using zero and 3000 ppm span gas.
- The PM sensor is a scattering photometer. Inside the sensor there is 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.
- The pressure transducer 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.
- The flue temperature sensor is required to calculate the density of exhaust air in order to calculate the mass flow of emissions. Do not put the temperature sensor in water.
- The thermocouple temperature sensor is used to record the water temperature of the pot. The thermocouple temperature output is linear up to 400 C, and the thermocouple probe provided with the PEMS is rated for temperatures up to 250 C.

4. Setting Up the System

4.1 Choosing a Location

The system should be hung from a pulley so that there is approximately 40 cm of space between the pot and the bottom of the canopy. All the smoke should be collected. Incoming breezes should be avoided. It is best to set up the system near walls to help prevent smoke from drifting outside the canopy.

Flexible or rigid ducting may be used to direct the exhaust out a door, window, or vent hole. The smoke should not re-circulate back into the canopy. The length, diameter, roughness, and bends of the exhaust vent will determine the head loss. The total vent head loss should be within 0.04 to 0.24 inches of H20. Once the PEMS is fully installed, check that the head loss (and the flow rate through the duct) is suitable by plugging in the blower fan and reading the Magnahelic pressure gauge. The gauge should read between 0.3 and 0.5 inches of H20. Using larger diameter vent pipe, having fewer bends, and using smooth-walled pipe will decrease the head loss. The following table lists theoretical head loss for smooth walled and flexible ducting at the PEMS flow rate. Use the table as a tool when choosing a location for the PEMS and designing an appropriate exhaust vent.

Theoretical Head Loss of Vent Pipe for PEMS Flow (in inches of H20)

	6 inch diameter (15 cm)	**8 inch diameter (20 cm)**
Smooth Duct Straight Pipe	0.028 inH20 per meter	0.006 in H2O per meter
Smooth Pipe 90º Bend	0.085 inH20 per bend	0.015 inH20 per bend
Flexible Duct Straight	0.034 inH20 per meter	0.010 in H20 per meter
Flexible Duct 90 º Bend	0.103 inH20 per bend	0.031 inH2O per bend

4.2 The Exhaust Tube and Blower Structure

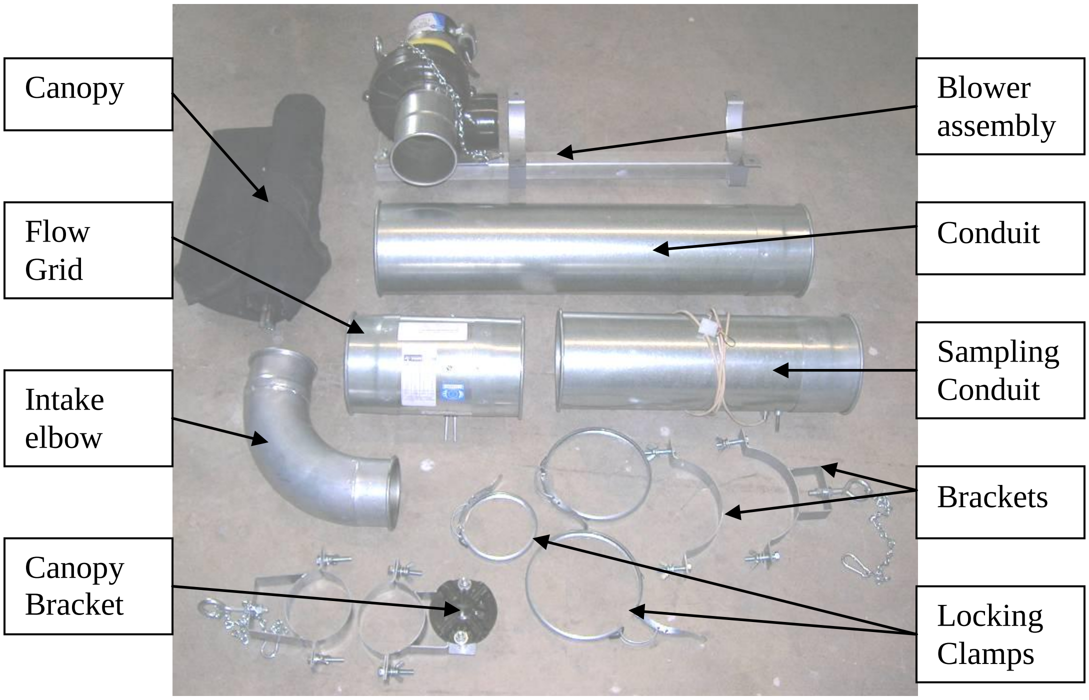


Photo 5: Disassembled hood

Secure the long section of 15cm exhaust conduit into the blower assembly with the bracket. Align the end of the conduit in the same plane as the end of the plastic blower tube so that an open annulus is created for air entry. Tighten down the wing nuts on the bracket “finger tight”. Do not over tighten. Later iterations of this part include a metal housing around the blower to protect it during shipment.

Photo 6: Blower properly aligned with duct

Photo 7: Second bracket installed on the right

Install the second bracket (with chain attached) on the other end of the conduit and tighten down the clamp. Do not use a wrench or over tighten.

Fit the short “flow grid” section of conduit onto the longer piece and secure in place with one of the locking clamps. Make sure that the two short pipes protruding form the flow grid are angled down at approximately 45° below horizontal. Make sure that the red arrow indicating the direction of flow is pointed away from the blower.

Photo 8: Flow grid section attached with sample ports and flow direction oriented correctly

Photo 9: Sampling conduit attached

Attach the third section of conduit onto the “flow grid” using the second locking clamp. Be sure that the sampling tube and temp sensor are angled downward about 45º and are located at the end away from the blower.

Mount the 10 cm elbow onto the intake of the blower using the small locking clamp. The arrow on the elbow should point toward the blower and the elbow should be angled vertically downward perpendicular to the long 15 cm conduit

Photo 10: Right angle elbow attached

Photo 11: Small bracket attached at the correct angle

Install the small bracket (with chain attached) on the blower inlet and slide it outward next to the elbow flange and lock it into place with the wing nuts. The bracket should be rotated so the eye bolt points towards the anchor point at the other end of the 3 chains.

Loosely mount the canopy bracket (with black plastic or Teflon canopy support) on the bottom of the elbow. Insert the canopy collar in-between the mounting bracket and the elbow. Properly orient the canopy and canopy bracket, then tighten the canopy bracket onto the elbow to clamp down the collar.

Photo 12: Canopy bracket attached to elbow

Photo 13: Canopy bracket attached to elbow with canopy collar clamped in between

Photo 14: Proper orientation of canopy and canopy bracket

Attach the three chains to a central ring and hoist the apparatus to working height using a rope and pulley.

Photo 15: Hanging PEMS

4.3 The Canopy

Once the canopy is clamped collar is clamped, and the PEMS is hanging in place, insert the four tent poles into the guides on the canopy. The metal ends of the poles go into the canopy bracket. Loosen the canopy bracket, if necessary, to rotate the canopy into the proper position.

Photo 16: Top view of canopy properly oriented with tent poles inserted

Photo 17: Side view of canopy properly oriented with tent poles inserted

4.3.1 When Testing Stoves with Chimneys

When testing a chimney stove, it is recommended to replace the fabric canopy with a dilution cap. The dilution cap is extremely easy to build with materials available locally. It consists of a metal cylinder with a closed top of at least 35 cm diameter and a 10 cm hole in the side. A 10 cm diameter flexible tube connects the chimney cap to the intake elbow. The top of the cylinder is suspended at least 15 cm above the exit of the chimney. The smoke will collect in the cylinder and be drawn through the emissions system. The incoming dilution air around the chimney ensures that the blower does not affect the draft through the stove.

Instead of using the chimney cap, it is also possible to position the chimney exit under the existing fabric canopy. It is essential that at least 40 cm of space is left between the chimney exit and the fabric of the hood. Using the canopy for chimney stoves is not ideal for several reasons. In order to fit under the canopy, the chimney likely will need to be much shorter than it would be normally installed. This may affect performance. It can also be more cumbersome. Also, the emissions out of the chimney are concentrated and very hot which may harm the fabric canopy or the blower fan.

Photo 18: Dilution cap over chimney stove

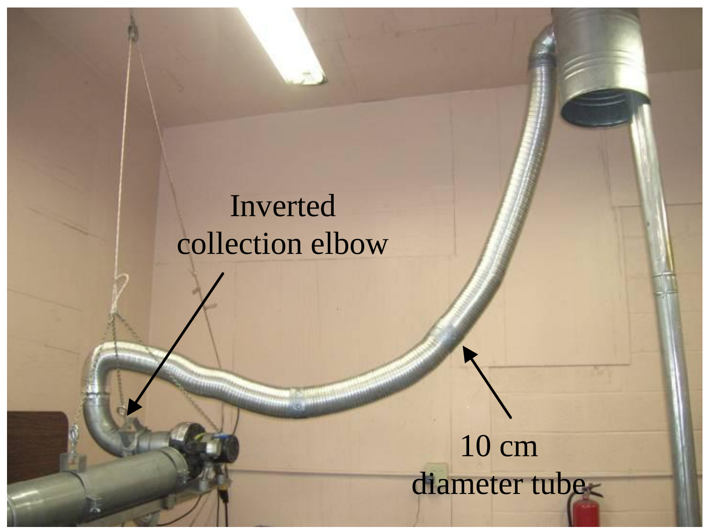
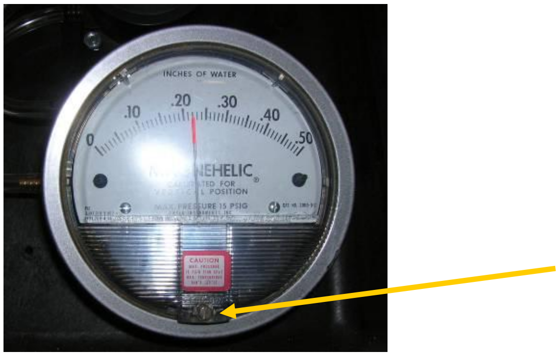


Photo 19: Chimney cap attached to PEMS elbow with 10 cm diameter corrugated vent pipe.

4.4 The Pressure Measurement Device

The two flow grid ports are labeled high and low. Connect the corresponding high and low clear plastic tubes from the sensor box.

Photo 20: Arrow on flow grid showing direction of flow



Ensure the sensor box is set in a stable, level position and the lid is all the way open. The Magnahelic pressure gauge should be vertical. 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.

Photo 21: Zeroing screw of the Magnahelic pressure gauge

4.5 The Sensor Box

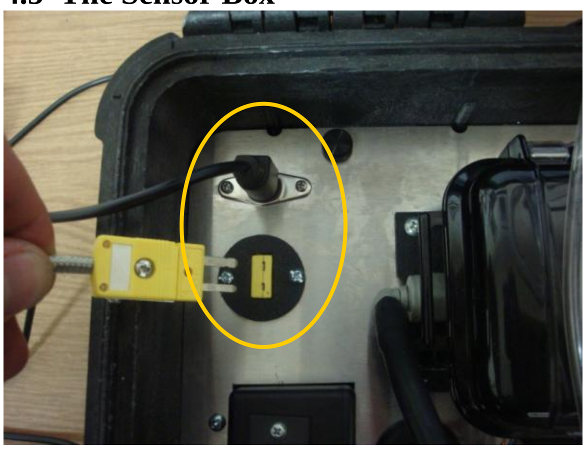


Photo 22: Connecting the temperature sensors

Connect the cord of the flue temperature sensor and the thermocouple to the corresponding plugs in the sensor box.

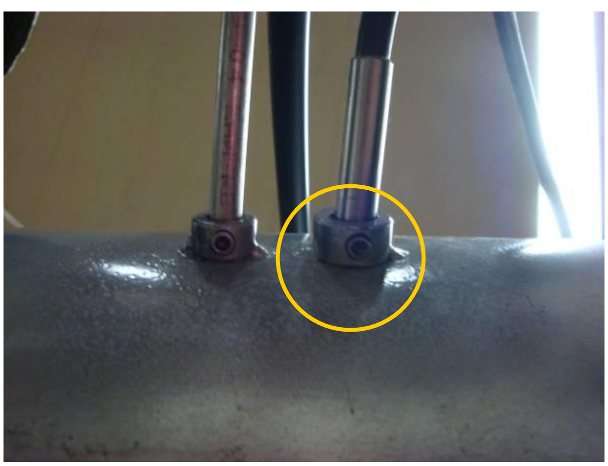
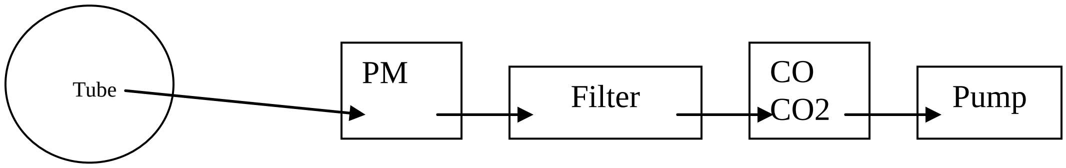


Photo 23: Temperature sensor probe

On the other end of the flue temperature cord, the temperature probe is clamped in a collar on the exhaust duct with a set screw. The set screw can be adjusted with a 3/32” hex key.

Connect the black tube of the sample line to the port at the end of the exhaust tube and the inlet of the PM sensor. The air flow pattern through the sensors is as follows:



4.6 Powering the System

4.6.1 Powering the Sensor Box

Supply 110 VAC power to the plug on the power supply. If the local power supply is 220-240 VAC, be sure to use the provided power transformer to supply 110 VAC, with the selector on the back of the transformer set appropriately.

If you are in the field where no power is available, wires connected to a car battery may be used instead. Insert these into the two wire clips on the power supply. Red/fuse line is positive and black is negative. Note the switch will not work for DC power, so turn the supply on and off by inserting or removing the red wire. A 15A fuse with spares is provided in case of an accidental short with these wires.

Photo 24: PEMS sensor box power supply with DC and AC power terminals

<u>SPECIAL NOTE:</u> You *can* supply both AC and 12 VDC power at the same time to help protect from data loss during AC power "brown outs." To do this, plug the power cord into a wall outlet and also connect the red and black terminals to a 12V battery. Car batteries work best for this, but many types of 12V battery can be used. This way, if the power goes out, no data is missed. The power from the battery is not used unless the AC power goes out.

4.6.2 Powering the Blower

The blower **must** receive 110 VAC power. If the local supply is 220V - 240V, always use the included power converter box to supply 110 to the blower. On the back of the power converter is a selector for the input power, from 200 to 240 VAC.

If you are in the field where no grid power is available, the blower may easily be run off a car battery. This **must** be done through a 350W (700W peak) inverter with 110 VAC output. Connect the inverter directly to the battery using the clips (red is positive and black is negative) and plug the blower into the inverter. An extension cord between the inverter and blower can be used. A typical battery should last about 2 hours while powering the blower and the sensor box, depending on size and charge.

- **Be sure to stop the test or switch batteries when the low-power alarm on the inverter starts to sound**. Otherwise, your battery will be drained to a level where recharging is not effective.
- If the battery is in a car, the car can be turned on to help recharge the battery. The engine may need to be revved to generate enough power to charge the battery.
- It is best to use a separate, or have a spare, battery so that the car will be able to start after the test.

4.6.3 Powering the Computer

The computer can be run off any grid power with the proper power adapter. If you are in the field with no electrical power and the rest of the system is running off a car battery, you can plug the laptop into the inverter, along with the blower, to help maintain the battery if needed.

4.7 Installing the Software and Connecting the PEMS

The following steps explain how to install the PEMS software:

- Insert the PEMS CD and run the PEMS Software Installer. The installer will ask you to verify the directory to install to. For computers with multiple partitions, make sure that the directory is “C:\Program Files”, not “C:\Program Files (x86)”. The installer creates the folders C:\Program Files\Emissions and C:\Emissions-Output. The installer also adds desktop icons for the Logger program and Livegraph.
- Once the installation is complete, go the C:\Program Files\Emissions folder and run the Java installer. Java is required to use Livegraph. If you plan to use the Prolific USB adapter provided with the PEMS, then you must run the PL-2303 driver which is also located in the C:\Program Files\Emissions folder. If this driver doesn’t work, you will have to download an updated Prolific USB to Serial driver for your particular operating system: http://www.prolific.com.tw/eng/downloads.asp?id=31
- Copy the provided files called PEMS_Processing_WBT.xls and PEMS_Processing_CCT.xls from the PEMS CD into the C:\Emissions-Output folder. Save a copy of these files in safe location in case the files get overwritten. These spreadsheets are also available at www.aprovecho.org.
- 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.”

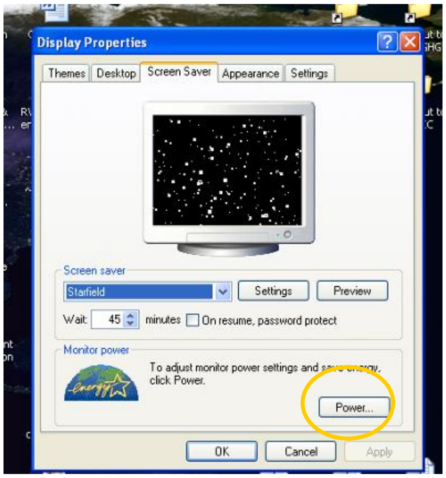


Photo 25: Windows XP screen saver menu

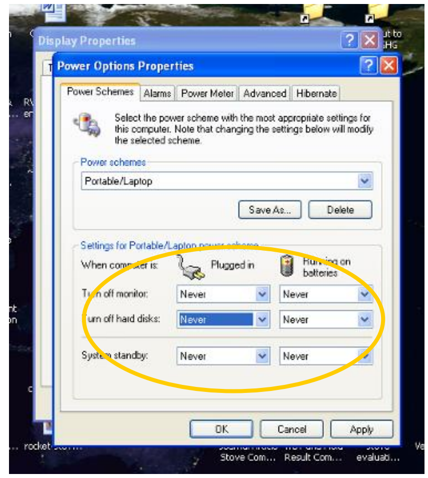


Photo 26: Windows XP power saver menu

- Also ensure that Macros are enabled in Excel so that the automatic processing can take place. This can be done by choosing (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.

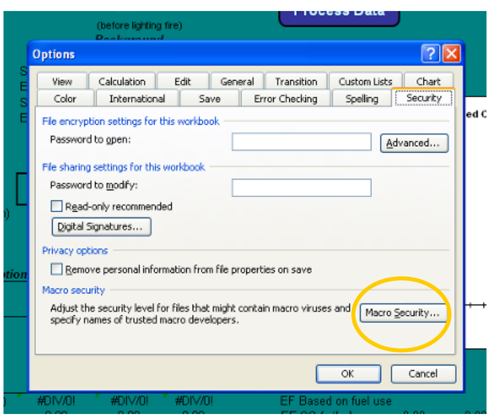


Photo 27: Microsoft Excel Options

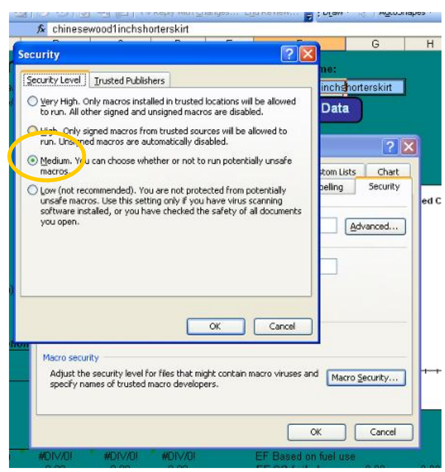


Photo 28: Set Macro security to medium

4.7.1 Establishing a Connection Between the PEMS and Computer

The PEMS outputs data through an RS-232 serial port. The most reliable way to connect the PEMS to the computer is to plug the 9 pin connector of the PEMS cord directly into an RS-232 port on the computer (COM1). 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. Make sure port = 1 and save any changes.

If your computer does not have an RS-232 serial port, we recommend purchasing and installing a serial port card for your computer. If you don't want to do that, then connect to the PEMS with the USB adapter provided. The USB adapter is susceptible to electromagnetic interference. The USB adapter driver must be installed on the computer for it to work. For Prolific PL-2303 adapters, you can download and install the driver from the following link:

www.waltech.com/software-win/PL-2303_Driver_Installer.exe

It is an .exe file and you must reboot after it is installed. To check that the driver was successfully installed, go to Control Panel, then System, then the Hardware tab, then Device Manager. Click the plus sign in front of Ports:(COM & LPT) to see the recognized ports. You should see the Prolific listed as one of the ports available. If there is a yellow exclamation point next to the port name then the driver was not successfully installed, in which case you should try downloading the latest driver for your operating system:

http://www.prolific.com.tw/eng/downloads.asp?id=31

Once the USB adapter driver is successfully installed, go to Device Manager and make sure the USB adapter is showing COM4 as the port number. If a port other than COM4 is assigned to the USB adapter, then you must change it to COM4 by double-clicking on the port. In the Port Settings tab select click Advanced. Change the port in the drop-down menu to COM4. Windows may ask you to verify that you want to change the port number. The last step is to check the port settings in the Logger software. Go 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. Make sure port = 4 and save any changes.

4.8 Additional Gas Sampling

The PEMS can be equipped with an add-on system that collects a sample of the emissions for analysis of other compounds such as methane, nitrous oxide, total unburned hydrocarbons, etc. This is done by a very low flow rate pump which sends about 5-20 cc per minute into a special Tedlar bag. This integrated sample can then later be analyzed at a capable laboratory equipped with FTIR or a gas chromatograph.

If you have ordered the extra gas sampling system, the instructions for use are as follows:

Connect the system as shown, with the shortest tube lengths possible. Turn on the pump and set it at the low flow option in the menu per the pump's instruction manual. Practice filling a bag, adjusting the small screw in the low-flow connector until the rate of bag filling matches the duration of test that you expect. Tightening the screw will slow the flow. This may take several tries to find the proper flow rate, since the flow rate will need to be very low.

Photo 29: Gas sampling system

The pump can be powered by its internal battery during testing. It may be more reliable to run with the pump plugged in to an AC outlet or inverter, if possible.

The distance between the sample port and bag should be as short as possible. The volume of sample throughout the tube and pump system should be considered when deciding the appropriate time to connect the bag after the start of the test, and when to disconnect upon completion of the test. The pump can be let run, and the bag connected and disconnected as needed to ensure only the fire-time samples are filled into the bag.

Key sample handling procedures:

- Do not fill bag more than 80% full
- Analyze sample as soon as possible (<2 weeks delay is necessary)
- Keep samples in dark to prevent light degradation
- Do not ship by air in un-pressurized cargo hold

When choosing a lab for analysis, ensure they are able to measure resolutions less than 10 ppm. Many labs can measure on the % (i.e., 10,000 ppm) level, but few have resolution on the ppm scale.

4.9 Additional Particle Sampling

The PEMS can be equipped with an additional system for in-depth analysis of particle composition and OC/EC (black/white carbon) ratio. This system consists of two filter holders containing three filters, a sampling line with constant flow rate, and an impactor for separating out particles of 2.5 microns and smaller. Filters must be analyzed at a capable lab, likely with a Sunset brand analyzer, for particle composition.

Key filter handling procedures:

- Keep filters as cold as possible (frozen is best) when not in use
- Handle filters with forceps and gloves only
- Seal filter containers with Teflon tape to prevent contamination

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 PEMS cord into the computer.
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 is recognized as COM4. Once this has been verified, it does not need to be done again, provided the same USB port is used each time.
4. Open the "Logger" icon on the desktop and follow the on-screen steps.
5. When the message says "Power up or reset logger now", use the switch on the power supply to turn the PEMS on (Photo 24). If the PEMS is already on then simply hold the red reset button down to reset the data logger. The reset button must be held down for AT LEAST ONE FULL SECOND in order to reset the data logger. When the PEMS is on, you will hear the suction pump running and a faint orange light on the CO2 sensor will blink.

Photo 30: Reset button

6. Click "okay" and the Tera Term window will display the incoming PEMS data:

```
# type cal (in 5 seconds)
# 'log' command starts logging >log
#logging
```

```
##,##
# ,.087,.263,13.6, ,.00381,.1
seconds,CO,CO2,PM,flow,gas temp,pot temp
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 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 degrees C. You can apply a scaling factor of 0.1 to the thermocouple reading to see the output in degrees C.

4. Plot window

   -move cursor over a point to see the coordinates

5.3 Checking the Readings

- Take a quick look at the readings with the blower off. Scroll over each line on the graph 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. CO should be reading in the range of 0 - 100, CO_2 should be about 3000, Flow should be about 10,000 with the blower off, PM should be 100 -300, and flue temperature should be about 5000 (262 logunits per deg C). All outputs are in logunits (0 - 65535), except for the pot temperature (thermocouple) which has units of degrees C x 10.

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 Magnahelic using the small screw to ensure it is reading 0 (Photo 21).
- The background period starts 4 minutes after the PEMS 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. So 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 Magnahelic 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 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 canopy 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. The CO_2 sensor is self-zeroing, so it must be started with ambient air inside the case.
- Then simply 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. This file is called "PEMS_Processing_WBT/CCT.xls."
- Open the data processing file. Click "Enable Macros" when the box appears to warn you that you are about to open a Macro file.

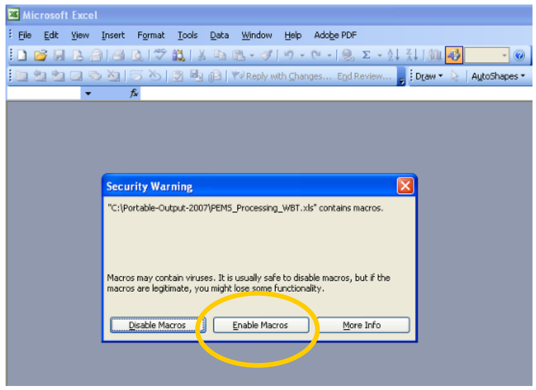
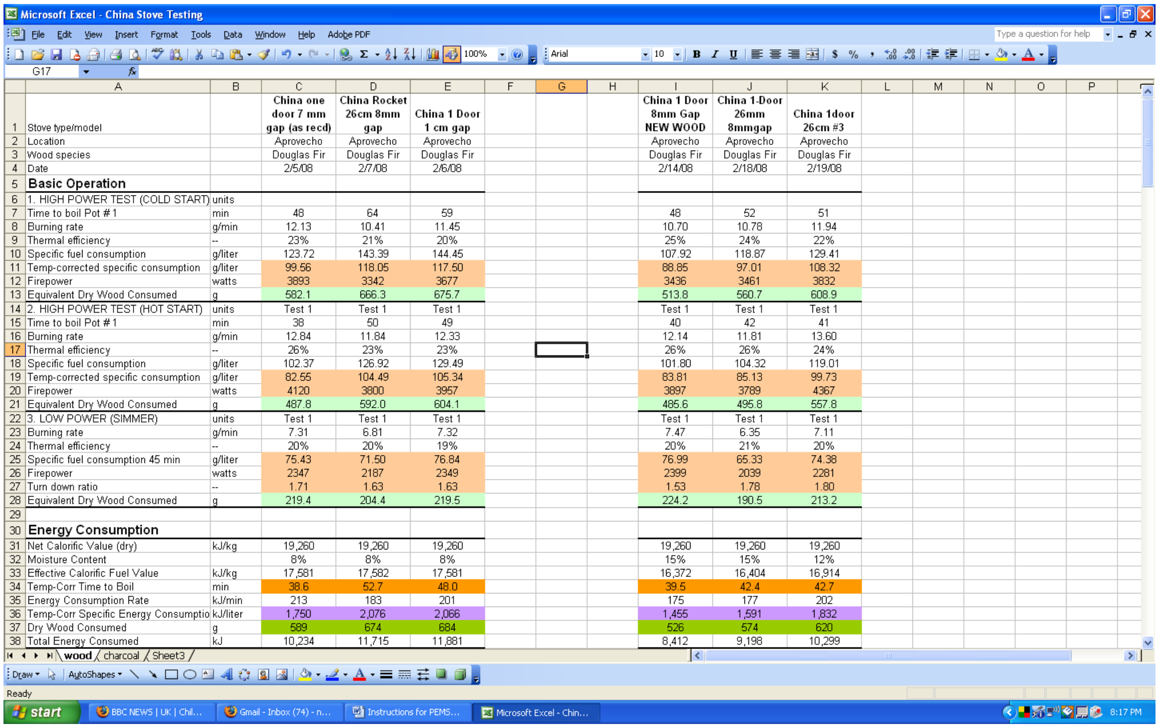


Photo 31: Microsoft Excel 2003 macro security warning pop-up window

- Select the Data Import sheet. Enter the PEMS serial number and the file name in the orange cells, then verify the carbon content of the fuel. The PEMS serial number identifies the data file format for the spreadsheet.
- Then 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 sheet. 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.



	A	B	C	D	E	I	J	K
1	Stove type/model		China one door 7 mm gap (as recd)	China Rocket 26cm 8mm gap	China 1 Door 1 cm gap	China 1 Door 8mm Gap NEW WOOD	China 1-Door 26mm 8mmgap	China 1door 26cm #3
2	Location		Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho	Aprovecho
3	Wood species		Douglas Fir	Douglas Fir	Douglas Fir	Douglas Fir	Douglas Fir	Douglas Fir
4	Date		2/5/08	2/7/08	2/6/08	2/14/08	2/18/08	2/19/08
5	**Basic Operation**							
6	1. HIGH POWER TEST (COLD START)	units						
7	Time to boil Pot # 1	min	48	64	59	48	52	51
8	Burning rate	g/min	12.13	10.41	11.45	10.70	10.78	11.94
9	Thermal efficiency	--	23%	21%	20%	25%	24%	22%
10	Specific fuel consumption	g/liter	123.72	143.39	144.45	107.92	118.87	129.41
11	Temp-corrected specific consumption	g/liter	99.56	118.05	117.50	88.85	97.01	108.32
12	Firepower	watts	3893	3342	3677	3436	3461	3832
13	Equivalent Dry Wood Consumed	g	582.1	666.3	675.7	513.8	560.7	608.9
14	2. HIGH POWER TEST (HOT START)	units	Test 1	Test 1	Test 1	Test 1	Test 1	Test 1
15	Time to boil Pot # 1	min	38	50	49	40	42	41
16	Burning rate	g/min	12.84	11.84	12.33	12.14	11.81	13.60
17	Thermal efficiency	--	26%	23%	23%	26%	26%	24%
18	Specific fuel consumption	g/liter	102.37	126.92	129.49	101.80	104.32	119.01
19	Temp-corrected specific consumption	g/liter	82.55	104.49	105.34	83.81	85.13	99.73
20	Firepower	watts	4120	3800	3957	3897	3789	4367
21	Equivalent Dry Wood Consumed	g	487.8	592.0	604.1	485.6	495.8	557.8
22	3. LOW POWER (SIMMER)	units	Test 1	Test 1	Test 1	Test 1	Test 1	Test 1
23	Burning rate	g/min	7.31	6.81	7.32	7.47	6.35	7.11
24	Thermal efficiency	--	20%	20%	19%	20%	21%	20%
25	Specific fuel consumption 45 min	g/liter	75.43	71.50	76.84	76.99	65.33	74.38
26	Firepower	watts	2347	2187	2349	2399	2039	2281
27	Turn down ratio	--	1.71	1.63	1.63	1.53	1.78	1.80
28	Equivalent Dry Wood Consumed	g	219.4	204.4	219.5	224.2	190.5	213.2
29								
30	**Energy Consumption**							
31	Net Calorific Value (dry)	kJ/kg	19,260	19,260	19,260	19,260	19,260	19,260
32	Moisture Content		8%	8%	8%	15%	15%	12%
33	Effective Calorific Fuel Value	kJ/kg	17,581	17,582	17,581	16,372	16,404	16,914
34	Temp-Corr Time to Boil	min	38.6	52.7	48.0	39.5	42.4	42.7
35	Energy Consumption Rate	kJ/min	213	183	201	175	177	202
36	Temp-Corr Specific Energy Consumptio	kJ/liter	1,750	2,076	2,066	1,455	1,591	1,832
37	Dry Wood Consumed	g	589	674	684	526	574	620
38	Total Energy Consumed	kJ	10,234	11,715	11,881	8,412	9,198	10,299

Photo 32: PEMS Processing Sheet results column comparison sheet

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

- Heat transfer results, such as specific fuel consumption, temp-corrected time to boil, firepower, etc. Separated for each test phase.
- Mass emissions for each test phase
- 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)
- The average of cold and hot starts
- A carbon balance based on fuel input and carbon output. The carbon balance is only as good as the estimate of fuel carbon content, so the values are fairly rough, and any value between 70% and 120% should be okay, though the ideal is about 95%.
- Consolidated results: fuel use and emissions to complete the WBT, highlighted in green, is the most useful because it incorporates both heat transfer and emissions as an average of cold and hot start added to simmer. This is the most frequently used measure of stove performance, and is used in the Aprovecho benchmarks of performance. **This is the most important data in the results, and the best measure for comparing stove tests**.
- If additional gas sampling was done, the results of these follow.

8. Changing Parameters in Setup Mode

Setup mode allows you to change:

1. Calibration constants displayed in the header of the data file
2. Channel names displayed in the header of the data file
3. Zero offsets of each channel

To enter setup mode, connect to the PEMS 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 PEMS 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>. The DAQ will eat the letter "c" and only "al" will be displayed on the screen. If you miss your chance to enter the word, or if you type something other than "cal", then the PEMS 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
 enter 1,2,3 >
```

To exit setup mode turn off the PEMS.

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 PEMS data processing spreadsheets, the calibration constants are in units of:

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

8.3 Change Zero Offsets

Enter “3” from the main menu and the display will show:

```
Offset Entry Menu (positive, 65535 max)

channel:  name, Offset
0: CO 150
1: CO2 0
2: PM 0
```

3: flow 0
4: gas temp 0
5: pot temp 0

enter channel number to change >

Only positive offsets can be added. Enter the channel number that you would like to change the offset for and the display will be:

you entered: 3
enter new offset >

Once you enter the new offset value the prompt will return to the main menu. Enter "3" again to check that the new offset was stored correctly. Turn off the PEMS to exit setup mode.

10. Adding Additional Channels

The PEMS is equipped with a Waltech 21 channel 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 PEMS port and turn on the PEMS 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 PEMS. For more information about which channels are available and how to configure new channels, contact Aprovecho for the Waltech Configurable DAQ Manual.

9. Special Notes

- Never run a stove without a pot of water under the canopy. The pot cools the flames enough so that the canopy and blower do not overheat. If the blower shuts off, it is likely it has overheated.
- The canopy is made of fire resistant fabric, but will melt if exposed to direct flames or the exit of a chimney. It may be a good idea to build a sheet metal hood for stationary lab tests, and save the fabric hood for portable uses. Chimney stoves are best tested using a Dilution Cap rather than the canopy.
- 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 stack of stoves with chimney can be measured by placing the canopy about 40 cm above the top of the chimney. The best option is to use a dilution cap on the chimney, without the hood.
- ❖ The PEMS_Processing.xls 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. If there is too much emissions for the blower to collect, they will leak out of the canopy, and the emissions concentrations can become too high for the sensors. Reducing the head loss in the exhaust duct and cleaning the blower will allow the PEMS to handle higher concentrations of emissions.

10. Care and Maintenance

10.1 Cleaning

The PEMS 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. Record a history of the PM baseline and the full flow Magnahelic pressure reading for every test. It is time to clean the PEMS 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.

10.1.1 PM Sensor

A build up of particles inside the sensor can cause false readings. Access the smoke chamber by opening the Pelican case 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 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, but don’t shine the laser in your eye. 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.

Photo 33: Cleaning the smoke chamber with rubbing alcohol

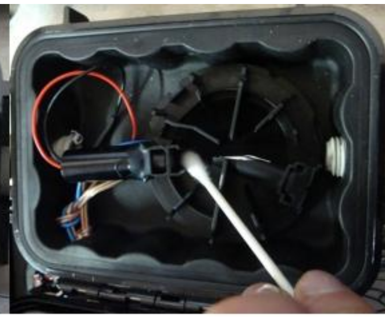


Photo 34: Cleaning the laser lens with rubbing alcohol

Photo 35: Cleaning the mirror chamber with distilled water

10.1.2 Flow Grid

The flow grid pressure reading will become attenuated as the holes become clogged with soot. Before cleaning, remove the flow grid from the exhaust tube by releasing the clamps. There are four holes facing upstream that need to be free of soot. 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 vent.

10.1.3 Blower

When the flow rate in the duct slows down, it is likely the blower needs to be cleaned. This can be done by lowering the system and disconnecting the intake elbow from the blower. Open the protective housing for the blower. There are five screws holding the plastic blower housing together. These can be removed, and 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.

10.1.4 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. Please 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.

10.1.5 Filter Replacement

The large white filter underneath the sensor panel 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 searching the internet for the filter part number, listed on the filter.

10.2 Calibration

The sensors can be calibrated in-house when possible or sent back to Aprovecho for calibration. If in-house calibration is possible, the recommended frequency is once per month. For those who cannot calibrate themselves, the sensor box alone can be sent to Aprovecho for calibration for a small fee.

The CO and CO2 sensors are calibrated using zero and span gas. For the span gas, a mixture of 100 ppm CO and 3000 ppm CO2 can be used. The ppm/unit calculation is then used as the calibration factor, entered in the “Assumptions” sheet of both the WBT and CCT software.

There are a few ways to calibrate the PM sensor:

1. Connect the nephelometer in-line with the sampling system, just before the PM sensor. Run a stove under the hood with varying smoke emissions, and then compare the signal between the two instruments for a calibration. It is easier to compare the two signals if the smoke output is a constant concentration.
2. Generate smoke in a barrel or cardboard box. Mix the smoke with a fan, then draw off a sample through the neph and the PM sensor.
3. Use a gravimetric pump and filter system in-line with the PM sensor.

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.

10.3 Travel

When packing the PEMS for shipment, there are a few important considerations.

It is generally best to pack all of the emissions collection structure into a full sized suitcase. The weight of this structure plus suitcase (minus the power transformer) is usually about 50 pounds, the weight limit for most airlines. 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. Also try to pack the metal tubes so that the sample and flow ports are protected.

The sensor case should be packed separately, such as in a personal suitcase surrounded by clothing.

11. Troubleshooting

11.1 Software

11.1.1 Tera Term

- Logger COM4 Error: The communication software could not find the USB serial adapter on COM4.
    - The serial adapter may not be assigned to COM4. This can be corrected in the Control Panel.
    - For Prolific 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 gets corrupted during transfer. 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 PEMS cord directly to an RS-232 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. Otherwise, try a shorter USB cable, ground PEMS panel, and ground exhaust duct.

11.1.2 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".

11.1.3 Data Processing Spreadsheet

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

11.2 If the Blower is Not Working

- Ensure it is receiving 110 VAC power from the power transformer supplied.
- Ensure the input power on the back of the transformer is set correctly (i.e. 220V or 240V).
- Open the blower and ensure there is nothing inside the housing and that the parts are not caked in soot and spin freely.
- Sometimes during shipping, the cylindrical case around the motor can get jammed too far onto the motor. If this has happened, contact Aprovecho for instructions for removing the blower motor and resetting the cover.
- If the blower slows or stops during a test, it is possible that it has overheated. Let the blower cool, and retry. Always ensure there is a pot on the stove being tested.

If an extremely large fire is being tested, it may be that this firepower is too great for the flow provided by the blower and exhaust. Provide a cooler sample in the future, either by raising the PEMS higher over the fire or reducing the fire size.

11.3 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.

11.4 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.

11.5 If the 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.

11.6 If the CO2 is Giving Strange Readings

- Always ensure that when the sensors are turned on, the air in the CO/CO2 box is clean. The CO2 sensor is self-zeroing, so if a high concentration of CO2 is in the box at start-up, the zero will be affected. 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 CO_2 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 CO_2 sensor. Ensure this has not happened.

12. Technical Support

Please contact Ryan Thompson at Aprovecho Research Center for technical support:
rt@aprovecho.org
541-767-0287 (US Pacific Time Zone)