WHO Household Multiple Emission Sources (HOMES) and Performance Target (PT) Model: Input Parameter Protocol – Stove Usage

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Version 2.3

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Model parameter: Emissions source usage times / cooking time

Objective

Measure the daily average usage time for the emissions sources used in the WHO Household Multiple Emission Sources (HOMES) and Performance Target (PT) models. With this input data, along with the other input parameter, the model can be used to estimate daily average room-level pollutant concentrations and personal exposure.

Background and context

There are different approaches to measuring the amount of time that emissions sources are running, which include: direct measurement with stove use sensors, assessment from participant reports, and direct observations by study staff. Direct, sensor-based stove usage measurements are considered the most accurate and reliable method for determining cooking time. Surveys or time activity diaries can also be used to estimate cooking time, but alone, they are limited due to participant recall bias and inaccurate memory. It is recommended that direct usage measurements or direct enumerator observations are used in addition to surveys.

This document provides guidance on applying techniques for measuring stove usage, focusing on sensor-based measurements. Example instructions using iButton sensors are provided in the Annex, though all stoves, sensors, and contexts require their own specific procedures, which should be piloted extensively prior to large-scale deployments.

The WHO air quality model requires stove use time as an input, as the longer stoves are in use, the greater the contributions to the indoor air pollution, and vice versa. The protocols described here provide the means to estimate the mean and standard deviation inputs required for the model.

Equipment required

- Stove usage monitor (if using the direct measurement method)
    - Stove usage monitor accessories vary, but may include hardware for mounting, insulation material, waterproofing material, extra batteries, thermocouple probes, data sharing accessories like cellular phone data credits, and computer adapters for launching/downloading.
- Usage/time activity questionnaires for both the direct and indirect measurement approaches.

Sensor-based usage measurements

The table below outlines a variety of stove use monitoring sensors. Each project is different and a number of considerations should be taken into account when selecting the sensor(s) to be used. For example, the stove types, desired temperature sensing range, battery duration, budget, and processing/analyses needs all play important roles in selecting the right sensors. This table is only intended as a general resource and is not exhaustive of all options, nor does it contain detailed operating instructions as may be obtained from the manufacturers.

Table 1. Selected devices for measuring stove use

Device[1]	Data collection capacity	Placement requirements	Made/sold by	Best for monitoring	Other factors
Dots (thermocouple logger, $$)	**Memory:** 1 year **Battery:** 1 year **Reusable:** Yes	Thermocouple based data logger. Small box mountable to most stove types.	Geocene	Any cookstove (with appropriate testing)	Data downloaded wirelessly, has an automatic cookstove identification feature and a web-based dashboard for analysis. Measures >500 C°
EXACT (infrared logger, $)	**Memory:** 2.5 months **Battery:** up to 4 years **Reusable:** No	Place on stove or up to 2m from stove. Sensor should be pointed at a part of the stove that heats up quickly.	Climate Solutions Consulting	Good for stationary stoves for which direct sensor placement on the stove is difficult.	Data downloaded wirelessly, has an automatic cookstove event identification feature. Measures >500 C°
iButton (direct-mount sensor, $-$$)	**Memory:** 7-28 days **Battery:** 1 year **Reusable:** No	Small and unobtrusive for quick installation.	Made by Maxim. Sold by Berkeley Air Monitoring Group	Low thermal mass portable stoves.	Mobile platform for instrument launching and data download. Maximum temperature limit from 85-125 C° can make data analysis challenging for high thermal mass stoves.
kSUMs (thermocouple logger, $$$)	**Memory:** 2-3 months **Battery:** 2 months **Reusable:** Yes	Data logger plus three thermocouple leads allow measurement of up to three pot openings plus ambient.	Berkeley Air Monitoring Group	Built in, high thermal mass flaming stoves, multiple burner stoves.	Rechargeable internal battery. Measures >500 C°
SWEETSense (thermocouple logger, $$$)	**Memory:** 6-18 months **Battery:** 6-18 months **Reusable:** Yes	Medium sized box, can be mounted to most stove types.	SWEETSense	Any cookstove (with appropriate testing)	Uses cellular network to upload data to an internet database where data is analyzed and summarized. Measures >500 C°
StoveTrace (bar-mounted thermistor, $$$)	**Memory:** Storage is configurable to preferences. Currently stores up to 1 year on device, and infinitely on the dashboard **Battery:** Up to 3 days rechargeable battery **Reusable:** Yes	Needs a safe stationary place for wireless data transmission equipment.	NexLeaf Analytics	Any cookstove (with appropriate testing)	Automatically logs data and transmits real-time to a centralized server with customizable analytics. Measures up to 300 C°
Wellzion (thermocouple logger, $)	**Memory:** 3.5 months **Battery:** up to 12 months **Reusable:** Yes	Thermocouple based data logger. Small, can be directly mounted to most stove types.	Wellzion	Any cookstove (with appropriate testing)	Requires additional enclosure for weather-proofing. Measures >500 C°

[1] Cost: $ < 35USD, 35 < $$ < 100, $$$ > 100

Notes on stove usage device installation and analysis

Installation: Although the different instruments have varying installation requirements, placement of the device should generally follow these key guidelines:

- Temperature sensor and logger should not be placed in a location that will exceed their maximum operating/sensing temperatures.
- Sensor placements should provide maximum temperature differential between ambient and stove/combustion temperature (without exceeding maximum operating temperature for sensor).
- It is highly recommended that the project stoves' temperature profiles during burn events be analyzed before the field campaign so that the optimal placement can be determined according to the above two points.
- If the stoves and sensing units (e.g. thermocouple leads) can be kept out of direct sunlight, this will help reduce false positives from sensors heating up due to the radiant heat of the sun.
    - Data analysis can be challenging for stoves that are frequently moved indoors and outdoors for cooking, due to solar radiation affecting heating and cooling rates, so piloting placement of temperature monitors or probes is critical for such applications.
- Sensor placement should be standardized as much as possible between stoves.
- Sensor and logger placement should not interfere with participants' normal activities and should minimize risk of the sensor being accessed/moved/damaged by children, or other risk factors in the household like water, insects or animals, and other people.
- Explain to the participants that the SUMs are for measuring temperature and they should not be tampered with, including pressing buttons, moving parts, or connecting it to computers or power.
- Collecting data over all seasons is recommended in order to identify usage behaviors that may vary with season, like food and fuel availability.
- Measuring houses for multiple weeks at a time also reduces the effects of day-to-day variability on the overall usage results.

Stove temperature analysis: As with the sensor placement, analysis of the signals to derive cooking time are specific to the sensors and the stoves being analyzed. Even so, there are some general guidelines that can be helpful for conducting the analysis.

- After use events, stoves generally will cool down and thus care should be taken to determine at which point during that cool down period should the end of an event be considered. Determining this point can be especially difficult if the sensors are measuring temperature of a high thermal mass stove, which will cool down more slowly.
- Subtracting ambient temperature generally improves the ability to resolve a temperature response during stove use from normal diurnal and seasonal temperature variation.
- Cooking event identification using sensors with lower operating temperature limits has presented challenges in previous works (e.g. Pillarisetti et al., 2015). Thermocouple and thermistor type sensors have performed well in the few validation studies performed (Thomas et al., 2013; Graham et al., 2014).
- Perform validation or sense checks on the algorithms used to determine stove use. These can include:

- Having a person with expertise manually inspect at least a subset of analyzed files to check that the algorithm is determining apparent cooking events as intended.
- Using observational data of use events to cross-reference with the analyzed data.
- Use common sense checks with what is generally known about cooking behaviors in the region. For example, if only 20 minutes per day is showing up as cooking when it's known that people are using several kg of fuel every day, the data should be checked/flagged.

Direct observation

Direct observation of stove use provides an objective means to determine how long stoves are in use. Surveyors may use structured forms to help systematically record when stoves are and are not being used. This approach has the advantage of being able to collect additional information about what is being cooked and how the stove is being operated. However, this method is labor intensive and not well-suited for measuring how stove use patterns change over time. An important caveat is that the presence of researchers may affect participant behavior. Assessment of stove stacking with direct observation would require a large sample (hundreds or more) of spot checks randomly distributed over the day, which again, is labor intensive and difficult to implement over long time periods.

Survey-based estimates for stove usage

Reported stove use estimates are generally the fastest and least expensive ways to collect large quantities of device usage time estimates. Data collection tools can include paper surveys, time-activity diaries filled out by participants, electronic platforms such as tablets or smart forms, or audio recorders. A major concern with participant-reported stove use estimates is that they can be biased or unreliable (Thomas et al., 2013; Simons et al., 2014; Piedrahita et al., 2016). General guidelines are provided here:

- Let the participants know in advance of collecting the data that they will be asked about the amount of time they use their stoves.
- Prompt participants about their usage times of day (e.g. morning), events (e.g. heating water), and disaggregate by stoves used for different events.
- Ask only about the previous day of stove use estimates, in order to reduce error from uncertain recall.
- Include questions on whether the reported day was a normal day of stove use.
- Include questions on whether the amount of stove use during that time of year is different from other times of the year.
- If possible compare subsets of simultaneously collected observational or sensor-based estimates with the reported stove use times. If there is clear systematic bias in the reported results, adjust as needed based on the direct stove use measures.
- If appropriate for the campaign, explain to the cooks that accurate information is important for the work, and there are no penalties for answering in ways that they think the surveyors may not be pleased with.

References

Graham, E. A., Patange, O., Lukac, M., Singh, L., Kar, A., Rehman, I. H., & Ramanathan, N. (2014). Laboratory demonstration and field verification of a Wireless Cookstove Sensing System (WiCS) for determining cooking duration and fuel consumption. *Energy for Sustainable Development*, 23: 59–67. https://doi.org/10.1016/j.esd.2014.08.001

Piedrahita, R., Dickinson, K. L., Kanyomse, E., Coffey, E., Alirigia, R., Hagar, Y., Hannigan, M. (2016). Assessment of cookstove stacking in Northern Ghana using surveys and stove use monitors. *Energy for Sustainable Development*, 34: 67–76. https://doi.org/10.1016/j.esd.2016.07.007

Pillarisetti, A., Vaswani, M., Jack, D., Balakrishnan, K., Bates, M. N., Arora, N. K., & Smith, K. R. (2014). Patterns of Stove Usage after Introduction of an Advanced Cookstove: The Long-Term Application of Household Sensors. *Environmental Science & Technology*. https://doi.org/10.1021/es504624c

Simons, A. M., Beltramo, T., Blalock, G., & Levine, D. I. (2014). Comparing methods for signal analysis of temperature readings from stove use monitors. *Biomass and Bioenergy*. https://doi.org/10.1016/j.biombioe.2014.08.008

Thomas, E. A., Barstow, C. K., Abadie Rosa, G., Majorin, F., & Clasen, T. F. (2013). Use of remotely reporting electronic sensors for assessing use of water filters and cookstoves in Rwanda. *Environmental Science & Technology*. https://doi.org/10.1021/es403412x

Annex: Example instructions for Monitoring with iButtons

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MONITORING GROUP

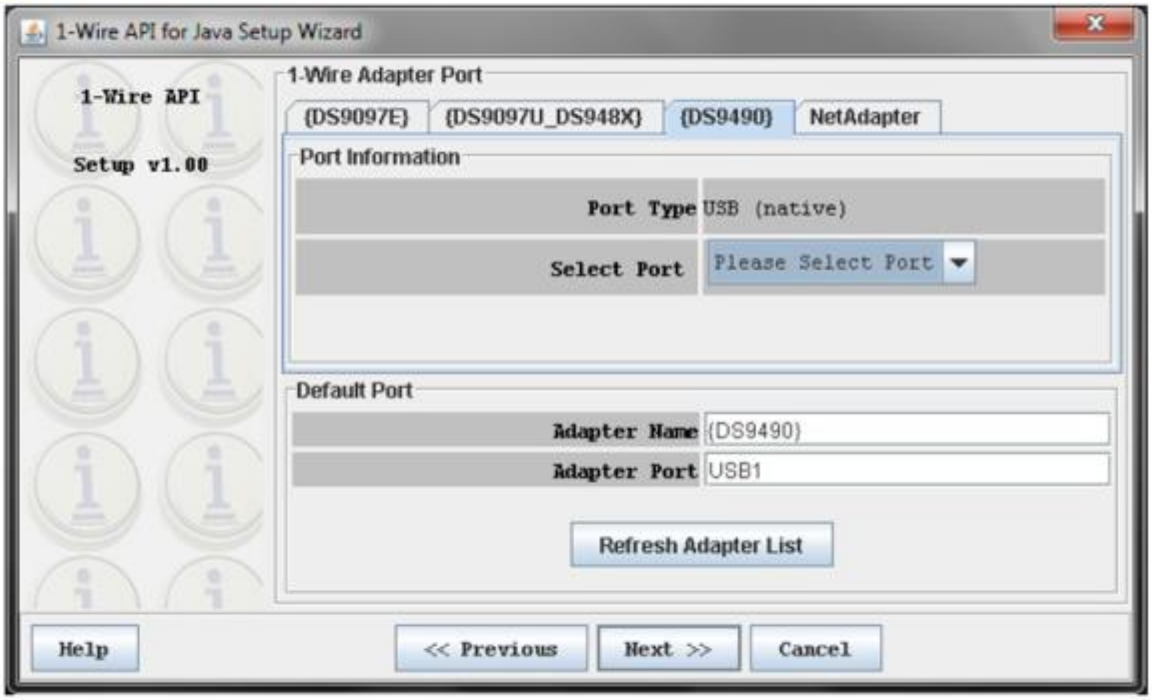
SUMS User Guide

What's Included in the SUMS Kit

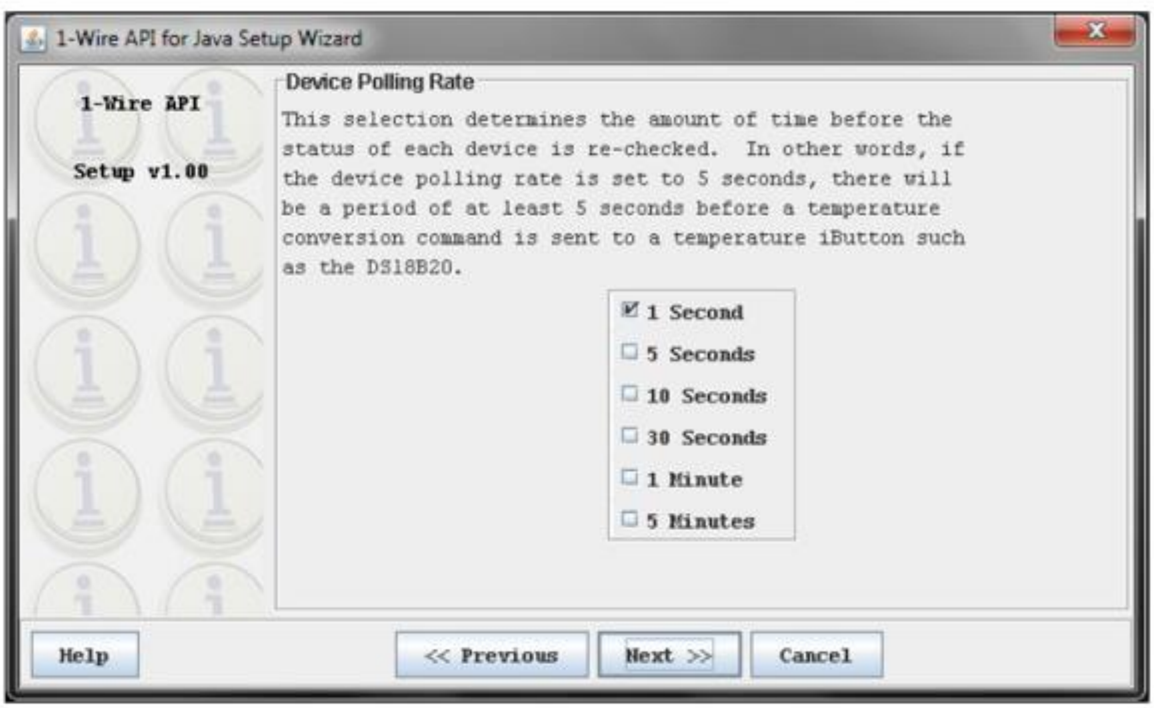
1. Logging temperature sensors (iButtons)
2. Probe and USB converter – used to connect the temperature sensors to your computer for launching and downloading
3. SUMS software CD, which contains:
    a. SUMS User Guide
    b. SUMS iButton R10 – folder containing the program (*SUMS iButton*) to view and process SUMS files
    c. Install_1_wire_drivers_x86_v403 – installer for the program (*OneWireViewer*) to launch and download data from the sensors (this is 32-bit software compatible with Windows 7, Vista, and XP SP2 or higher; 64-bit software is available for download at the 1-wire website: www.maxim-ic.com/products/ibutton/software/tmex/download_drivers.cfm)
4. Heat resistant tape – can be used to attach sensors to stove

Installing the Software

1. *SUMS iButton*: The software package is currently in beta testing and does not yet fully install on the computer. To run simply open the SUMS ibutton application. Note that the file must be located in the same folder as the "SUMS.Excel9.Interop" application extension in order to work properly.
2. *OneWireViewer*: must be installed onto computer from the installer (Install_1_wire_drivers_x86_v403) found on the CD
    a. Open the file "Install_1_wire_drivers_x86_v403" and follow the on-screen instructions to install the software
    b. After installation is complete, the folder "1-wire Drivers x86" will appear in your program menu
    c. Plug in the probe and USB converter. Your computer should automatically recognize the device and install the drivers for its use.
    d. Once the device drivers have been installed successfully, open the "OneWireViewer.exe" program (this is the program used to launch and download data from the sensors) from the "1-wire Drivers x86" folder.
    e. The following window will appear:



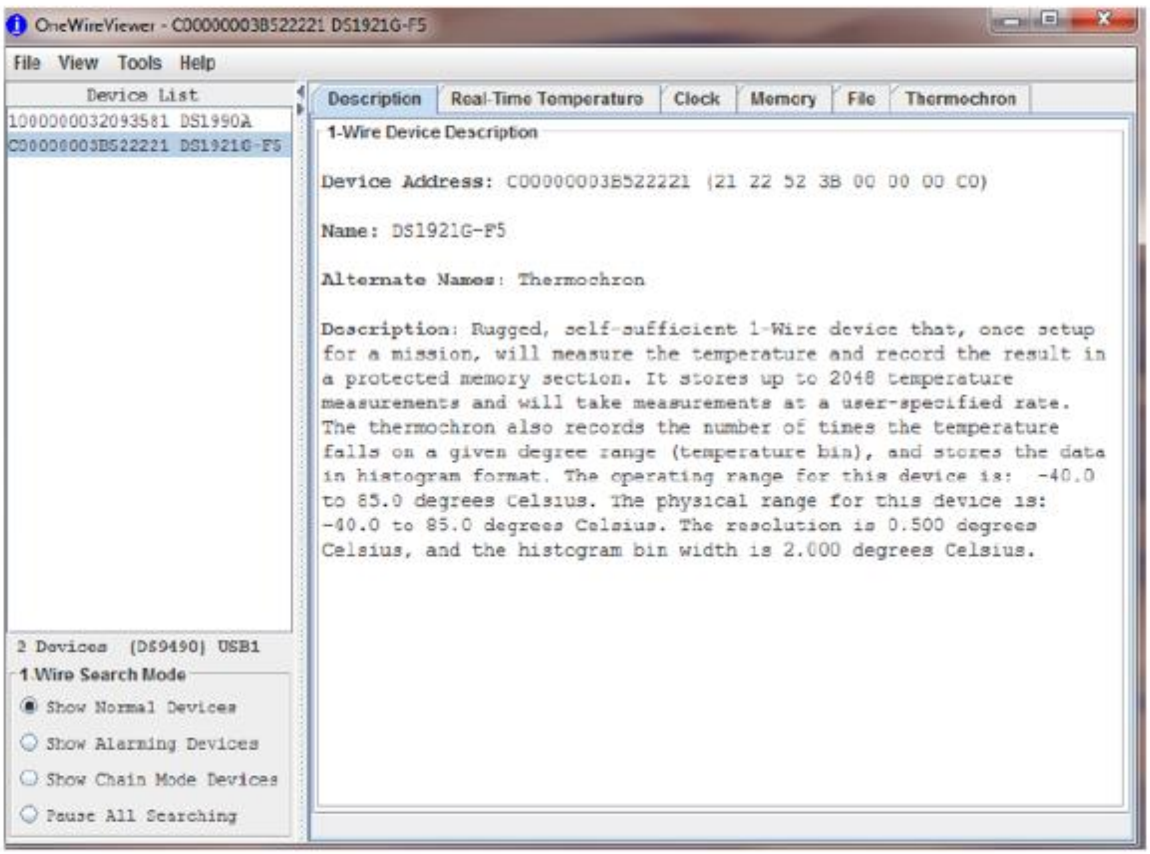
f. Ensure that the correct port is selected and click "Next".
g. The next window asks how often you want the software to refresh communication with the sensor. For best results, select "1 Second" and click "Next".



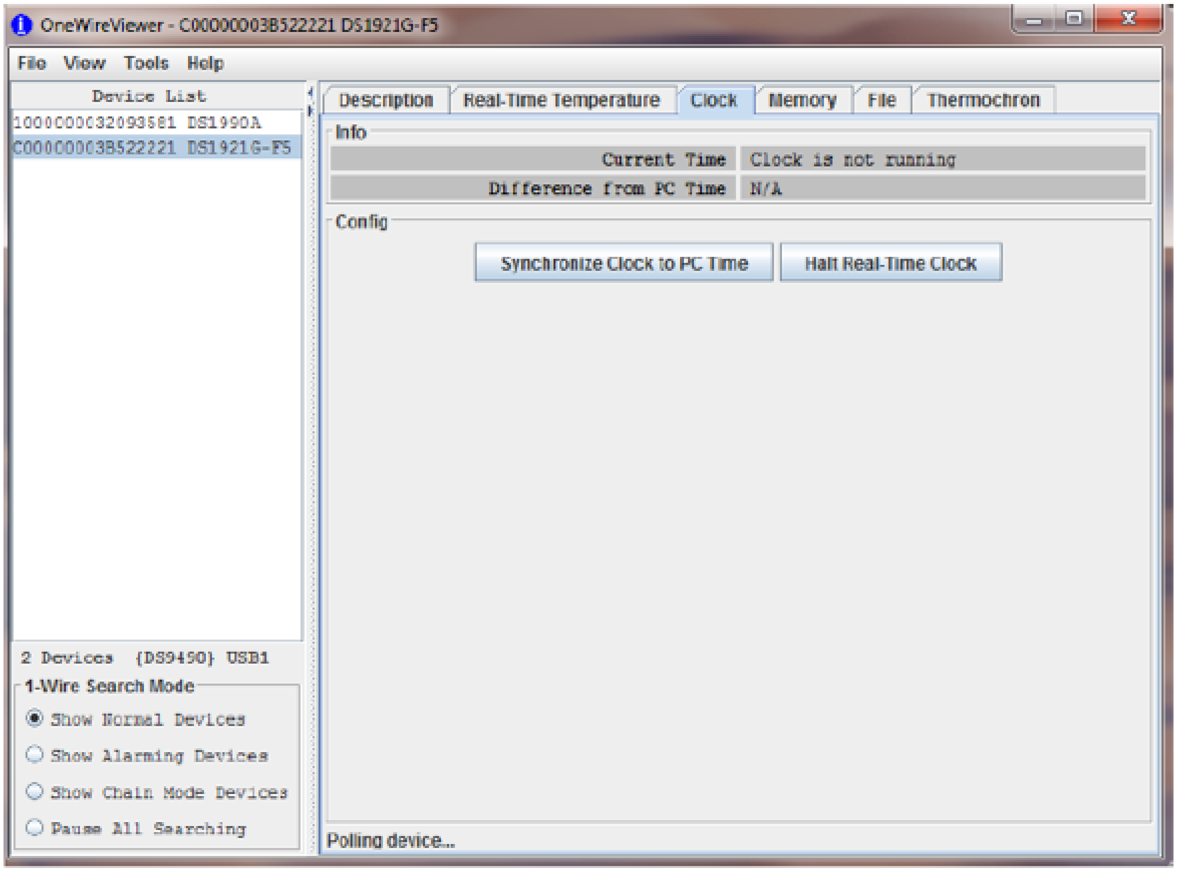
h. In the final window, select “Show Normal Devices” and click “Finish”.
i. This setup process occurs only the first time you open the software. After the initial setup, it will go directly to the *OneWireViewer* home screen.

Launching the Sensors

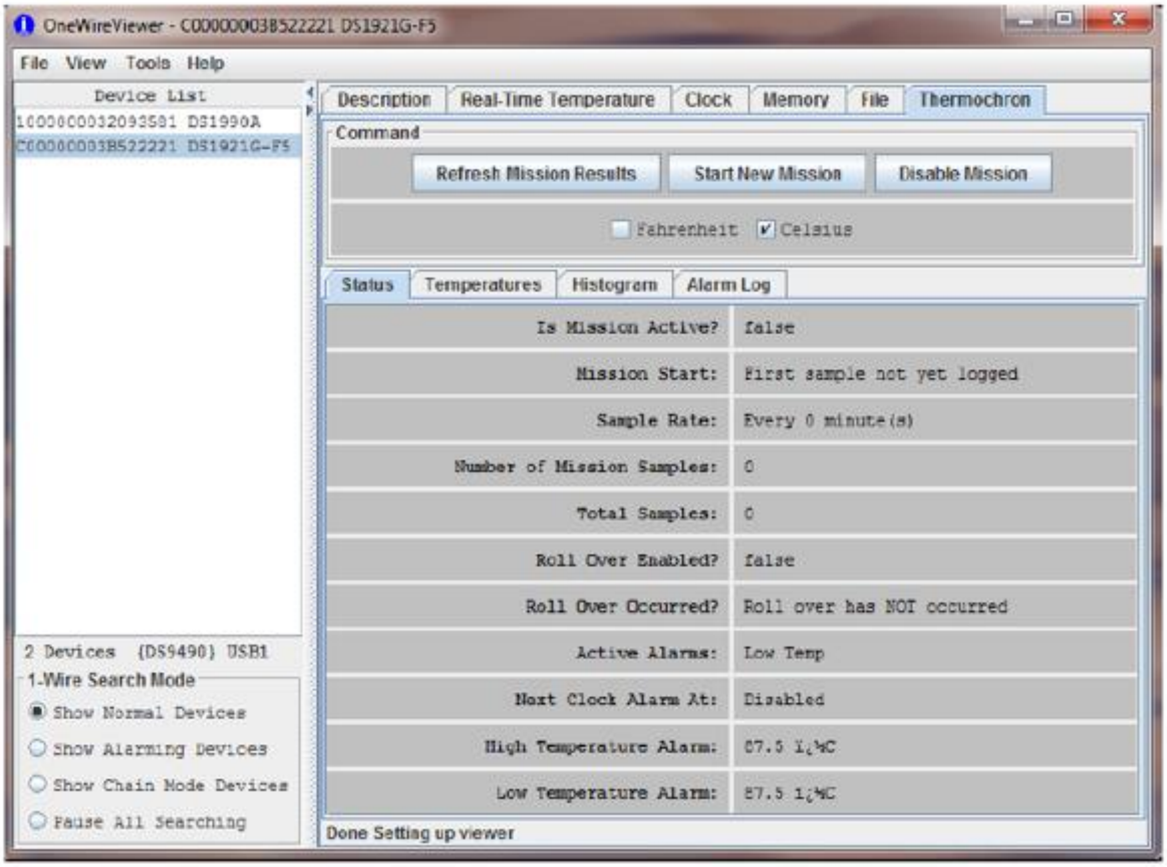
1. Connect the probe and USB converter.
2. Launch the *OneWireViewer* software, and the home screen will appear.
3. Attach the sensor to the probe.
4. The device you just attached should appear in the “Device List” on the left side of the screen.



5. Select this sensor from the “Device List”, and the information and options for this device will appear in the box to the right.
6. Click on the “Clock” tab above the box with the “1-Wire Device Description”.

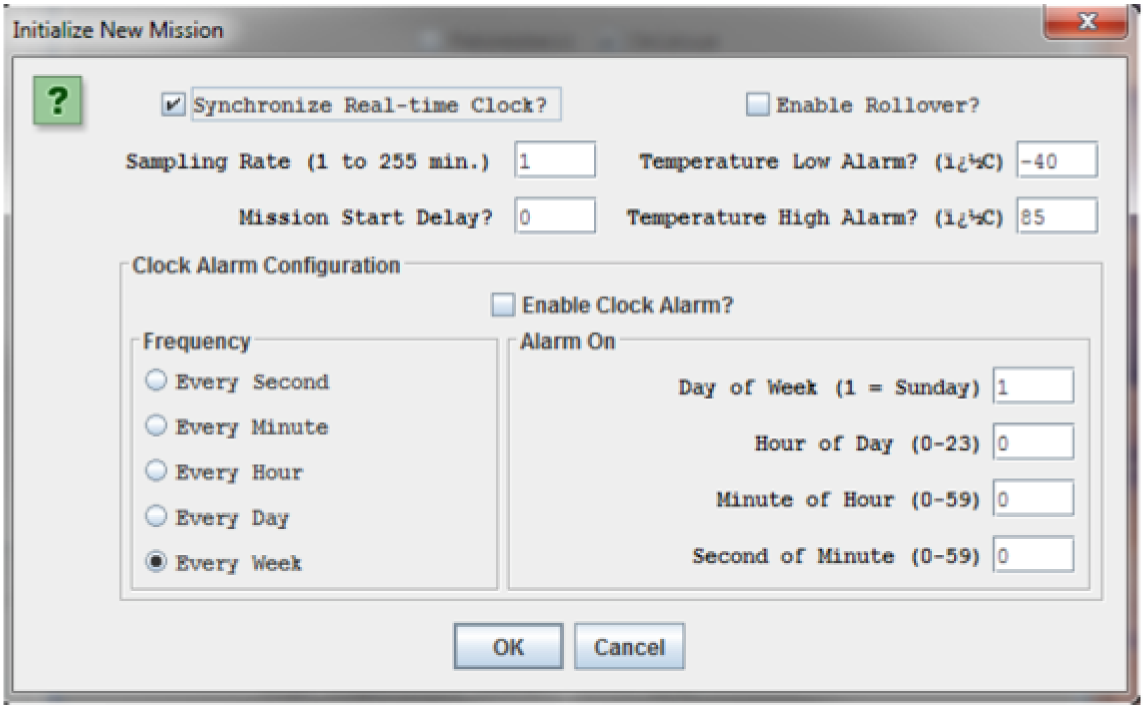


7. Ensure that your computer's clock is correct, and then click "Synchronize Clock to PC Time".
8. The sensor's internal timer is now be synchronized to your computer time, and this is what will be used future temperature logging. This step should be repeated each time the device is connected to your computer to ensure accurate data.
9. Now click the "Mission" tab.



*Note: If the sensor was not previously being used, the "Mission on Progress" column should read "false". If it says "true" then the sensor is already in use and the previous mission must be disabled before relaunching the device (see "Downloading the Data" for more information).

10. Select "Start New Mission", and the "Initialize New Mission" window will pop up.

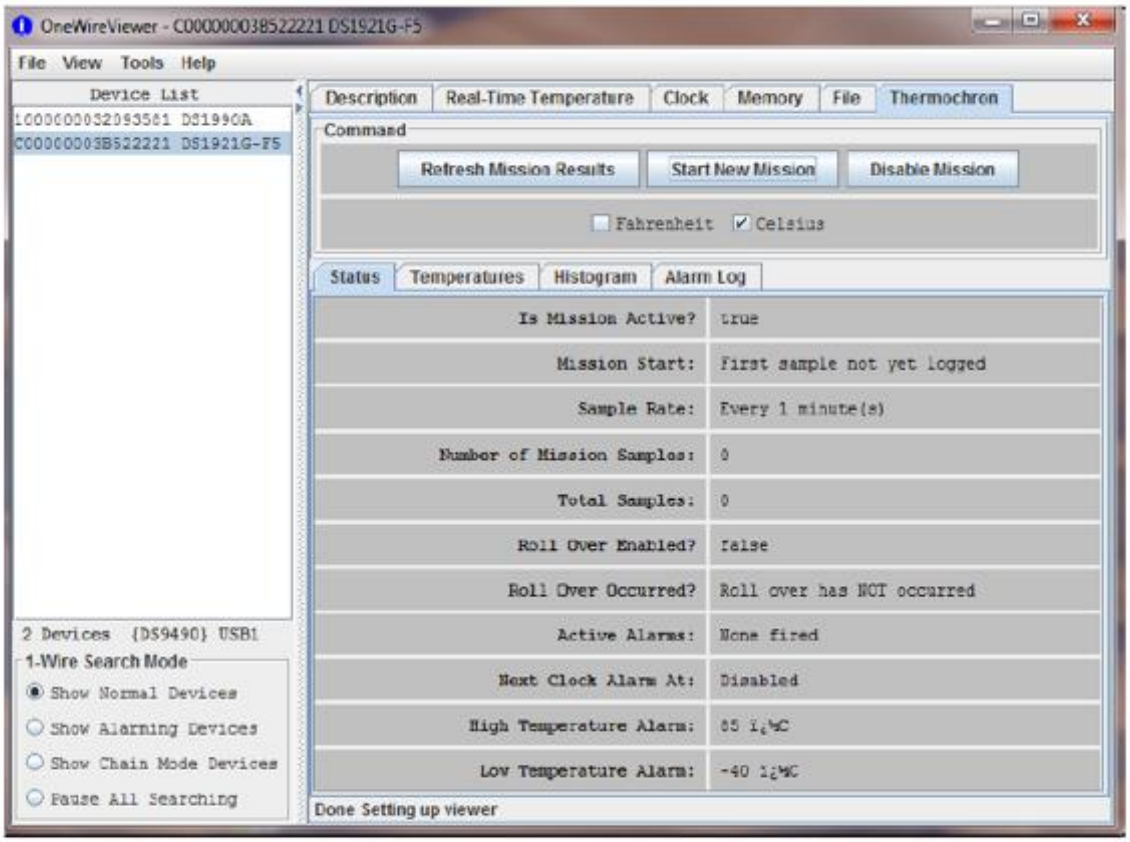


11. The recommended settings are as follows:
    a. Synchronize Clock: check this box to ensure accurate timestamps.
    b. Enable rollover: UNCHECK this box. We recommend that you do not enable rollover, because if it occurs when the memory is full, data will be lost.
    c. Sampling Rate: the rate you choose depends on how long you need the memory to last. At 0.5° resolution, the DS1922T iButtons can record 8,192 measurements while they record only 4,096 measurements at 0.0625° resolution. Here are some examples of sampling rates and the associated duration the sampling will last at 0.5° resolution.

Sampling Rate (minutes)	Sampling Rate (seconds)	Sampling Duration (days)
7	420	39.8
5	300	28.4
3	180	17.1
1	60	5.7

    d. Start Delay: Input a start delay time if you would like the sensor to only start longing after a set period of time (i.e. if the sensors are being placed the next morning, the start delay can be used to postpone logging until that time). If the start delay is left at zero, the sensor will begin to record data immediately after it is launched.
    e. Enable sampling: check this box.
    f. Resolution: This is the accuracy at which the SUMS log temperature data. 0.5°C should provide adequate resolution for SUMS. Using the higher resolution setting

requires more memory which limits the amount of time SUMS can be launched for.
   g. Enable Alarms: uncheck.
   h. Low Alarm: leave blank.
   i. High Alarm: leave blank.
   j. Enable SUTA: uncheck.
12. Click "OK" to begin mission.
13. You will be returned to "Mission" page and the status will refresh after a few seconds.



14. Review the following:
   a. Mission in Progress: true
   b. Sample Rate: ensure that the rate has been inputted correctly.
   c. Mission Start Time: ensure that the start time is correct.
      - If it says "First sample has not yet logged":
         - You can wait until at least the interval of time listed in the sample rate has passed and then click "Refresh Mission Results". The correct start time should now appear.
         - If there was a start delay, no start time will appear until after the logging interval begins.
   d. Roll Over Enabled: false (no rollover occurred)
15. The sensor has now been launched and you may detach it from the probe.

*Note: The sensor can be attached at any time to view its current status. You can click the "Refresh Mission Results" button when the sensor is attached and already launched to update the status display.

Sensor Placement

Ideally, the temperature sensor will be placed in a location on the stove where it will not be in the way of the pot, where it will obstruct or interrupt the cooking, and where liquids are likely to get collected or boiled over.

Additionally, the sensor is placed in a location that the temperature variation during stove use is maximized, yet it must be far enough from the flame that temperature does not exceed the measuring limits of the device. For example, The DS1922T sensor can withstand temperatures from 0°C (32°F) to 125°C (257°F). It is also possible to use the DS1922L sensor which has limits of -40°C (-40°F) to 85°C (185°F) in colder areas if the stove has a high thermal mass so that temperature does not exceed the sensor limit during cooking.

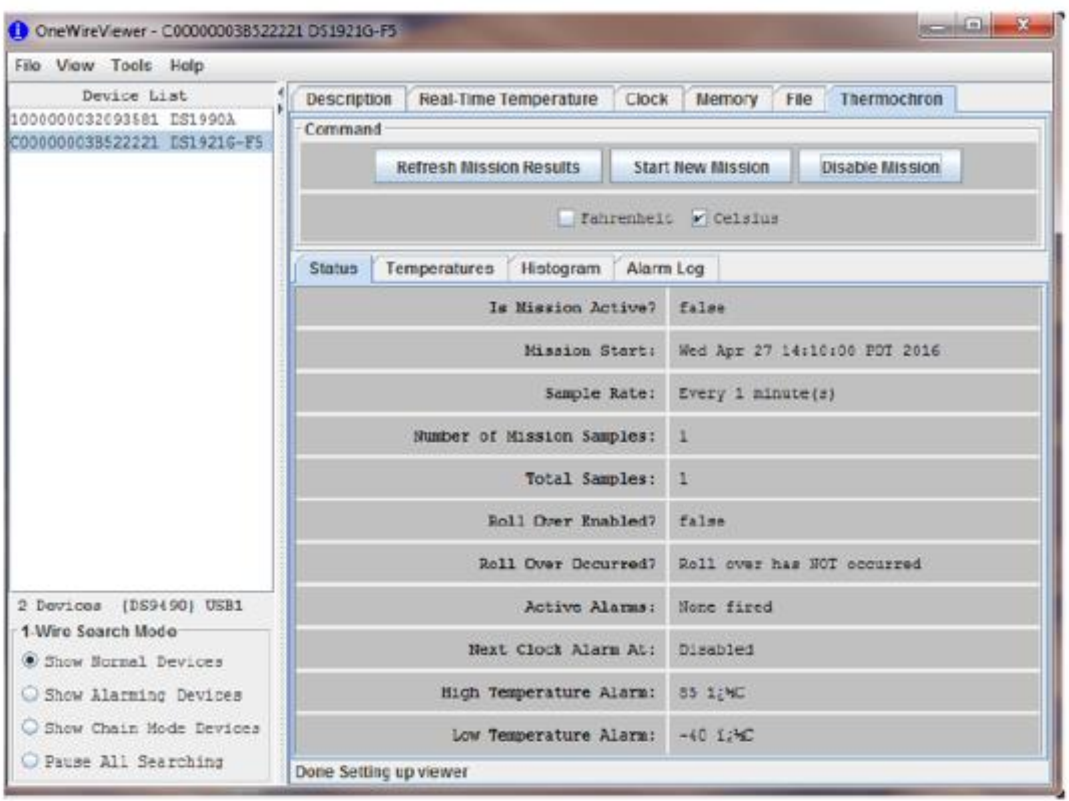
Placement should also be as consistent as possible so that temperature traces across stoves are similar. The stove type will influence how you actually attach the iButton to the predetermined location on or near to the stove to be monitored. The following examples show sensor placements that have been successful in the past.

(a) Sensor affixed to kerosene stove with heat resistant tape.
(b) Sensor affixed to metal bucket stove with heat resistant tape.
(c) Sensor affixed to base of LPG stove with heat resistant tape.
(d) Sensor affixed to traditional Indian ceramic stove with copper wire.

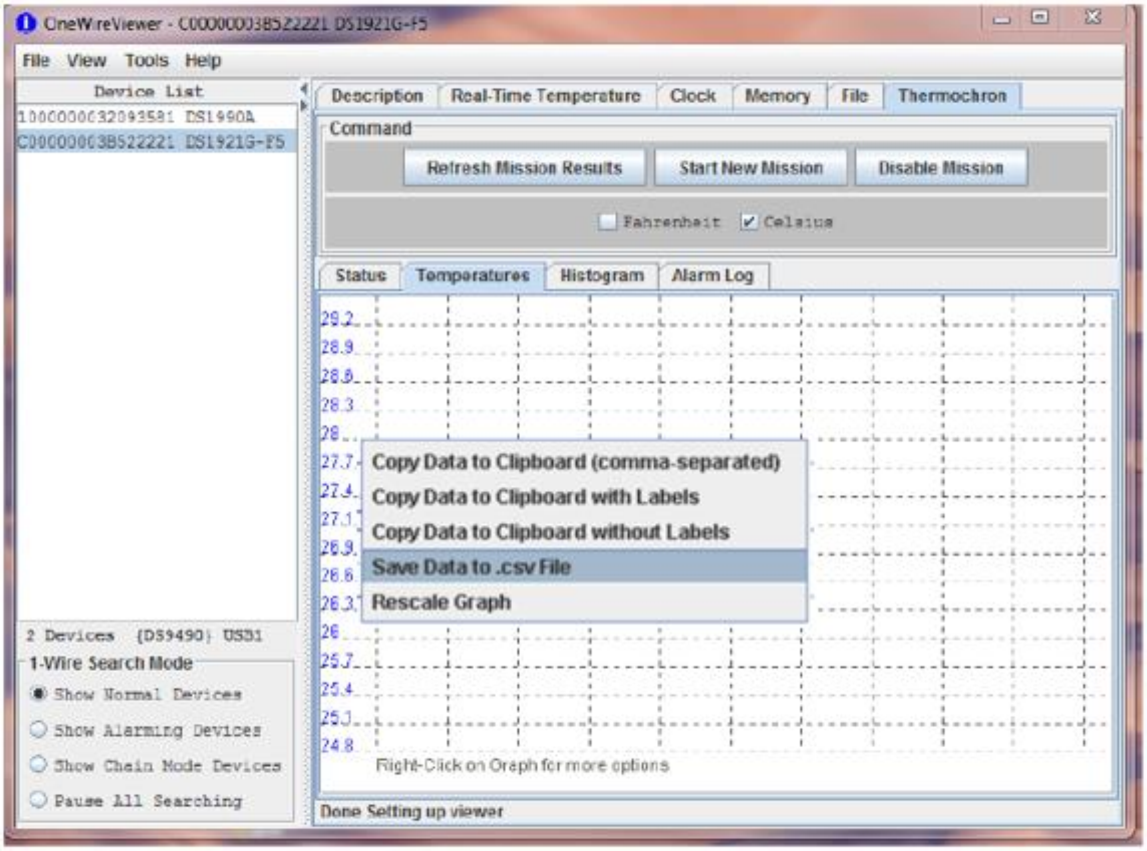
Placement pilot is highly recommended for all stove types. Place iButton for pilot in 2-3 homes for 2-3 days.

Downloading the Data

1. Connect the probe and USB converter.
2. Launch the *OneWireViewer* software, and the home screen will appear.
3. Attach the sensor to the probe.
4. The device you just attached should appear in the "Device List" on the left side of the screen.
5. Select this sensor from the "Device List", and the information and options for this device will appear in the box to the right.
6. Click on the "Mission" tab above the box with the "1-Wire Device Description".
7. Ensure that the "Mission on Progress" column reads "true". This means that the sensor is currently logging data.
8. Click "Disable Mission".
9. The "Status" of the mission should update, and the "Mission in Progress" column should now read "false".



10. Click on the "Temperature Data Log" tab.



11. Right click on the graph area and select "Save Data to .csv File".
12. Select the destination folder, input the file name, and click save.
13. The mission statistics and data log can be viewed in the .csv file.

*Note: If you are not planning on re-launching the iButton or if it will not be used for an extended period of time, go to the "Clock" tab and select "Halt Real-Time Clock". This will stop the iButton's internal timer and will conserve battery.

Example of SUMS data collection form

Stove Use Monitoring Form (SUMS)	HHID:	Surveyor ID:	Stove codes:			
	Stove 1:		Stove 2:		Stove 3:	
iButton ID						
Describe placement						
Photos	Check box if taken: ☐		Check box if taken: ☐		Check box if taken: ☐	
Start date and time	YY/MM/DD	HH:MM:SS	YY/MM/DD	HH:MM:SS	YY/MM/DD	HH:MM:SS
Download date and time	YY/MM/DD	HH:MM:SS	YY/MM/DD	HH:MM:SS	YY/MM/DD	HH:MM:SS
New ID if iButton replaced						
Notes						
Download date and time	YY/MM/DD	HH:MM:SS	YY/MM/DD	HH:MM:SS	YY/MM/DD	HH:MM:SS
New ID if iButton replaced						
Notes						