The Water Boiling Test (WBT)

November 30, 2011

VERC Training

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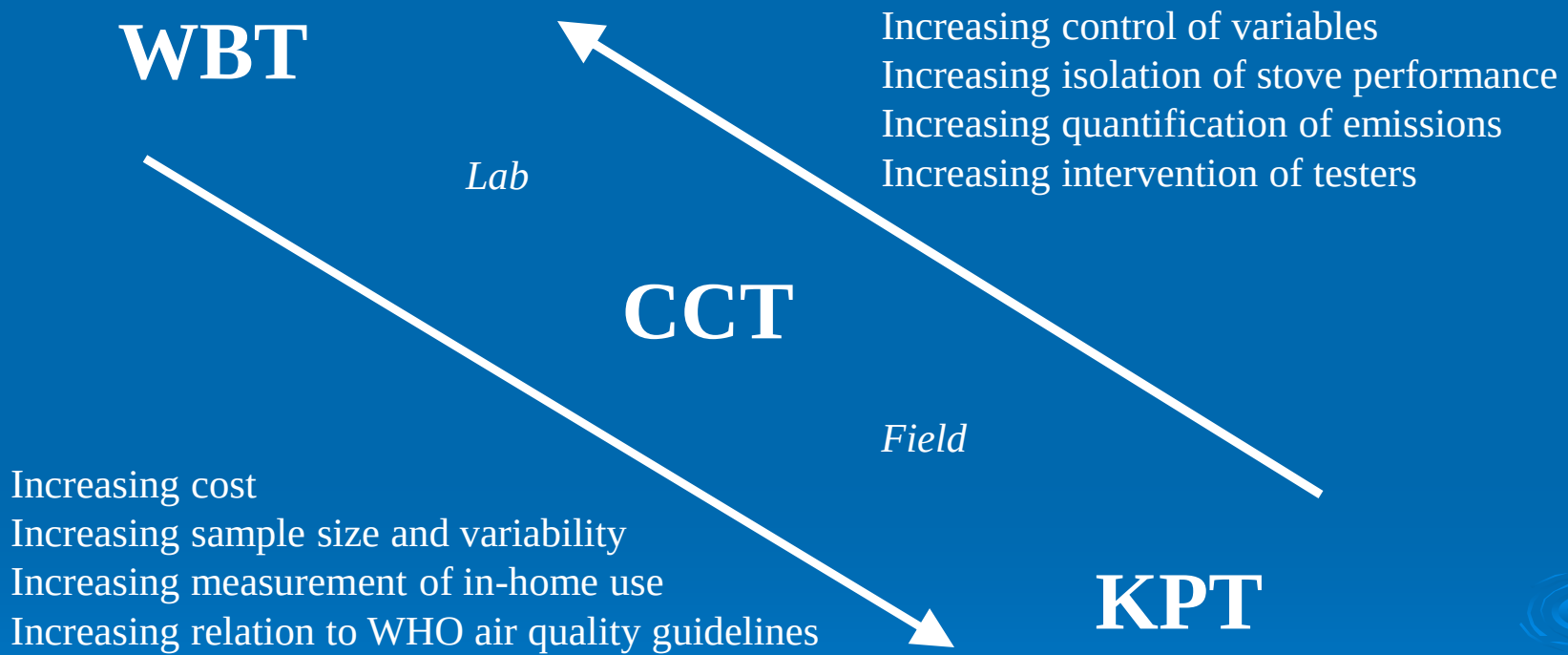
The Water Boiling Test (WBT)

- Standardized, reproducible lab test
- Boil and simmer water
- Measure the boil time, fuel use, efficiency, and optionally emissions
- Trained tester carefully tends the fire
- High and low power test phases
- Cold stove and hot stove test phases
- Allows for multiple pots on one stove

Stove Testing Continuum



Purpose of WBT

- Effective design tool to evaluate design changes of a stove
- "…a simple method with which stoves made in different places and for different cooking applications can be compared through a standardized and replicable test."

Advantages of the WBT

- Reproducible, standardized
- Stoves from around the world can be compared
- A target performance level (benchmark) can be set based on comparisons
- Effects stove design changes can be observed quite clearly and relatively quickly

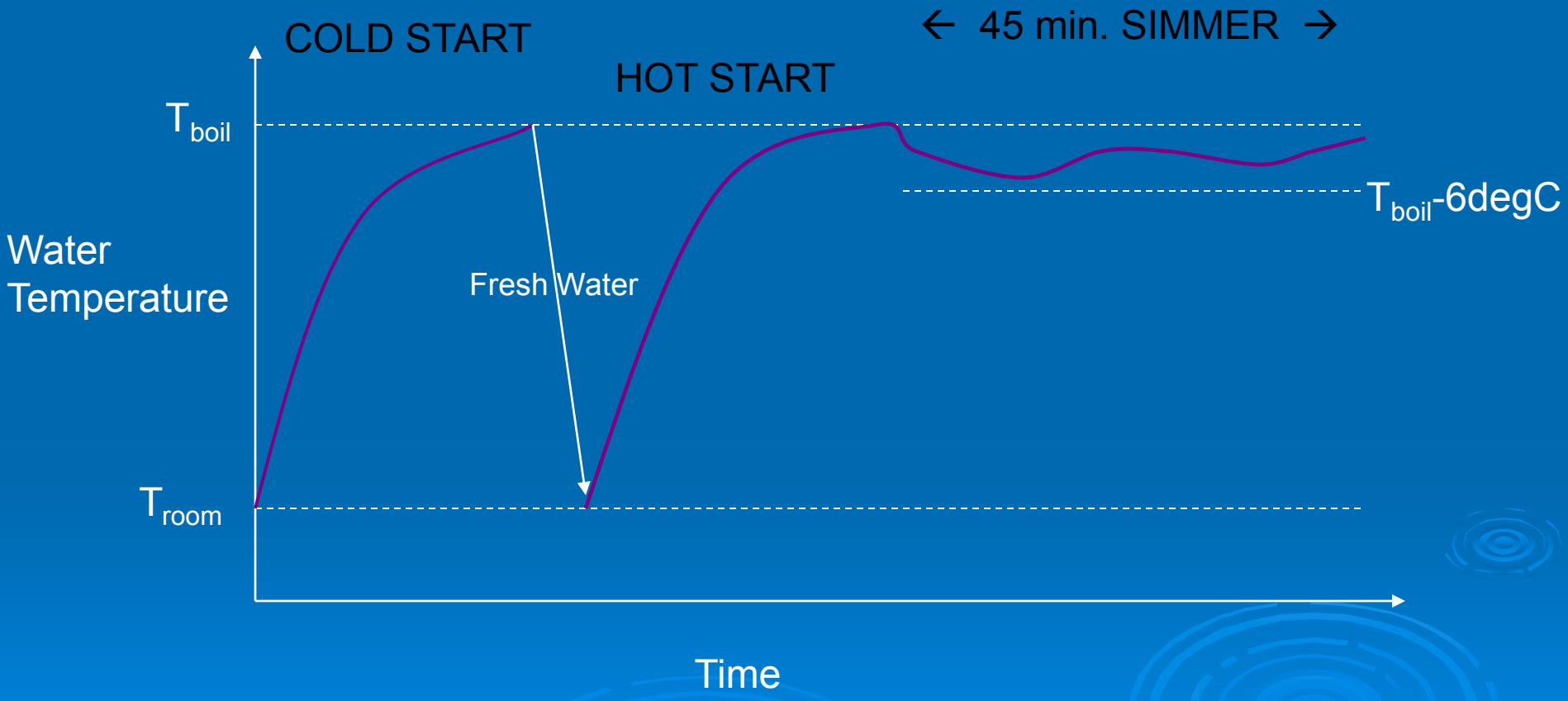
Disadvantages of the WBT

- Not always reproducible
  - When the tester or fuel changes
- Not representative of field use
  - Only one simulated cooking task
- Hard to do for some stoves
  - Batch-loading stoves: TLUD's, charcoal

WBT Procedure

Phase	COLD START	HOT START	SIMMER
Task	Bring to Boil 5L in first pot	Bring to Boil fresh 5L in first pot	Simmer remaining 5L for 45 minutes
Record	Time Fuel Water Charcoal	Time Fuel Water *Assume Same Charcoal as Cold Start*	Time Fuel Water Charcoal

WBT Procedure



WBT – Preparing for the Test

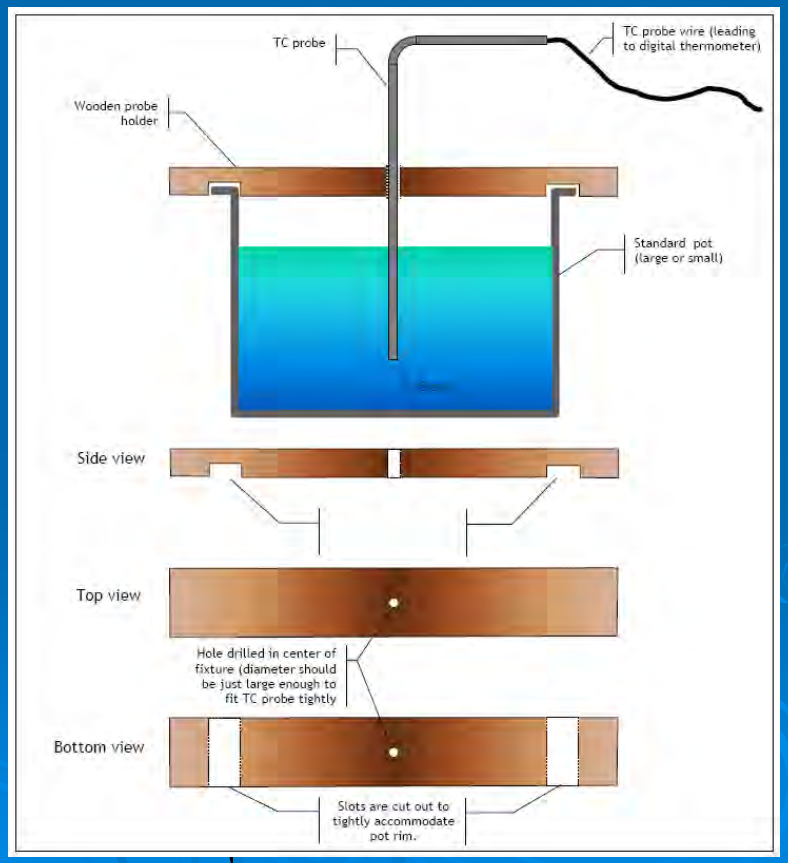
First do a practice test to:

- Get familiar with the stove
- Determine if the stove should be tested with 2.5 or 5 liters
- Determine how much fuel is required
- Determine boiling temperature of water

WBT – Preparing for the Test

Gather Supplies

1. Scale - 6000g range, 1g resolution
2. Temperature sensor – waterproof
3. Fixture for suspending temperature sensor
4. Wood moisture meter or oven for fuel MC

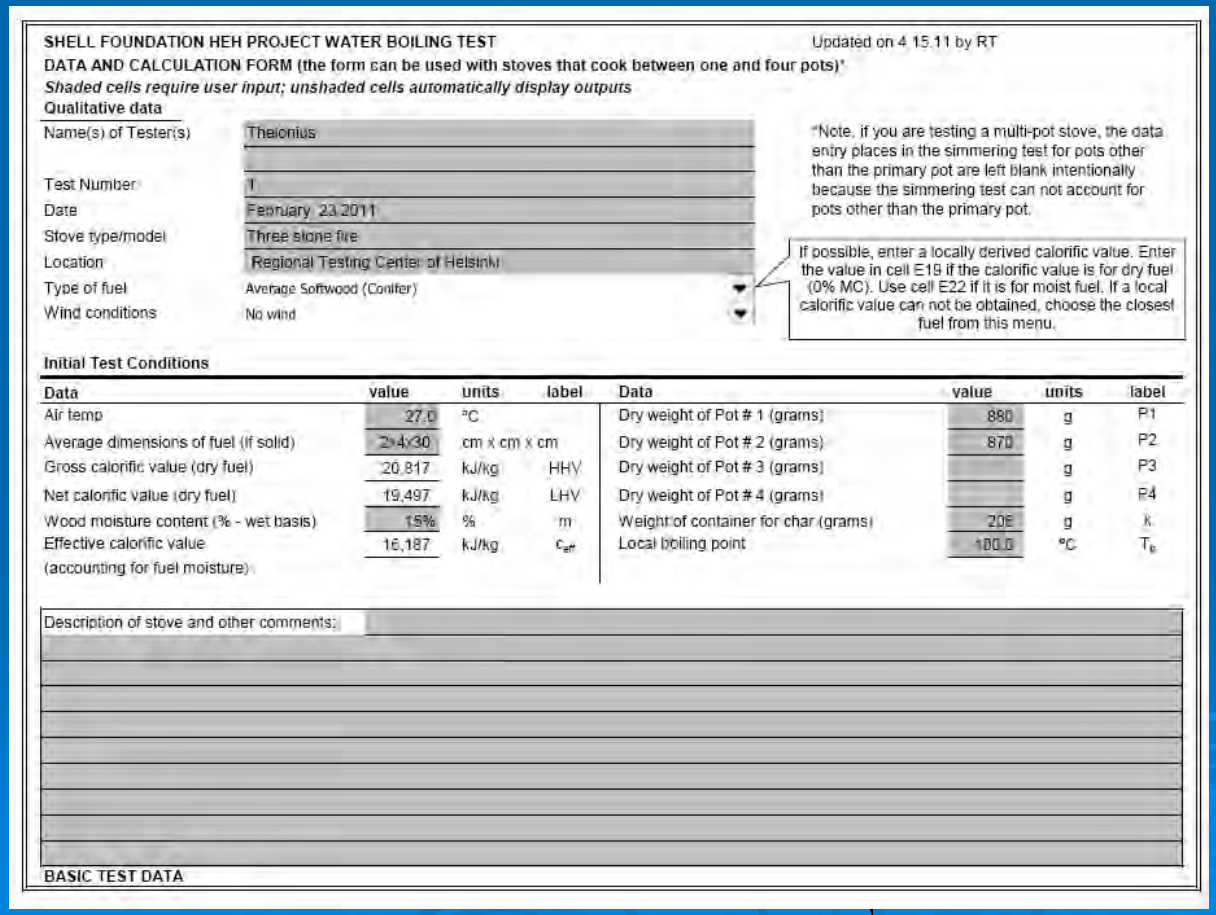


WBT – Preparing for the Test
Gather Supplies

5. Timer or watch
6. Pot – standard or dedicated, no lid
7. Heat resistant pad for scale
8. Charcoal scooper/tongs
9. Char tray
10. Heat resistant gloves
11. Water – room temp,
    - at least 10 liters
12. Fuel – air dried, uniform
    - 2 bundles ~ 2kg each

WBT – Preparing for the Test

Fill out page 1 of the Data and Calculation Sheet



SHELL FOUNDATION HEH PROJECT WATER BOILING TEST Updated on 4 15.11 by RT

DATA AND CALCULATION FORM (the form can be used with stoves that cook between one and four pots)*

Shaded cells require user input; unshaded cells automatically display outputs

Qualitative data

Name(s) of Tester(s)	Theionius
Test Number	1
Date	February 23 2011
Stove type/model	Three stone fire
Location	Regional Testing Center of Helsinki
Type of fuel	Average Softwood (Conifer)
Wind conditions	No wind

*Note, if you are testing a multi-pot stove, the data entry places in the simmering test for pots other than the primary pot are left blank intentionally because the simmering test can not account for pots other than the primary pot.

If possible, enter a locally derived calorific value. Enter the value in cell E19 if the calorific value is for dry fuel (0% MC). Use cell E22 if it is for moist fuel. If a local calorific value can not be obtained, choose the closest fuel from this menu.

Initial Test Conditions

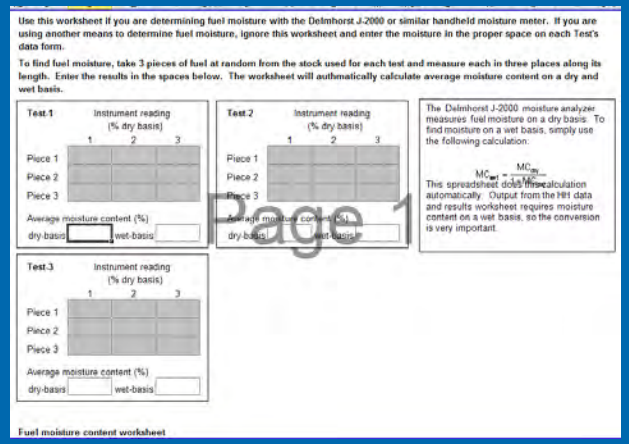
Data	value	units	label	Data	value	units	label
Air temp	27.0	°C		Dry weight of Pot # 1 (grams)	880	g	P1
Average dimensions of fuel (if solid)	2x4x30	cm x cm x cm		Dry weight of Pot # 2 (grams)	870	g	P2
Gross calorific value (dry fuel)	20,817	kJ/kg	HHV	Dry weight of Pot # 3 (grams)		g	P3
Net calorific value (dry fuel)	19,497	kJ/kg	LHV	Dry weight of Pot # 4 (grams)		g	P4
Wood moisture content (% - wet basis)	15%	%	m	Weight of container for char (grams)	205	g	k
Effective calorific value (accounting for fuel moisture)	16,187	kJ/kg	c_{ef}	Local boiling point	100.0	°C	T_b

Description of stove and other comments:

BASIC TEST DATA

WBT – Preparing for the Test

Fill out page 1 of the Data and Calculation Sheet



Use this worksheet if you are determining fuel moisture with the Delmhorst J-2000 or similar handheld moisture meter. If you are using another means to determine fuel moisture, ignore this worksheet and enter the moisture in the proper space on each Test's data form.

To find fuel moisture, take 3 pieces of fuel at random from the stock used for each test and measure each in three places along its length. Enter the results in the spaces below. The worksheet will authmatically calculate average moisture content on a dry and wet basis.

Test 1 Instrument reading (% dry basis) — 1 2 3 — Piece 1, Piece 2, Piece 3 — Average moisture content (%) dry-basis wet-basis

Test 2 Instrument reading (% dry basis) — 1 2 3 — Piece 1, Piece 2, Piece 3 — Average moisture content (%) dry-basis wet-basis

The Delmhorst J-2000 moisture analyzer measures fuel moisture on a dry basis. To find moisture on a wet basis, simply use the following calculation:

$$MC_{wet} = \frac{MC_{dry}}{1 + MC_{dry}}$$

This spreadsheet does this calculation automatically. Output from the HH data and results worksheet requires moisture content on a wet basis, so the conversion is very important.

Test 3 Instrument reading (% dry basis) — 1 2 3 — Piece 1, Piece 2, Piece 3 — Average moisture content (%) dry-basis wet-basis

Page 1

Fuel moisture content worksheet

Determining Moisture Content

Method 1:

-Use hand-held moisture to measure the MC_{dry}
-Then convert to MC_{wet} using the Fuel Moisture Sheet of the Excel WBT spreadsheet

Method 2:

Oven drying method

WBT – Conducting the Test

Phase 1: High Power Cold Start

- Set the pots on the stove with 5000g of water with the temp sensor suspended in the water of Pot 1.
- Record:
- Starting weight of pots with water
- Starting water temperatures
- Initial mass of the bundle of fuel
- Light the fire - record start time
- Tend fire and bring water to a boil

		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
		Start		Finish: when Pot #1 boils		Start		Finish: when Pot #1 boils		Start:when Pot #1 boils		Finish: 45 min after Pot #1 boils	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
Time (in 24 hour units)	hr:min	11:16	t_{ci}		t_{cf}		t_{hi}		t_{hf}		t_{si}		t_{sf}
Weight of wood	g	2500	f_{ci}		f_{cf}		f_{hi}		f_{hf}		f_{si}		f_{sf}
Water temperature, Pot # 1	°C	25.0	$T1_{ci}$		$T1_{cf}$		$T1_{hi}$		$T1_{hf}$		$T1_{si}$		$T1_{sf}$
Water temperature, Pot # 2	°C	25.0	$T2_{ci}$		$T2_{cf}$		$T2_{hi}$		$T2_{hf}$	$T1_{si}$ is set equal to T_s because the simmer test starts after the pot has boiled.			
Water temperature, Pot # 3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$				
Water temperature, Pot # 4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$				
Weight of Pot # 1 with water	g	5880	$P1_{ci}$		$P1_{cf}$		$P1_{hi}$		$P1_{hf}$		$P1_{si}$		$P1_{sf}$
Weight of Pot # 2 with water	g	5870	$P2_{ci}$		$P2_{cf}$		$P2_{hi}$		$P2_{hf}$	$P1_{si}$ should be the mass remaining in pot one at the end of the hot start test ($P1_{hf}$).			
Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$				
Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$				
Fire-starting materials (if any)	--	10 grams paper											
Weight of charcoal+container	g				c_c				c_h				c_s

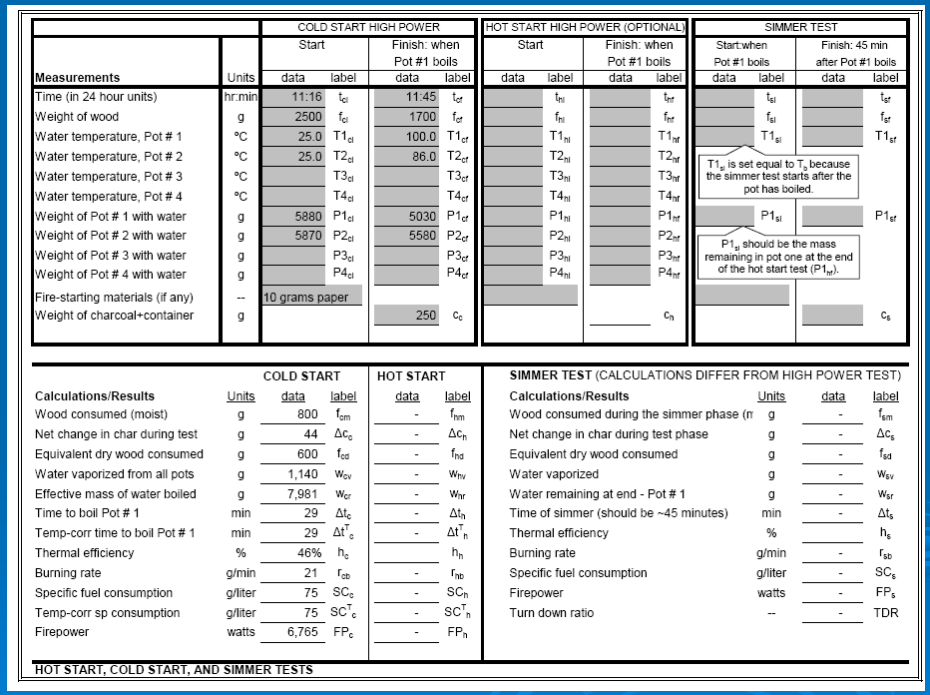
		COLD START		HOT START		SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST)			
Calculations/Results	Units	data	label	data	label	**Calculations/Results**	Units	data	label
Wood consumed (moist)	g	2,500	f_{cm}	-	f_{hm}	Wood consumed during the simmer phase (n	g	-	f_{sm}
Net change in char during test	g	-	Δc_c	-	Δc_h	Net change in char during test phase	g	-	Δc_s
Equivalent dry wood consumed	g	2,080	f_{cd}	-	f_{hd}	Equivalent dry wood consumed	g	-	f_{sd}
Water vaporized from all pots	g	11,750	w_{cv}	-	w_{hv}	Water vaporized	g	-	w_{sv}
Effective mass of water boiled	g	583	w_{cr}	-	w_{hr}	Water remaining at end - Pot # 1	g	-	w_{sr}
Time to boil Pot # 1	min	(676)	Δt_c	-	Δt_h	Time of simmer (should be ~45 minutes)	min	-	Δt_s
Temp-corr time to boil Pot # 1	min	(676)	Δt^T_c	-	Δt^T_h	Thermal efficiency	%		h_s
Thermal efficiency	%	63%	h_c		h_h	Burning rate	g/min	-	r_{sb}
Burning rate	g/min	(3)	r_{cb}	-	r_{hb}	Specific fuel consumption	g/liter	-	SC_s
Specific fuel consumption	g/liter	3,566	SC_c	-	SC_h	Firepower	watts	-	FP_s
Temp-corr sp consumption	g/liter	3,566	SC^T_c	-	SC^T_h	Turn down ratio	--	-	TDR
Firepower	watts	(1,000)	FP_c	-	FP_h				

HOT START, COLD START, AND SIMMER TESTS

WBT – Conducting the Test

Phase 1: High Power Cold Start

- When Pot 1 boils record:
  - Time
  - Temperature of all pots
  - Pot plus water weights
  - Fuel remaining
    - Break char off tips of burned sticks
    - Put char on tray and record weight of char plus tray



		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
		Start		Finish: when Pot #1 boils		Start		Finish: when Pot #1 boils		Start:when Pot #1 boils		Finish: 45 min after Pot #1 boils	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
Time (in 24 hour units)	hr:min	11:16	t_{ci}	11:45	t_{cf}		t_{hi}		t_{hf}		t_{si}		t_{sf}
Weight of wood	g	2500	f_{ci}	1700	f_{cf}		f_{hi}		f_{hf}		f_{si}		f_{sf}
Water temperature, Pot # 1	°C	25.0	$T1_{ci}$	100.0	$T1_{cf}$		$T1_{hi}$		$T1_{hf}$		$T1_{si}$		$T1_{sf}$
Water temperature, Pot # 2	°C	25.0	$T2_{ci}$	86.0	$T2_{cf}$		$T2_{hi}$		$T2_{hf}$	$T1_{si}$ is set equal to T_c because the simmer test starts after the pot has boiled.			
Water temperature, Pot # 3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$				
Water temperature, Pot # 4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$				
Weight of Pot # 1 with water	g	5880	$P1_{ci}$	5030	$P1_{cf}$		$P1_{hi}$		$P1_{hf}$		$P1_{si}$		$P1_{sf}$
Weight of Pot # 2 with water	g	5870	$P2_{ci}$	5580	$P2_{cf}$		$P2_{hi}$		$P2_{hf}$	$P1_{si}$ should be the mass remaining in pot one at the end of the hot start test ($P1_{hf}$).			
Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$				
Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$				
Fire-starting materials (if any)	--	10 grams paper											
Weight of charcoal+container	g			250	c_c				c_h				c_s

		COLD START		HOT START	
Calculations/Results	Units	data	label	data	label
Wood consumed (moist)	g	800	f_{cm}	-	f_{hm}
Net change in char during test	g	44	Δc_c	-	Δc_h
Equivalent dry wood consumed	g	600	f_{cd}	-	f_{hd}
Water vaporized from all pots	g	1,140	w_{cv}	-	w_{hv}
Effective mass of water boiled	g	7,981	w_{cr}	-	w_{hr}
Time to boil Pot # 1	min	29	Δt_c	-	Δt_h
Temp-corr time to boil Pot # 1	min	29	Δt^T_c	-	Δt^T_h
Thermal efficiency	%	46%	h_c		h_h
Burning rate	g/min	21	r_{cb}	-	r_{hb}
Specific fuel consumption	g/liter	75	SC_c	-	SC_h
Temp-corr sp consumption	g/liter	75	SC^T_c	-	SC^T_h
Firepower	watts	6,765	FP_c	-	FP_h

SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST)			
Calculations/Results	Units	data	label
Wood consumed during the simmer phase (n	g	-	f_{sm}
Net change in char during test phase	g	-	Δc_s
Equivalent dry wood consumed	g	-	f_{sd}
Water vaporized	g	-	w_{sv}
Water remaining at end - Pot # 1	g	-	w_{sr}
Time of simmer (should be ~45 minutes)	min	-	Δt_s
Thermal efficiency	%		h_s
Burning rate	g/min	-	r_{sb}
Specific fuel consumption	g/liter	-	SC_s
Firepower	watts	-	FP_s
Turn down ratio	--	-	TDR

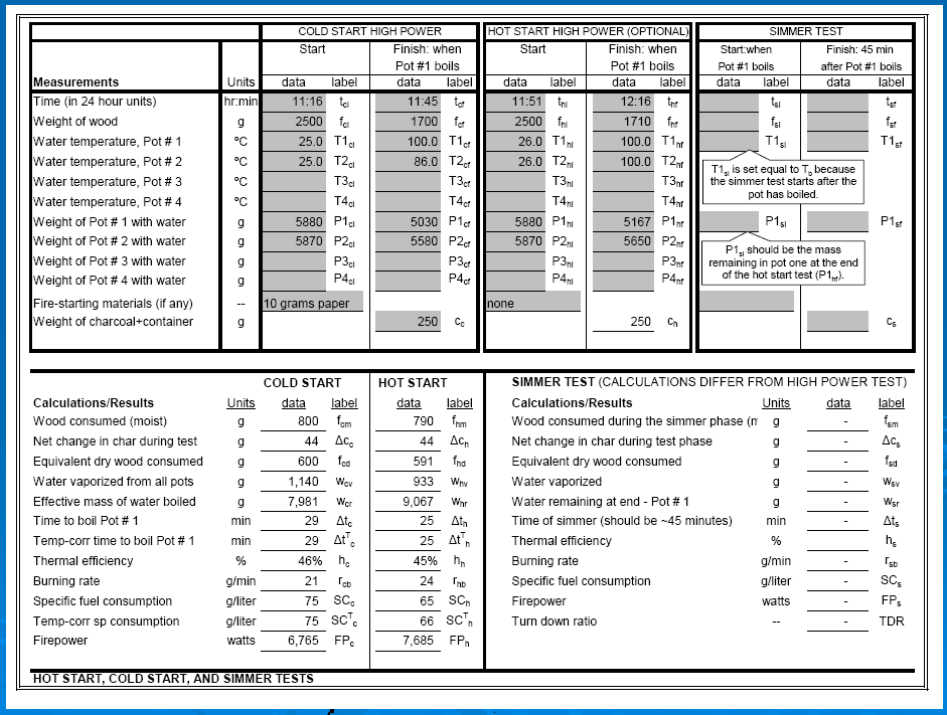
HOT START, COLD START, AND SIMMER TESTS

WBT – Conducting the Test

Phase 2: High Power Hot Start

- Refill the pots with cool water and repeat the boil procedure starting with a hot stove

- Use a new bundle of wood
- This time, when Pot 1 boils keep the char in the combustion chamber. DO NOT WEIGH THE CHAR
- Weight the pots and place them back on the stove
- Weigh the wood, place it back in the combustion chamber, then re-light it.



		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
		Start		Finish: when Pot #1 boils		Start		Finish: when Pot #1 boils		Start:when Pot #1 boils		Finish: 45 min after Pot #1 boils	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
Time (in 24 hour units)	hr:min	11:16	t_{ci}	11:45	t_{cf}	11:51	t_{hi}	12:16	t_{hf}		t_{si}		t_{sf}
Weight of wood	g	2500	f_{ci}	1700	f_{cf}	2500	f_{hi}	1710	f_{hf}		f_{si}		f_{sf}
Water temperature, Pot # 1	°C	25.0	$T1_{ci}$	100.0	$T1_{cf}$	26.0	$T1_{hi}$	100.0	$T1_{hf}$		$T1_{si}$		$T1_{sf}$
Water temperature, Pot # 2	°C	25.0	$T2_{ci}$	86.0	$T2_{cf}$	26.0	$T2_{hi}$	100.0	$T2_{hf}$				
Water temperature, Pot # 3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$				
Water temperature, Pot # 4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$				
Weight of Pot # 1 with water	g	5880	$P1_{ci}$	5030	$P1_{cf}$	5880	$P1_{hi}$	5167	$P1_{hf}$		$P1_{si}$		$P1_{sf}$
Weight of Pot # 2 with water	g	5870	$P2_{ci}$	5580	$P2_{cf}$	5870	$P2_{hi}$	5650	$P2_{hf}$				
Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$				
Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$				
Fire-starting materials (if any)	--	10 grams paper				none							
Weight of charcoal+container	g			250	c_c			250	c_h				c_s

$T1_{si}$ is set equal to T_s because the simmer test starts after the pot has boiled.

$P1_{si}$ should be the mass remaining in pot one at the end of the hot start test ($P1_{hf}$).

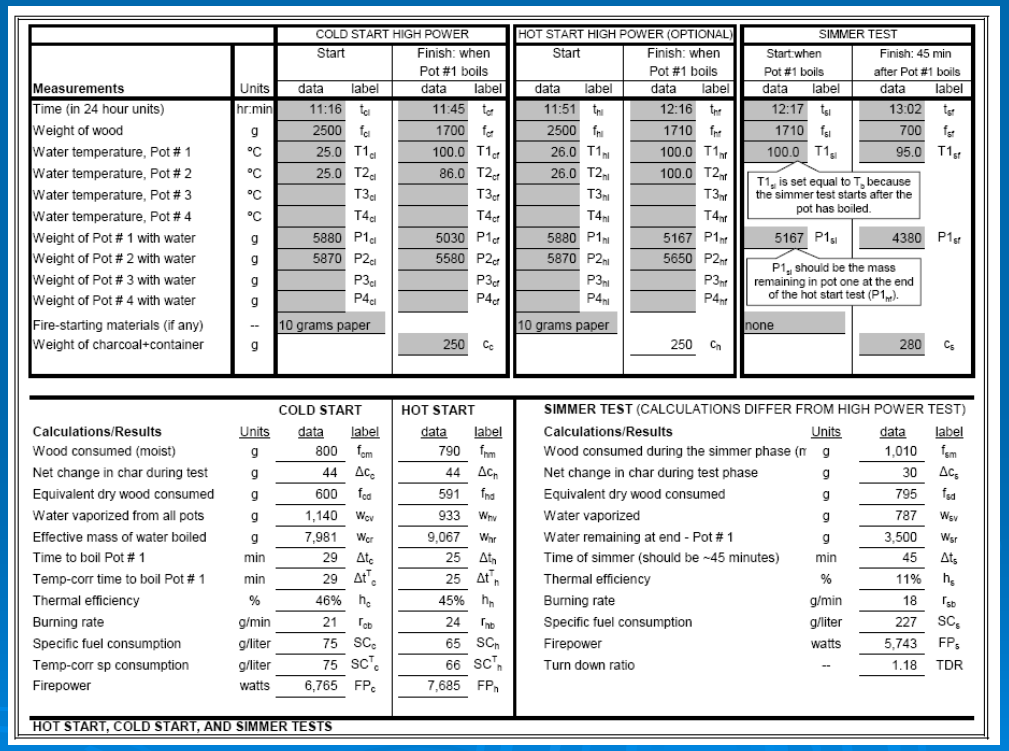
		COLD START		HOT START		SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST)			
Calculations/Results	Units	data	label	data	label	**Calculations/Results**	Units	data	label
Wood consumed (moist)	g	800	f_{cm}	790	f_{hm}	Wood consumed during the simmer phase (m	g	-	f_{sm}
Net change in char during test	g	44	Δc_c	44	Δc_h	Net change in char during test phase	g	-	Δc_s
Equivalent dry wood consumed	g	600	f_{cd}	591	f_{hd}	Equivalent dry wood consumed	g	-	f_{sd}
Water vaporized from all pots	g	1,140	w_{cv}	933	w_{hv}	Water vaporized	g	-	w_{sv}
Effective mass of water boiled	g	7,981	w_{cr}	9,067	w_{hr}	Water remaining at end - Pot # 1	g	-	w_{sr}
Time to boil Pot # 1	min	29	Δt_c	25	Δt_h	Time of simmer (should be ~45 minutes)	min	-	Δt_s
Temp-corr time to boil Pot # 1	min	29	Δt^T_c	25	Δt^T_h	Thermal efficiency	%		h_s
Thermal efficiency	%	46%	h_c	45%	h_h	Burning rate	g/min	-	r_{sb}
Burning rate	g/min	21	r_{cb}	24	r_{hb}	Specific fuel consumption	g/liter	-	SC_s
Specific fuel consumption	g/liter	75	SC_c	65	SC_h	Firepower	watts	-	FP_s
Temp-corr sp consumption	g/liter	75	SC^T_c	66	SC^T_h	Turn down ratio	--	-	TDR
Firepower	watts	6,765	FP_c	7,685	FP_h				

HOT START, COLD START, AND SIMMER TESTS

WBT – Conducting the Test

Phase 3: Low Power Simmer

- Record the start time once the fire is lit
- Transfer over the fuel weight, pot and water weight, and water temp from the results column at the end of the hot start
- Tend the fire to keep the water temp of Pot 1 at 3 degrees C below boiling for 45 min
- After 45 min of simmer record:
  - Final water temperature
  - Weight of Pot 1 plus water
  - Final weight of fuel and char remaining



		COLD START HIGH POWER				HOT START HIGH POWER (OPTIONAL)				SIMMER TEST			
		Start		Finish: when Pot #1 boils		Start		Finish: when Pot #1 boils		Start:when Pot #1 boils		Finish: 45 min after Pot #1 boils	
Measurements	Units	data	label	data	label	data	label	data	label	data	label	data	label
Time (in 24 hour units)	hr:min	11:16	t_{ci}	11:45	t_{cf}	11:51	t_{hi}	12:16	t_{hf}	12:17	t_{si}	13:02	t_{sf}
Weight of wood	g	2500	f_{ci}	1700	f_{cf}	2500	f_{hi}	1710	f_{hf}	1710	f_{si}	700	f_{sf}
Water temperature, Pot # 1	°C	25.0	$T1_{ci}$	100.0	$T1_{cf}$	26.0	$T1_{hi}$	100.0	$T1_{hf}$	100.0	$T1_{si}$	95.0	$T1_{sf}$
Water temperature, Pot # 2	°C	25.0	$T2_{ci}$	86.0	$T2_{cf}$	26.0	$T2_{hi}$	100.0	$T2_{hf}$	$T1_{si}$ is set equal to T_s because the simmer test starts after the pot has boiled.			
Water temperature, Pot # 3	°C		$T3_{ci}$		$T3_{cf}$		$T3_{hi}$		$T3_{hf}$				
Water temperature, Pot # 4	°C		$T4_{ci}$		$T4_{cf}$		$T4_{hi}$		$T4_{hf}$				
Weight of Pot # 1 with water	g	5880	$P1_{ci}$	5030	$P1_{cf}$	5880	$P1_{hi}$	5167	$P1_{hf}$	5167	$P1_{si}$	4380	$P1_{sf}$
Weight of Pot # 2 with water	g	5870	$P2_{ci}$	5580	$P2_{cf}$	5870	$P2_{hi}$	5650	$P2_{hf}$	$P1_{si}$ should be the mass remaining in pot one at the end of the hot start test ($P1_{hf}$).			
Weight of Pot # 3 with water	g		$P3_{ci}$		$P3_{cf}$		$P3_{hi}$		$P3_{hf}$				
Weight of Pot # 4 with water	g		$P4_{ci}$		$P4_{cf}$		$P4_{hi}$		$P4_{hf}$				
Fire-starting materials (if any)	--	10 grams paper				10 grams paper				none			
Weight of charcoal+container	g			250	c_c			250	c_h			280	c_s

		COLD START		HOT START	
Calculations/Results	Units	data	label	data	label
Wood consumed (moist)	g	800	f_{cm}	790	f_{hm}
Net change in char during test	g	44	Δc_c	44	Δc_h
Equivalent dry wood consumed	g	600	f_{cd}	591	f_{hd}
Water vaporized from all pots	g	1,140	w_{cv}	933	w_{hv}
Effective mass of water boiled	g	7,981	w_{cr}	9,067	w_{hr}
Time to boil Pot # 1	min	29	Δt_c	25	Δt_h
Temp-corr time to boil Pot # 1	min	29	Δt^T_c	25	Δt^T_h
Thermal efficiency	%	46%	h_c	45%	h_h
Burning rate	g/min	21	r_{cb}	24	r_{hb}
Specific fuel consumption	g/liter	75	SC_c	65	SC_h
Temp-corr sp consumption	g/liter	75	SC^T_c	66	SC^T_h
Firepower	watts	6,765	FP_c	7,685	FP_h

SIMMER TEST (CALCULATIONS DIFFER FROM HIGH POWER TEST)

Calculations/Results	Units	data	label
Wood consumed during the simmer phase (r	g	1,010	f_{sm}
Net change in char during test phase	g	30	Δc_s
Equivalent dry wood consumed	g	795	f_{sd}
Water vaporized	g	787	w_{sv}
Water remaining at end - Pot # 1	g	3,500	w_{sr}
Time of simmer (should be ~45 minutes)	min	45	Δt_s
Thermal efficiency	%	11%	h_s
Burning rate	g/min	18	r_{sb}
Specific fuel consumption	g/liter	227	SC_s
Firepower	watts	5,743	FP_s
Turn down ratio	--	1.18	TDR

HOT START, COLD START, AND SIMMER TESTS

WBT Results

Once you have tested the stove 3 times, copy the data from your data sheet to the Excel spreadsheet.

The performance metrics are listed on the Results sheet for each of the three phases: The important ones are:

1. Time to Boil (temp corrected)
2. Thermal Efficiency
3. Specific Fuel Consumption (temp corrected)
4. Firepower
5. Turndown Ratio

Results of three water boiling tests - all cells are linked to data worksheets, no entries are required

Stove type/model	Three stone fire
Location	Regional Testing Center of Helsinki
Wood species (specify if different for each test)	Average Softwood (Conifer)
Wind conditions (specify if different for each test)	No wind

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	29	27	30	28.5	1.6
Temp-corrected time to boil Pot # 1	min	29	27	30	28.5	1.6
Burning rate	g/min	21	23	21	21.9	1.3
Thermal efficiency	%	46%	44%	43%	45%	2%
Specific fuel consumption	g/liter	75	78	81	78.0	2.7
Temp-corrected specific consumption	g/liter	75	78	81	78.0	2.7
Firepower	watts	6,765	7,593	6,963	7107	432.0

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev
Time to boil Pot # 1	min	25	26	25	25.3	0.6
Temp-corrected time to boil Pot # 1	min	25	26	25	25.7	0.6
Burning rate	g/min	24	22	24	23.5	0.9
Thermal efficiency	%	45%	46%	44%	45%	1%
Specific fuel consumption	g/liter	65	64	67	65.5	1.2
Temp-corrected specific consumption	g/liter	66	65	68	66.4	1.2
Firepower	watts	7,685	7,306	7,880	7624	291.8

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev
Burning rate	g/min	18	16	15	16.0	1.6
Thermal efficiency	%	11%	12%	13%	12%	1%
Specific fuel consumption	g/liter	227	201	187	205.2	20.3
Firepower	watts	5,743	5,082	4,734	5186	512.7
Turn down ratio	--	1.18	1.49	1.47	1.38	0.2

WBT Results

Temperature Corrected Time to Boil (min)

$$= \frac{75}{T_{boil} - T_{init}} * (t_{boil} - t_{start})$$

Normalized to a standard change in temperature of 75 C

WBT Results

Thermal Efficiency (%)

$$= \frac{energy\ to\ heat\ water + energy\ to\ evap\ water}{energy\ released\ by\ fuel} * 100$$

High efficiency ≠ low fuel consumption

because high power stoves evaporate lots of water and also use lots of fuel

WBT Results

Temperature Corrected Specific Fuel Consumption (g/L)

$$= \frac{75}{T_{boil} - T_{init}} * \frac{eqvivalent\ dry\ wood\ consumed\ (g)}{liters\ of\ water\ remaining\ (L)}$$

Eq. dry wood consumed = dry wood mass – wood mass that was consumed to evaporate the moisture in the wood -- equivalent mass of wood stored as char

Best indicator of fuel consumption

WBT Results

Average Firepower (W)

$$= \frac{total\ energy\ released\ by\ fuel\ during\ the\ test\ period\ (Joules)}{length\ of\ test\ period\ (seconds)}$$

WBT Results

Turndown Ratio

$$= \frac{average\ boil\ firepower(W)}{average\ simmer\ firepower\ (W)}$$

Indicates a stove's ability to adjust the firepower to match low power and high power cooking tasks

WBT Measuring Emissions

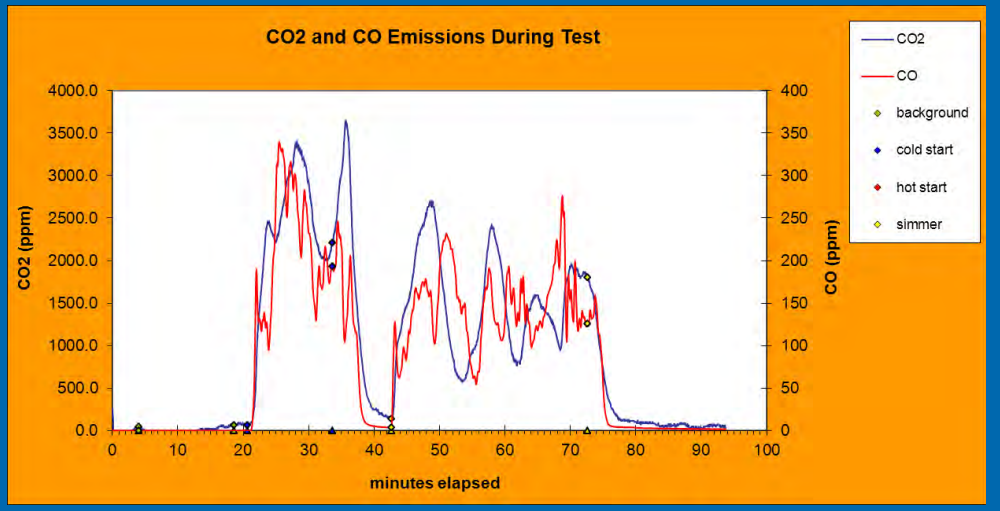
PEMS

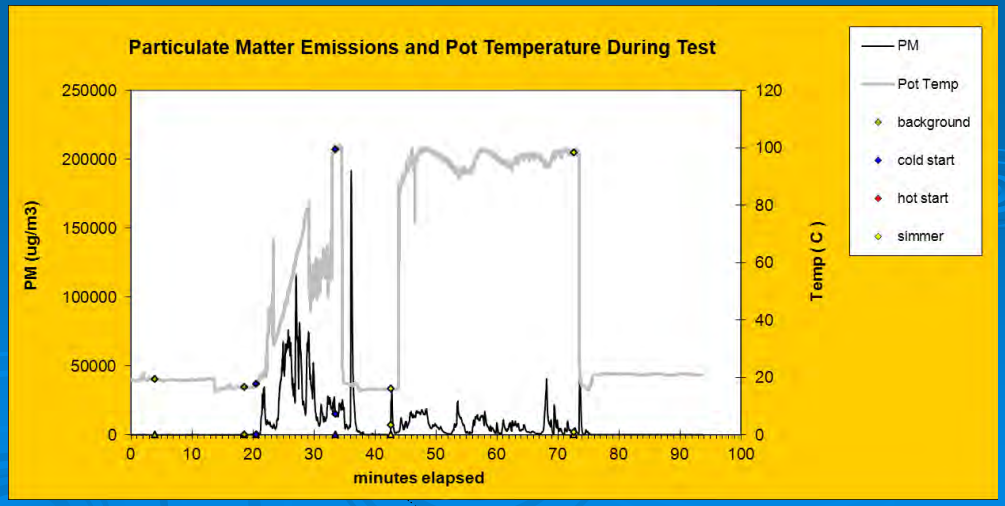
- Portable Emissions Measurement System collects and measures real-time emissions
- This data is processed using the PEMS spreadsheet to provide WBT results in the form of:
  - Total Emissions (grams)
  - Emission Factors (grams emission per kg fuel burned)
  - Pollutant/CO_2 ratios
  - Specific Emissions (grams of emissions per liter of water cooked)
  - Emissions to Complete the WBT (grams) - used for benchmarking

WBT Results

Emissions

Total Emissions			
COLD START			(cold start)
CO		grams	16.52
CO2		grams	293
appx PM		mg	2220
SIMMER			(simmer)
CO		grams	27.75
CO2		grams	449
appx PM		grams	1172
Specific Emissions (Corrected for starting temp, moistu			
COLD START	Correction Factor		0.2421
CO		gr/liter	4.0
CO2		gr/liter	71.0
appx PM mg		mg/liter	537.5
SIMMER	Correction Factor		0.6169
CO		gr/liter	25.7
CO2		gr/liter	415.9
appx PM mg		mg/liter	1084.4
Other Emission Measures			
COLD START			
Wood (g) based on Carbon		g	174
CO/CO2 Ratio (molar)		%	8.8%
EF-CO (g/kg) based on Carbon		g/kg	94.85
EF-CO2 (g/kg) based on Carbon		g/kg	1684
EF-PM (g/kg) based on Carbon		g/kg	12.75
SIMMER			
Wood (g) based on Carbon		g	269
CO/CO2 Ratio (molar)		%	9.7%
EF-CO (g/kg) based on Carbon		g/kg	103.21
EF-CO2 (g/kg) based on Carbon		g/kg	1671
EF-PM (g/kg) based on Carbon		g/kg	4.36
Standard Performance Measures			3stone 3.5in
CO to Cook 5L (20)		g	84.2
PM to Cook 5L (1500)		mg	5398.6
CO2 to Cook 5L		g	1394.7





WBT Sample Size

- At least three full tests per stove design are recommended
- Then do more tests if necessary to achieve the desired statistical significance measured by the COV (Coefficient of Variation)

$$COV = \frac{standard\ deviation}{average\ value} * 100 \quad (\%)$$

- COV is a measure of how much your results vary
- COV indicates how good you are at getting repeatable results
- For stove testing
  - COV = 5% is very good
  - COV = 10% or 25% is also acceptable

WBT Sample Size

COV Example

Do more tests to lower the COV

Results of three water boiling tests - all cells are linked to data worksheets, no entries are required

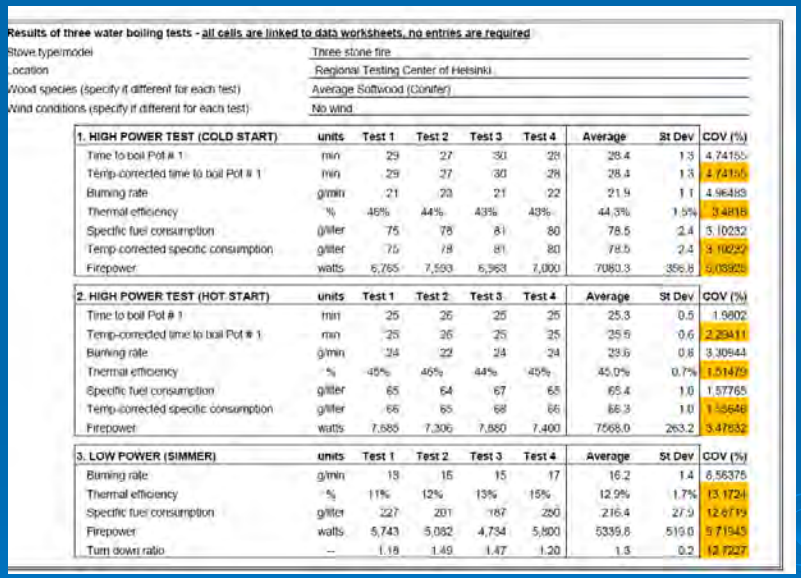
Stove type/model	Three stone fire
Location	Regional Testing Center of Helsinki
Wood species (specify if different for each test)	Average Softwood (Conifer)
Wind conditions (specify if different for each test)	No wind

1. HIGH POWER TEST (COLD START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV (%)
Time to boil Pot # 1	min	29	27	30	28.5	1.6	5.66559
Temp-corrected time to boil Pot # 1	min	29	27	30	28.5	1.6	5.66559
Burning rate	g/min	21	23	21	21.9	1.3	6.07892
Thermal efficiency	%	46%	44%	43%	45%	2%	3.5326
Specific fuel consumption	g/liter	75	78	81	78.0	2.7	3.50325
Temp-corrected specific consumption	g/liter	75	78	81	78.0	2.7	3.50325
Firepower	watts	6,765	7,593	6,963	7107	432.0	6.07892

2. HIGH POWER TEST (HOT START)	units	Test 1	Test 2	Test 3	Average	St Dev	COV (%)
Time to boil Pot # 1	min	25	26	25	25.3	0.6	2.27901
Temp-corrected time to boil Pot # 1	min	25	26	25	25.7	0.6	2.27901
Burning rate	g/min	24	22	24	23.5	0.9	3.82698
Thermal efficiency	%	45%	46%	44%	45%	1%	1.85487
Specific fuel consumption	g/liter	65	64	67	65.5	1.2	1.86681
Temp-corrected specific consumption	g/liter	66	65	68	66.4	1.2	1.86681
Firepower	watts	7,685	7,306	7,880	7624	291.8	3.82698

3. LOW POWER (SIMMER)	units	Test 1	Test 2	Test 3	Average	St Dev	COV (%)
Burning rate	g/min	18	16	15	16.0	1.6	9.88486
Thermal efficiency	%	11%	12%	13%	12%	1%	9.64316
Specific fuel consumption	g/liter	227	201	187	205.2	20.3	9.88486
Firepower	watts	5,743	5,082	4,734	5186	512.7	9.88486
Turn down ratio	--	1.18	1.49	1.47	1.38	0.2	12.7572

Sample size = 3



Sample size = 4

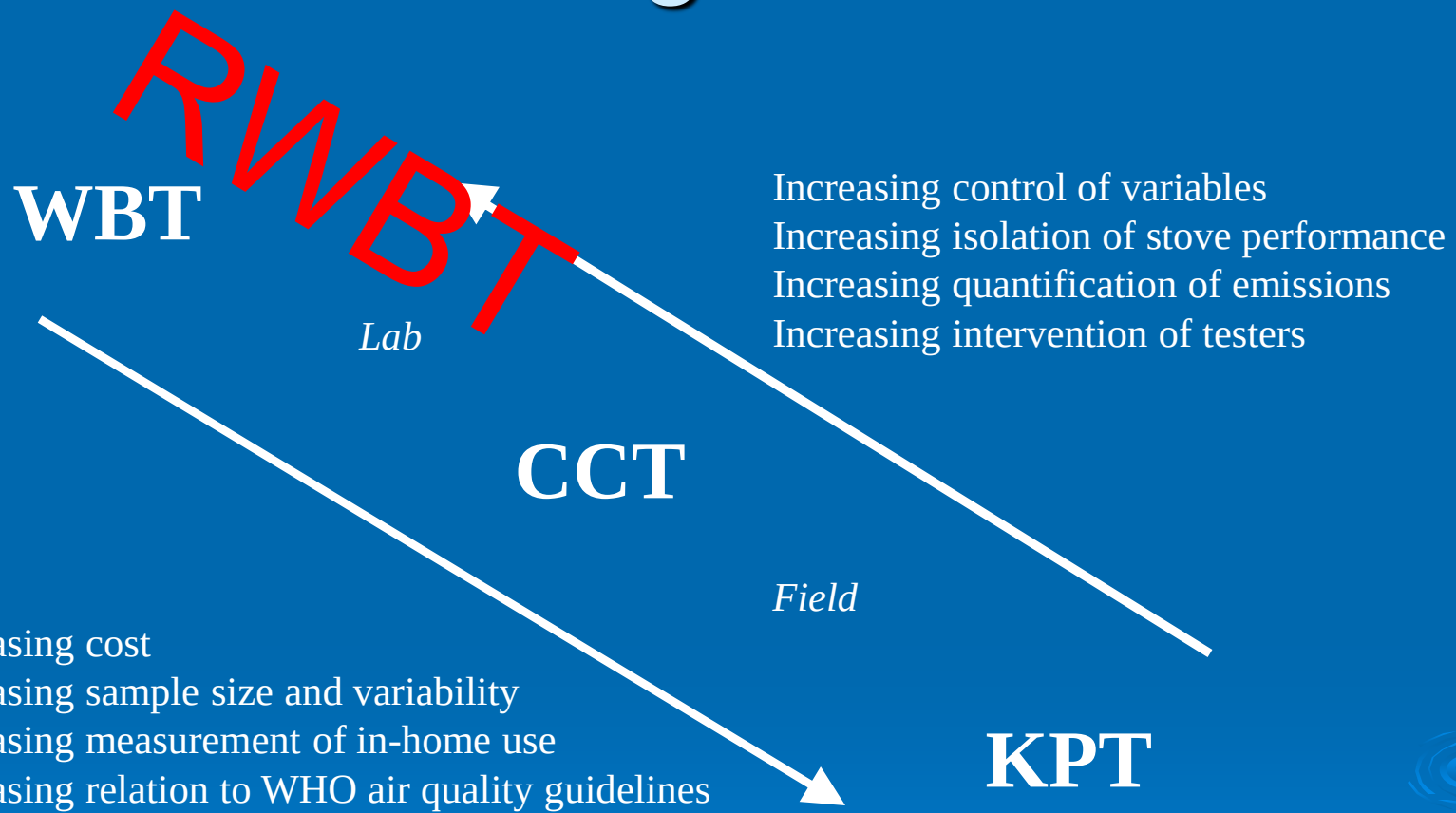
After doing a 4th test, the variation decreased for the cold start and hot start but not for the simmer

Regional Water Boiling Test (RWBT)

- Same control of variables as the WBT

  (same repeatability as WBT)
- Change the cooking task to be more realistic
  - Local pot (and lid)
  - Local fuel (as long as it doesn't increase variability)
  - Simulate local cooking tasks

Stove Testing Continuum



Regional Water Boiling Test (RWBT) Advantages

- A lab test that is more representative of field results
  - better approximation of actual cooking
- Same repeatability as the WBT
- Prepares stoves for the CCT better

Regional Water Boiling Test (RWBT) Disadvantages

- Not internationally comparable
- Could be abused as a substitute for field data

Regional Water Boiling Test (RWBT) Example: RWBT for West Africa

Difference from WBT protocol: RWBT uses a pot has lid because cooks in West Africa usually use a lid to cook rice or beans.

During the WBT, simmering without a lid requires 1000 W firepower due to heat loss by evaporation

During the RWBT, simmering with a lid requires 100 W firepower by blocking evaporation

Excess firepower = wasted fuel. RWBT shows us which stoves can save fuel at low power. WBT does not test stove at low power.

The WBT does not evaluate the stove performance below 1000 W, so the RWBT is a more appropriate test for that cooking task.

Documentation

- www.aprovecho.org/lab/pubs/testing

Download testing protocols