
STOVE PERFORMANCE REPORT

NKS D1, TAO CONCRETE, TAO THAI, TAO DUM-AUGUST2013

S+ / LAO PDR WB CSI

OCTOBER 2013



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LIST OF ACRONYMS

S+	Stove +
WB CSI	World Bank Clean Stove Initiative
G-BEL	GERES Biomass Energy Laboratory
NKS	Neang Krongrey Stove
WBT	Water Boiling Test
LEMS	Laboratory Emissions Monitoring System
AWBT	Adapted Water Boiling Test
CO	Carbon Monoxide
CO2	Carbon Dioxide
PM	Particulate Matter
UE	Useful Energy
TTB	Time to Boil
TTT	Time to Test
PFS	Potential Fuel Saving

ABSTRACT

The **Tao Thai** and **Tao Concrete stoves**, received at G-BEL in June 2013, and the **Tao Dum-August2013**, received in August 2013, are produced and used in **Laos**. They constitute the main **baseline stoves** for the S+ / WB CSI project in Northern Laos. Their performances will be compared with the ones of the **NKS** stove –size D1-. The NKS is an improved cookstove produced and used in Cambodia. The aim of this study is to underline the improvements that could be done by introducing a stove similar to the NKS in Laos. This report explains the methodology used to test the stoves and it presents the performances of Lao baseline stoves compared to the NKS stove.



Figure 1: NKS D1



Figure 2: Tao Concrete



Figure 3: Tao Thai



Figure 4: Tao Dum-August13

Standard laboratory testing was conducted to determine the performance of the stove against the ISO IWA benchmark. The stoves were tested using the **Water Boiling Test** WBT 4.2.2 under the Laboratory Emissions Monitoring System (LEMS) emission hood developed by Aprovecho Research Centre (ARC). They were also tested using the **Adapted Water Boiling Test** (AWBT), developed by GERES. The safety test was conducted following the IOWA Biomass Stove **Safety Test** Protocol.

The comparison of the results obtained with the WBT shows a potential fuel saving of 228g of wood-fuel (**21.5%**) per cooking cycle (high power phase + low power phase) by introducing the NKS stove compared to the Tao Concrete, 62g of wood-fuel (**6.9%**) compared to the Tao Thai and 121g of wood-fuel (**12.7%**) compared to the Tao Dum-August2013. AWBT (2 high power phases) results are quite similar: the NKS will potentially save **27.5%** of fuel compared to the Tao Concrete, **10.8%** compared to the Tao Thai and **17.1%** compared to the Tao Dum-August2013.

The NKS has a high power thermal efficiency of 31.3%, which is a little bit higher than the Tao Thai stove (30.5%) and the Tao Dum-August2013 (29.2%) and much higher than the Tao Concrete stove (25.8%).

As for particulate matter (PM2.5) and carbon monoxide (CO) emissions, the 4 stoves are positioned in similar tier (tiers 0 and 1 for PM and tiers 1 and 2 for CO) except for CO emission during **high power** phase for which the NKS receives a **tier 4** whereas the Lao stoves receive **tiers 1 and 2**. When considering **total emissions**, improvements with the NKS are slight compared to the Tao Thai (**7.8%** CO reduction and **3.1%** PM2.5 reduction) but are quite important compared to the Tao Concrete (**32.5%** CO reduction and **23%** PM2.5 reduction) and to the Tao Dum-August2013 (**5.7%** CO reduction and **41.1%** PM2.5 reduction).

Concerning **safety**, all the stoves are rated **tiers 2** (with scores: 79.5/100 for the Tao Concrete, 77.5/100 for the Tao Thai, 81/100 for the Tao Dum-August2013 and 86.5/100 for the NKS).

INTRODUCTION

1- ABOUT GERES CAMBODIA

GERES (*Group for the Environment, Renewable Energy and Solidarity*) is a non-governmental, non-profit organization created in 1976 and specializing in the implementation of efficient energy solutions adapted to developing countries to improve the living conditions of their inhabitants.

Operating in Cambodia since 1994, the vision of GERES Cambodia is for South East Asian population to take ownership of achieving sustainable management of natural resources in their landscape and make informed decisions that lead to access to renewable energy, mitigation of, and adaptation to climate change, and improved livelihoods.

2- THE LABORATORY: G-BEL

In 2009, GERES established a biomass energy laboratory (G-BEL) in Phnom Penh, Cambodia. This testing facility was set up in partnership with the Institute of Standards of Cambodia (ISC) and the Ministry of Industry, Mines and Energy (MIME).

The initial objectives were to improve the quality of the clay material used to make stoves, and to conduct biomass analysis for improved charcoal production. During 2010, this work was expanded to include emissions testing and improvements to stove performance. The measurement of indoor air pollution was incorporated into the laboratory's expanding workload at the beginning of 2011.

3- TESTING SERVICE

G-BEL uses the Laboratory Emissions Monitoring System (LEMS) with the PM2.5 gravimetric measurement module from Aprovecho Research Center for stove performance testing. Other installed laboratory equipment includes precision scales, an oven and a muffle kiln. This equipment is used by G-BEL for a range of purposes including biomass analysis, stove testing, clay testing and ceramic material development.

The laboratory provides testing services as following:

- Characterization of biomass fuel: moisture, ash rate, volatile matter, fixed carbon content
- Characterization of ceramic materials: thermal and mechanical resistances, porosity
- Equipment performance testing: characterization and optimization of biomass combustion equipment (stove, kiln, etc.), at the laboratory and in the field
- Emission testing: CO, CO2 and PM2.5 at the laboratory
- IAP testing: measurement of indoor air pollution (CO, PM) in the field

4- OBJECTIF OF THE STUDY

The objective of this study is to compare the following performances of the NKS, Tao Thai and Tao Concrete stoves:

- Efficiency
- Potential fuel saving
- Total Emissions
- Indoor Air Emissions
- Safety

METHODOLOGY

1- WATER BOILING TEST AND EMISSIONS PERFORMANCE

The Water Boiling Test (WBT) is a simplified simulation of the cooking process. It is intended to measure how efficiently a stove uses fuel to heat water in a cooking pot and the quantity of emissions produced while cooking. Efficiency and emissions must be tested with the same protocol, because changes in stove operation and design affect both.

The WBT consists of three phases that immediately follow each other:

- 1) The **cold-start high-power** phase: the stove is at ambient temperature. The quantity of fuel to boil a measured quantity of water in a standard pot is measured. Then, the boiled water is replaced with a fresh pot of ambient-temperature water to perform the second phase.
- 2) The **hot-start high-power** phase is conducted after the first phase while the stove is still hot. The protocol is the same except that the stove is hot.
- 3) The **simmer** phase provides the amount of fuel required to simmer a measured amount of water at just below the boiling point for 45 minutes.

The stoves were tested using the WBT 4.2.2 and Aprovecho WBT 4.2.2 data sheet, updated on April 30th, 2013.

2- ADAPTED WATER BOILING TEST

The Adapted Water Boiling Test (AWBT) has been designed by GERES to be **more representative of local** in-use operation and to **ease the implementation** of the test in developing countries.

The WBT is regularly revised and modified, making implementation by local technicians difficult and complex. The AWBT is easier, more precise (**less error sources**) and accessible to local development agencies and organizations working on the evaluation and dissemination of cookstoves.

However, the AWBT developed by GERES is favoring stoves able to operate in **high power**, the common way of cooking in the region.

This protocol is used for laboratory testing, not to define an energetic yield but to provide a comparison of fuel usage between two cookstoves: this test will not calculate stove efficiency but a relative difference between useful energies of two stoves when tested with the same fuel. Then, a potential fuel saving can be calculated based on useful energies.

Unlike the WBT, in the AWBT protocol, the quantity of fuel is fixed at the beginning of the test and will be the same for all tests and stoves that will be compared.

The AWBT consists of two phases that immediately follow each other:

- 1) The **cold-start high-power** phase: at ambient temperature, the stove is loaded/fed with a fixed quantity of fuel to bring to a boil 3 liters of water in a standard pot.
- 2) The **evaporating high-power** phase consists on evaporating the remaining water until water temperature drops 3°C below boiling point.

The quantity of water evaporated during each phase of the AWBT is measured. The useful energy (UE) is then calculated. It represents the energy absorbed by the mass of water (Mw) to raise its initial temperature Ti to the boiling temperature Tb (sensible heat: Q sensible) and the energy absorbed by the mass of water evaporated (Mwe) to change its phase from liquid to vapor (latent heat: Q latent).

$$UE [kJ] = Q \text{ sensible } [kJ] + Q \text{ latent } [kJ]$$

$$Q \text{ sensible } [kJ] = Mw [kg] * C * (Tb - Ti) [^{\circ}C]$$

$$Q_{\text{latent}} [\text{kJ}] = M_{\text{we}} [\text{kg}] \cdot L_v$$

Where: C is the specific heat capacity = 4.18 kJ/kg. °C

L_v is the specific latent heat of vaporization = 2257 kJ/kg. °C

3- SAFETY TEST

The stoves were also evaluated for safety using the method outlined in Nathan Johnson's Master's Thesis, "Risk analysis and safety evaluation of household stoves in developing nations," Iowa State University, 2005.

The Safety Test addresses the basic safety issues that should be considered in the design of stoves. It consists of 10 tests:

1. **Sharp Edges and Points** on the exterior surface of the cookstove
2. **Cookstove Tipping** to determine stability
3. **Containment of Fuel** to evaluate if burning fuel can be expelled from a combustion chamber or spilled when a stove become overturned
4. **Obstruction near Cooking Surface** to check for protrusions along the upper edges of the cooking surface with which pots can collide when being moved
5. **Surface Temperature** of the exterior surface of the stove
6. **Heat Transfert to the Environment:** heat transmission to surroundings may ignite combustibles or construction in the area of the cookstoves
7. **Handle Temperature** is meant to measure parts of the cookstove that need to be touched during regular operation
8. **Chimney Shielding**
9. **Flames Surrounding Cooking pot:** flames touching the pot should be concealed and not able to come into contact with hands or clothing
10. **Flames Exiting Fuel Chamber**

4- IWA PERFORMANCE TIERS

In February 2012, more than 90 stakeholders from 23 countries met in The Hague to establish an ISO IWA that provides interim guidance for rating cookstoves on four performance indicators: efficiency, total emissions, indoor emissions and safety. Each of the four indicators has multiple Tiers of Performance 0 to 4 (see Appendix 1).

The following chart categorized stoves based on their different performance tiers:

Tier 0	Typical, Unimproved, 3-stone fire
Tier 1	Measureable Improvement
Tier 2	Substantial Improvement
Tier 3	Stretch Goals Which Achieve Significant, Measurable Health and/or Environmental Goals
Tier 4	Aspirational Goal

Tiers have been established for safety and for the WBT following metrics:

- High Power Thermal Efficiency
- Low Power Specific Fuel Consumption
- High Power CO
- Low Power CO
- High Power PM
- Low Power PM
- Indoor CO Emissions
- Indoor PM Emissions

5-WOOD USED AND STARTING METHOD

For the **WBT**, local Cambodian hardwood **cut to size (1.5x1.5x40cm)** at 12% moisture content was used.

For the **AWBT**, local Cambodian hardwood at 16% moisture content was used. The wood is **roughly cut** to have an average size of **2x2.5x40cm**. For the AWBT, the wood used is not sized, as it is how the wood is sold in local market and used by household. 0.9kg of wood was used for each AWBT test.

There was no specification for the **starting phase**. In both WBT and AWBT, fire was started with 50g of small **woodchips** (average size of 0.3x0.3x10cm) fired with a lighter (during around 1 minute). For AWBT, around 50g of **wood sticks** with an average size of 1x1x10cm were added to the starting woodchips.



Figure 5: Wood cut to size for WBT (left), Wood from the market for AWBT (right)



Figure 6: Woodchips for WBT and AWBT starting phase (average size: 0.3x0.3x10cm)



Figure 7: Wood sticks for AWBT starting phase (average size: 1x1x10cm)

6-POT USED AND WATER QUANTITY

For the **WBT**, a flat bottom pot (28cm diameter and 15cm height) filled with **5 liters** of water was used for all tests. No lid was used.

For the **AWBT**, a flat bottom pot (24cm diameter and 12cm height) filled with **3 liters** of water was used for all tests. No lid was used.



Figure 8: Pot used for WBT (left) and AWBT (right)

7-LIMITATION

The WBT protocol is an approximation of the cooking process to compare the effectiveness of different designs at performing similar tasks but it is less representative of local cooking habits than the AWBT.

Notice that following the WBT protocol, the tester does not weigh the charcoal after the hot-start test, so estimates of the fuel used during the hot-start and simmer tests are not exact.

The AWBT is supposed to be adapted to the local context. We have assumed that Lao population uses the same type of wood and cooking pot as in Cambodia.

Local wood sticks bought in the market have different sizes: roughly from 2x2x40cm to 5x5x40cm. If the wood stick is too big, Cambodian families usually cut it lengthwise into 2. We have noticed that the Tao Thai and the NKS can be fed with all sizes of wood sticks but the stove Tao Concrete could not burn well big size of wood sticks (more than 2.5x3x40cm). Finally, we have conducted all AWBT tests with wood sticks with an average size of 2x2.5x40cm in order to have the same type of wood for the 3 stoves.

RESULTS AND DISCUSSION

1- WBT RESULTS

The stoves were tested using the WBT 4.2.2 and Aprovecho WBT 4.2.2 data sheet, updated on April 30th, 2013.



Figure 9: NKS D1, Tao Thai, Tao Concrete and Tao Dum-August2013 (left to right) during WBT

The comparison of the results obtained with the 3 stoves tested with WBT is presented in the charts below. The detailed results of each stove can be seen in Appendix 2, 3, 4 and 5 for the NKS D1, the Tao Thai, the Tao Concrete and the Tao Dum-August2013 respectively.

1. HIGH POWER TEST (COLD START)	units	NKS D1	Tao Thai	Tao Concrete	Tao Dum-August2013
Time to boil Pot # 1	min	24	23	30	26
Burning rate	g/min	14.24	16.23	15.27	15.97
Thermal efficiency	--	30%	29%	25%	28%
Specific fuel consumption	g/liter	71.42	76.47	97.19	86.49
Temp-corrected specific consumption	g/liter	75.7	79.7	101.0	89.8
Firepower	watts	4369	4981	4686	4900
Equivalent Dry Fuel Consumed	g	345.0	367.9	461.4	409.3

2. HIGH POWER TEST (HOT START)	units	NKS D1	Tao Thai	Tao Concrete	Tao Dum-August2013
Time to boil Pot # 1	min	20	23	25	23
Burning rate	g/min	16.00	15.39	17.30	16.19
Thermal efficiency	--	33%	32%	27%	30%
Specific fuel consumption	g/liter	66.06	73.47	91.91	79.84
Temp-corrected specific consumption	g/liter	70.3	77.7	92.9	83.3
Firepower	watts	4910	4723	5310	4969
Equivalent Dry Fuel Consumed	g	318.5	350.7	437.6	379

3. LOW POWER TEST (SIMMER)	units	NKS D1	Tao Thai	Tao Concrete	Tao Dum-August2013
Burning rate	g/min	7.98	8.47	9.72	8.47
Thermal efficiency	--	32%	30%	26%	34%
Specific fuel consumption 45 min	g/liter	92.9	99.6	114.6	103.6
Firepower	watts	2450	2601	2982	2601
Turn down ratio	--	1.90	1.87	1.68	1.91
Equivalent Dry Fuel Consumed	g	359.2	381.4	437.3	381.3

► Benchmark values

The benchmark values combine the phases of cold start, hot start and simmer into one value for the overall test. The Standard Performance Measures are derived from the specific fuel consumption and the specific emissions based on the water remaining.

The basic equation is:

$$5 * [\text{Specific Measure to Boil (average cold and hot starts)} + \text{Specific Measure to Simmer}]$$

Where Measure is either fuel consumption or emissions.

BENCHMARK VALUES (for 5L)	units	NKS D1	Tao Thai	Tao Concrete	Tao Dum-August2013
Fuel to Cook 5L	g	829.7	891.5	1057.5	950.5
CO to Cook 5L	g	45.1	48.9	66.8	47.8
PM to Cook 5L	mg	3219.6	3324.2	4183.3	5464.4
Energy to Cook 5L	kJ	15279	16417	19473	17503
Time to Boil	min	23.4	23.9	28.6	25.5
CO2 to Cook 5L	g	1230.5	1330.8	1694.3	2037.8

Using WBT benchmark values, an upgrade from the Tao Concrete to the NKS will result in a saving of 228g wood-fuel (21.5%) per cooking cycle, an upgrade from the Tao Thai to the NKS will result in a saving of 62g wood-fuel (6.9%) and an upgrade from the Tao Dum-August2013 to the NKS will result in a saving of 121g wood-fuel (12.7%).

► IWA Performance tiers

The emissions are characterized following the specifications of the ISO IWA. Two sets of measures are reported, one for outdoor pollution, and one for indoor pollution. For high power outdoor, the measures are specific to the amount of energy delivered to the cooking pot. For low power outdoor, they are specific to the amount of water remaining, and to the length simmer period. By using the length of the simmer period the metric recognizes that stoves that simmer for longer leave behind less water. For indoor pollution there are no power levels and the measure is specific to time.

The thermal efficiency is calculated from the ratio of the energy embodied in the water after the test, and the energy embodied in the fuel consumed during the test. The ISO IWA adds a new metric for low power fuel efficiency that is specific to water remaining and length of simmer in the same way as the low power outdoor emissions measure.

The tiers of performances defined in the ISO IWA can be seen in Appendix 1.

IWA Performance Metrics and Tiers	units	NKS D1		Tao Thai		Tao Concrete		Tao Dum-August2013	
		Metrics	Tier	Metrics	Tier	Metrics	Tier	Metrics	Tier
High Power Thermal Efficiency	%	31.3%	2	30.5%	2	25.8%	2	29.2%	2
Low Power Specific Consumption Rate	MJ/min.L	0.038	2	0.041	1	0.047	1	0.042	1
High Power CO	g/MJd	7.89	4	9.55	2	11.90	1	9.80	2
Low Power CO	g/min.L	0.13	1	0.13	2	0.18	1	0.12	2
High Power PM	mg/MJd	920.0	1	984.2	0	1072.0	0	1536.4	0
Low Power PM	mg/min.L	6.25	1	5.64	1	7.93	1	9.11	0
Indoor Emissions CO	g/min	0.69	1	0.85	1	0.90	1	0.84	1
Indoor Emissions PM	mg/min	81.4	0	87.5	0	83.2	0	132.2	0

The following graphs situate the 4 stoves NKS, Tao Concrete, Tao Thai and Tao Dum-August2013 within the IWA proposed tiers in different categories: fuel use, high and low powers emissions and indoor emissions.

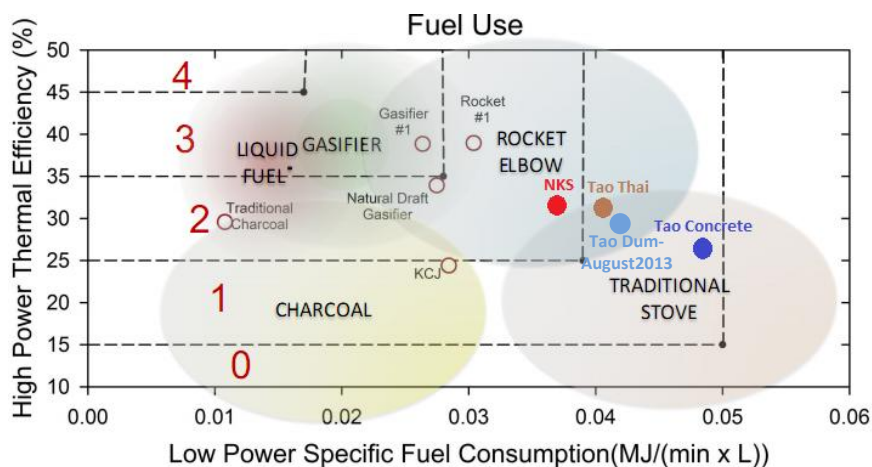


Figure 10: Fuel Use and Proposed Tiers

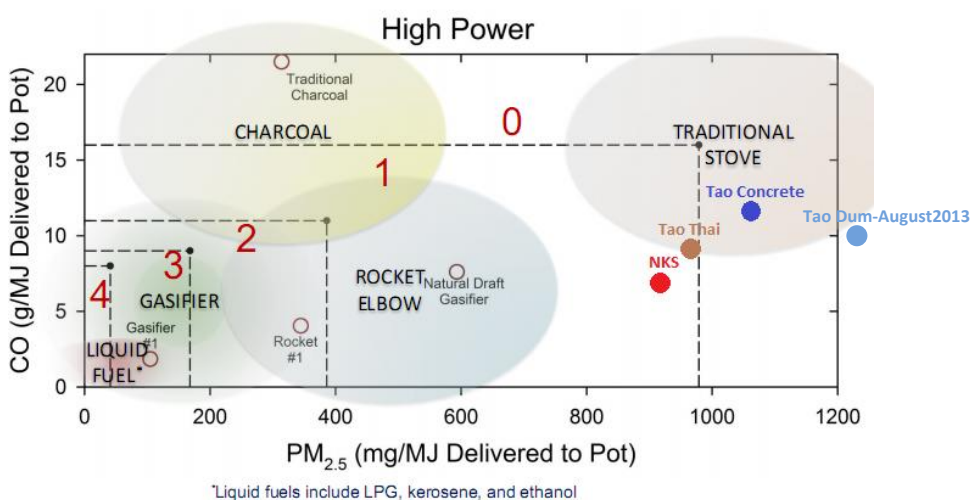


Figure 11: High Power Emissions and Proposed Tiers

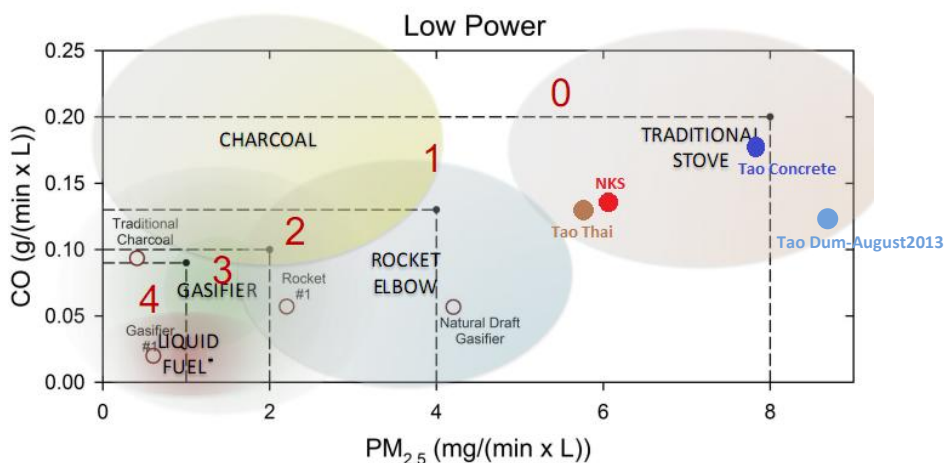


Figure 12: Low Power Emissions and Proposed Tiers

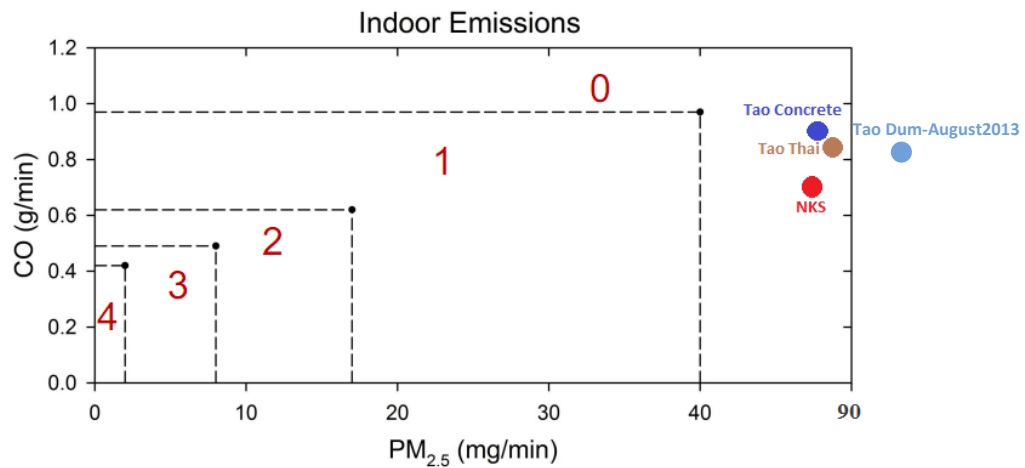


Figure 13: Indoor Emissions and Proposed Tiers

► WBT conclusion

Globally, the WBT results show that the NKS has better performances than the Tao Thai, the Tao Concrete and the Tao Dum-August2013:

- Less emissions should be produced when using the NKS rather than the Tao Thai, the Tao Concrete or the Tao Dum-August2013.
- The NKS high power thermal efficiency (31.3%) is similar to the Tao Thai one (30.5%) and the Tao Dum-August2013 one (29.2%) and higher than the Tao Concrete one (25.8%).
- The low power specific consumption rate is lower when using the NKS than the 3 Lao stoves.

However, the WBT protocol is an approximation of the cooking process that is less representative of local cooking habits than the AWBT.

2-AWBT RESULTS

The comparison of the results obtained with the 4 stoves tested with AWBT is presented in the charts below. The detailed results of each stove can be seen in Appendix 6, 7, 8 and 9 for the NKS D1, the Tao Thai, the Tao Concrete and the Tao Dum-August2013 respectively.

COLD START - HIGH POWER		NKS D1	Tao Thai	Tao Concrete	Tao Dum-August2013
M water (kg)	Mass of water	3	3	3	3
Tb (°C)	Boiling temperature	99.2	99.2	99.2	99.1
Ti (°C)	Initial temperature	28.5	28.6	28.8	27.9
Q sensible (kJ)	Sensible heat	886.160	884.906	883.234	893.684
M w after high power (kg)	Mass of water after high power	2.919	2.908	2.840	2.911
M we (kg)	Mass of water evaporated - cold start	0.081	0.092	0.160	0.0893
Q latent (kJ)	Latent heat	182.065	208.396	361.120	201.625
UE (kJ)		1068.225	1093.302	1244.354	1095.309

EVAPORATING PHASE - HIGH POWER		NKS D1	Tao Thai	Tao Concrete	Tao Dum-August2013
Q sensible (kJ)	Sensible heat	0	0	0	0
M w after evaporating phase (kg)	Mass of water after evaporating phase	1.325	1.549	1.892	1.683
M we (kg)	Mass of water evaporated - evap. phase	1.594	1.359	0.948	1.228
Q latent (kJ)	Latent heat	3597.658	3066.511	2138.884	2771.596
UE (kJ)		3597.658	3066.511	2138.884	2771.596

TOTAL TEST		NKS D1	Tao Thai	Tao Concrete	Tao Dum-August2013
M water (kg)	Initial mass of water	3	3	3	3
Tb (°C)	Boiling temperature	99.2	99.2	99.2	99.1
Ti (°C)	Initial temperature	28.5	28.6	28.8	27.9
Q sensible (kJ)	Sensible heat	886.16	884.906	883.234	893.684
M w after test (kg)	Mass of water after test	1.325	1.549	1.892	1.683
M we (kg)	Total mass of water evaporated	1.675	1.451	1.108	1.317
Q latent (kJ)	Latent heat	3779.723	3274.907	2500.004	2973.221
UE (kJ)		4665.883	4159.813	3383.238	3866.905
TTB (hh:mm:ss)	Time to boil	0:11:47	0:12:54	0:17:26	0:16:14
TTT (hh:mm:ss)	Time to test	1:07:48	1:03:53	0:59:36	0:59:53

► Time to boil and time to test

The graph below shows the time to boil (TTB) and the time to test (TTT) when testing the 4 stoves with AWBT.

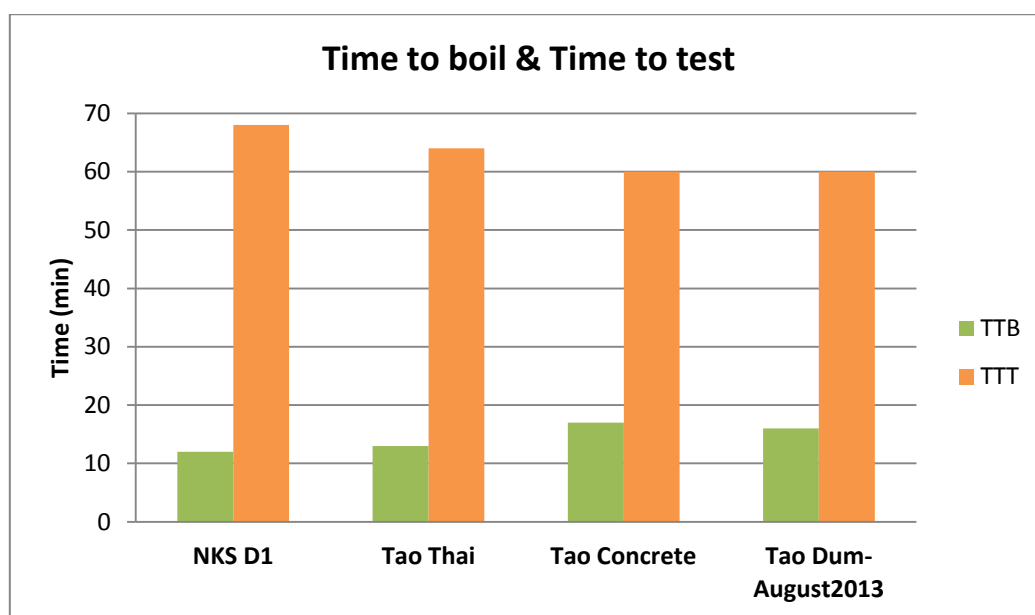


Figure 14: Comparison of TTB and TTT

The NKS and the Tao Thai have similar TTB: it takes 12 minutes for the NKS to bring 3 liters of water to a boil and 13 minutes for the Tao Thai. With the Tao Concrete and the Tao Dum-August2013, it takes few minutes more: 17 minutes and 16 minutes respectively.

With the same amount of fuel, the time to test is longer for the NKS with 68 minutes than for the Tao Thai (64 minutes), the Tao Concrete (60 minutes) and the Tao Dum-August2013 (60 minutes).

That means the stove **NKS** can bring 3 liters of water to a boil **faster** than the 3 other Lao stoves and it can keep the water at high temperature (the test stops when water temperature drops 3°C below boiling point) **for a longer time**.

► Useful energy (UE) and potential fuel saving (PFS)

The potential fuel saving is the ratio of the useful energy provided by the cookstoves. This ratio shows the potential fuel differences between two cookstoves. It starts to be significant above 10%.

The potential fuel saving is calculated with the following formula:

$$\text{PFS [\%]} = 100 * (\text{UE improved} - \text{UE traditional}) / \text{UE improved}$$

The useful energy calculated for the NKS stove is 4666 kJ, which is higher than for Tao Concrete (3383 kJ), Tao Thai (4160 kJ) and Tao Dum-August2013 (3867 kJ). As a result, the NKS stove will potentially save **27.5%** of fuel compared to the Tao Concrete, **17.1%** compared to the Tao Dum-August2013 and **10.8%** compared to the Tao Thai.

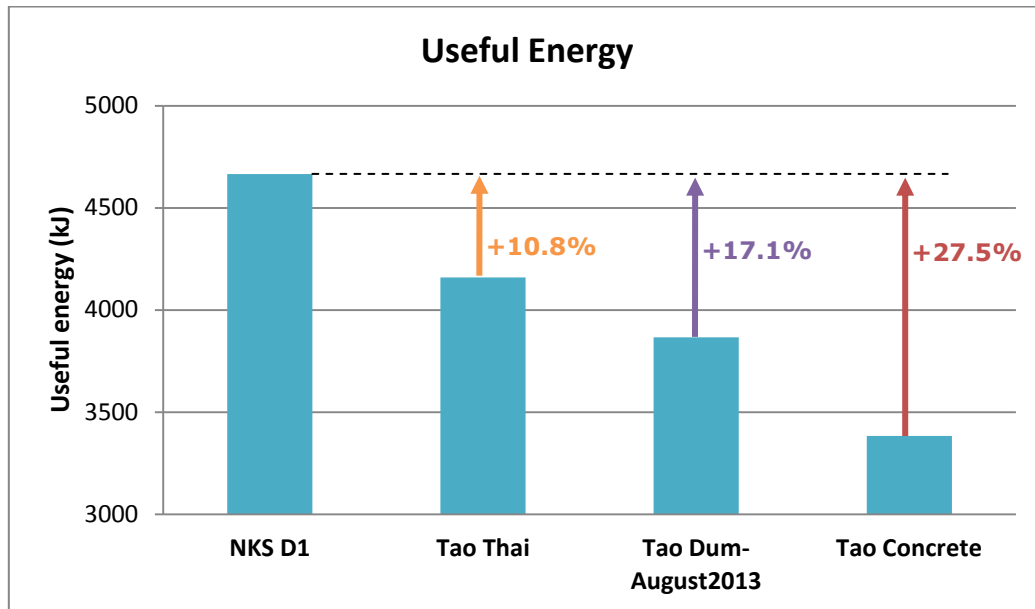


Figure 15: Comparison of useful energies and potential fuel saving

► AWBT conclusion

The AWBT results are coherent with the WBT conclusions. The introduction of the NKS has a potential fuel saving of 27.5% compared to the Tao Concrete, 17.1% compared to the Tao Dum-August2013 and 10.8% compared to the Tao Thai.

3-SAFETY TEST RESULTS

The stoves NKS, Tao Thai, Tao Concrete and Tao Dum-August2013 have been tested for safety. The tests results in different categories are shown in the chart below.

Safety Evaluation	NKS D1				
	Rating	Value	Weight	Total	Comments
Sharp Edges/Points	Best	4	1.5	6.0	The stove has no sharp points that could cause cuts to the user, or get entangled to a cloth.
Cookstove Tipping	Best	4	3	12	The stove is very stable on the ground, with a tipping ratio of 0.73. The cook pot and its contents are not likely to spill if the stove is tipped.
Containment of Fuel	Good	3	2.5	7.5	Area exposed: 91 cm ²
Obstructions Near Cooking Surface	Good	3	2	6	The cooking height is 1.5cm lower than obstructions height. The obstructions cause low risks when placing or removing the pot from the stove.
Surface Temperature	Poor	1	2	2	The stove surface temperature reaches a maximum of 137.9°C. This high temperature may cause burns if touched by users (especially by children if the stove is placed below the child line).
Heat Transfer to Surroundings	Best	4	2.5	10	The temperature at the bottom of the stove reaches a maximum of 51.2°C.
Cookstove Handle Temperature	Best	4	2	8	No operation during cooking.
Chimney Shielding	Best	4	2.5	10	No chimney.
Flames/Heat Surrounding Cookpot	Good	3	3	9	The amount of uncovered flames touching the cook pot depends on how much the user fed the stove. There can be uncovered flames around the cooking pot, especially during the starting phase but they are often less than 4cm up sides.
Flames/Heat Exiting Fuel Chamber	Best	4	4	16	No flame exiting fuel chamber.
Total Score /100	86.5				
Stove Rating	GOOD				
Stove Safety IWA Tier	2				

Figure 16: Safety evaluation of the NKS

Safety Evaluation	Tao Thai				
	Rating	Value	Weight	Total	Comments
Sharp Edges/Points	Poor	1	1.5	1.5	The stove has some sharp points that could cause cuts to the user, or get entangled to a cloth.
Cookstove Tipping	Best	4	3	12	The stove is very stable on the ground, with a maximum tipping ratio of 0.72. The cook pot and its contents are not likely to spill if the stove is tipped.
Containment of Fuel	Fair	2	2.5	5	Area exposed: 169 cm ²
Obstructions Near Cooking Surface	Fair	2	2	4	The cooking height is 2.5cm lower than obstructions height. There are obstructions near the cooking surface that could cause risks when placing or removing the pot from the stove.
Surface Temperature	Poor	1	2	2	The non-metallic surface temperature reaches a maximum of 88.5°C and the metallic surface temperature reaches a maximum of 83.9°C. This high temperature may cause burns if touched by users (especially by children if the stove is placed below the child line).
Heat Transfer to Surroundings	Best	4	2.5	10	The temperature at the bottom of the stove reaches a maximum of 49.6°C.
Cookstove Handle Temperature	Best	4	2	8	No operation during cooking.
Chimney Shielding	Best	4	2.5	10	No chimney.
Flames/Heat Surrounding Cookpot	Good	3	3	9	The amount of uncovered flames touching the cook pot depends on how much the user fed the stove. There can be uncovered flames around the cooking pot, especially during the starting phase but they are often less than 4cm up sides.
Flames/Heat Exiting Fuel Chamber	Best	4	4	16	No flame exiting fuel chamber.
Total Score /100	77.5				
Stove Rating	FAIR				
Stove Safety IWA Tier	2				

Figure 17: Safety evaluation of the Tao Thai

Safety Evaluation	Tao Concrete				
	Rating	Value	Weight	Total	Comments
Sharp Edges/Points	Poor	1	1.5	1.5	The stove has some sharp points that could cause cuts to the user, or get entangled to a cloth.
Cookstove Tipping	Best	4	3	12	The stove is very stable on the ground, with a maximum tipping ratio of 0.64. The cook pot and its contents are not likely to spill if the stove is tipped.
Containment of Fuel	Fair	2	2.5	5	Area exposed: 184 cm ²
Obstructions Near Cooking Surface	Good	3	2	6	The cooking height is 2cm lower than obstructions height. The obstructions cause low risks when placing or removing the pot from the stove.
Surface Temperature	Poor	1	2	2	The stove surface temperature reaches a maximum of 118.3°C. This high temperature may cause burns if touched by users (especially by children if the stove is placed below the child line).
Heat Transfer to Surroundings	Best	4	2.5	10	The temperature at the bottom of the stove reaches a maximum of 57.3°C.
Cookstove Handle Temperature	Best	4	2	8	No operation during cooking.
Chimney Shielding	Best	4	2.5	10	No chimney.
Flames/Heat Surrounding Cookpot	Good	3	3	9	The amount of uncovered flames touching the cook pot depends on how much the user fed the stove. There can be uncovered flames around the cooking pot, especially during the starting phase but they are often less than 4cm up sides.
Flames/Heat Exiting Fuel Chamber	Best	4	4	16	No flame exiting fuel chamber.
Total Score /100	79.5				
Stove Rating	FAIR				
Stove Safety IWA Tier	2				

Figure 18: Safety evaluation of the Tao Concrete

Safety Evaluation	Tao Dum-August2013				
	Rating	Value	Weight	Total	Comments
Sharp Edges/Points	Poor	1	1.5	1.5	The stove has some sharp points that could cause cuts to the user, or get entangled to a cloth.
Cookstove Tipping	Best	4	3	12	The stove is very stable on the ground, with a maximum tipping ratio of 0.64. The cook pot and its contents are not likely to spill if the stove is tipped.
Containment of Fuel	Good	3	2.5	8	Area exposed: 89 cm2
Obstructions Near Cooking Surface	Best	4	2	8	The cooking height is 0.5cm lower than obstructions height. There is no obstruction near the cooking surface that could cause risks when placing or removing the pot from the stove.
Surface Temperature	Poor	1	2	2	The stove non-metallic surface temperature reaches a maximum of 109.0°C and the stove metallic surface temperature reaches a maximum of 111.6°C. This high temperature may cause burns if touched by users (especially by children if the stove is placed below the child line).
Heat Transfer to Surroundings	Best	4	2.5	10	The temperature at the bottom of the stove reaches a maximum of 59.8°C.
Cookstove Handle Temperature	Best	4	2	8	No operation during cooking.
Chimney Shielding	Best	4	2.5	10	No chimney
Flames/Heat Surrounding Cookpot	Fair	2	3	6	The amount of uncovered flames touching the cookpot (but usually not the handles) depends on how much the user fed the stove. There are uncovered flames around the cooking pot during firing.
Flames/Heat Exiting Fuel Chamber	Best	4	4	16	No flame exiting fuel chamber.
Total Score /100	81.0				
Stove Rating	FAIR				
Stove Safety IWA Tier	2				

Figure 19: Safety evaluation of the Tao Dum-August2013

The 4 stoves receive a **tier 2** for safety mainly because the surface temperature, heavily weighted measures in the evaluation, is hot enough to cause burns during use.

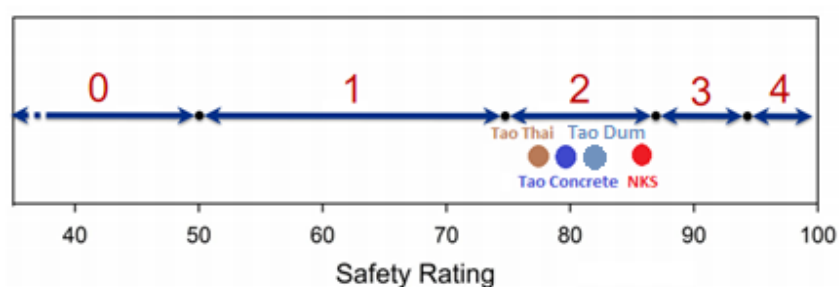


Figure 20: Safety Rating and Tiers

CONCLUSION

The 4 stoves NKS D1, Tao Thai, Tao Concrete and Tao Dum-August2013 have been tested with the WBT, the AWBT and the safety test.

When tested with the WBT:

The **NKS D1** boils **5L** of water in **23 minutes**, uses **830 g** of equivalent dry wood to cook 5L and has an energy use of **15,279 kJ**. It has a thermal efficiency of **31.3%** during the high power phase and **32%** during simmering. To cook 5L of water, it emits **45.1 g of CO** and **3,220 mg of PM2.5**.

The **Tao Thai** boils **5L** of water in **24 minutes**, uses **892 g** of equivalent dry wood to cook 5L and has an energy use of **16,417 kJ**. It has a thermal efficiency of **30.5%** during the high power phase and **30%** during simmering. To cook 5L of water, it emits **48.9 g of CO** and **3,324 mg of PM2.5**.

The **Tao Concrete** boils **5L** of water in **29 minutes**, uses **1,058 g** of equivalent dry wood to cook 5L and has an energy use of **19,473 kJ**. It has a thermal efficiency of **25.8%** during the high power phase and **26%** during simmering. To cook 5L of water, it emits **66.8 g of CO** and **4,183 mg of PM2.5**.

The **Tao Dum-August2013** boils **5L** of water in **26 minutes**, uses **951 g** of equivalent dry wood to cook 5L and has an energy use of **17,503 kJ**. It has a thermal efficiency of **29.2%** during the high power phase and **34%** during simmering. To cook 5L of water, it emits **47.8 g of CO** and **5,464 mg of PM2.5**.

Energy performance results obtained with the AWBT are similar; the NKS has potential fuel savings of **10.8%**, **27.5%** and **17.1%** compared to the Tao Thai, the Tao Concrete and the Tao Dum-August2013 respectively.

WBT and AWBT results are coherent and give the same conclusions: the NKS obtained better performances than the 3 other stoves. These performances improvement in both energy and emissions are slight compared to the Tao Thai (**6.9%** and **10.8%** potential fuel saving depending on the testing protocol, **7.8%** CO reduction and **3.1%** PM2.5 reduction) but are quite important compared to the Tao Concrete (**21.5%** and **27.5%** potential fuel saving, **32.5%** CO reduction and **23%** PM2.5 reduction) and the Tao Dum-August2013 (**12.7%** and **17.1%** potential fuel saving, **5.7%** CO reduction and **41.1%** PM2.5 reduction).

With regards to safety, the 4 stoves obtained similar rating.

APPENDIX

Appendix 1: ISO IWA tiers of performances

EMISSIONS		
	High Power CO (g/MJ)	Low Power CO (g/min.L)
Tier 0	>16	>0.20
Tier 1	≤16	≤0.20
Tier 2	≤11	≤0.13
Tier 3	≤9	≤0.10
Tier 4	≤8	≤0.09
	High Power PM (mg/MJ)	Low Power PM (mg/min.L)
Tier 0	>979	>8
Tier 1	≤979	≤8
Tier 2	≤386	≤4
Tier 3	≤168	≤2
Tier 4	≤41	≤1

EFFICIENCY		
	High Power Thermal Efficiency (%)	Low Power Specific Consumption (MJ/min.L)
Tier 0	<15	>0.050
Tier 1	≥15	≤0.050
Tier 2	≥25	≤0.039
Tier 3	≥35	≤0.028
Tier 4	≥45	≤0.017

INDOOR EMISSIONS**		
	Indoor Emissions CO (g/min)	Indoor Emissions PM (mg/min)
Tier 0	>0.97	>40
Tier 1	≤0.97	≤40
Tier 2	≤0.62	≤17
Tier 3	≤0.49	≤8
Tier 4	≤0.42	≤2

SAFETY	
	Total Point Score
Tier 0	SUM < 45
Tier 1	45 ≤ SUM < 75
Tier 2	75 ≤ SUM < 88
Tier 3	88 ≤ SUM < 95
Tier 4	SUM ≥ 95
Poor	25 ≤ SUM ≤ 75
Fair	76 ≤ SUM ≤ 83
Good	84 ≤ SUM ≤ 92
Best	93 ≤ SUM ≤ 100

** Based on room size of 30m³, air exchange of 15 per hour, and assuming perfect mixing

Appendix 2: The NKS D1 WBT results

Stove type/model	NKS D1		
Location	G-BEL		
Fuel species	Average hardwood		
Date	8/8/13	8/9/13	8/15/13

IWA Performance Metrics	units	T1	T2	T3	Average	COV
High Power Thermal Efficiency	%	32.0%	29.9%	32.0%	31.3%	3.8%
Low Power Specific Consumption Rate	MJ/min.L	0.034	0.039	0.041	0.038	8.6%
High Power CO	g/MJd	8.48	7.26	7.91	7.89	7.7%
Low Power CO	g/min.L	0.12	0.14	0.13	0.13	8.6%
High Power PM	mg/MJd	965.9	856.2	937.7	920.0	6.2%
Low Power PM	mg/min.L	6.35	6.14	6.26	6.25	1.7%
Indoor Emissions CO	g/min	0.74	0.63	0.71	0.69	7.9%
Indoor Emissions PM	mg/min	84.5	75.0	84.6	81.4	6.8%

	Tier	Tier	Tier	Average
High Power Thermal Efficiency	2	2	2	2
Low Power Specific Consumption Rate	2	1	1	2
High Power CO	3	4	4	4
Low Power CO	2	1	2	1
High Power PM	1	1	1	1
Low Power PM	1	1	1	1
Indoor Emissions CO	1	1	1	1
Indoor Emissions PM	0	0	0	0

Standard Performance Measures					Average	COV
Fuel to Cook 5L (850/1500)	g	769.6	867.5	852.0	829.7	6.3%
CO to Cook 5L (20)	g	43.4	46.8	45.0	45.1	3.7%
PM to Cook 5L (1500)	mg	3279.7	3098.8	3280.2	3219.6	3.2%
Energy to Cook 5L (15,000/25,000)	kJ	14172	15974	15689	15279	6.3%
Time to Boil	min	23.4	24.0	22.9	23.4	2.4%
CO2 to Cook 5L	g	1128.4	1307.8	1255.2	1230.5	7.5%

Basic Operation	units				Average	COV
COLD START						
Time to boil Pot # 1	min	25	25	24	24	2.0%
Burning rate	g/min	14.13	14.32	14.26	14.24	0.7%
Thermal efficiency	--	29%	30%	31%	30%	2.1%
Specific fuel consumption	g/liter	71.54	73.10	69.62	71.42	2.4%
Temp-corrected specific consumption	g/liter	76.5	77.9	72.7	75.7	3.5%
Firepower	watts	4336	4395	4376	4369	0.7%
Equivalent Dry Fuel Consumed	g	346.4	350.9	337.7	345.0	1.9%
HOT START						
Time to boil Pot # 1	min	19	20	20	20	2.6%
Burning rate	g/min	14.92	17.13	15.95	16.00	6.9%
Thermal efficiency	--	35%	30%	33%	33%	7.6%
Specific fuel consumption	g/liter	59.71	72.70	65.79	66.06	9.8%
Temp-corrected specific consumption	g/liter	63.4	77.9	69.6	70.3	10.3%
Firepower	watts	4578	5257	4896	4910	6.9%
Equivalent Dry Fuel Consumed	g	289.4	350.0	316.1	318.5	9.5%
SIMMER						
Burning rate	g/min	7.47	8.07	8.40	7.98	5.9%
Thermal efficiency	--	30%	33%	32%	32%	4.9%
Specific fuel consumption 45 min	g/liter	83.9	95.6	99.2	92.9	8.6%
Firepower	watts	2294	2477	2578	2450	5.9%
Turn down ratio	--	1.94	1.95	1.80	1.90	4.5%
Equivalent Dry Fuel Consumed	g	336.4	363.2	378.0	359.2	5.9%

Appendix 3: The Tao Thai WBT results

Stove type/model	Tao Thai		
Location	G-BEL		
Fuel species	Average hardwood		
Date	8/8/13	8/12/13	8/14/13

IWA Performance Metrics	units	T1	T2	T3	Average	COV
High Power Thermal Efficiency	%	32.4%	30.2%	28.9%	30.5%	5.8%
Low Power Specific Consumption Rate	MJ/min.L	0.042	0.038	0.042	0.041	6.3%
High Power CO	g/MJd	9.42	10.01	9.21	9.55	4.3%
Low Power CO	g/min.L	0.14	0.13	0.11	0.13	11.0%
High Power PM	mg/MJd	930.2	1064.0	958.5	984.2	7.2%
Low Power PM	mg/min.L	5.93	4.89	6.09	5.64	11.5%
Indoor Emissions CO	g/min	0.85	0.90	0.78	0.85	7.2%
Indoor Emissions PM	mg/min	84.1	96.9	81.6	87.5	9.4%

	Tier	Tier	Tier	Average
High Power Thermal Efficiency	2	2	2	2
Low Power Specific Consumption Rate	1	2	1	1
High Power CO	2	2	2	2
Low Power CO	1	2	2	2
High Power PM	1	0	1	0
Low Power PM	1	1	1	1
Indoor Emissions CO	1	1	1	1
Indoor Emissions PM	0	0	0	0

Standard Performance Measures					Average	COV
Fuel to Cook 5L (850/1500)	g	876.8	854.1	943.6	891.5	5.2%
CO to Cook 5L (20)	g	51.4	49.6	45.7	48.9	6.0%
PM to Cook 5L (1500)	mg	3233.6	3313.3	3425.7	3324.2	2.9%
Energy to Cook 5L (15,000/25,000)	kJ	16146	15728	17375	16417	5.2%
Time to Boil	min	22.9	23.2	25.6	23.9	6.2%
CO2 to Cook 5L	g	1293.4	1281.3	1417.7	1330.8	5.7%

Basic Operation	units				Average	COV
COLD START						
Time to boil Pot # 1	min	23	24	22	23	4.3%
Burning rate	g/min	15.65	16.04	17.00	16.23	4.3%
Thermal efficiency	--	30%	29%	29%	29%	1.9%
Specific fuel consumption	g/liter	74.26	78.79	76.37	76.47	3.0%
Temp-corrected specific consumption	g/liter	77.9	81.6	79.6	79.7	2.3%
Firepower	watts	4802	4923	5217	4981	4.3%
Equivalent Dry Fuel Consumed	g	357.5	378.0	368.1	367.9	2.8%
HOT START						
Time to boil Pot # 1	min	21	21	27	23	16.1%
Burning rate	g/min	14.82	16.47	14.87	15.39	6.1%
Thermal efficiency	--	35%	31%	29%	32%	9.4%
Specific fuel consumption	g/liter	63.54	71.21	85.67	73.47	15.3%
Temp-corrected specific consumption	g/liter	67.1	75.2	90.6	77.7	15.4%
Firepower	watts	4549	5055	4564	4723	6.1%
Equivalent Dry Fuel Consumed	g	306.6	342.6	403.0	350.7	13.9%
SIMMER						
Burning rate	g/min	8.84	8.04	8.54	8.47	4.8%
Thermal efficiency	--	28%	30%	32%	30%	6.7%
Specific fuel consumption 45 min	g/liter	102.9	92.4	103.6	99.6	6.3%
Firepower	watts	2713	2468	2621	2601	4.8%
Turn down ratio	--	1.72	2.02	1.87	1.87	8.0%
Equivalent Dry Fuel Consumed	g	397.9	361.9	384.4	381.4	4.8%

Appendix 4: The Tao Concrete WBT results

Stove type/model	Tao Concrete G-BEL Average hardwood 8/9/13 8/12/13 8/14/13		
Location			
Fuel species			
Date			

IWA Performance Metrics	units	T1	T2	T3	Average	COV
High Power Thermal Efficiency	%	24.7%	26.9%	25.7%	25.8%	4.3%
Low Power Specific Consumption Rate	MJ/min.L	0.044	0.049	0.047	0.047	4.8%
High Power CO	g/MJd	13.42	10.85	11.42	11.90	11.3%
Low Power CO	g/min.L	0.18	0.17	0.19	0.18	4.6%
High Power PM	mg/MJd	1066.8	1150.8	998.4	1072.0	7.1%
Low Power PM	mg/min.L	6.43	7.76	9.61	7.93	20.2%
Indoor Emissions CO	g/min	1.00	0.88	0.84	0.90	9.2%
Indoor Emissions PM	mg/min	80.6	94.1	74.9	83.2	11.9%

	Tier	Tier	Tier	Average
High Power Thermal Efficiency	1	2	2	2
Low Power Specific Consumption Rate	1	1	1	1
High Power CO	1	2	1	1
Low Power CO	1	1	1	1
High Power PM	0	0	0	0
Low Power PM	1	1	0	1
Indoor Emissions CO	0	1	1	1
Indoor Emissions PM	0	0	0	0

Standard Performance Measures					Average	COV
Fuel to Cook 5L (850/1500)	g	1032.7	1054.6	1085.2	1057.5	2.5%
CO to Cook 5L (20)	g	68.2	63.5	68.6	66.8	4.2%
PM to Cook 5L (1500)	mg	3696.2	4405.9	4447.9	4183.3	10.1%
Energy to Cook 5L (15,000/25,000)	kJ	19017	19419	19983	19473	2.5%
Time to Boil	min	29.0	26.3	30.5	28.6	7.5%
CO2 to Cook 5L	g	1600.0	1668.8	1813.9	1694.3	6.4%

Basic Operation	units				Average	COV
COLD START						
Time to boil Pot # 1	min	32	27	33	30	10.1%
Burning rate	g/min	14.62	17.03	14.15	15.27	10.1%
Thermal efficiency	--	25%	25%	26%	25%	2.5%
Specific fuel consumption	g/liter	96.84	96.08	98.67	97.19	1.4%
Temp-corrected specific consumption	g/liter	101.0	99.3	102.8	101.0	1.7%
Firepower	watts	4488	5228	4342	4686	10.1%
Equivalent Dry Fuel Consumed	g	461.4	459.4	463.5	461.4	0.5%
HOT START						
Time to boil Pot # 1	min	24	27	26	25	6.5%
Burning rate	g/min	18.31	16.14	17.45	17.30	6.3%
Thermal efficiency	--	25%	29%	26%	27%	8.7%
Specific fuel consumption	g/liter	89.32	91.36	95.07	91.91	3.2%
Temp-corrected specific consumption	g/liter	95.0	84.3	99.3	92.9	8.3%
Firepower	watts	5619	4953	5356	5310	6.3%
Equivalent Dry Fuel Consumed	g	431.2	431.7	449.7	437.6	2.4%
SIMMER						
Burning rate	g/min	9.42	10.20	9.53	9.72	4.4%
Thermal efficiency	--	25%	23%	29%	26%	12.3%
Specific fuel consumption 45 min	g/liter	108.5	119.2	116.0	114.6	4.8%
Firepower	watts	2891	3131	2925	2982	4.4%
Turn down ratio	--	1.75	1.63	1.66	1.68	3.8%
Equivalent Dry Fuel Consumed	g	423.9	459.1	428.9	437.3	4.4%

Appendix 5: The Tao Dum-August2013 WBT results

Stove type/model	Tao Dum-August2013		
Location	G-BEL		
Fuel species	Average hardwood		
Date	10/1/13	10/1/13	10/2/13

IWA Performance Metrics	units	T1	T2	T3	Average	COV
High Power Thermal Efficiency	%	31.3%	27.7%	28.7%	29.2%	6.4%
Low Power Specific Consumption Rate	MJ/min/L	0.046	0.043	0.038	0.042	9.8%
High Power CO	g/MJd	10.42	10.04	8.93	9.80	7.9%
Low Power CO	g/min/L	0.11	0.12	0.11	0.12	6.2%
High Power PM	mg/MJd	1462.6	1625.8	1520.9	1536.4	5.4%
Low Power PM	mg/min/L	9.62	10.40	7.30	9.11	17.7%
Indoor Emissions CO	g/min	0.87	0.86	0.78	0.84	5.7%
Indoor Emissions PM	mg/min	123.4	139.4	133.8	132.2	6.2%

	Tier	Tier	Tier	Average
High Power Thermal Efficiency	2	2	2	2
Low Power Specific Consumption Rate	1	1	2	1
High Power CO	2	2	3	2
Low Power CO	2	2	2	2
High Power PM	0	0	0	0
Low Power PM	0	0	1	0
Indoor Emissions CO	1	1	1	1
Indoor Emissions PM	0	0	0	0

Standard Performance Measures					Average	COV
Fuel to Cook 5L (850/1500)	g	956.3	998.9	896.4	950.5	5.4%
CO to Cook 5L (20)	g	46.9	51.1	45.3	47.8	6.2%
PM to Cook 5L (1500)	mg	5295.5	6111.4	4986.4	5464.4	10.6%
Energy to Cook 5L (15,000/25,000)	kJ	17,609	18,395	16,506	17,503	5.4%
Time to Boil	min	25.2	26.8	24.5	25.5	4.6%
CO2 to Cook 5L	g	1972.9	2225.9	1914.6	2037.8	8.1%

Basic Operation	units				Average	COV
COLD START						
Time to boil Pot # 1	min	26	26	25	26	2.8%
Burning rate	g/min	15.25	16.01	16.64	15.97	4.3%
Thermal efficiency	--	28%	28%	28%	28%	0.7%
Specific fuel consumption	g/liter	82.09	89.76	87.62	86.49	4.6%
Temp-corrected specific consumption	g/liter	84.9	94.5	89.9	89.8	5.4%
Firepower	watts	4,681	4,912	5,106	4,900	4.3%
Equivalent Dry Fuel Consumed	g	391.8	421.5	414.5	409.3	3.8%
HOT START						
Time to boil Pot # 1	min	23	25	23	23	4.8%
Burning rate	g/min	14.16	17.67	16.75	16.19	11.3%
Thermal efficiency	--	34%	27%	29%	30%	11.7%
Specific fuel consumption	g/liter	67.96	92.42	79.15	79.84	15.3%
Temp-corrected specific consumption	g/liter	70.6	96.9	82.2	83.3	15.9%
Firepower	watts	4,345	5,424	5,140	4,969	11.3%
Equivalent Dry Fuel Consumed	g	324.4	435.3	377.4	379.0	14.6%
SIMMER						
Burning rate	g/min	9.30	8.31	7.81	8.47	8.9%
Thermal efficiency	--	32%	36%	34%	34%	6.6%
Specific fuel consumption 45 min	g/liter	113.5	104.0	93.2	103.6	9.8%
Firepower	watts	2,855	2,549	2,398	2,601	8.9%
Turn down ratio	--	1.58	2.03	2.14	1.91	15.4%
Equivalent Dry Fuel Consumed	g	418.6	373.8	351.6	381.3	8.9%

Appendix 6: The NKS D1 AWBT results

NKS D1					
COLD START - HIGH POWER	T1	T2	T3	Average	COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99.2	99.2	99.2	99.2	
Ti (°C)	28.5	28.7	28.4	28.5	
Q sensible (kJ)	886.578	884.07	887.832	886.160	
M w after high power (kg)	2.918	2.924	2.916	2.919	5.2%
M we (kg)	0.082	0.076	0.084	0.081	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	185.074	171.532	189.588	182.065	
UE (kJ)	1071.652	1055.602	1077.420	1068.225	1.1%

EVAPORATING PHASE - HIGH POWER	T1	T2	T3	Average	COV
Q sensible (kJ)	0	0	0	0	
M w after evap. phase (kg)	1.191	1.34	1.445	1.325	8.0%
M we (kg)	1.727	1.584	1.471	1.594	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	3897.839	3575.088	3320.047	3597.658	
UE (kJ)	3897.839	3575.088	3320.047	3597.658	8.0%

TOTAL TEST	T1	T2	T3	Average	COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99.2	99.2	99.2	99.2	
Ti (°C)	28.5	28.7	28.4	28.5	
Q sensible (kJ)	886.578	884.07	887.832	886.160	
M w after test (kg)	1.191	1.34	1.445	1.325	7.6%
M we (kg)	1.809	1.66	1.555	1.675	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	4082.913	3746.62	3509.635	3779.723	
UE (kJ)	4969.491	4630.69	4397.467	4665.883	6.2%
TTB (hh:mm:ss)	0:11:40	0:11:12	0:12:30	0:11:47	5.6%
TTT (hh:mm:ss)	1:10:50	1:05:47	1:06:47	1:07:48	3.9%

Appendix 7: The Tao Thai AWBT results

Tao Thai					
COLD START - HIGH POWER	T1	T2	T3	Average	COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99.2	99.2	99.2	99.2	
Ti (°C)	28.8	28.8	28.3	28.6	
Q sensible (kJ)	882.816	882.816	889.086	884.906	
M w after high power (kg)	2.907	2.905	2.911	2.908	3.3%
M we (kg)	0.093	0.095	0.089	0.092	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	209.901	214.415	200.873	208.396	
UE (kJ)	1092.717	1097.231	1089.959	1093.302	0.3%
EVAPORATING PHASE - HIGH POWER					COV
Q sensible (kJ)	0	0	0	0	
M w after evap. phase (kg)	1.633	1.477	1.537	1.549	5.8%
M we (kg)	1.274	1.428	1.374	1.359	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	2875.418	3222.996	3101.118	3066.511	
UE (kJ)	2875.418	3222.996	3101.118	3066.511	5.8%
TOTAL TEST					COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99.2	99.2	99.2	99.2	
Ti (°C)	28.8	28.8	28.3	28.6	
Q sensible (kJ)	882.816	882.816	889.086	884.906	
M w after test (kg)	1.633	1.477	1.537	1.549	5.4%
M we (kg)	1.367	1.523	1.463	1.451	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	3085.319	3437.411	3301.991	3274.907	
UE (kJ)	3968.135	4320.227	4191.077	4159.813	4.3%
TTB (hh:mm:ss)	0:12:22	0:12:50	0:13:30	0:12:54	4.4%
TTT (hh:mm:ss)	1:03:02	1:02:00	1:06:37	1:03:53	3.8%

Appendix 8: The Tao Concrete AWBT results

Tao Concrete					
COLD START - HIGH POWER	T1	T2	T3	Average	COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99.2	99.2	99.2	99.2	
Ti (°C)	28.8	29.1	28.4	28.8	
Q sensible (kJ)	882.816	879.054	887.832	883.234	
M w after high power (kg)	2.850	2.824	2.846	2.840	8.8%
M we (kg)	0.15	0.176	0.154	0.160	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	338.55	397.232	347.578	361.120	
UE (kJ)	1221.366	1276.286	1235.410	1244.354	2.3%

EVAPORATING PHASE - HIGH POWER					COV
Q sensible (kJ)	0	0	0	0	
M w after evap. phase (kg)	1.936	1.842	1.899	1.892	3.6%
M we (kg)	0.914	0.982	0.947	0.948	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	2062.898	2216.374	2137.379	2138.884	
UE (kJ)	2062.898	2216.374	2137.379	2138.884	3.6%

TOTAL TEST					COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99.2	99.2	99.2	99.2	
Ti (°C)	28.8	29.1	28.4	28.8	
Q sensible (kJ)	882.816	879.054	887.832	883.234	
M w after test (kg)	1.936	1.842	1.899	1.892	4.3%
M we (kg)	1.064	1.158	1.101	1.108	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	2401.448	2613.606	2484.957	2500.004	
UE (kJ)	3284.264	3492.66	3372.789	3383.238	3.1%
TTB (hh:mm:ss)	0:18:45	0:17:10	0:16:22	0:17:26	7.0%
TTT (hh:mm:ss)	1:01:45	1:00:27	0:56:35	0:59:36	4.5%

Appendix 9: The Tao Dum-August2013 AWBT results

Tao Dum-August2013					
COLD START - HIGH POWER	T1	T2	T3	Average	COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99	99.2	99.2	99.1	
Ti (°C)	27.2	28.1	28.3	27.9	
Q sensible (kJ)	900.372	891.594	889.086	893.684	
M w after high power (kg)	2.899	2.919	2.914	2.911	11.7%
M we (kg)	0.101	0.081	0.086	0.089	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	227.957	182.817	194.102	201.625	
UE (kJ)	1128.329	1074.411	1083.188	1095.309	2.6%

EVAPORATING PHASE - HIGH POWER					COV
Q sensible (kJ)	0	0	0	0	
M w after evap. phase (kg)	1.717	1.7	1.631	1.683	4.2%
M we (kg)	1.182	1.219	1.283	1.228	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	2667.774	2751.283	2895.731	2771.596	
UE (kJ)	2667.774	2751.283	2895.731	2771.596	4.2%

TOTAL TEST					COV
M water (kg)	3	3	3	3	
C (kJ/kg.°C)	4.18	4.18	4.18	4.18	
Tb (°C)	99	99.2	99.2	99.1	
Ti (°C)	27.2	28.1	28.3	27.9	
Q sensible (kJ)	900.372	891.594	889.086	893.684	
M w after test (kg)	1.717	1.7	1.631	1.683	3.5%
M we (kg)	1.283	1.3	1.369	1.317	
Lv (kJ/kg.°C)	2257	2257	2257	2257	
Q latent (kJ)	2895.731	2934.1	3089.833	2973.221	
UE (kJ)	3796.103	3825.694	3978.919	3866.905	2.5%
TTB (hh:mm:ss)	0:16:30	0:16:23	0:15:49	0:16:14	2.3%
TTT (hh:mm:ss)	0:56:07	1:01:48	1:01:45	0:59:53	5.5%