David BERITAULT
Jean-Francois ROZIS

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Regional Testing and Knowledge Centre

Lab-based prediction of field performance

Study of local cooking habits and Adapted Water Boiling Test

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Groupe Énergies Renouvelables, Environnement et Solidarités
Group for the Environment, Renewable Energy and Solidarity

House no.350, Street 350 • Sangkat Boeung Keng Kang 3, P.O.Box 2528 • Phnom Penh 12304 • Cambodia
Tel: +855 (0)23 986 891 • Fax: +855 (0)23 221 314

www.cambodia.geres.eu • cambodia@geres.eu

CONTENT

1. ACRONYMS

AWBT: Adapted Water Boiling Test
CCT: Controlled Cooking Test
CFSP: Cambodian Fuelwood Saving Project
GACC: Global Alliance for Clean Cookstove
GERES: Group for the Environment, Renewable Energies and Solidarity
KhRoS: Khmer Rocket Stove
KPT: Kitchen Performance Test
NLS: New Lao Stove
PFS: Potential Fuel Saving
RTKC: Regional Testing and Knowledge Center
SPT: Standard Performance Test
VITA: Volunteer in Technical Assistance
WBT: Water Boiling Test

2. INTRODUCTION

Assessment of stove performance was initiated 30 years ago by a group of scientists and stove practitioners. They developed a set of Stove Performance Test (SPT) including:

- Water Boiling Test (WBT)
- Controlled Cooking Test (CCT) and
- Kitchen Performance Test (KPT).

In 1985, this work was revised and endorsed as provisional standard with the publication of *Testing the efficiency of wood burning cook stoves* by Volunteers in Technical Assistance (VITA).

In 1999, GERES started working on cook stoves with the Cambodian Fuelwood Saving Project (CFSP) in Cambodia. Following field observations of local cooking habits, it soon became clear that the WBT was not fully aligned with Cambodian cooking practices. Thus, a modified version of the WBT protocol was developed, the Adapted Water Boiling Test (AWBT).

The AWBT protocol was used to validate design changes in the Thai bucket stove and develop the New Lao Stove (NLS). The protocol was also used for quality control (QC) monitoring during the 10-year carbon credit period. However, a comparative study between the two methodologies had never been performed and the superiority of the AWBT in predicting stove performance had not been proven scientifically.

This study, commissioned in 2013 by the Global Alliance for Clean Cookstove (GACC) within the framework of the Regional Testing and Knowledge Center (RTKC), is meant to compare WBT and AWBT by verifying the correlation between laboratory data and field data for stove performance in the Cambodian context. For this purpose, laboratory results obtained both with WTB and AWBT have been compared with the results of a Kitchen Performance Test (KPT) conducted in the field. The NLS and the Khmer Rocket Stove (KhRoS) have been used as case studies.

The study starts with an overview of Cambodian cooking practices and test methodologies. The process of adaptation of the WBT into AWBT is described. The study undertaken to assess the correlation between laboratory and field results with both WBT and AWBT is then discussed. Eventually, conclusions are drawn on whether AWBT is more representative of local cooking practices and therefore more reliable in predicting the stove performance in the field in the Cambodian context.

3. THE CAMBODIAN COOKING CONTEXT

Cooking habits differ from one country to the other: people cook for longer or shorter time, with a certain amount of power, certain types of fuel, certain tools etc. Identifying these habits is essential in order to design a laboratory test that allows making a more reliable prediction of a stove performance in the field.

Field observations conducted by GERES in 2011 using the NLS A1 as case study reveal that, in Cambodia, high-power cooking accounts for almost 90% of the cooking time in the Cambodian context. As a result of this study, the WBT, as a simplified laboratory simulation of a cooking process, was deemed not fully representative of the local cooking habits. The AWBT was developed as a laboratory test protocol that favors high-power cooking over low-power cooking and that reproduces more closely the local cooking practices. Parameters for conducting the AWBT in the Cambodian context were also defined.

3.1. ADAPTATION OF THE WATER BOILING TEST

In 2011, habits and requirements of a representative sample of 3 medium-size Cambodian families were observed and analysed. The sample was using the NLS A1 as main stove and charcoal as only cooking fuel. In addition to quantitative information, the study delivered a detailed description of the family, the kitchen and the tools, and the cooking process. More information is presented:

- in the report "*DBT_11Oct10_NLS_CookingHabits_ENG_vf*"
- and in Annex 2 of this report "*Study of Cambodian cooking habits*".

As a result of field observations, the WBT was adapted into AWBT with the purpose of delivering a more accurate comparison of fuel use between cook stoves. In fact, the AWBT is better suited to measure the performance of stoves operating in high-power conditions, which corresponds to the common way of cooking in the region. In addition, the AWBT is designed to be simpler, reducing sources of error and making its implementation by local technicians not too complex.

As the AWBT is not meant to deliver an energetic yield, information on fuel properties such as moisture content and calorific value is not provided.

3.1.1 POWER LEVEL

The main cooking tasks performed in Cambodia are boiling, grilling and frying, mostly done at high power. Power regulation is done by adding or removing charcoal from the stove during the cooking process. The removal of charcoal is done mostly during rice cooking, a task that is performed twice daily for about 20min, of which 10min at high power and 10min at low power.

Considering a single low-power phase of 10min during rice cooking, and a total daily cooking time of 2h30min, high power accounts for almost 90% of the cooking time in the Cambodian context. The predominance of high power validates the adoption of the AWBT protocol.

3.1.2 PARAMETERS FOR THE ADAPTED WATER BOILING TEST

Based on the observation of local habits, the parameters of the Cambodian AWBT have been fixed as follows:

- *Quantity of charcoal*: 400g (the average quantity of charcoal to be loaded at the startup is 300g but it can increase up to 500g depending on cooking task)
- *Type and quantity of starter*: 5g of traditional starter (tree leaves stuck together with resin), corresponding to common startup time of 5min
- *Pot type and dimension*: the medium-size pot most commonly used is a flat-bottom pot with a 24cm diameter
- *Quantity of water*: 3L, corresponding to 2/3 of the pot capacity

4. METHODOLOGY

For this study, 3 different protocols are used to measure stove performances of 2 different stoves. The potential fuel savings measured in the laboratory with both AWBT and WBT protocols are then compared with field measurements done with the KPT.

The study is carried out on the New Lao Stove (NLS) A1, an adapted version of the Thai Bucket Stove that is able to use both charcoal and wood, and the Khmer Rocket Stove (KhRoS), an optimized charcoal stove recently developed by GERES as a result of the careful assessment of Cambodian user needs and habits.

Figure 1: Pictures of the NLS (left) and the KhRoS (right)

For this study, both stoves are operated with charcoal. For both AWBT and WBT, local traditional charcoal from the same source is used. The average size is 2.5x3x4-5cm and the moisture content 3.6% (wet basis).

4.1. LABORATORY TESTS

4.1.1 THE WATER BOILING TEST (WBT)

The Water Boiling Test[1] (WBT) is a simplified simulation of a 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.

The WBT consists of 3 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 procedure 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 (Tboil) for 45 minutes. The water temperature should be maintained at around Tboil-3°C and should not go below Tboil-6°C.

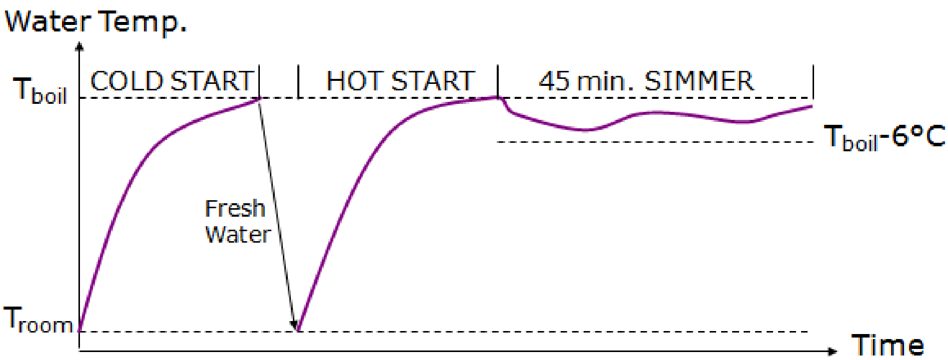

Figure 2: Temperature diagram of the WBT

[1] http://www.cleancookstoves.org/our-work/standards-and-testing/learn-about-testing-protocols/protocols/downloads/wbt-protocol.pdf

► **Benchmark values**

The benchmark values result as a combination of the single results for each of the phases of cold-start, hot-start (if tested) and simmer. 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*[Specific Measure to Boil (average cold and hot starts) + Specific Measure to Simmer]

- Where Measure is either fuel consumption or emissions.

► **For this study**

For this study, 3 tests are repeated on each stove. Tests are carried out following the guidelines for testing charcoal stoves with the WBT[2], with the following modifications:

- Use of local cooking pots of 28cm-diameter, filled with 5L of water
- Use of a lid during the entire test
- No hot-start high-power phase
- Power regulation of the stove done by manipulating the air entry door on the KhRoS and by removing charcoal on the NLS (as per local customs).

The heating value of the fuel is required for the WBT calculations. Although it is possible to use default values from the literature, it is recommended to determine the real calorific value of the testing fuel with a bomb calorimeter.

4.1.2 The Adapted Water Boiling Test (AWBT)

The Adapted Water Boiling Test[3] (AWBT) is a laboratory testing protocol. It is intended to provide a comparison of fuel use of different cook stoves. This test does not measure the stove efficiency but the difference between the useful energy (UE) of different stoves using the same fuel quantity. Potential fuel savings can be calculated based on the comparison of the stoves UE.

In Cambodia, the AWBT consists of 2 phases that immediately follow each other:

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

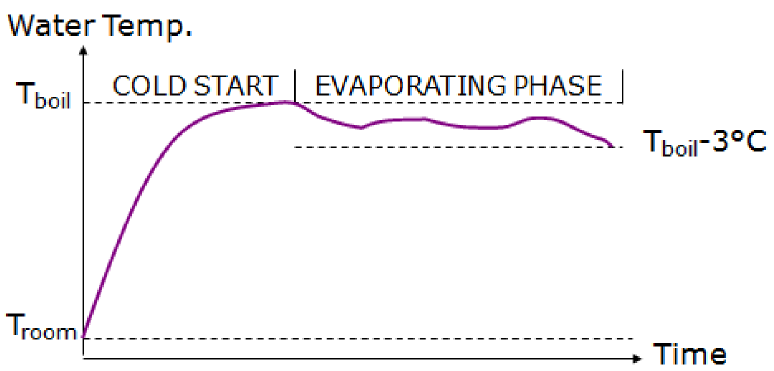

Figure 3: Temperature diagram of the AWBT

The quantity of water evaporated is measured. The useful energy (UE) is then calculated.

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[2] http://www.cleancookstoves.org/our-work/standards-and-testing/learn-about-testing-protocols/protocols/downloads/wbt-additional-guidelines-for.pdf

[3] http://www.cleancookstoves.org/our-work/standards-and-testing/learn-about-testing-protocols/protocols/downloads/awbt-protocol.pdf

► **Useful energy (UE)**

The useful energy (UE) consists of the sum between 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 vapour (latent heat: Q latent).

$$UE\ [kJ] = Q\ sensible\ [kJ] + Q\ latent\ [kJ]$$

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

- Where: C is the specific heat capacity = 4.18 kJ/kg.°C
  Lv is the specific latent heat of vaporization = 2257 kJ/kg

► **Potential fuel saving (PFS)**

The potential fuel saving (PFS) is the ratio of the useful energy provided by different stoves. This ratio shows the potential fuel difference between different cook stoves.

The potential fuel saving is calculated with the following formula:

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

► **For this study**

For this study, 3 tests are repeated on each stove. A 24cm-diameter pot, uncovered and filled with 3L of water, is used.

4.2. FIELD TEST

4.2.1 THE KITCHEN PERFORMANCE TEST (KPT)

The Kitchen Performance Test[4] (KPT) is an international procedure to evaluate household fuel consumption. The version 3.0 of the procedure was developed by the Household Energy and Health Programme of the Shell Foundation. The test is composed of qualitative surveys of stove performances and acceptability and quantitative surveys of fuel consumption.

► **For this study**

For this study, the KPT was designed with the following characteristics:

- Paired-sampling method: measurement of fuel consumption with the baseline technology and with the new technology within the same household.
- Selection criteria for households: participants were randomly selected provided they used NLS as their stove and charcoal as their cooking fuel.
- Testing period: fuel consumptions were measured during 5 consecutive days for each period.
- Energy mix: households using a combination of stoves/fuels such as LPG, charcoal and wood were also selected as participants as long as charcoal was their main cooking fuel. Quantities of each fuel consumed were measured and then converted into energy.

[4] http://www.cleancookstoves.org/our-work/standards-and-testing/learn-about-testing-protocols/protocols/downloads/kpt-protocol.pdf

5. TEST RESULTS

The results presented below are the average results of each test, with an exclusive focus on the thermal performance of the stoves tested. The detailed results are available in the following documents:

- Lab tests: "*2014-02_LIV_Comparison_WBT_AWBT_NLS_KhRoS*"
- Field test: "*2014-02_DBT_GBEL_KhRoS_KPT_Report_Eng_vf*"

5.1. WBT RESULTS

The results of the WBT presented in the chart below are the average of 3 tests repeated on each stove:

1. HIGH POWER TEST (COLD START)	units	NLS A1	KhRoS
Time to boil Pot # 1	min	24	23
Burning rate	g/min	7.87	6.66
Thermal efficiency	--	24%	28%
Specific fuel consumption	g/liter	46.43	39.17
Temp-corrected specific consumption	g/liter	49.1	41.2
Firepower	watts	3,699	3,129
Equivalent Dry Fuel Consumed	g	232.5	196.0
2. LOW POWER TEST (SIMMER)	**units**	**NLS A1**	**KhRoS**
Burning rate	g/min	1.07	1.17
Thermal efficiency	--	27%	28%
Specific fuel consumption 45 min	g/liter	10.1	11.0
Firepower	watts	502	549
Turn down ratio	--	7.42	5.70
Equivalent Dry Fuel Consumed	g	48.0	52.5

Figure 4: Results of the WBT

BENCHMARK VALUES (for 5L)	units	NLS A1	KhRoS
Fuel to Cook 5L	g	295.8	260.6
Time to Boil	min	25.0	24.4

Figure 5: WBT Benchmark values

The benchmark values for the fuel to cook 5L are 295.8g for the NLS A1 and 260.6g for the KhRoS. A t-test was performed and shows that the two averages can be considered significantly different at 95%. The difference between these two figures gives a **potential fuel saving of 11.9% for the KhRoS compared to the NLS A1**.

5.2. AWBT RESULTS

The results of the AWBT presented in the chart below are the average of 3 tests repeated on each stove:

Adapted Water Boiling Test		NLS A1	KhRoS
M water (kg)	Initial mass of water	3	3
Tb (°C)	Boiling temperature	99	99
Ti (°C)	Initial temperature	27.3	27.1
Q sensible (kJ)		899.12	901.63
M w after test (kg)	Mass of water after test	2.230	1.836
M we (kg)	Total mass of water evaporated	0.770	1.164

Q latent (kJ)		1737.14	2627.15
UE (kJ)		2636.26	3528.77
TTB (hh:mm:ss)	Time to boil	0:16:08	0:21:12
TTT (hh:mm:ss)	Time to test	0:43:30	1:07:34

Figure 6 : Results of the AWBT

We can see that the KhRoS is able to evaporate more water with the same amount of fuel. As a result, its useful energy (UE) is higher with 3529 kJ compared to 2636 kJ for the NLS A1. A t-test was performed and shows that the two averages are significantly different at 95%. The difference between these two figures is consistent with a **potential fuel saving of 25.3% for the KhRoS compared to the NLS A1**.

5.3. KPT RESULTS

A first round of KPT was conducted with a sample of 50 households using the NLS as their charcoal burning stove. The tests with 5 households could not be taken into account due to the non-respect of the testing procedure.

After data analysis, the sample size was not deemed large enough to reach the condition of statistical validity according to the 90/10 rule. A second round of KPT was thus conducted with 40 additional households. The test conducted with 1 household was not taken into account due to the non-respect of the testing procedure. 22 households were removed from the sample as not using the NLS as their charcoal burning stove.

The valid results of the 45 households of the first round are below combined with the valid results of the 17 households of the second round:

	NLS	KhRoS
Average Spec. Cons [kJ/a.eq]	12686.22	9831.59
Standard deviation	5390.78	4253.31
CV	0.42	0.43
Pooled CV	0.43	

Minimum Sample Size (Paired Sampling)		
95/5 rule (CDM)	90/10 rule (CDM)	90/30 rule (GS)
283	50	6

Energy Saving [%]	**22.50%**

Figure 7: Results of the KPT

The energy savings obtained by using the KhRoS when combining the results of round 1 and 2 with families using the NLS as their charcoal burning stove is 22.5%. A t-test was performed and showed that the energy consumption is significantly different between the two periods. With a total of 62 valid tests, the sample size is large enough to achieve the condition of statistical validity according to the 90/10 rule.

6. DISCUSSION

A summary of the results obtained with the 3 testing protocols is presented in the chart below:

Testing protocol	Relative difference KhRoS/NLS
AWBT	25 %
WBT	12 %
KPT	22.5 %

Figure 8: Results of the 3 testing protocols

We can see that there is a significant difference in the results obtained with the two laboratory test protocols. The AWBT gives a potential fuel saving of 25% for the KhRoS compared to the NLS while the difference with the WBT is only 12%.

When comparing the results obtained under laboratory conditions with the real fuel savings obtained in the field, AWBT show a better correlation with the KPT results. The deviation of the AWBT results with the KPT results is only 11% compared to a deviation of 47% for the WBT.

The reason thereof might be explained in terms of difference in power levels between the AWBT and the WBT. The AWBT is a high power test only, while the WBT combines high and low power phases, with the low power phase lasting about 2/3 of the total test. The study of local cooking habits in Cambodia has shown a predominance of high power cooking, representing about 90% of the total cooking time. The power levels used for the simulation of the cooking process in the WBT diverge from Cambodian real cooking practices: this is likely the reason of the high deviation between the WBT and the KPT results.

7. Conclusion

The objective of the study was to compare two laboratory test protocols, the Water Boiling Test (WBT) and its adapted Cambodian version (AWBT), with real fuel saving obtained in the field with the Kitchen Performance Test (KPT), in order to assess their relative ability to measure stove performance in the Cambodian cooking context. The New Lao Stove (NLS) and the Khmer Rocket Stove (KhRoS) were considered as case study.

The results show a significant difference in performance between the two laboratory test protocols. The results of the AWBT show a better correlation with the real fuel savings obtained in the field with the KPT, if compared with the ones of the WBT. This is due to the fact that the AWBT, being a high-power test only, better represents the local cooking practices, which involve mainly high power cooking.

As a result, in specific contexts where high power cooking is predominant (for example in Asia with the preparation of sticky rice, or in West Africa with the practice of steaming rice), the use of the WBT can be misleading. From a R&D perspective, it can lead to the design of a stove that performs best during low power cooking, and therefore not suited to the local cooking context. In addition, using the WBT for measurements within the context of Carbon Finance methodologies can lead to significant under or overestimation of real fuel savings.

Annexes

ANNEX 1: PROTOCOL FOR DETERMINATION OF LOCAL COOKING HABITS

1. Aim and overview:

This protocol has been developed to identify and describe local cooking habits. Cooking habits differ from one country to the other: people cook for longer or shorter time, with a certain amount of power, certain types of fuel, certain tools etc. Identifying these habits is essential in order to design a laboratory test that allows making a more reliable prediction of a stove performance in the field.

This protocol was used to develop the Adapted Water Boiling Test (AWBT).

2. Conditions and limitations:

In order to be as representative as possible, the test should be done at least with 5 families, followed up during 3 full days (breakfast, lunch, dinner). Depending on the size and/or income of the families, data might change. These families should be representative of future target families. Different groups can be established (i.e. low and middle class, rural or urban families...).

3. Equipment and tools:

- ***Measuring tools***
  - Stopwatch
  - Tape measure
  - Scale (capacity of 6kg with a precision of 1g)
  - Humidity meter
- ***Laboratory equipment (moisture content)***
  - Precision scale
  - Oven
- ***Utensil***
  - Pliers to removed burning fuel
  - Metal pot/tray to weight burning fuel
- ***Others***
  - Camera

4. Steps:

Even though some quantitative measurements need to be taken, the most important task is to provide a qualitative description of the family, the kitchen and the cooking process. Complementary information could be collected to allow the improvement of equipment specifications/constraints.

1- Family:
- Number of people
- Frequency of cooking: breakfast, lunch, dinner
- Most common meals (List of the main dishes cooked by the sampled families)

2- Kitchen: (take pictures and some measurements)
- Description: location, arrangement, size, specificities
- Stove used: type, number, name, size, specificities
- Fuel used: type, size, source, humidity
- Pots in use: type, diameters

3- Cooking process:

All different tasks performed during the cooking process (meal preparation and cooking, stove operation, power regulation…) are observed and recorded. A standard day of cooking is described (time, type of meal, common pot/utensil, quantities, time high/low power, durations, specificities...). Name of the meal in preparation and the starting time are also recorded.

Following measurements should be carried out:

- Weight the initial quantity of fuel and starter, and note the type
- Weight the quantity of water in the pot, note the diameter of the pot
- Start the stopwatch
- Record the time of each task and describe the pot used (diameter, shape…)
- During a task, weight the quantity of fuel and water added or removed and note the time
- Between each task, estimate (or weight if possible) the remaining fuel inside the stove
- At the end, note the final time and weight the remaining fuel

Additional information:

- What can be a special day (week end, festival...)? What specific needs are required (second stove, specific pot...)?
- Is the stove used to boiled water (drinking, baby's bottle…)? How many litres are boiled per day? When?
- Is the stove used for other heating purposes (hot water…)?

5. Data analysis:

a. Type and quantity of starter

Determine the common type of starter and the average quantity used

b. Cooking pot

Determine the type of pot and its size, the pot should be representative of the most common meal cooked.

c. Quantity of fuel and water

i. Whole cooking process

- Total quantity of fuel
- Total quantity of water
- Total duration
- Total power

Calculate the average quantity of fuel and water for 1 hour of cooking.

ii. Per tasks

- Consumption of fuel and water per task
- Duration of each task
- Specific power per task

Identify the most powerful task and the respective quantities of water and fuel

Analysis to link with the AWBT

Depending on the context, the parameter of the AWBT can be determined with the total cooking process or with the most powerful task.

Analysis linked with improved stoves

In relation with this situation (two tasks can be done same time, two stoves regroup by a same (high/low power, hot water production...)

Annex 2: Study of Cambodian cooking habits

Information presented below was extracted from the report "*DBT_11Oct10_NLS_CookingHabits_ENG_vf*", following a study conducted with 3 medium-size Cambodian families using the NLS A1 as their main stove and charcoal as their only cooking fuel.

1. Aim and overview:

The main objective of the study was to understand Cambodian cooking habits and requirements. In addition to quantitative information, the study provides a description of the family, the kitchen and the cooking process. Complementary information is also provided to serve as reference for further improvement of equipment specifications and constraints.

During the cooking process, different tasks (meal preparation and cooking, stove operation, power regulation…) were observed and described. A standard day of cooking was described for an average family (time, meal, utensils, quantities, time high/low power, duration, specificities...). The name of the meal being prepared and the starting time were recorded.

2. General information:

► Stove used

Families own from 2 to 3 stoves. Two of the surveyed families have a gas stove, which is occasionally used for urgent cooking task. It has been noticed in all the families that the top fuel door of the NLS is usually kept open to allow the regulation of the stove by adding of removing charcoal.

► Fuel used

All the families are using a mix of fuel (wood, charcoal, and occasionally gas) depending on the price and availability of the fuel. Wood is used when it can be collected and when the price of charcoal is high. Charcoal is preferred as it cooks faster with less smoke.

► Starter used

Instead of the common starter, households are using plastic cans, piece of flip-flop, fabrics… The starter is used to light small pieces of wood which is used to light the charcoal.

► Pot used

Task	***Type of pot***	***Size***
Porridge / rice	Flat-bottom pot	18/22 cm in diameter
Soup	Flat-bottom pot	24 cm in diameter
Fry	Pan	37.5 cm in diameter
Water boiling	Kettle	6-7 L capacity

Figure 9: Pot used in Cambodia

► Additional utensils

Traditionally in Cambodia, a protective pot is used to avoid the pot becoming black. It is especially the case during the startup phase when using charcoal. In some cases the protective pot is use during the whole cooking process. The protective pot reduces the contact surface between the pot and the heat from the stove, impacting the thermal transfer and thus the global efficiency of the process.

Figure 10: NLS A1 with a protective pot

3. **Cooking process:**

► **Quantity of fuel and water**

- Quantity of fuel and water in a standard day of cooking

	Charcoal [kg]	Water [L]	Time [min]
Breakfast	0.5	8.5	65
Lunch	0.4	2.5	50
Dinner	0.3	1	40
Total	**1.2 kg**	**12 L**	**2h35min**

Figure 11: Standard day of cooking

The average consumption of charcoal per day is **1.2 kg for 12 liters of water**, which corresponds to a specific consumption of **0.1 kg of charcoal per liter of water**. The average total time of cooking is **2 hours and 35 minutes**, which corresponds to an average cooking power of **3.35 kW**.

- Quantity of fuel and water per tasks
  - *Breakfast*

Meal	Charcoal [kg]	Water [L]	Time [min]	Specific power [kW]
Porridge	0.23	1.5	30	3.32
Fried eggs	0.07		10	3.03
Boiled water	0.2	7	25	3.46
Total	**0.5 kg**	**8.5 L**	**65 min**	**3.33 kW**

  - *Lunch*

Meal	Charcoal [kg]	Water [L]	Time [min]	Specific power [kW]
Rice	0.125	1	20	2.71
Soup	0.275	1.5	30	3.97
Total	**0.4 kg**	**2.5 L**	**50 min**	**3.46 kW**

  - *Dinner*

Meal	Charcoal [kg]	Water [L]	Time [min]	Specific power [kW]
Rice	0.120	1	20	2.6
Grill/Fry	0.180		20	3.9
Total	**0.3 kg**	**1 L**	**40 min**	**3.25 kW**

Figure 12: Standard day of cooking divided per tasks

► **Description of the cooking process**

- Breakfast

Startup

Small pieces of wood are placed in the stove and lighted with the starter (plastic, flip-flop, fabric…). When the wood is burning, around 300g to 400g of charcoal are loaded into the stove. The charcoal is usually split into small and medium size pieces. It takes around 5 minutes for the charcoal to be well ignited and to start the cooking task.

Porridge
During the startup phase, rice is cleaned with water at least two times before filling the pot with around 1.5 liters of water. The "protective pot" is placed on the stove and then the pot covered with a lid. It takes around 15 minutes to bring the water to a boil, then the protective pot is usually removed and the lid is partially opened to keep the rice cooking at high power for around 15 more minutes. The pot is then removed and the charcoal kept in the stove for the next task. During this task, no regulation of the power is done.

Fried eggs
The wok is placed on the stove and oil is poured and heated up for 2 to 3 minutes. Then eggs are cooked on both sides during few more minutes. No additional charcoal is needed for this fast task. All the food is now cooked for breakfast; while eating, a kettle of water is brought to a boil for purification.

Boiled water
Around 100 to 200g of charcoal is added into the stove and after few minutes, the kettle with a capacity of around 7 liters is placed on the stove. It takes around 25 minutes to bring the water to a boil. When the water starts to boil, the kettle is removed. A part of the water is stored in a hot water container, the remaining is cooled down and stored in the drinking container. The drinking container is sometime a water filter, the water being first boiled to kill the bacteria and then filtered to remove any deposit. The remaining charcoal in the stove is also removed and placed in a closed pottery box to be kept for the next cooking time.

- Lunch

Start up
Same as breakfast

Rice
During the startup phase, rice is cleaned with water at least two times before filling the pot with around 1 liter of water. The "protective pot" is placed on the stove and then the pot covered with a lid. It takes around 10 minutes to bring the water to a boil, then the protective pot is usually removed and 150 to 200g of charcoal are removed from the stove and put out in the pottery box. Charcoal is removed to decrease the power of the stove and cook gently the rice during 10 more minutes. The pot is then removed and the charcoal kept in the stove for next task.

Soup
Around 250 to 300g of charcoal is added into the stove. While the charcoal start to be well ignited, the pot is filled with 1.5 liter of water and put on the stove with the protective pot and the lid. It takes around 10 minutes to bring the water to a boil. Then the ingredients, which have been prepared during this time, are put into the pot. The order depends on the type of soup prepared but usually it starts with the meat/fish which is cooked alone during few minutes before adding the vegetables. The pot is covered with the lid and heated for 20 minutes. Then the pot is removed together with the remaining charcoal.

- Dinner

Startup
Same as Breakfast

Rice
Same as Lunch

Fry
Around 150 to 200g of charcoal is added into the stove. After few minutes, the wok is placed on the stove and oil is poured into it and heated for few minutes. Then garlic, chopped into small pieces, is put into the wok and roasted. Meat is put into the wok and stirred well with condiments such as sugar, salt, fish sauce, seasoning and black pepper. Then vegetables are put into the wok and stirred with meat and condiments. This task last around 20 minutes, when finished the remaining charcoal is removed and put out in the pottery box.

4. **Data analysis:**

The main cooking tasks identified are boiling, grilling and frying, mostly done at high power. Power regulation is done by adding or removing charcoal from the stove during the cooking process. The removal of charcoal is done mostly during rice cooking. This task lasts for about 20min and is done approximately 50% at high power and 50% at low power.

Considering a single low power phase of 10 min during rice cooking (performed twice daily), and a total cooking time of 2h30min, high power accounts for almost 90% of the cooking time in the Cambodian context.

Annex 3: AWBT protocol

1. Aim and overview:

This protocol has been developed as an alternative to the international Water Boiling Test (WBT) used to compare energetic performances of cook stoves. The Adapted Water Boiling Test (AWBT) has been designed by GERES to facilitate its implementation in developing countries, minimize sources of error, and take into account local cooking practices. The WBT is regularly revised and modified, making implementation by local technicians difficult and complex. The AWBT is easier, more precise and accessible to local development agencies and organizations working on the evaluation and dissemination of cook stoves. In order to develop an AWBT for a particular context, a preliminary study should be performed to determine local cooking habits (cf. Annex 1 "*Protocol for determination of local cooking habits*").

The main characteristics of the AWBT are:

- both cook stoves are tested at the same time;
- the same quantity of fuel is used in both cook stoves;
- there is no "hot starting" step;
- the fuel is not weighed during or at the end of the test;
- local cooking conditions are reproduced (type of pot, quantity of water, type of fuel, geographic and climate conditions).

This protocol is used for laboratory testing to provide a comparison of fuel use between two cook stoves. The AWBT doesn't provide an energetic yield, but a measure of the useful energy provided by each stove.

It has been validated in different countries and has provided a good approximation of field testing. Of course, the final test to characterize a cook stove is the field test, the only test that provides the real fuel savings, and the test that should be used for carbon reduction calculations.

2. Conditions and limitations:

Tests are performed with an uncovered pot. Even though people may use a cover during cooking (depending on local cooking habits), this is a potential source of error, because there is no control of the pressure inside the pot.

Testing should be done in laboratory. If a laboratory is not available, the location must fulfil the following conditions:

- windless, to avoid air flow fluctuations;
- out of direct sunlight, to maintain a constant room temperature;
- quiet, to avoid external disturbances to the testers;
- well ventilated, to avoid smoke inhalation (the use of an extraction hood is recommended).

3. Equipment and materials:

- ***Measuring tools***
  - Stopwatch
  - Scale (capacity of 6kg with a precision of ±1g)
  - Digital thermometer with 2 thermocouples, or 2 thermometers (with a range of 0-100°C, and a precision of ±1°C)
  - Oven, to control fuel humidity, or humidity meter

- ***Utensils and fuel***
  - Pots, preferably the ones most commonly used by the target population
  - Metal bars or sticks of wood to fix the thermocouple in the middle of the pot, around 2cm from the bottom
  - The type of fuel used by the target population. The fuel must have a homogeneous size and shape. The moisture content should also be homogenous, with an ideal moisture level of 15% (general hygroscopic equilibrium) for wood and 5% for charcoal.

- ***Starter***

  - The same type and quantity of starter used by the target population.

- ***Water***

  - The quantity of water should be similar to local cooking habits, usually between 3 and 5L, or enough water to fill 2/3 of the cooking pot used for the test. If the temperature of the water is not constant throughout the day, a water tank can be used to limit the temperature variation.

- ***Data sheet***

  - For each test, the operator fills in a data sheet, which will be used to complete the data entry and analysis afterwards.

4. Steps:

Both stoves are tested simultaneously in the same conditions. A preliminary study should be conducted to determine the following parameters:

1- the types and quantities of fuel and starter (ideally, the minimal quantity required to facilitate quick and reproducible fuel ignition);
2- the type of pots;
3- the quantity of water.

Preliminary tests must be done to get used to cook stove operation, especially for wood-burning cook stoves (identifying the initial quantity of fuel required, how to reload the fuel, etc.) and to determine the local boiling point (depending on the altitude and local water characteristics). It is very important to always operate the stove the same way to reduce external errors. To validate the AWBT, we will introduce a COV (Coefficient of Variation), which should be under 10% to confirm appropriate operational conditions.

- Measure the ambient room and water temperatures.

- Weigh the empty pots and the quantities of fuel, starter and water fixed for the local context.

- Make sure the stoves are at ambient temperature and clean (no ash or soot).

- Put the fuel in the stoves and light the starters, using the same procedure with both stoves to avoid errors (arrangement of fuel, location of the starter…). Allow time (usually a few minutes) for the fuel to begin to burn easily (usually when the starter has been exhausted).

- Put the pots on the stoves and start the stopwatch. Install the thermocouples and start to record the water temperatures every 3 min until they reach a boiling point. The boiling point is reached when the temperature is constant for 10 consecutive seconds.

- Record the Time to Boil (TTB), which is the time from the start of the stopwatch until the end of the 10 seconds which indicate the boiling point has been reached.

- Keep the water simmering within a maximum range of 3°C below the boiling point. If the water temperature drops more than 5°C below the boiling point during the test, that test's results are rejected.

- When the fuel is exhausted to the point that the temperature of the water drops 3°C below the boiling point, record the Total Time of Test (TTT).

- Remove the pots from the stoves and immediately weigh the remaining water.

The remaining fuel in the stoves can be weighed for comparison, but this measurement is not used for the AWBT calculation. The stove performances are evaluated by comparing the useful energy provided to the water, which integrates combustion efficiency and thermal transfer. An efficient stove should be able to consume all the loaded fuel while maintaining a sufficient simmering phase.

If in the local context, one of the purposes of the cook stove is to provide fuel after the cooking period is completed (for example, through conversion of biomass to char), the fuel remaining after the AWBT is completed can be removed from the cook stove, weighed and incorporated into the cook stove analysis.

5. Data analysis:

A minimum of three comparative tests should be performed to compare the two stoves in the same conditions. Four parameters will be used to evaluate the stoves: the TTB (time to boil), the TTT (total time of test), the useful energy and then the potential fuel use differences.

- **Time to Boil (TTB)**

The time to boil is the time from when the pot is placed on the stove until the water has reached the boiling point. Generally, the lower the TTB, the more efficient the stove is. It is a good indicator of the thermal transfer ability of the stove. The TTB of an "improved cook stove" should not be too different from a traditional cook stove, to maximize the adoption of the improved cook stove by the target community.

- **Total Time of Test (TTT)**

This is the total time of the test, from when the pot is placed on the cook stove until the temperature of the water drops 3°C below the temperature recorded at TTB.

- **Useful energy (UE)**

The useful energy is the sum of the sensible heat ($Q_{SENSIBLE}$) and the latent heat (Q_{LATENT}) absorbed by the water.

$$UE\ (kJ) = Q_{SENSIBLE}\ [kJ] + Q_{LATENT}\ [kJ]$$

The sensible heat ($Q_{SENSIBLE}$) is the energy absorbed by the mass of water (M_W) to raise its initial temperature (T_I) to the boiling temperature (T_B)

$$Q_{SENSIBLE}\ [kJ] = M_W\ [kg] * C * (T_B - T_I)\ [^\circ C]$$

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

The latent heat (Q_{LATENT}) is the energy absorbed by the mass of water evaporated (M_{WE}) to change its phase from liquid to vapour.

$$Q_{LATENT}\ [kJ] = M_{WE}\ [kg] * L_V$$

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

- **Potential fuel differences**

This is the ratio of the useful energy provided by the cook stoves. This ratio shows the potential fuel differences [PSF] between two cook stoves. It starts to be significant above 10%.

$$PFS\ [\%] = 100 * (EU_{IMPROVED} - EU_{TRADITIONAL}) / EU_{IMPROVED}$$

By multiplying this ratio with the current quantity of fuel used, an estimation of the fuel difference can be done. This difference should then be validated in real conditions with another test: the Household Fuelwood Cooking Test (HFCT).

6. Accuracy and reproducibility tests:

A minimum of three comparative tests should be performed, and results are considered statistically valid if the Coefficient of Variation (COV) for the useful energy of each stove is below 10%. If this requirement is not fulfilled, one additional test should be performed and analysed.

When possible we strongly recommend **testing two stoves simultaneously** to ensure the same external conditions. This strongly reduces the influence of external parameters on test data, improving the accuracy of the test results.

7. References:

1. Rob Bailis, Damon Ogle, Nordica MacCarty, Dean Stil, Kirk R. Smith and Rufus Edwards, *The Water Boiling Test Version 3*, Shell Foundation: Oregon, 2007.
2. JF Rozis, *Protocole de Test d'Ébullition de l'Eau Comparatif*, GERES Cambodge: Phnom Penh, 2008.