COMPARATIVE FUEL TESTING FOR THE PHILIPS STOVE (MODEL HD4012) – **CAMBODIA**

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1. Introduction

Background & Rationale

As a part of its renewable energy sector activities in Cambodia, SNV is implementing the Advanced Clean Cooking Solutions (ACCS) [www.advancedcleancooking.org] project to bring to scale a business model based on a product combination of the most effective advanced clean cook stoves with the most effective renewable biomass fuels. The focus is on clean and healthy biomass cooking solutions [stove + fuel + behavioral change]. The project brings proven advanced clean cooking technologies to Cambodia to complement existing improved cookstove product offerings available to end-users. To address absence of existing market structures for these stoves, a comprehensive suite of market-making activities will be implemented that result in a self-sustaining commercial sector with private entities as main actors.

Part of this project includes the testing of fuel types (e.g. woodchips, pellets) with gasifier stove technologies to understand optimal and most feasible combination for commercial replication. The combined use of the woody biomass fuel products and advanced clean cookstoves are expected to halve the cooking costs compared with charcoal.

Objectives

The objective of the present assignment is to determine the optimal fuel source for fan powered gasifier stoves, more specifically in this case for the Philips stove (model HD4012) ("Philips stove"), for cooks in Cambodia, and compare performances against baseline stove models.

Abstract

The Philips stove is a high performance, improved and clean cookstove. To evaluate its potential successful introduction in Cambodia, a variety of tests have been carried out, assessing its operation with locally available traditional and innovative fuel types and comparing it to traditional cookstoves and cooking practices.

The stove has been tested with over 13 types of fuel, first qualitatively and then quantitatively through water boiling tests and controlled cooking tests. In all tests, the Philips stove performed better than the traditional cookstoves available in Cambodia, and its performances showed an impressive consistency through very low standard deviations of the average values obtained in the different tests.

The stove's main strength appears to be its versatility in functioning well with a vast diversity of types of fuel and its easy and consistent operation. The qualitative feedback received from the cooks performing the controlled cooking tests was positive, in terms of appealing design, ease of use and fuel consumption, with the exception on deep concerns about the potential price of the stove.

For its future potential commercialization, fuel seems to be the key aspect in terms of possible cost saving, overall performances and consequent acceptance. A few fuels have been selected and suggested to accompany the commercialization of the new stove, based on their performances, availability, prices and preprocessing requirements.

2. The Philips stove

The Philips stove is a modern "gasifier stove" designed by Philips Research Laboratories in Eindhoven, with the aim of reducing cooking fuel consumption and at the same time indoor air pollution while cooking.

The stove principle is not complicated: air is forced into a combustion chamber at the top and bottom of the chamber. Intense heat at the bottom "gasifies" the fuel (biomass) and the injected air burns the gases at the cooking surface.

The stove has a modern and appealing design. The outside of the stove is made of stainless steel, while the combustion chamber is isolated with ceramic material, which contributes effectively to containing the heat and avoiding that the exterior of the stove gets excessively hot.

Figure 1 – technical drawing of the Philips Stove

The flame is mostly smokeless once the stove is running (differing however on the type of fuel used). Through a knob positioned at the base of the stove it is possible to regulate the speed of the fan, giving the possibility to regulate the intensity of the combustion (gasification) of the fuel. The regulation has a continuous spectrum between the two extremes:

- low fan speed – low power/lower temperature, low fuel consumption
- high fan speed – high power/higher temperature, higher fuel consumption

The battery has a capacity for a cooking duration of about 21 hours per manufacturer's specifications. SNV staff validated this by running a new Philips stove continuously for 24 hours before the fan turned off. The cookstove comes with a battery charger, which can charge the battery in 2-3 hours. A useful light on the battery charger, signals when the battery is charging and when completely full (red --> charging; green --> full). The stove can be used also while attached to the battery charger. The manufacturer recommends a 5 watt solar panel, which is combined with a special regulator to reduce the voltage to 7.2V, to charge the Philips 6V battery.

2.1. Qualitative feedback on the stove about appearance and usage

Figure 2 – examination of the new stoves

Four Philips stoves have been used for the testing activities. In general, the stoves have a very appealing design and raised a significant interest in those that observed it for the first time.

Taking a closer look at the stoves, when taken out of the box, small scratches could be observed, especially at the bottom of the stove and small breaks at the inner ceramic insulation's top edge. In addition some stoves were mostly covered in dust, which seemed to be dust from the ceramic material used for the inner insulation. All these small imperfections seem to derive from careless handling of the materials and the stoves during the stove assembling, storing and packaging in the manufacturing factory. Even though the few scratches, small breaks and dust don't affect the operation of the stove, they could negatively impact a potential buyer's quality perception, who examines the stove when it is taken right out of the box.

The stove is surprisingly light, especially compared to traditional stoves in Cambodia, and it is very practical to handle. The stove has two useful handles on the sides and also during operation, and after cooking, the outer skirt doesn't heat up excessively, which permits to touch the stove without getting burned. However

Figure 3 – touching the stove while operating at full power

this is not always the case and some precautions need to be taken. The stove is the coolest on the outside skirt, while running with the fan at full power. The secondary air flowing inside the stove, contributes to keeping the outside skirt cool, even though the temperature inside the combustion chamber is at its highest. When operating the stove at low power, the secondary airflow is weaker, and despite the lower temperature inside the combustion chamber, the outside skirt of the stove heats up and it requires some attention to avoid burns. When turning off the stove completely after cooking, the air insulation represented by the secondary air is completely missing and the outside skirt of the stove can heat up significantly and it requires attention to avoid burns. In fact, for a new user, which doesn't understand the operation principle of the stove, the heating behavior of the outskirt of the stove could result counter intuitive and therefore it would eventually require some preliminary warning or practice to understand it.

The stove works remarkably well, in terms of efficiency of the combustion chamber and heat transmission to the cooking pot, with a high variety of fuels. Also its operation in terms of fuel loading, ignition, fuel "reloading" and cleaning/emptying, is quite practical, however the fuel used needs to be of a relatively small size. This subject is further discussed in detail in the following paragraphs.

3. Types of fuel and qualitative tests

3.1. Types of fuel identified in Cambodia

The fuels identified and used for the qualitative testing of the Philips stove are the following:

1. Commercial fuel wood

- *Description*: commercial wood is defined as firewood that can be bought in shops in Cambodia. It is composed by a mix of different tree species, ranging from Eucalyptus and Acacia wood (higher quality firewood) to rubber tree wood (low quality firewood). Commercial wood is sold in bundles of dry cut "wood-sticks" and priced by the bundle. Average weight of the bundle is 2 kg, the length of wood sticks is about 33 cm and a bundle contains an average number of 3 to 5 sticks.

- *Source and availability*: commercial wood can be purchased and is widely available in shops in Phnom Penh and in provincial towns. These small shops usually sell basic groceries and household products and an assortment of cooking fuels, from LPG, traditional charcoal, char-briquettes and wood.

- *Price*: 500 Riel/bundle --> 250 Riel/kg

- *Preprocessing requirements*: commercial wood needs to be cut in an approximate size of 9cm x 1.5cm x 1.5cm. The cutting of the wood can be done with a small axe. Cambodians are already used to cutting and chipping traditional charcoal and wood for cooking, but usually not at the small size as required by the Phillips stove. A possible solution for the future could be to preprocess and sell the wood fuel already in the required size.

- *Effectiveness*: commercial wood (when cut small) works very well to fuel the Philip stove. It makes no visible smoke, no sparks, a bright regular flame and has a long duration.

2. Natural wood (Acacia wood)

- *Description*: natural wood is defined as the wood directly harvested from trees. In this case, small very dry branches of Acacia were used. Acacia trees belong to the fast growing species widely present in Cambodia, for example planted at road sides and to delimitate land borders.

- *Source and availability*: natural wood is cut directly from trees and is the main source of cooking fuel in the provinces, where it is largely available. It can also be found and it is used in suburban areas, but it is quite uncommon, and its supply and use is occasional.

- *Price*: usually for free, just needs to be directly harvested and eventual transportation costs.

- *Preprocessing requirements*: natural wood has been cut in an approximate size of 9 cm length with a diameter of 1.2 cm. The cutting of the wood can be done by hand (breaking), when the branches are small, or with a small axe. Cambodians are already used to cutting and chipping traditional charcoal and wood for cooking, but usually not at the small size as required by the Phillips stove. Natural wood, when freshly harvested, also needs to be dried first for about 2-3 weeks, before it can be efficiently used for cooking purposes.

- *Effectiveness*: during the tests, very small dry branches were used. The combustion (gasification) produced a good flame, with no sparks and no smoke. However, the fuel was consumed relatively quickly.

3. Corn cobs

- *Description*: corn cobs are defined as the inner part of the corn cob. After the corn seeds are removed, the inner part remains as agricultural waste. When supplied, it is usually already very dry and comes in a practical small cylindrical size of approximate 5cm length and 2.5 in diameter.

- *Source and availability*: besides small quantities deriving from the use of corn in the city (for food), corn cobs are largely available in the provinces with corn plantations and farms (Battambang, Pailin, Ratanakiri, Kandal). The seeds are separated from the cob with machinery, directly at the farms and the inner cob is the remaining waste. The corn cobs are either thrown away or sold to factories running gasifiers. In the city, the corn cobs waste (deriving from food waste) are sometimes used as fuel by street food vendors (not regularly, only when available).

- *Price*: 1 bag (20-25 kg) – 2000 Riel/bag (this price was charged by an ice-factory in Phnom Penh, which runs a gasifier also with corn cobs).

- *Preprocessing requirements*: the corn cobs need practically no preprocessing. It is a very soft material and eventually it can be broken with the hands if needed.

- *Effectiveness*: the corn cob is a suitable fuel for the Philips stove. It burns with a clear flame, with no smoke and no sparks. The duration of the combustion is medium/short compared to the natural wood.

4. Coconut shells

- *Description*: coconut shells are the hard shells of the mature coconut, after the husk (the fresh green fiber on the outside) has been removed.

- *Source and availability*: the coconut shells are widely available in markets in Cambodia, where stalls process mature coconuts, extracting the water and the meat, leaving the empty shells.

- *Price*: prices range between 50USD-75USD per metric ton + transportation costs. Coconut shells are usually sold by metric tons and not at retail level.

- *Preprocessing requirements*: the coconut shells when purchased come in half shells. Before being used in the stove they need to be crushed in smaller pieces of an approximate size (area) of 6cm x 5 cm, and the shells have an average thickness of 0.5 cm. The crushing can be done with a hammer or with an axe, but could result quite difficult, labor intensive and not practical. For the testing, the coconut shells were crushed with an industrial biomass crushing machine.

- *Effectiveness*: Coconut shells are within the best fuels tested in the Philips stove. It is comparable with commercial wood in terms of good flame intensity, no sparks and no smoke.

5. Coconut husk

- *Description*: the coconut husk is the outside fiber of the coconuts.

- *Source and availability*: the coconut husk is widely available in Cambodia in markets or from coconut vendors on the streets.

- *Price*: fresh coconut husk can be collected for free on the side of markets and streets, and also directly from shops (eventually transportation costs). A bag of already dry coconut husk has been purchased for 1,000 Riel (7kg/bag).

Figure 4 – Crushing of coconut husk

- *Preprocessing requirements*: the coconut husk usually needs to be dried before it can be used as fuel. The drying can take up to a couple of weeks in the sun. The coconut husk also needs to be cut or crushed before it can be used in the stove. The cutting by hand is quite difficult and labor intensive, while the crushing is done with industrial machinery.

- *Effectiveness*: when burned, the small hand cut coconut husk produces small to high amounts of smoke (depending on the fan speed) and it presents some difficulties to reload the stove while cooking, due to the sizes of the pieces.

  The crushed coconut husk (by machine) becomes a very airy "wool-like" material, which is easier to feed inside the stove, it produces a high flame, with some smoke and some sparks, and it burns relatively quickly, resulting in unpractical use for cooking, since the cook needs to constantly refill the stove with fuel.

Figure 3 – sparks produced by coconut husk used in the Philips stove

6. Sugar cane waste

- *Description*: the sugar cane waste consists in the already pressed, squeezed sugar cane, once the juice has been extracted.

- *Source and availability*: the sugar cane waste is a widely available waste, collectable from sugar cane juice vendors and in markets.

- *Price*: sugar cane waste can be collected for free (eventually transportation costs).

- *Preprocessing requirements*: the sugar cane waste usually contains high moisture content and it needs to be dried at the sun for up to one week. It is a very soft material, which can be cut by hand with an axe or a knife.

- *Effectiveness*: sugar can waste burns very quickly, producing a very big flame, including smoke and in some cases a lot of sparks. Its density is very low, which means that one full load in the Philips stove can contain maximum 50 gram, requiring the stove operator (the cook) to constantly refill the fuel.

7. Bamboo

- *Description*: bamboo is a widely available fast growing species. Bamboo waste is defined as the bamboo which is disposed at the end of its lifetime (when it can't be used anymore for its original purpose).

- *Source and availability*: bamboo is widely used as scaffolding material and in construction all over Asia. After several years (over 4-5 years), when the bamboo starts deteriorating it is disposed and usually used as combustion material.

- *Price*: unknown

- *Preprocessing requirements*: fresh bamboo needs to be dried before it can be used as fuel. In provinces, when bamboo is harvested for fuel, it gets cut and split before drying which can take a few weeks. In urban areas, the available bamboo waste is usually already very dry. When collected in urban areas, the bamboo needs to be cut in pieces, since it comes usually in long poles, and needs to be further split to fit the Philips stove. The average size used in the testing is 7.5cm x 1.8cm x 1.5cm. The cutting (in length) can be done with an axe (labor intensive) or with machinery equipment, as for example an electric wheel saw. The splitting can be easily done by hand with a small axe.

- *Effectiveness*: dried bamboo is a quite good fuel, just a little bit below commercial wood. It burns with a clear flame, with no sparks and no smoke, and is easy to ignite.

8. Rice husk

- *Description*: rice husk is an agricultural waste, the outer fibrous case of the rice, which results after the cleaning of the rice.

- *Source and availability*: rice husk is widely available in Cambodia, since Cambodia is one of the main rice producing countries in the world. Rice husk can be purchased from rice processing factories in bags in large quantities in the provinces as well as in urban areas (for example in Phnom Penh).

- *Price*: 2,000 Riel/bag (1 bag ~ 20kg, price in Phnom Penh).

- *Preprocessing requirements*: rice husk doesn't require any preprocessing. It actually is available already in two types. (i) whole rice husk (most common) and (ii) crushed, similar to saw dust and used also for animal (pigs) feeding. The size/type of rice husk depends from the machinery that is used for the processing/cleaning of the rice.

- *Effectiveness*: rice husk can be used as fuel in the Philips stove, which is not possible to do in the traditional Cambodian stoves. However, the combustion produces smoke and sparks, the temperatures reached are low and the stove needs to be constantly refilled. The main problem of this type of fuel is that after about 30 minutes at high power operation, the combustion chamber of the stove is filled up completely and it is not possible to continue using it, unless it is emptied.

Figure 6 – two types of rice husk

9. Rice straw

- *Description*: the rice straw is an agricultural waste and it is the stem where the rice seeds grow.

- *Source and availability*: rice straw is widely available in the provinces from rice farmers. It is sometimes used as food for cows, buffalos and horses when fresh grass is not available (very small utilization compared to the availability).

- *Price*: 10 USD for 1 full ox-cart

- *Preprocessing requirements*: Usually rice straw is collected into bundles. Rice straw can be easily cut with a knife or a common scissor, to fit the stove.

- *Effectiveness*: the maximum loading capacity is about 50 gram, but the fuel is consumed very quickly with a very big flame, and it produces some smoke and sparks.

Figure 7 – rice straw used as fuel in the Philips stove

10. Sugar Palm Fruit bunch

- *Description*: the sugar palm fruit comes from the Borassus flabellifer, the Asian palmyra palm, or Cambodian palm, which is native to the Indian subcontinent and Southeast Asia. The fruit bunch is an agricultural waste, once the meat of the fruit has been removed from inside.

- *Source and availability*: at Sugar Palm plantations (like Kampong Speu province) or as food waste also in urban areas.

- *Price*: unknown/free

- *Preprocessing requirements*: needs to be cut with a small axe which can present difficulties, due to the chewy/rubbery texture of the fruit bunch.

- *Effectiveness*: this type of fuel is very difficult to ignite; it hardly burns, producing a small flame and low heat. At the same time it also produces smoke.

11. Saw dust

- *Description*: Sawdust or wood dust is a by-product of cutting, grinding, drilling, sanding, or otherwise pulverizing wood with a saw or other tools; it is composed of fine particles of wood.

- *Source and availability*: It is available from small wood industries in Phnom Penh and in the provinces. It is widely available.

- *Price*: 2,000Riel/bag (1 bag ~ 30kg).

- *Preprocessing requirements*: none.

- *Effectiveness*: Saw dust actually surprisingly burns well in the Philips stove. However it creates a very high amount of sparks and the fuel needs to be constantly refilled while operating the stove, which makes it very unpractical.

12. Saw dust pellets

- *Description*: saw dust pellets are the most common type of fuel pellets. Pellets are made from compacted sawdust.

- *Source and availability*: Saw dust pellets are not available in Cambodia. For stove testing, wood pellets were ordered from Ho Chi Minh City in Vietnam. A factory producing wood pellets has been identified in Cambodia, which however produces only for the export market (Korea).

- *Price*: ~0.15-0.28 USD/kg

- *Preprocessing requirements*: none.

- *Effectiveness*: saw-dust pellets burn efficiently in the Philips stove, producing no sparks and no smoke. The ignition can be a little difficult and slow, needing to place a starter on top of the pellets and then more pellets need to be fed in for full ignition. Wood pellets can be easily refilled in the stove with a spoon.

13. Rice-husk pellets

- *Description*: Rice-husk pellets are made from compacted rice husk.

- *Source and availability*: Rice husk pellets are not available in Cambodia. For the Philips stove testing, rice-husk pellets have been imported from Ho Chi Minh City in Vietnam.

- *Price*: ~0.15-0.20 USD/kg

- *Preprocessing requirements*: none.

- *Effectiveness*: rice-husk pellets burn very similarly to saw-dust pellets, but with a visibly shorter duration. Rice-husk pellets can be easily refilled in the stove with a spoon.

3.2. Summary table of fuel used for testing the Philips stove

NO.	Type of Fuel	Source	Availability	Cost	Processing requirements
1	**Commercial wood** 	Shops in urban areas and provinces	VERY HIGH	500R/bunch 250R/kg (price for Phnom Penh)	Needs to be cut in small pieces (9x1.5x1.5cm) Can be cut with a small axe or with machine saw.
2	**Natural wood** 	Urban areas and provinces	Urban areas- VERY LOW Provinces – VERY HIGH	free	Needs to be cut in small pieces (9cm length; 1.2 diameter) Can be cut with a small axe or with machine saw.
3	**Corn cobs** 	Mainly farms in provinces (Battambang, Pailin, Ratanakiri, Kandal)	VERY HIGH	2000R/bag (20-25kg/bag) in Phnom Penh 80-100R/kg	NONE
4	**Coconut shells** 	Phnom Penh and province, at coconut processing shops in markets)	Phnom Penh – HIGH Provinces - UNKNOWN	200-300R/kg	Needs to be cut or crushed to an aprox. size of 5cmx6cm (thickness 0.5 cm)
5	**Coconut husk** 	Urban areas and provinces (coconut processing shops, different from coconut shells shops)	HIGH	already dry 1000R/bag (7kg/bag) fresh - FREE	Needs to be cut or crushed.
6	**Sugar cane waste** 	Sugar cane juice vendors in urban areas and provinces	HIGH	FREE	Can be easily cut with a small axe or knife
7	**Bamboo** 	Urban areas (after being used for scaffolding for construction) and provinces (fresh plants)	Urban areas UNKOWN Provinces VERY HIGH	Urban areas unknown Provinces 3700R/plant 1 Plant= 9m	Needs to be cut pieces of 9-10cm length and then chipped/splinted Can be done with an axe or with a machine saw
8	**Rice husk** 	Urban areas and provinces (at rice mills)	VERY HIGH	100 Riel/kg	No need for pre-processing. It comes already in two forms (whole and crushed)
9	**Rice straw** 	Provinces in rural area	VERY HIGH	10USD/ox cart	Needs to be cut with a scissor or a knife to fit the stove.

10	**Sugar Palm Fruit Bunch** 	Provinces (Kampong Speu)	UNKOWN	UNKOWN/ FREE	Needs to be cut with an axe (made difficult due to its rubbery texture)
11	**Sawdust** 	Small wood industries in urban areas and provinces	HIGH	60-70R kg (2,000R/bag; 1bag~30kg)	NONE
12	**Sawdust pellets** 	Imported from Vietnam Only one factory in Cambodia exporting all its production to Korea	LOCALLY NONE	0.15-0.28 USD/kg (import price from Vietnam)	NONE
13	**Rice husk** 	Imported from Vietnam	LOCALLY NONE	0.15-0.20 USD/kg (import price from Vietnam)	NONE

Figure 4 - Assortment of fuel, pre-processed and ready to be used in the Philips Stove

Figure 5 - Assortment of fuel, pre-processed and ready to be used in the Philips Stove

3.3. Qualitative tests results

The table below summarizes the qualitative tests performed on the Philips stove with the different types of fuel, specifying their indicative duration (from ignition until residual glowing, not being able anymore to provide significant heat – no flame) at different fan speeds (~100g of fuel), description of the flame, amount of smoke and sparks produced, the type of residues (char or ash) and the type of ignition used. For all tests, indirect ignition has been used, which means with an external starter (in this case coconut dust and wax cubes, produced by SGFE.)

Qualitative preliminary Testing											
N⁰	Fuel	Characteristic of Sample									
		Operation and loading of the stove		Combustion				Residues		Ignition	
		Level of air used	Loading mass (g)	Indicative duration min	Flame	Smoke	Spark	Char	ash	Direct	Indirect
1	Commercial wood	Min	101	32	Medium	No	No	+			+
		Mid	103	31	Medium	No	No	+			+
		Max	103	29	Medium	No	No	+			+
				AVG 30:40							
Starting instructions: - put starter in the middle (easy to make combustion and avoiding smoke) - All level of air using											
2	Natural wood	Min	101	27	Big	No	No	+			+
		Mid	100	24	Big	No	No	+			+
		Max	100	20	Big	NO	No	+			+
				AVG 23:40							
Starting instructions: - put starter in the middle (easy to make combustion and avoiding smoke) - All level of air using											
3	Corn cobs	Min	101	26	Medium	No	No	+			+
		Mid	100	23	Medium	No	No	+			+
		Max	101	15	Medium	No	No	+			+
				AVG 21:20							
Starting instructions: - put starter in the middle or above (easy to make combustion and avoiding smoke) - All level of air using											

Qualitative preliminary Testing											
		Characteristic of Sample									
		Operation and loading of the stove		Combustion				Residues		Ignition	
N⁰	Fuel	Level of air used	Loading mass (g)	Indicative duration min	Flame	Smoke	Spark	Char	ash	Direct	Indirect
4	Coconut shells	Min	100	34	Medium	Little bit	No	+			+
		Mid	101	32	Medium	No	No	+			+
		Max	101	31	Medium	No	No	+			+
				AVG 32:20							
Starting instructions: - put starter in the middle (easy to make combustion and avoiding smoke) - All level of air using											
5.1	Coconut husk cut, not crushed	Min	102	26	Medium	A lot	Little		+		+
		Mid	103	19	Medium	Little	Little		+		+
		Max	103	16	Medium	Little	Little		+		+
				AVG 20:20							
Starting instructions: - put starter in the middle (easy to make combustion and avoiding smoke) - High level of air using and fill the stove with 60% of small Coconut husk non-crushing (quickly add more)											
5.2	Coconut husk crushed	Min	102	16	Big	Little	Little		+		+
		Mid	101	16	Big	Little	Little		+		+
		Max	102	15	Big	Little	A lots		+		+
				AVG 15:40							
Starting instructions: - put starter above easy to make combustion and reducing smoke - All level of air using and fill the stove with 60% of Coconut husk crushing (burn very fast)											

Qualitative preliminary Testing											
Nº	Fuel	Characteristic of Sample									
		Operation and loading of the stove		Combustion				Residues		Ignition	
		Level of air used	Loading mass (g)	Indicative duration min	Flame	Smoke	Spark	Char	ash	Direct	Indirect
6	Sugar cane waste	Min	100	7	Big	Little	Little		+		+
		Mid	101	6	Big	Little	Little		+		+
		Max	102	6	Big	Little	A lot		+		+
				AVG 06:20							
Starting instructions: - put starter above (easy to make combustion and avoiding smoke) - All level of air using and fill the stove with 60% of sugar cane waste (burn very fast)											
7	Bamboo	Min	102	26	Medium	No	No	+			+
		Mid	103	23	Medium	No	No	+			+
		Max	101	18	Medium	No	No	+			+
				AVG 22:20							
- put starter in the middle and under (easy to make combustion and avoiding smoke) - All level of air using											
8.1	Small/crushed rice husk	Min	100	32	Medium	A lot	A little		+		+
		Mid	100	29	Medium	A lot	A lot		+		+
		Max	100	24	Medium	No	A lot		+		+
				AVG 28:20							
Starting instructions: - put starter above easy to make combustion and avoiding smoke (have smoke unless we fill much amount of rice husk in the stove) - High level of air using and fill the stove with 30% of small rice husk (quickly add more)											
8.2	Big/whole rice husk	Min	100	27	Medium	A lot	A little		+		+
		Mid	100	19	Medium	A little	A little		+		+
		Max	100	16:55	Medium	NO	A lot		+		+
				AVG 20:40							
Starting instructions: - put starter above easy to make combustion and avoiding smoke (have smoke unless we fill much amount of rice husk in the stove) - All level of air using and fill the stove with 30% of big rice husk (quickly add more)											

Qualitative preliminary Testing											
N⁰	Fuel	Characteristic of Sample									
		Operation and loading of the stove		Combustion				Residues		Ignition	
		Level of air used	Loading mass (g)	Indicative duration min	Flame	Smoke	Spark	Char	ash	Direct	Indirect
9	Rice straw	Min	100	11	Big	Little	Little		+		+
		Mid	101	10	Big	Little	little		+		+
		Max	102	9	Big	Little	A lot		+		+
				AVG 10							
Starting instructions: - put starter above (easy to make combustion and avoiding smoke) - All level of air using and fill the stove with 60% of rice straw (burn very fast)											
10	Sugar Palm fruit bunch	Min	101	Difficult to make fire							
		Mid	103								
		Max	105								
Starting instructions: NONE											
11	Saw dust	Min	100	29	Small	a lot	Little bit		+		+
		Mid	100	28	Small	a lot	A lot		+		+
		Max	100	25	Small	No	A lot		+		+
				AVG 27:20							
Starting instructions: - put starter above (easy to make combustion and avoiding smoke in the condition of using air max) - High level of air using and fill the stove with 30% of saw dust(quickly add more)											
12	Saw dust pellets	Min	100	27	Medium	No	no		+		
		Mid	100	26	Medium	No	no		+		
		Max	100	25	Medium	A little	no		+		
				AVG 26:00							
Starting instructions: - put starter above (put starter above, slow start even using air max) - All level of air using											

Qualitative preliminary Testing											
N^0	Fuel	Characteristic of Sample									
		Operation and loading of the stove		Combustion				Residues		Ignition	
		Level of air used	Loading mass (g)	Indicative duration min	Flame	Smoke	Spark	Char	ash	Direct	Indirect
13	Rice husk Pellets	Min	100	24	Medium	No	no		+		
		Mid	100	23	Medium	No	no		+		
		Max	100	21	Medium	A little	no		+		
				AVG 22:40							

Starting instructions:

- put starter above (put starter above, slow start even using air max)
- All level of air using

4. Water Boiling Test

4.1. Methodology

For the following Water Boiling Tests (WBT), the version 3.0 (2007) for the Household Energy and Health (HEH) Programme of the Shell Foundation has been taken as reference.

The WBT is a rough simulation of the cooking process that is intended to help understand how well energy is transferred from the fuel to the cooking pot.

The WBT developed for the Shell HEH program consists of three phases that immediately follow each other:

1) In the first phase, the cold-start high-power test, the tester begins with the stove at room temperature and uses a pre-weighed amount of fuel to boil a measured quantity of water in a standard pot. The tester then replaces the boiled water with a fresh pot of cold water to perform the second phase of the test.

2) The second phase, the hot-start high-power test, follows immediately after the first test while stove is still hot. Again, the tester uses a pre-weighed amount of fuel to boil a measured quantity of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot.

3) The third phase follows immediately from the second. Here, the tester determines the amount of fuel required to simmer a measured amount of water at just below boiling for 45 minutes. This step simulates the long cooking of legumes[1] or pulses[2].

This combination of tests measures some aspects of the stove's performance at both high and low power outputs, which are associated with the stove's ability to conserve fuel. However, rather than report a single number indicating the thermal efficiency of the stove, which is not necessarily a good predictor of stove performance, this test is designed to yield several quantitative outputs. The outputs are:

- time to boil (adjusted for starting temperature);
- burning rate (adjusted for starting temperature);
- specific fuel consumption (adjusted for starting temperature);
- firepower
- turn-down ratio (ratio of the stove's high power output to its low power output); and
- thermal efficiency

In the context of the present testing of the Philips stove, the focus has been set on the different types of fuel. In fact, the WBT is usually used to compare the efficiency of different stoves with the same type of fuel (or comparable fuel). In this case, the emphasis is set on the ability of the same stove (the Philips stove) to perform with different fuels. In addition, a baseline test has been conducted with a traditional Cambodian stove with the most common cooking fuels used in Cambodia, firewood and charcoal. The model of "traditional" stove used as baseline is the New Lao Stove (NLS), which is the best and most disseminated improved cookstove available in Cambodia (designed and introduced by GERES Cambodia). The NLS has been designed specifically to be used with charcoal as a fuel. In fact all results of the tests below show better performances of the NLS fueled with charcoal, than with commercial wood. However, in Cambodia the NLS is also used with wood and also with this fuel, it performs better than other traditional cookstoves and obviously better than a basic three stone stove.

Because of the high variety of fuel types used, it was decided to not consider the moisture content of the fuels as a variable in the calculations (default value of zero has been used). Indeed, the purpose is to compare the performance of the Philips stove with the different types of fuel as they are available at supply (independently from their moisture content).

[1] The term "legume" refers to the plants whose fruit is enclosed in a pod. Well-known legumes include alfalfa, clover, fresh peas, lupins, mesquite, soy and peanuts.
[2] Pulses are part of the legume family, but the term "pulse" refers only to the dried seed. Dried peas, edible beans, lentils and chickpeas are the most common varieties of pulses.

The quantitative outputs examined are the following:

- Time to boil (minutes)
- Specific fuel consumption (g/liter – grams of fuel needed per liter of water)
- burning rate (g/minutes – grams of fuel burned per minute)
- Firepower (watts)
- Thermal efficiency (% - a comparison only between the Philips stove and the traditional stove with commercial wood as fuel).

For all WBTs, 7 liter standard pots have been used, boiling 5 liters of water without a lid.

4.2. Water Boiling Test results

Below are the graphs related to the quantitative outputs examined for each type of fuel and stove.

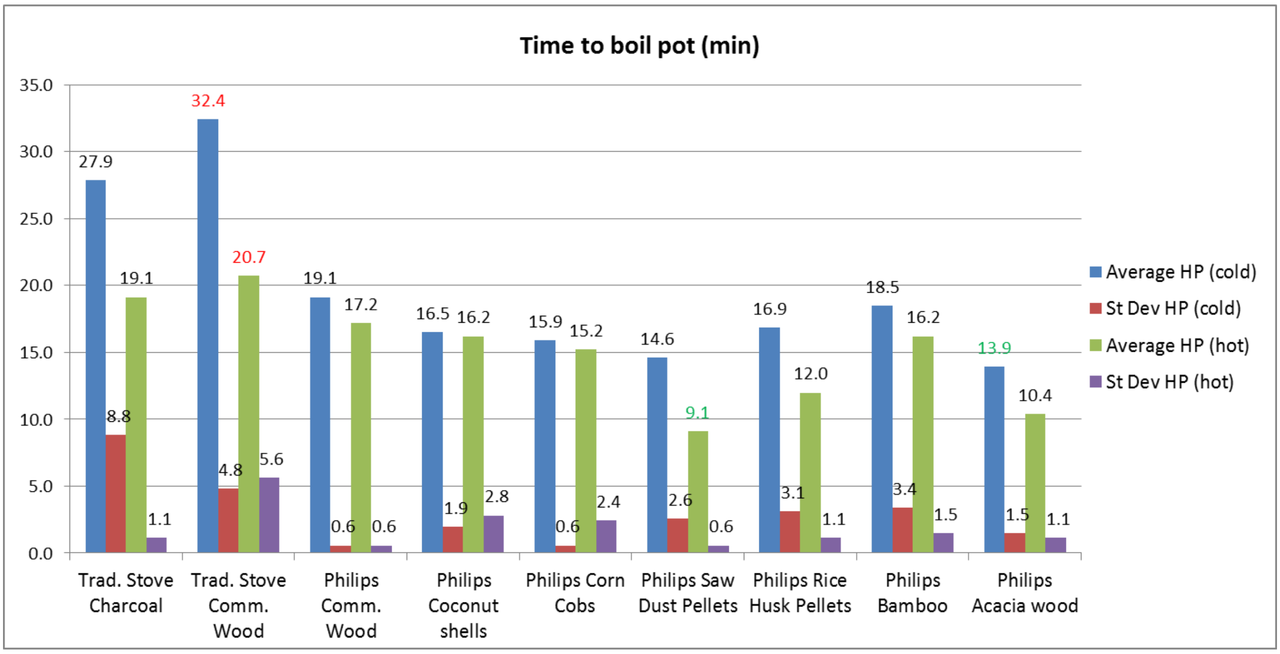

Figure 6 – WBT – Time to boil

The "time to boil" parameter shows a clear advantage for the Philips stove, especially in the case of the High Power (HP) cold start. Also in the case of the HP hot start, the Philips stove performs better than the traditional stove, but the difference is not so marked.

A directly comparable parameter is between the traditional stove and the Philips stove, both using commercial wood (2nd and 3rd in the graph above). The difference for the traditional stove in the hot start and in the cold start is quite relevant. The reason is probably that the traditional stove, in a cold start, initially absorbs a lot of heat, while the Philips stove transfers the heat directly to the stove. As a matter of fact, in a hot start, the performances between the two stoves are more similar, since the traditional stove is already hot and therefor absorbs less heat, which is used instead by the pot to boil the water.

For both types of fuel used in the traditional stove (charcoal and commercial wood), the performance between the cold and hot start improves visibly, while the difference in the Philips stove is less marked. This confirms the higher heat absorption by the traditional stove in a cold start, then by the Philips stove.

The worst performance in terms of "time to boil" for all tested fuels is of the traditional stove with commercial wood, both for the cold and hot start. On the other hand, the best performances were measured for the Philips stove fueled with Acacia wood in the cold start and fueled with saw dust pellets in the hot start. The good performance of the Acacia wood in general, is due to the very low moisture content and the very small size of the used fuel, which led to a relatively higher burning rate and fire power (graphs below), enabling the stove to transfer the heat to the pot in the shortest time.

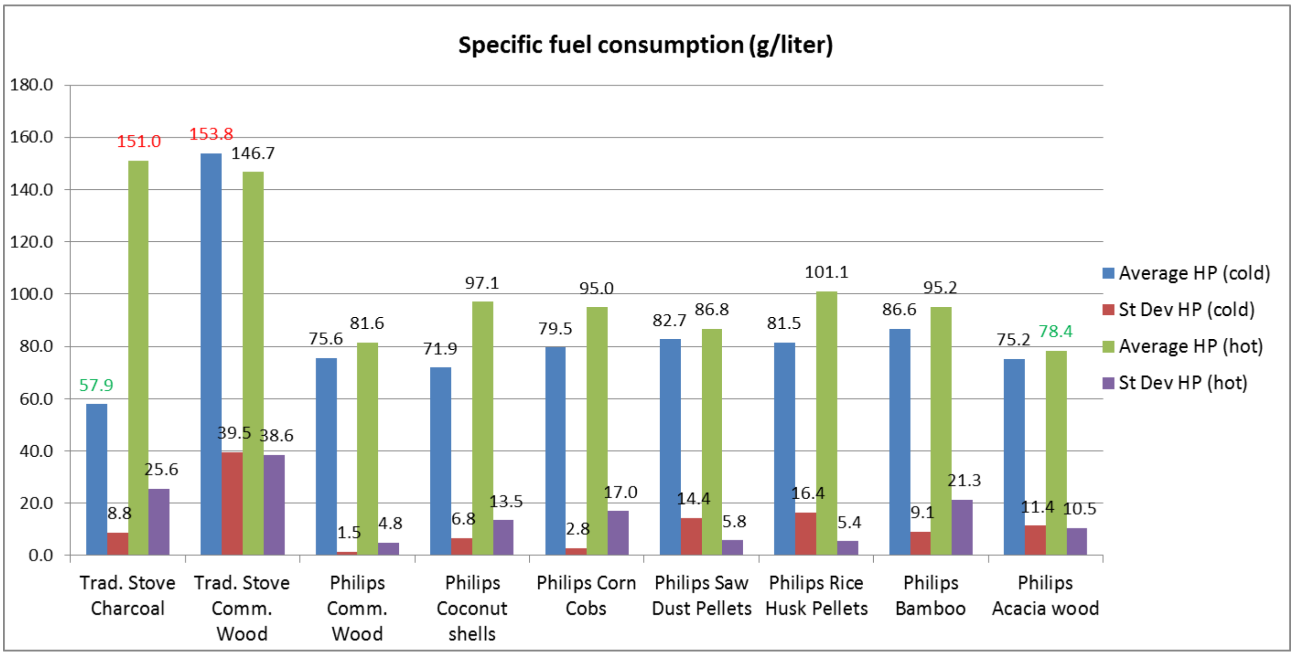

Figure 7 – WBT – Specific fuel consumption

Also the "specific fuel consumption" parameter shows overall better performances of the Philips stove, compared to the traditional stove. All hot start tests show a higher specific fuel consumption (gram of fuel per liter of water) compared to the cold starts, with the exception of the traditional stove, fueled with commercial wood, where the specific fuel consumption in the hot start is lower than in the cold start. The average higher specific fuel consumption in the hot start is due to the higher burning rate (grams of fuel per minute – in the chart below) and higher fire power obtained in both stoves, when the stove is already hot.

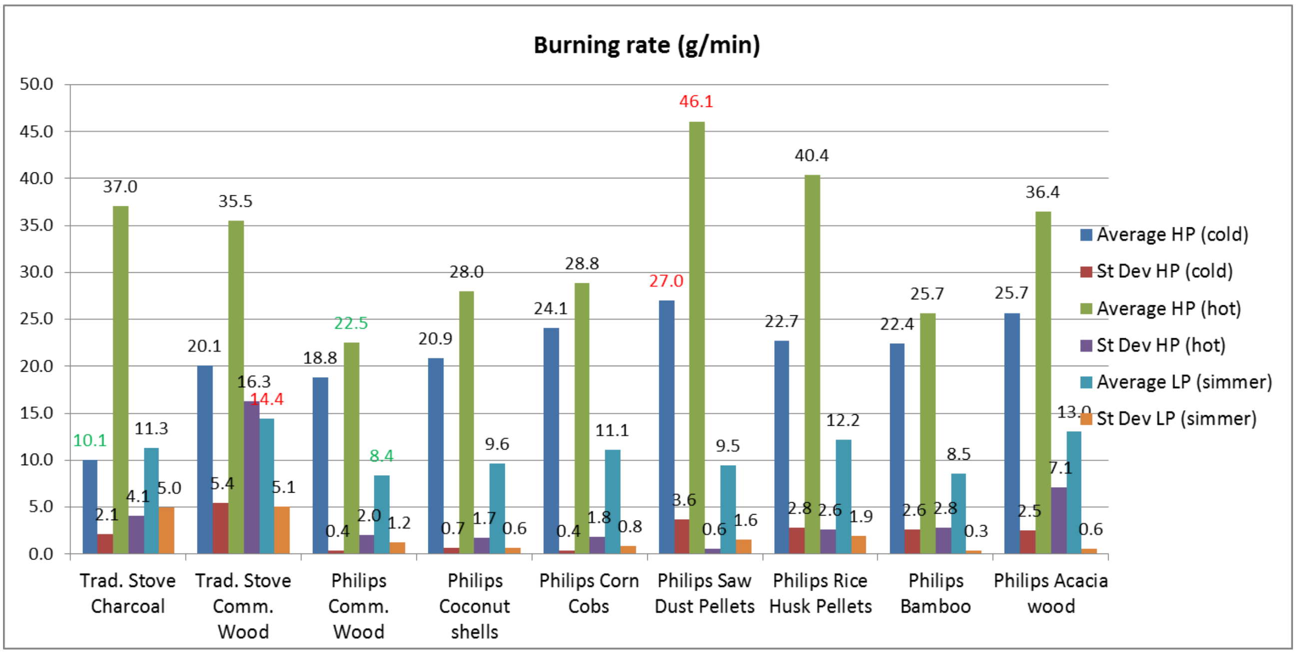

Figure 8 – WBT – Burning rate

The burning rate chart shows the difference in fuel consumption at high power (cold and hot start) and at low power (simmer test). All burning rates in the hot start tests are visibly higher than those in the cold start test. The greatest difference can be noted for the charcoal in the traditional stove. In general charcoal is relatively slow to ignite and presents for short time cooking relatively low burning rates. However, in the case of a hot start, the charcoal ignites much faster and reaches more quickly higher temperatures, which results in a higher burning rate.

Interesting to notice is the evident better performance (lower burning rate) of the Philips stove during the low power tests (the simmering tests). This data derives from the lower dispersion of heat and from the ease to regulate the power in the Philips stove, through the fan speed.

In fact, as the graph on firepower below shows clearly, during the low power test, it was possible to maintain an average lower fire power (measured in watts) in the Philips stove, during the 45 minutes simmering test. The low fan speed enables to decrease the firepower in the Philips stove, keeping at the same time the water at a temperature between 97 and 100 degrees owing to the good heat transmission capabilities of the Philips stove.

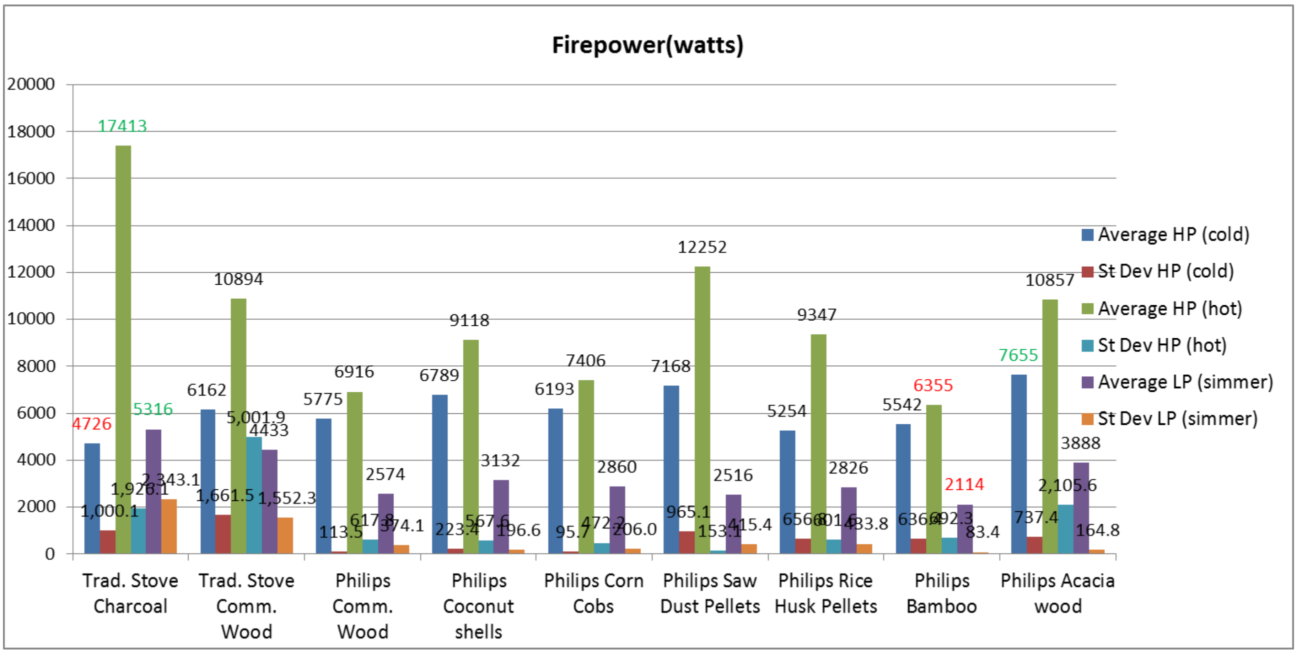

Figure 9 – WBT – Firepower

In general, there is one important common element in all results obtained and described above. All parameters[3] have been measured and calculated on three tests in controlled indoor conditions, with all fuels and for both stoves. All graphs above present the average result over the three tests and also the standard deviation of the results.

The standard deviations of the measurements obtained with the traditional stoves, for both types of fuel tested (charcoal and wood), are significantly higher than the standard deviations obtained in all measurements made on the Philips stove. This indicates a very high consistency of operation and performance of the Philips stove in all different tests (high power cold and hot start, and low power), compared to the traditional stove.

For example, the standard deviation of the time to boil parameter in the traditional stove averages about 5 minutes (HP cold and hot start with wood as fuel) and reaches also 8.8 minutes (traditional cookstove with charcoal), while the standard deviation of the time to boil parameter in the Philips stove with all fuels averages between 2 and 3 minutes and goes as low as 0.6 minutes.

The same consistency of the Philips stove is observed in all other performance parameters measured and calculated with all different types of fuel tested.

At last, a comparison between the traditional stove and the Philips stove with commercial wood fuel has been calculated, considering the thermal efficiency (with a 20% standard moisture content value of the fuel).

[3] Parameters include: (1) Time to boil (minutes); (2) Specific fuel consumption (g/liter – grams of fuel needed per liter of water); (3) burning rate (g/minutes – grams of fuel burned per minute); and (4) Firepower (watts)

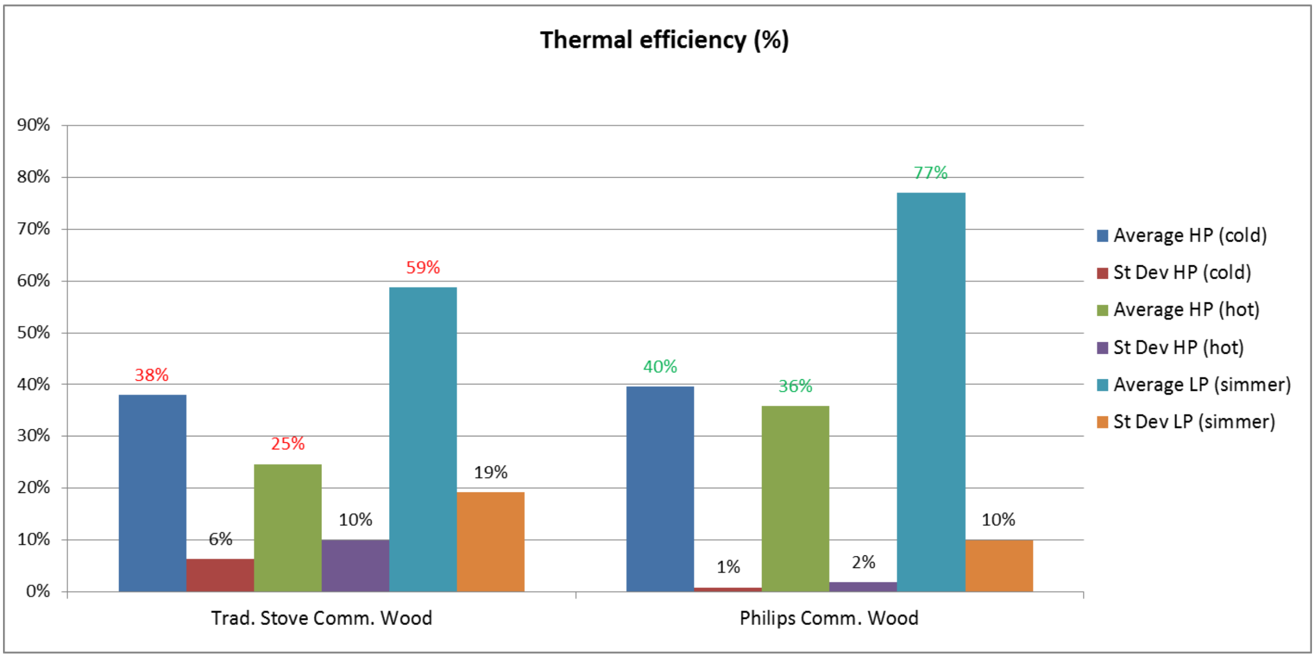

Figure 10 – WBT – comparative thermal efficiency analysis of traditional stove and Philips stove

The direct comparison shows clearly a better performance of the Philips stove in the WBTs (HP cold start, HP hot start and simmer). Also in this case, it is interesting to notice the lower standard deviation of the average thermal efficiency measured on the Philips stove, which confirms the consistency of its performance. The WBT test compares closely to the US EPA testing on the Philips stove (model HD4012), which was published in the journal of Environmental Science and Technology, October 2, 2012[4]. The results of the EPA test show an average thermal efficiency (Hot Start and Cold Start) of 38.4%. This US EPA test result is also published on the Global Alliance for Clean Cookstoves (GACC) website at http://catalog.cleancookstoves.org/#/test-results/426.

[4] Jetter et al. Pollutant Emissions and Energy Efficiency under Controlled Conditions for Household Biomass Cookstoves and Implications for Metrics Useful in Setting International Test Standards. Environmental Science and Technology. 2012 Oct 2; 46(19):10827-34. Available for download at http://ehs.sph.berkeley.edu/krsmith/?p=1387.

5. Controlled Cooking Test

5.1. Methodology

The Water Boiling Test is the most controlled of tests developed to assess stove performances, and thus it is probably the least like local cooking. Although the WBT is a useful tool it is only an approximation of the cooking process and is conducted in controlled conditions by trained technicians. Laboratory test results might differ from results obtained when cooking real foods. In order to confirm the results obtained in the WBT, the Philips stove's performances has been measured under (more) real conditions of use.

During the Controlled Cooking Test (CCT), the traditional stove and the Philips stove have been compared as they perform a standard cooking task that is closer to the actual cooking that Cambodian people do every day. However, the tests are designed in a way that minimizes the influence of other factors and allows for the test conditions to be reproduced.

The testing activities for the CCT were the following:

1) Choice of cooking task: it was decided to cook a full meal, including 3 dishes, representative of a common Cambodia family meal.

<table>
<tr><th>Dish</th><th>Ingredients</th><th>Quantity (g)</th><th>Directions</th></tr>
<tr><td rowspan="8">Fried beef with ginger</td><td>Ginger</td><td>300</td><td rowspan="8">- Put oil in to the frying pan and cook until it reaches frying temperature
- add ginger until it appears of a darker yellow color and emits a strong smell
- take the ginger out of the pan onto a plate on the side.
- fry the garlic with oil in the same pan
- add beef and fry it until its cooked
- then add the seasoning: sugar, fish sauce and glutamine.
- add again the fried ginger with the beef in the pan and stir it until fully cooked
- at last add the onion leafs</td></tr>
<tr><td>Oil</td><td>100</td></tr>
<tr><td>Garlic</td><td>15</td></tr>
<tr><td>Beef</td><td>300</td></tr>
<tr><td>Sugar</td><td>25</td></tr>
<tr><td>Fish sauce</td><td>25</td></tr>
<tr><td>Glutamine</td><td>10</td></tr>
<tr><td>Onion leafs</td><td>25</td></tr>
<tr><td rowspan="3">Pork soup with zucchini</td><td>Water</td><td>1500</td><td rowspan="3">- Put water in to the pot and bring it to boiling temperature
- add the pork and let it cook for a while
- then add all the seasoning
- and add the zucchini until all ingredients are fully cooked
- A last add the onion leafs</td></tr>
<tr><td>Pork</td><td>320</td></tr>
<tr><td>Seasoning (sugar=25g, salt= 12g, glutamine=10g and pepper=3g)</td><td>50</td></tr>
</table>

	Zucchini	500	
	Onion leaf	25	
Rice	Rice	1000	- Put the rice into the pot - Add the water and wait until it is cooked.
	Water	1325	

The above described cooking task is also a good test for the stove, since it foresees a combination of "high power" (frying, boiling water) and "low power" (simmer rice) cookstove utilization. The quantities are defined for a meal of at least 5 people.

Figure 11 – Fried beef with ginger

2) Selection and training of cooks: three cooks were chosen to perform the cooking task. All three cooks use the traditional cookstove on a daily basis with firewood. Before starting the actual test, the cooks were extensively trained for 2 days on performing the selected cooking task with all types of fuel selected for the CCT.

Figure 12 – the 3 cooks performing the controlled cooking test

3) All preparations (washing, pealing, cutting, etc.) have been done before the start of the tests, along with weighing all ingredients and arranging pre-weighted bundles of fuel.

Figure 13 – Preparation of all ingredients (pre-weighted and portioned) for the CCT

4) The cooking task was performed by all three cooks with a selection of fuel with the Philips stove and the traditional stove.

5) During the cooking task, the weight of fuel, food and remaining char/ash was weighted and recorded, as well as the duration and the local conditions (temperature, wind, etc.).

In addition to the quantitative data, feedback was collected from all cooks, regarding the Philips stove and the different types of fuel used in the CCT (charcoal, wood, coconut shells, corn cobs, sawdust pellets and rice-husk pellets).

5.2. Controlled Cooking Test results

The graphs below describe the main quantitative outcomes of the CCT.

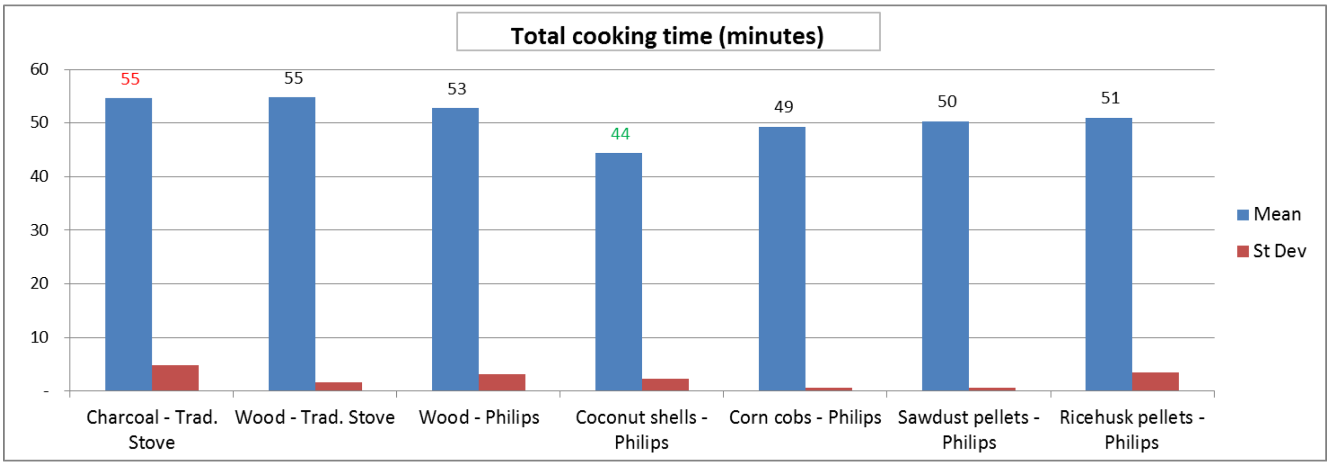

Figure 18 – CCT – Total cooking time

All cooking times were quite similar differing usually less than 10%, with exception of the coconut shells with the Philips stove, which is 20% shorter than the longest cooking time. The longest cooking times have been recorded for the traditional stove using both, charcoal and wood.

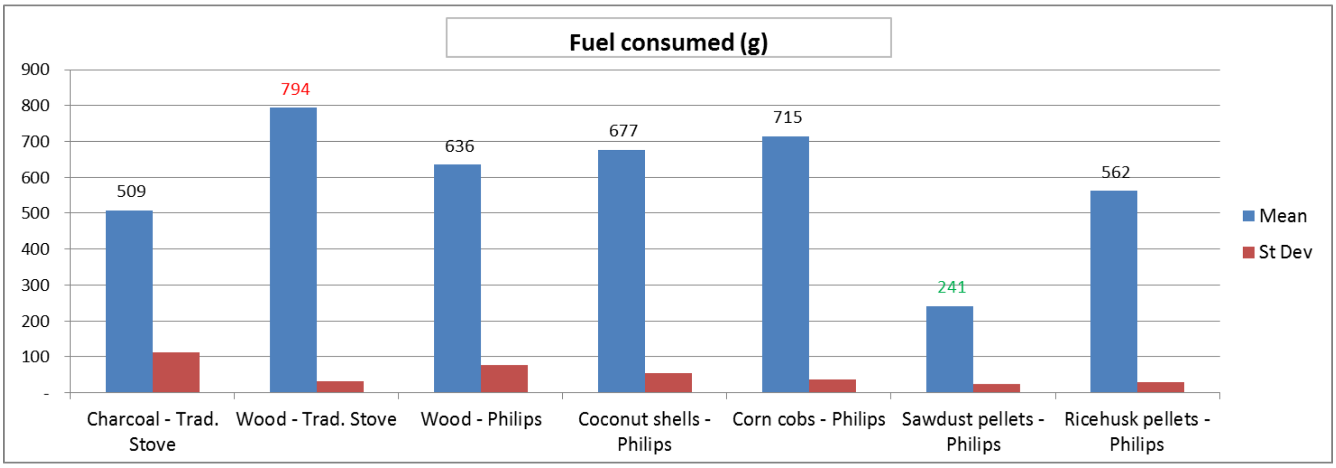

Figure 19 – CCT – Fuel consumed

In terms of fuel consumption, the differences are more significant. The far lowest fuel consumption has been recorded for the Philips stove using sawdust pellets as fuel, with only 241 grams, while the highest fuel consumption was recorded for the traditional cookstove using wood, with 794 grams.

The consumption of charcoal with the traditional stove is also significantly low with only 509 grams. This result is explained by the fact that charcoal has a much higher calorific content than the other biomass fuels.

To further examine the fuel consumption's implication, the graph below compares the cost of the fuel used for the specific cooking task (prices taken from the summary table of fuels in section 2.2).

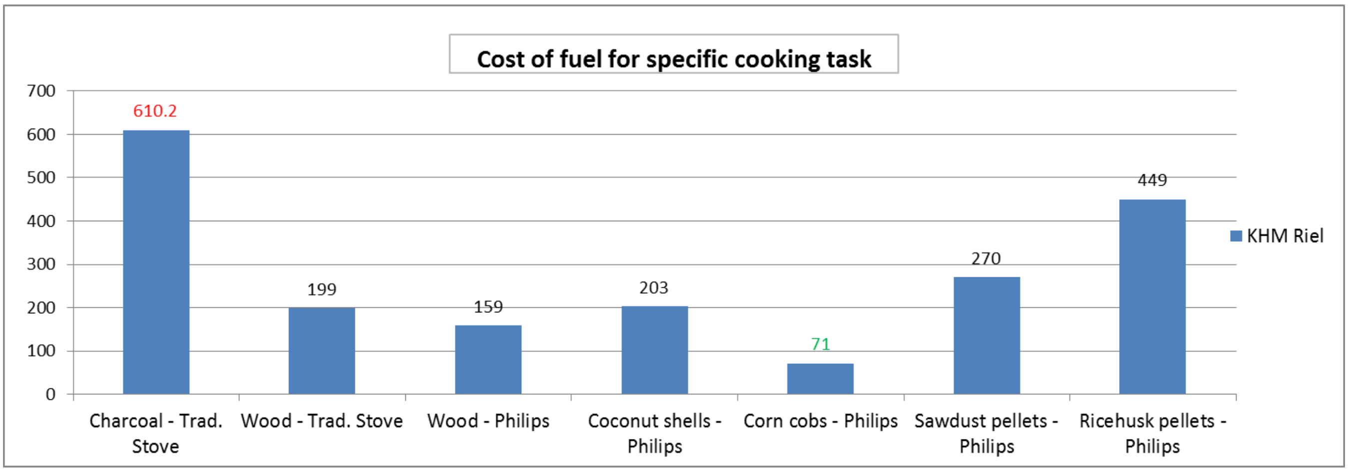

Figure 20 – CCT – Cost of fuel for specific cooking task

This graph shows that even though the charcoal consumption had been relatively low, the cost of the fuel puts it at the first place (1,200 Riel/kg) and also the price for sawdust pellets, despite the extremely low consumption, raises it in third place in terms of cost, after charcoal and rice husk pellets. Wood with the traditional stove and coconut shells with the Philips stove, show about the same cost related to fuel consumption, while the Philips stove enables to save up to almost 25% of the fuel cost for commercial wood and over 50% considering the utilization of corn cobs.

5.3. Qualitative feedback from the cooks performing the CCT

At first look, all three cooks really liked the stove for its modern and "stylish" design. They all liked as well cooking with the stove, appreciating the light weight, its handiness and they appreciated the easy maintenance (easy cleaning of the outer stainless steel cover, making it always look new and shiny).

All three cooks usually cook on the traditional stove using wood (commercial or also collected around their house). However they relatively quickly understood and mastered the use of the Philips stove in terms of loading of the fuel and use of the knob to regulate the power.

The main characteristic that surprised the cooks is the variety of fuel which can be used with the Philips stove. After the termination of the tests, the cooks were asked to rank their preferred fuels.

Position	Cook 1	Cook 2	Cook 3
1.	Sawdust pellets	Wood (Philips)	Corncobs
2.	Rice-husk pellets	Wood (trad. stove)	Coconut shells
3.	Coconut shells	Corncobs	Wood (Philips)
4.	Charcoal (trad. stove)	Sawdust pellets	Sawdust pellets
5.	Wood (Philips)	Rice-husk pellets	Rice-husk pellets
6.	Corn cobs	Charcoal (trad. stove)	Wood (trad. stove)
7.	Wood (trad. stove)	Coconut shells	Charcoal (trad. stove)

Cook 1 said that she liked the pellets best, despite the longer and more difficult starting time, since she assumes that these are better for her health. In fact, she puts the traditional stove with wood at the last

place, since she doesn't like the smoke that it makes and she is worried for her health. However, she is not sure about the price of the pellets (she doesn't know the price), which could make her change idea. Right after the pellets she mentions the coconut shells and the charcoal, which she appreciates, because she defines them as "high power" fuels. Regarding coconut shells, she believes it is a good fuel also because it might be easy and cheap to find.

Cook 2 prefers to cook on wood, at first place with Philips stove and at second place with traditional cookstove. She is used to cook on wood and in general likes fuels that are easy and quick to start. For the same reason she states corncobs at third place, valuing the fact that it ignites quickly and enables her to start cooking right away. She also thought that coconut shells make more smoke than the other fuels which might depend on the moisture content of the coconut shells). At last she stated that she is very price sensitive in her choice of fuel.

Cook 3 puts corncobs at first place, because she said it reminds her of cooking with gas (LPG). She also values significantly the speed and simplicity to ignite and start cooking with them. In addition, cook 3 is also price sensitive in her choice of fuel and believes that corncobs might be the cheapest/easiest to find (eventually for free) and for the same reason, lists coconut shells at second place. However, she liked the Philips stove so much that in the last two places she has mentioned the fuels with the traditional stove, even though they might be cheaper than other fuels as for example pellets.

All three thought that the reference price of 70 USD for the Philips stove was out of reach for their financial possibilities. They believed that if the Philips stove had the same price as traditional stoves (3-4 USD), everybody in Cambodia would buy them. However, cook 1 stated that she would pay up to 5 USD for the Philips stove, cook 2 would spend up to 10 USD and cook number 3 would eventually be able to pay up to 15 USD. It has to be mentioned though, that all three cooks come from the poorest segments of the population.

Figure 14 – The 3 cooks that have performed the CCTs with the Philips stove

6. Conclusions

Overall, during all tests (qualitative, WBT and CCT) the Philips stove has confirmed its higher performances compared to traditional stoves, in terms of shorter cooking time and reduced fuel consumption. In addition, the stove is appealing from the design point of view, it is very practical to use (light weight, it doesn't get hot on the outskirt) and has functional handles. The stove also enables to regulate the flame through the power of the fan, which enables to perform more accurately different cooking tasks. Most importantly, the stove is very easy to use, and the testers and the cooks who used it learned very quickly to use it efficiently.

As a first feedback, the local population really likes the stove and appreciates using it, but it is concerned about the price. In fact, the price of the Philips stove is over 20 times more expensive, compared to the most successful improved cookstove available in Cambodia (price about 3-4 USD).

The characteristic most appreciated about the stove, seems to be its versatility in being able to function with different fuels. As a matter of fact, the stove was tested with 13 different types of fuel (15 including the two types of rice husk and two types of coconut husk). The stove was able to operate practically with all of them.

The versatility of the stove to operate with different types of fuel could be its main feature in marketing the stove. Depending on the geographical area, urban or rural areas (where in rural areas, there might also might be different availability of different agricultural residues) and on the livelihood of the target customers (poor, middle and high class), the users will be able to adopt their preferred fuel (in terms of functionality and price).

Commercial wood and natural wood are already widely available in Cambodia and can be used with the Philips stove, undergoing some basic cutting/shortening process, which the end-user can do by itself. The other types of fuel tested are today not in commerce as cooking fuel and end-users should somehow supply them autonomously.

Considerations for new cooking fuel potentials, to be commercialized along with the Philips stove are the following:

- **Rice husk and sawdust/wood pellets**: these fuels work very well with the cookstove, but are the only ones not available in Cambodia. The setting up of a new production facility only for the Philips stove seems costly and risky. Instead they could be imported from neighboring Vietnam, but the price range would be relatively high compared to other types of fuel locally available.

- **Commercial wood:** to fit in the Philips stove, the firewood which today can be purchased in Cambodia is too long and needs to be further cut. This can be done directly by the end-user, but could also be processed before commercialization, as for example cutting or chipping. However, given the uncertain provenience of the wood (there is no wood tracking or certification in Cambodia), the use of firewood for the Philips stove may implicate environmental concerns.

- **Coconut-shells:** coconut-shells is a type of fuel which would be innovative in the cooking sector in Cambodia. The coconuts need to be crushed before being used in the Philips stove. SGFE could be a potential actor in commercializing crushed coconut shells, as well as other actors could easily enter the market if a demand is proven.

- **Corn-cobs:** the commercialization of corncobs as cooking fuel for the Philips stove seems the cheapest and easiest short term solution. It doesn't require any preprocessing and it would need only the establishing of the new supply chain and distribution network (introduction of intermediaries).

- **Bamboo:** bamboo has also a great potential to be developed as an efficient fuel for the Philips stove. Bamboo is a fast growing species, widely available in Cambodia, which means it would potentially represent a vast feedstock for the utilization in a developed Philips stove market. However bamboo needs some preprocessing, as chipping and drying.

In conclusion, in a first pilot commercialization of the Philips stove, two types of fuel could easily be commercialized along with the stove: the corn cobs and the coconut shells. Communication and marketing of the stove should highlight the incredible versatility of the stove to function with different types of fuel, so that potential customers could actually test and choose their own preferred fuel. In addition to the already available fuels as wood, the two new fuels would surely emphasize the good performance of the stove and could be commercialized with very little investment along with the stove. A taking up of the Philips stove by consumers could in a second moment suggest higher investments in alternative fuels as bamboo first and then eventually pellets, when the market is already mature.

7. ANNEX

7.1. ACTIVITIES REPORT

A. Identification, analysis and supply of available fuel (week 1)

SGFE's staff identified evaluated and supplied up to 12 types of potential fuels. The types of fuel include conventional fuels, already available in shops and markets, and "experimental" fuels. All fuel types have been purchased/collected and stored at SGFE's premises.

B. Qualitative preliminary testing (week 2)

SGFE hired 2 chemical engineers, graduated from the Institute of Technology of Cambodia (ITC). Their responsibilities included the implementation of all testing activities (the qualitative testing, the water boiling tests and supervision of the controlled cooking tests) and the data collection and elaboration in excel format.

During the preliminary testing, the testers became familiar with the operation of the stove, and tested qualitatively and noted the efficacy of all different types of fuel which have been identified (13 types of fuel). At the same time, all testing equipment and tools have been defined and purchased (scales, thermometers, pots, pans, gloves, etc.). At the end of the preliminary testing phase, a selection of 9 fuel types were made, which were then used in the following testing phase (WBT).

C. Water Boiling Test (week 3/week 4)

WBTs were performed for 9 types of fuels (7 with the new Philips Stove and 2 with a traditional Cambodian stove). For each fuel, the WBT has been performed 3 times, for a total of 27 tests. The tests have been performed in a controlled environment (indoor) and all data have been recorded on excel sheets. The present report describes the aggregated results in form of mean and average and standard deviation. At the end of the WBT phase, a selection of 7 fuel types were made, which were used in the following testing phase (CCT).

D. Controlled Cooking Test (week 4/week 5)

For the Controlled Cooking Test, 3 Cambodian women were hired to perform a typical cooking task to be repeated on the Philips stove with 5 different types of fuel and on a traditional stove with the most common Cambodian cooking fuels (firewood and charcoal). Tests were conducted in a semi-open environment (out-door, with 2 walls protecting from excessive wind), which represented a common environment for Cambodians to cook in. In addition to the analytical data, during the WBTs qualitative information from the cooks was collected, evaluating the new Philips Stove.

E. Results Reporting (week 5/week 6)

Collection, analysis and reporting of the results were performed throughout the entire duration of the project and have been included in the present report.

activities\weeks	W1	W2	W3	W4	W5	W6
A.	■					
B.		■				
C.			■	■		
D.					■	
E.	■	■	■	■	■	■

18th of December 2013

SMART DEVELOPMENT WORKS

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