

## **Zamorano Improved Stove Certification Center: Evaluation of seven improved efficiency stoves in the laboratory and local communities**

Although improved efficiency firewood stoves have been promoted over the last 35 years, there is still a great need to evaluate these efforts in Central America. Local and national governments, with international cooperation, have continued to implement projects to substitute traditional wood burning stoves even though it has not significantly reduced deforestation nor the respiratory diseases of rural families. This is largely due to the diversity of stoves that have been constructed based on ecological criteria but without solid technical criteria, for example the dimensional variability of the combustion chambers, the height of the chimneys, the use of ash, and other aspects which directly affect the stoves' performance if these factors are not controlled. To date there is no organization that regulates or controls the quality of the stoves constructed nor that certifies that the stoves performance meets their original objectives. Therefore it is important to standardize construction materials, design specifications and environmental performance of the various stove models to help insure the intended reduction of environmental impact with the replacement of the traditional stoves. Additionally, this will help insure that the model of stove selected is the most appropriate for the conditions of the area where it is installed.

This phase of the project consisted in the establishment of the Improved Stove Certification Center at Zamorano University to achieve the following objectives:

- Evaluate heating efficiency by type of fuel and pollution production of five of the most commonly used improved stoves, and a normal stove in campus.
- Test the same stoves' efficiency and pollution production within households at Yeguaré Valley.
- Create a certification standard on stove construction materials, to be used for projects and direct sales in Guatemala, El Salvador, Honduras and Nicaragua.

To accomplish these goals, within the framework Improved Stove Certification Center, financed by the TPW Energy Collaborative, seven improved efficiency firewood stoves were evaluated. The stoves evaluated were: Justa (Honduras), Justa 2 x 3 (Honduras), Onil (Guatemala), Ecofogón (Nicaragua, Brazil, Honduras), (5) Malena (Bolivia), Incawasi (Peru) and Patsari (Mexico). These stoves are the most common throughout Central and South America. In total eleven stoves were installed during this phase of the project: one of each of the stove models was built in the certification center and four stoves were installed in houses in the nearby communities. Household selection for participation in the project was based on their current use of a traditional stove, limited economic resources, and their willingness to participate in the project and help with the stove evaluation for one year.

For the stove evaluation the Water Boiling Test (WBT), the Controlled Cooking Test (CCT) protocols were utilized along with a Portable Emission Measurement System (PEMS) to measure the Carbon monoxide (CO), Carbon Dioxide, (CO<sub>2</sub>), and Particulate Matter (PM). Additionally, an Indoor Air Pollution Meter (IAP) was used to monitor cooks the exposure to CO and PM in the laboratory. In the local households the Kitchen Performance Test (KPT) was employed as was the CCT and exposure was measured with the IAP.

# 1. RESULTS

## Laboratory Results

### 1.1.1 Water Boiling Test (WBT)

**Table x. Comparison of seven improved efficiency fuel wood stoves during the Water Boiling Test.**

Indicadores	Unit	1	2	3	4	5	6	7
		Justa Tradicional	Justa 2 x 3 Proyecto Mirador	Onil	Ecofogón	Inkawasi	Patsari	Malena
Fuel to Cook 5L (850/1500)	g	3176.0	2962.2	3291.8	3033.5	1860.0	5092.5	3874.1
CO to Cook 5L (20)	g	56.5	37.8	28.6	38.1	21.7	252.3	42.0
PM to Cook 5L (1500)	mg	8270.7	5656.5	2377.3	4297.2	4228.1	34236.3	7550.0
Energy to Cook 5L (15,000/25,000)	kJ	58,483	54,546	60,616	55,860	34,249	93,773	71,338
Time to Boil	min	57.1	54.2	50.7	79.5	54.2	39.7	60.0
CO2 to Cook 5L	g	4488.7	3745.3	4207.8	4324.9	2444.5	3262.5	3669.7

### 1.1.2 Contaminación de Aire de Interiores (IAP)

During the WBT and CCT exposure to indoor air pollution, CO and PM were measured using the IAP. Each of the laboratory kitchens has similar ventilation thus influences caused by wind should be minimal when comparing across stove models.

#### 1.1.2.1 Particulate matter (PM)

Particulate matter is defined as the presence of solids in the air either naturally or generated by human activities. Depending on their size they can be highly hazardous to human health given that small particles can enter the lungs, reducing respiratory performance.

Taking into consideration the 1997 EPA National Air quality standards, and the results of the CCT, it was determined that five of the stoves fell within the allowed range of exposures. The following table presents the results.

**Tabla N° 3. Results of PM by model of stove.**

MODELO	PM ( $\mu\text{g}/\text{m}^3$ )	Time of exposure (min)	Exposure limit ( $\mu\text{g}/\text{m}^3$ ) (PM10)	Time of exposure for limit (hours)	Evaluation
Justa Tradicional	114	60 min	150	24	Within limits
Justa 2x3	77	44 min			Within limits
Ecofogón	76	1:14 min			Within limits
Onil	53	44 min			Within limits
Inkawasi	182	45 min			Exceeds limits

MODELO	PM ( $\mu\text{g}/\text{m}^3$ )	Time of exposure (min)	Exposure limit ( $\mu\text{g}/\text{m}^3$ ) (PM10)	Time of exposure for limit (hours)	Evaluation
<b>Patsari</b>	40	39 min			Within limits
<b>Malena</b>	1,932	52 min			Exceeds limits

**Fuente:** Reglamento para el control de emisiones generadas por fuentes fijas.

It should be noted that the stove models that exceeded the exposure limits, that is the Inkahuasi y Malena, are stoves designed for direct fire contact and there is no metal plate used for heat transfer. Because of this, particulate matter exposure is higher.

### Carbon monoxide (CO)

Carbon monoxide is a gas produced by incomplete combustion of substances such as gasoline, charcoal, kerosene, petroleum, or in this case wood. In terms of human health, the danger of breathing elevated concentrations of CO is that the CO replaces oxygen in the hemoglobin of the blood causing serious complications, which could include death.

Taking into consideration the 1997 EPA National Air quality standards in regards to CO exposure levels, and the results of the CCT, all stove models were evaluated for CO exposure. The following table presents the results.

**Tabla N° 4** Results of the CO exposure according to stove model.

MODELO	Results			Exposure limit ( $\mu\text{g}/\text{m}^3$ )	Time of exposure for limit	Evaluation
	CO (ppm)	CO ( $\mu\text{g}/\text{m}^3$ )	Exposure time			
<b>Justa Tradicional</b>	0.2	229.8	60 min	30,000	1 hour	Within limits
<b>Justa 2x3</b>	0.2	229.8	44 min	30,000	1 hour	Within limits
<b>Ecofogón</b>	0.1	114.9	1:14 min	10,000	8 hours	Within limits
<b>Onil</b>	0.4	459.7	44 min	30,000	1 hour	Within limits
<b>Inkahuasi</b>	2.2	2528.4	45 min	30,000	1 hour	Within limits
<b>Patsari</b>	0.3	344.7	39 min	30,000	1 hour	Within limits
<b>Malena</b>	1.5	1723.9	52 min	30,000	1 hour	Within limits

**Fuente:** EPA, 1997. National Ambient Air Quality Standards for Particulate Matter: Final rule

According to the results, all of the stove models were within the allowable limits of CO exposure although the Inkahuasi had the highest levels which suggest incomplete combustion. In the case of the Ecofogon, the exposure limit was based on exposure levels of more than one hour.

## Results in the Communities

### 1.2.1 Kitchen Performance Test (KPT) with the traditional Justa

### 1.2.1.1 General Information

Prior to installing the stove in the household, the user had the opportunity to view the stove in the Improved Stove Certification Center. With this experience she decided to participate in the program and the stove was installed in her home.



Figure 9 Traditional Stove

Figure 10 Traditional Justa Stove

Before completing the KPT evaluation the cook had a three month adjustment period to become familiar to the stove, typically preparing food for six people. During the first 15 days of use the user expressed her complete acceptance of the stove. In terms of daily use and maintenance, the user reported that she was complying with the instructions given during the stoves installation. Additionally the projects technical personnel conducted periodic inspections to insure that the stove was performing correctly.

Table N° 5. Family members

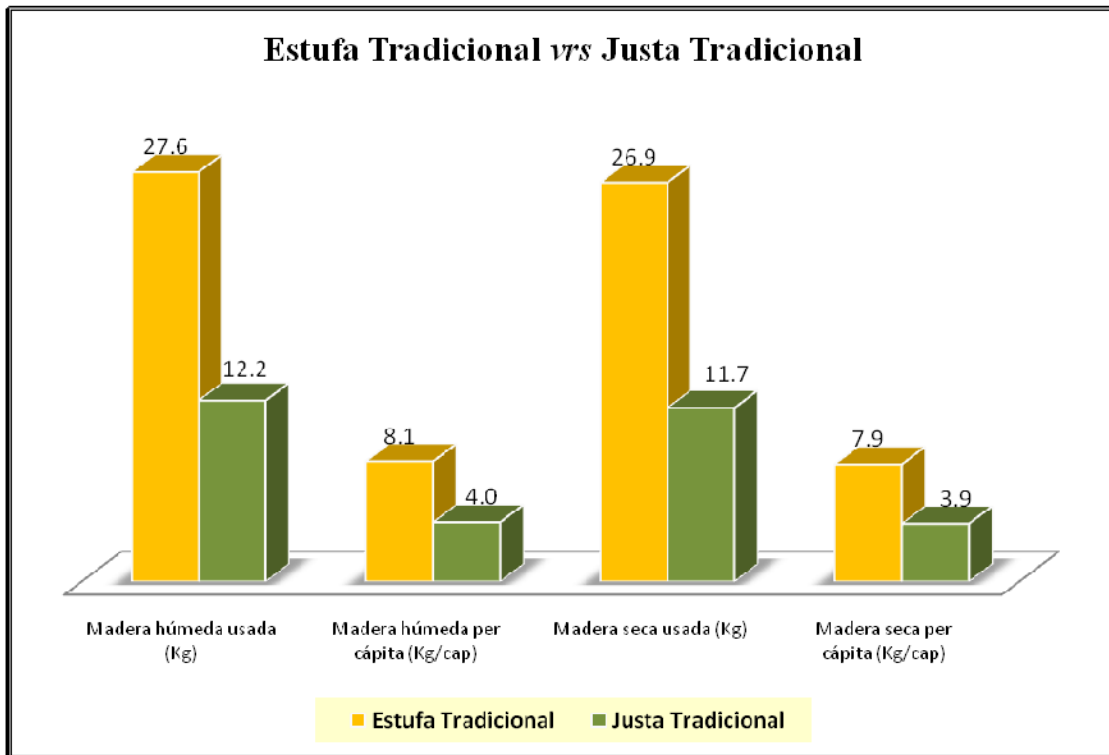
Criteria	Number of people
Children 0-14 years	2
Women > 14 years	3
Men 15-59 years	1
Total	6

### 1.2.1.2 Cook Characteristics

The user is a female adult, 33 years old, slender build, with a very low formal education level; she can neither read nor write. Her blood pressure was 123/74, and a pulse of 76 bpm, and a normal lung capacity. Neither she nor members of her family had symptoms of respiratory illness. In general terms, her health is satisfactory.

### 1.2.1.3 Results of the Kitchen Performance Test (KPT) in the Traditional Justa

In accordance to the methodology, the KPT evaluation was conducted during a consecutive three day time period utilizing carbon (*Mimosa tenuiflora*) as the principal source of fuel wood during the measurements. The weather was relatively normal with light rain and low temperatures. The principal results if the KPT follow:



**Graphic N° 15** Comparative results between the traditional stove and the Traditional Justa.

Similarly, below are the results of the energy used.

**Table N° 6** Comparative results between the traditional stove and the Traditional Justa

Criteria	Traditional Stove		Traditional Justa	
	Average	Stand. Dev.	Average	Stand. Dev.
Energy used (MJ)	442.3	297.1	195.6	54.9
Energy per capita (MJ/cap)	129.3	86.9	64.5	18.1

**Source:** Household data collected during the KPT protocol.

Based on these results, the following observations can be made:

- There was a reduction of 15.4 kg of fuel wood use per day, or a monthly saving of 462 kg, which represents a 55.8% reduction of fuel use compared with the traditional stove.
- On the other hand, the daily savings per person is 4.1 kg, representing a monthly reduction of 123 kg, or a reduction of 50.6% compared to the traditional stove.
- Similarly, the energy used was reduced significantly, indicating that the combustion chamber of the Justa Traditional is more efficient.

### 1.2.2 Kitchen Performance Test (KPT) of the Justa 2x3

### 1.2.2.1 General Information

Prior to installing the stove in the household, the user had the opportunity to view the stove in the Improved Stove Certification Center. With this experience she decided to participate in the program and the stove was installed in her home.



Before completing the KPT evaluation the cook had a three month adjustment period to become familiar to the stove, typically preparing food for six people. During the first 15 days of use the user expressed her complete acceptance of the stove. In terms of daily use and maintenance, the user reported that she was complying with the instructions given during the stoves installation. Additionally the projects technical personnel conducted periodic inspections to insure that the stove was performing correctly.

**Tabla N° 7. Family members**

Criteria	Number of people
Children 0-14 years	2
Women > 14 years	3
Men 15-59 years	1
Total	6

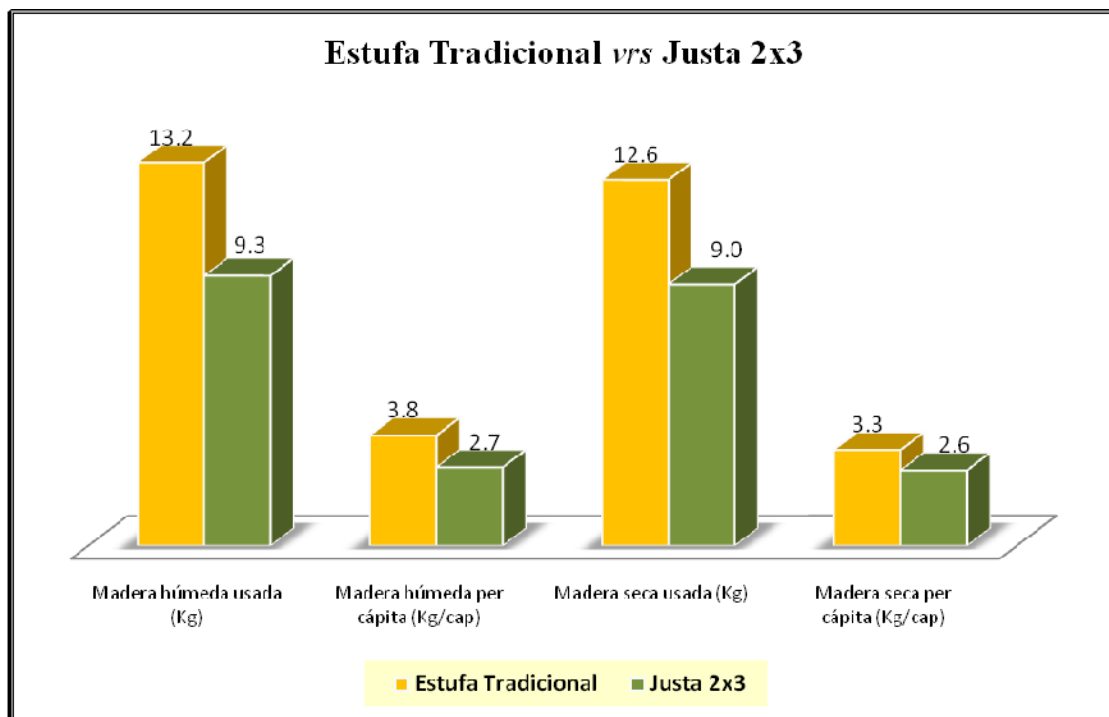
### 1.2.2.2 Cook Characteristics

The user is a female adult, 22 years old, slender build, she completed elementary school. Her blood pressure was 115/76, and a pulse of 72 bpm, and a normal lung capacity. In terms of respiratory illness, one adult member of the household has a cough and a 2 year old child regularly has a cold and cough.

### 1.2.2.3 Results of the Kitchen Performance Test (KPT) in the Justa 2x3

In accordance to the methodology, the KPT evaluation was conducted during a consecutive three day time period utilizing carbon (*Mimosa tenuiflora*) as the principal

source of fuel wood during the measurements. The weather was relatively normal with light rain and low temperatures. The comparative results if the KPT between a Traditional stove and the Justa 2x3 follow:



**Graphic N° 16** Comparative results between the traditional stove and the Justa 2x3

Similarly, below are the results of the energy used.

**Table N° 8** Comparative results between the traditional stove and the Justa 2x3

Critería	Traditional Stove		Justa 2x3	
	Average	Stand. Dev.	Average	Stand. Dev.
<b>Energy used (mj)</b>	210.5	42.4	149.5	32.2
<b>Energy per cápita (mj/cap)</b>	61.5	12.4	43.7	9.4

**Source:** Household data collected during the KPT protocol.

Based on these results, the following observations can be made:

- There was a reduction of 3.9 kg of fuel wood use per day, or a monthly saving of 117 kg, which represents a 70.4% reduction of fuel use compared with the traditional stove.
- On the other hand, the daily savings per person is 1.1 kg, representing a monthly reduction of 33 kg.
- Similarly, the energy used was reduced significantly, indicating that the combustion chamber of the Justa 2x3 is more efficient.

### 1.2.3 Kitchen Performance Test (KPT) with the Onil

### 1.2.3.1 General Information

Prior to installing the stove in the household, the user had the opportunity to view the stove in the Improved Stove Certification Center. She was concerned that the base made from cinder blocks didn't appear safe thus the base was modified with cemented adobe blocks, the rest of the design (stove) is identical to the laboratory model.



Figure 13 Traditional Stove



Figure 14 Onil Stove

Before completing the KPT evaluation the cook had a two month adjustment period to become familiar to the stove, typically preparing food for six people. During the first 15 days of use the user expressed her complete acceptance of the stove. In terms of daily use and maintenance, the user reported that she was complying with the instructions given during the stoves installation. Additionally the projects technical personnel conducted periodic inspections to insure that the stove was performing correctly.

Table N° 9. Family Members

Criteria	Number of people
Children 0-14 years	4
Women > 14 years	1
Men 15-59 years	1
Total	6

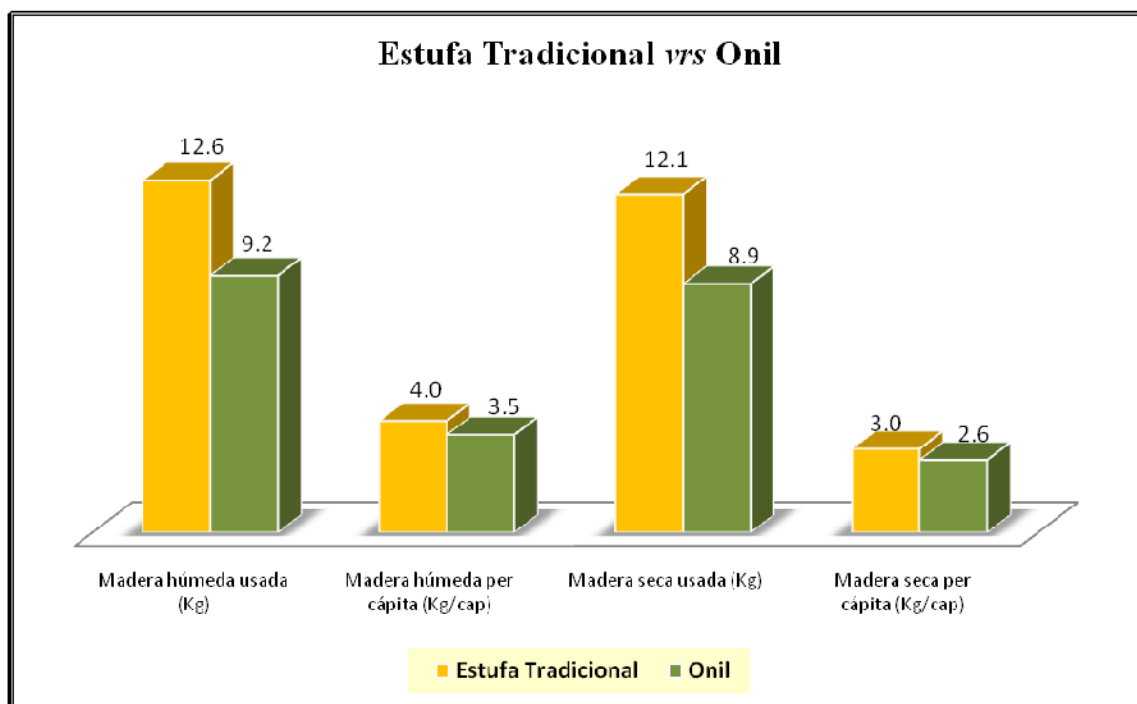
### 1.2.3.2 Cook Characteristics

The user is a female adult, 30 years old, slender build, she completed elementary school. Her blood pressure was 113/72, and a pulse of 71 bpm, and a normal lung capacity. In terms of respiratory illness, the children have a cold and cough about every five months.

### 1.2.3.3 Results of the Kitchen Performance Test (KPT)

In accordance to the methodology, the KPT evaluation was conducted during a consecutive three day time period utilizing carbon (*Mimosa tenuiflora*) as the principal source of fuel wood during the measurements. The weather was relatively normal with

light rain and low temperatures. The comparative results of the KPT between a Traditional stove and the Onil follow:



**Graphic N° 17** Comparative results between the traditional stove and the Onil

Similarly, below are the results of the energy used.

**Table N° 10** Comparative results between the traditional stove and the Onil

Criteria	Traditional Stove		Onil	
	Average	Stand. Dev.	Average	Stand. Dev.
<b>Energy used (MJ)</b>	201.4	51.0	146.5	44.7
<b>Energy per cápita (MJ/cap)</b>	64.2	16.3	55.5	16.9

Source: Household data collected during the KPT protocol.

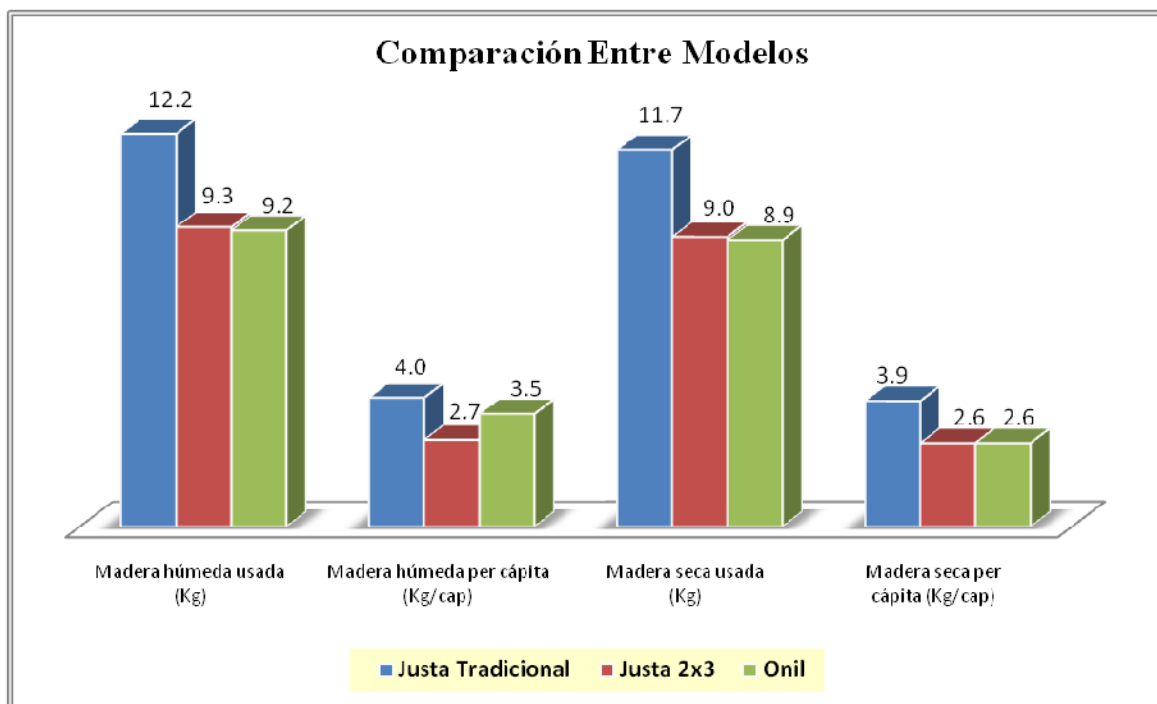
Based on these results, the following observations can be made:

- There was a reduction of 3.4 kg of fuel wood use per day, or a monthly saving of 102 kg, which represents a 73.01% reduction of fuel use compared with the traditional stove.
- On the other hand, the daily savings per person is 0.5 kg, representing a monthly reduction of 15 kg.
- Similarly, the energy used was reduced significantly, indicating that the combustion chamber of the Onil is more efficient.

#### 1.2.4 Comparison between the Traditional Justa, Justa 2 x 3 and Onil

The following presents the comparative results between the different stove models during the KPT. The parameters compared are the amount of humid and dry used daily as well as the energy used during the process.

It is important to note that during the different evaluations of the KPT there are variables that cannot be controlled such as the weather, the person operating the stove, the type of food being prepared, cooking habits, etc. However, it is hoped that these factors have not significantly affected the below results:



**Graphic N° 18** Comparative results between the Traditional Justa, Justa 2x3 and Onil

**Table N°** Comparative results between the Traditional Justa, Justa 2x3 and Onil

Criteria	Traditional Justa	Justa 2x3	Onil
<b>Energy used (mj)</b>	195.6	149.5	146.5
<b>Energy per capita (mj/cap)</b>	64.5	43.7	55.5

Based on these results, the following observations can be made:

- The Traditional Justa consumed the greatest amount of both humid and dry wood, which is directly related to the energy utilized. In general terms, this model is not as efficient as the other models.
- The Justa 2x3 and the Onil performed with very similar results, with the exception that the Justa 2x3 consumed 0.8 kg less humid wood per capita than the Onil.

## 1.2.5 Stove acceptance

### 1.2.5.1 Traditional Justa

During the first week of use the cook reported that she had to wake up a half hour earlier in the mornings to prepare food for her husband because the new model took more time to heat up than the traditional model.



**Figura 15.** Estufa Tradicional

During the following weeks the cook reported that the reduction of fire wood use was significant and now she had to only go to the mountain once a week to collect fire wood whereas before she had to go every other day. Additionally, she reported that the design of the Traditional Justa eliminates the need to blow directly on the embers to get the fire to ignite again.

Currently, the cook has her complete acceptance of the new model and at the same time expressed her gratefulness to the Project for allowing her the opportunity to own a Traditional Justa.

#### **1.2.5.2 Justa 2x3**

Prior to the installation of the new stove in the household the cook reported that she had seen this model in operation in a different part of the country and that she liked how it performed.

Therefore, from the beginning of the Justa 2x3 stove installation in the household, the cook anticipated the stove's reduction in fuel consumption and time in preparing foods.

Currently the cook has improved the cooking area, including the building of walls, repairing the floor and the installation of a new roof.

#### **1.2.5.3 Onil**

Similar to the other models during the first days of use the cook had difficulty starting the stove in the mornings, plus the tortillas stuck to the metal plate or burned.

Later, after time to become familiar with the stove, the cook commented that it no longer was difficult to start the stove and that the tortillas no longer were sticking, and even more, she reported that the stove heated too quickly and due to that she had to hurry more to finish grinding the corn in time.

Additionally, her original traditional stove radiated heat to the point of almost suffocating her during the hottest hours of the day. Now, with her using the Onil stove, this is no longer an issue even though the tin roof contributes to the heat of the kitchen. The stove is currently operating normally.

#### **1.2.5.4 Ecofogón**

Initially, the cook commented that the stove appeared nice and easy to use. However, during the first days of use she reported that it took a lot of work to ignite the stove and even longer to prepare the meals compared to her previous traditional stove. For these reasons, and because the stove was located outside of the House, the Zamorano technicians determined that the wind was probably a contributing factor to the inefficiency of the stove and recommended moving the stove inside or building a structure to protect the stove. However, the user was not able to comply with the recommendations because her husband did not agree.

Currently, the cook has rejected the stove and continues using the traditional stove, plus her husband purchased an electric stove. The eco-fogon will be installed in another location for evaluation.

## **2. CONCLUSIONS**

- During the evaluations in the local communities as well as the laboratory, it was obvious that the way that the user cooks can drastically influence the results of the evaluation, especially in the fuel wood consumption.
- The weather conditions of the season influence the humidity of the fuel wood used in the households, which influence the consumption due to the humidity's influence on combustion.
- The Kitchen Performance Test (KPT) is a useful and valuable tool in evaluating the monthly fuel wood consumption in the households. This is largely due to the fact that there are no external influences on the normal use of the stove when compared to the Controlled Cooking Test (CCT).
- The local diets and customs of the influence the type of models that can be installed in the local communities, illustrated by the fact that in the Yeguaré valley the cooks all rejected the installation of the Inkahuasi, Malena and Patsari models. This is largely due to the fact that these stoves do not have a metal plate to cook traditional foods.
- The savings of fuel wood consumption in the households were 55.8% with the Traditional Justa Tradicional, 70.4% with the Justa 2x3 and 73.1% with the Onil.

## **3. RECOMENDACIONES**

- Realize a greater number of evaluations in more households as well as the laboratory to reduce average influence of the variability caused due to user behaviors.
- To achieve a greater precision in the estimation of the monthly consumption of fuels during the Kitchen Performance Test (KPT) we recommend extending the test period from three to five days.
- Due to the influence of fuel wood humidity on the stove performance we recommend evaluating the influence of varying moisture contents on fuel consumption and emissions.
- Prior to installing stoves in a household, the cook should be offered an opportunity to use the stove to better insure acceptance.
- To better estimate the efficiency of the stoves a larger sample of households should be evaluated using the KPT.