Performance Evaluation of Traditional and Improved Biomass Cookstoves in Rural Guatemala

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This study aims to determine the energy needs of families living in rural Guatemala. It was conducted using *Community Based Participatory Research* -CBPR-. It gives a detailed analysis of the thermal energy efficiencies of different traditional and improved cooktoves based on the Water Boiling Test V4.2.3 -WBT- and the Controlled Cooking Test V2.0.-CCT-. It also includes an analysis of household air pollution exposure to women by using a low-cost real time cloud based air quality monitor. The study was conducted in the department of Chiquimula, where 492 people were involved, from 10 communities. It was found that 100% the families in the department use biomass cookstoves, even when some had access to LPG. The efficiency of traditional cookstoves was found to be in the range of 15% or below. Rocket-type stoves such as Berkeley and Envirofit gave the best efficiency results with values up to 35% for the cold/hot start of the WBT for the ignition phases and between 20-25% for the simmering phase. The indoor air quality tests displayed alarming levels both for PM2.5 and VOC concentrations, with concentrations reaching 2 order magnitude above the recommended level during the ignition phase and between 200-400 $\mu g/m^3$ during the remaining cooking process. It was also found that the culture does play a determinant role in the selecting cooking technology, and that better efficiency and pollution reduction are not sufficient condition to replace the traditional technologies.

Introduction

Humanity has never seen such a fast economic growth as in the last 200 years. Parallel to this, the advances in medicine, agriculture and technology allowed the population to grow from less than 2 billion in 1900, to 7.7 billion in 2019 (Roser, Ritchie, & Ortiz-Ospina, 2019). The cost of such development based on non-renewable resources and the unsustainable exploitation of natural resources is the environmental disaster happening right now. Mass extinction, desertification, resource depletion, displaced population, among others, to the extent of putting the survival of our on species to risk.

The economic and political systems that made this growth happen have also created an inequality with no precedents, not only in economic and life quality terms, but also in environmental vulnerability.

Those whom have contributed the least to climate change are not only the most affected, but also the most vulnerable (Kreft, Eckstein, Dorsch, & Fischer, 2015). Hence it is imperative to change the way in which we produce and consume, replace the energy with which we fuel our economy, and eliminate inequality. Only then the *Universal Declaration of Human Rights* will be a reality.

Fossil fuels are not the only problem, poverty also forces people to rely on low efficiency technologies which have significant harmful effects, both for the environment and the people themselves. Something as basic as cooking can have large effects when done in low efficiency technologies.

Guatemala is a country severely affected due to low-efficiency cooking technologies. The majority of its population relies on biomass for cooking, something to be expected as 60% of its population lives under the poverty line (Instituto Nacional de Estadística -INE-, 2014). It is also one of the countries most affected by climate change. During the period 1996-2015 Guatemala was ranked in the list of countries at highest risk to climate change (Eckstein, Künzel, & Schäfer, 2017).

This study aims to lay the groundwork of satisfying the need for clean, reliable, sustainable, affordable and culturally accepted energy for people living in poverty all over the world, starting in Guatemala. The investigation discusses about traditional biomass cooking technologies, their efficiencies, the meals that constitute the diet and their ways of preparing them; and a technical and cultural evaluation of the feasibility of replacing such technologies with top-tier cookstoves available in the market, both nationally and internationally.

World situation

Globally biomass energy accounts for nearly 9% of the world's total primary energy supply (IEA, 2017). More than half (nearly 55%) of this energy is being used in traditional technologies, such as low efficiency cookstoves (IEA, 2017). Figure 1 shows the share of biomass energy used by different sectors.

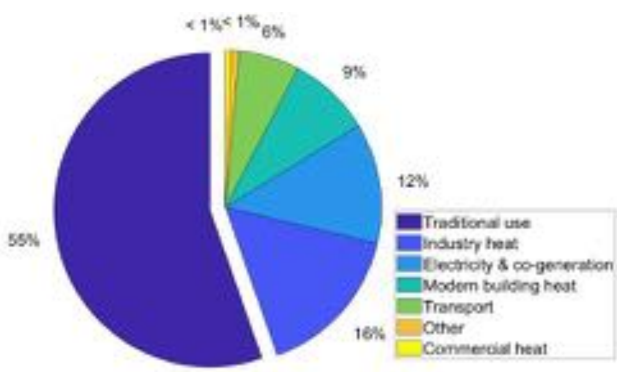

Figure 1. Biomass and waste resources consumption by end use (IEA, 2017)

It has been estimated that around 2.8 billion people still do not have access to clean cooking technologies and nearly 2.5 billion people (one third of the world's population) will continue to use solid biomass fuels for cooking (Daly & Walton, 2017).

In spite of having fast pace of global urbanization, still there are the same number of people (2.8 billion) currently not having access to clean cooking technologies as it was 30 years ago, which could be partly attributed to the global population increase (Puzzolo & Pope, 2017). Under the new policies scenario (International Energy Agency projections), it is expected that the people without clean cooking technologies will decline from 2.8 billion in 2016 to 2.3 billion in 2030 (IEA, 2017). Figure 2 shows population without access to clean cooking technologies by region, 2016 versus 2030 (IEA, 2017).

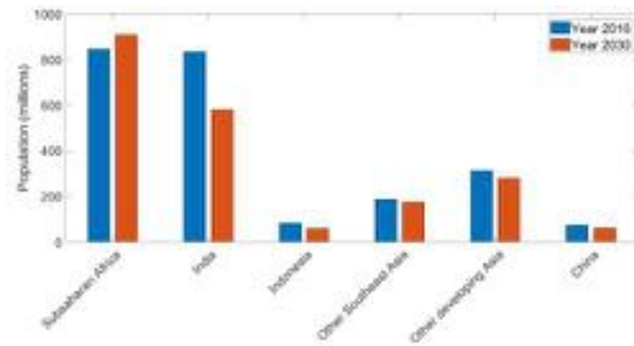

Figure 2. Population without access to clean cooking (IEA, 2017)

Annual carbon footprint of such cooking technologies is equivalent to 1.3-1.7 billion MT of CO2 emissions (Putti, Tsan, Mehta, & Kammila, 2015). It has been estimated by the WHO that indoor pollutants are 1000 times more likely to reach a human's lung as compared to the one released outdoors (Balakrishnan, Mehta, Kumar, & Kumar, 2003). According to Institute for Health Metrics and Evaluation, deaths due to household air pollution accounted to nearly 1.6 million in 2017 of which nearly 51,000 deaths are attributed to the countries of Latin America and Caribbean, of which 4,500 are Guatemalans (*Global Burden of Disease Study*, 2017).

Guatemala situation

The 95% of people living in rural Guatemala rely on biomass as their main source of energy for cooking, drying and heating water (IARNA-URL (Instituto de Agricultura, Recursos Naturales y Ambiente de la Universidad Rafael Landívar), 2012). This leads to an annual consumption of nearly 16 million tons of dry biomass (INAB, IARNA-URL & FAO/GFP, 2012).

Chiquimula is a department of Guatemala with the largest deforestation rate and it continues to increase. Only between the years 2006 - 2010, it lost 25 % of its forest. On top of the environmental crisis, the socio-economic situation is precarious. All municipalities of Chiquimula report a level of malnourishment in infants under 5. The lowest reported are from *Ipala* and *Concepción las Minas* Municipalities with 12.0 and 12.6 % and the ones with the highest are *Olopa* and *Jocotán* with 65.7 and 67.0 % (Sistema de Información Nacional de Seguridad Alimentaria y Nutricional, 2015).

Since deforestation and poverty along with biomass reliance and its negative effects from indoor air pollution are widespread in the department of Chiquimula, finding solutions to the energy needs could have a significant impact in the life quality of the people. Therefore, 10 communities from the Chiquimula were chosen to perform this study.

Traditional cookstoves. The most commonly found traditional cookstoves are: three stove fire (or open fire), poyeton and the iron plate. Here, the three stove fire is also put in the category of "cookstove" for simplicity of comparison.

Open fires (Figure 3) are the simplest way in which biomass can be burned. Usually it is arranged with three stones on which the cooking pots are put.

Figure 3. Open fire stove

Poyeton stoves (Figure 4) are also rather simple constructions of mud on top of which a metallic plate can be put and removed if necessary. Some of them have a chimney attached to it. They can be found in other parts of the world, e.g., India.

Figure 4. Poyeton stove

Iron plate stoves (Figure 5) main characteristic is that on top of the combustion chamber, a metallic plate is put on top of which the cooking pots are placed. Usually, a chimney is adhered at the end of the horizontal combustion chamber.

Figure 5. Iron stove

Methodology

The methodology used for this study was the *Community Based Participatory Research* (Toni, 2014) and it includes detailed field study with the active participation from fields workers, the community members and the researchers. The main objective of the study was to find ways to reduce the firewood consumption by increasing the cookstove efficiency, associated costs both direct and indirect, reduce indoor air pollution and overall improvement in the life quality of people.

Since cooking plays such an important role in the life of these families, a holistic understanding of the situation was necessary. So not only the technical aspects were investigated, such as the firewood consumption per family and efficiency of the traditional cookstoves, but also cooking patterns, importance of the cookstove as a center of the familiar dialogue, gender role in cooking, and other factors that could influence the selection of the cookstove.

Firewood consumption

One key variable was to determine the availability of biomass as an energy resource, and also the energy demand and consumption per capita. And although firewood is widely available, accurate determination of its consumption at any level, be it familiar, regional or national is a challenge. Therefore, three methods were employed and have been discussed below.

The first method was based on extensive literature review of the official publications and satellite mapping. The most complete reference was (INAB, IARNA-URL & FAO/GFP, 2012).

The second method consisted in a mix of surveys and interviews. It started by interviewing 10 families per each community, with a survey of 20 questions, this survey helped to understand the perception of firewood usage and its implication of the family relations, monthly consumption, time or money invested, and the way to obtain it. The questions were designed based on that used by (INAB, IARNA-URL & FAO/GFP, 2012). One of the drawbacks of the survey is that perception does not necessarily reflect reality, therefore a third method based on direct measurement was implemented.

The third method consisted of directly weighing the wood consumption per meal, noting the type of stove, and type and amount of food cooked, for a period of 4 days per family. Each of the involved families which voluntarily participated, was given a workshop in which the method was explained. This method was designed to serve two purposes, improving the accuracy of the measurement and involving the community in the process. It also allowed us to determine the cooking time of the two main family meals, the beans and nixtamal (corn with calcium hydroxide).

Household Air Quality

Since close to 70% of the cases that the national health system receives are due to respiratory related illnesses, it was fundamental to quantify the pollutants produced by the cookstoves. This poses a problem if the economic resources are scarce. In this study, it was desired to test the reliability of two low-cost measuring devices with real-time measuring and cloud storage capacities. This could open the door to a larger scale study on the health impact of indoor air pollution, and thus strategic information to find national scale solutions.

The chosen devices were a *Foobot* and *Air Quality Egg*, and a phone with unlimited data was used to broadcast internet since it was the only reliable connection to internet at the location (set up shown in Figure 6). The monitors were chosen after doing an extensive review of the technical aspects and after a comparison made by (Taylor, 2016). The targeted species were nitrogen oxide, carbon monoxide, volatile organic compounds and PM2.5 concentrations. Both devices had real-time monitoring capacity, with a rated error of less that 5% when compared against a laboratory level Grimm EDM 180 (idem).

The location was determined by the following conditions: a safe place for the monitors, stable electricity and cellular data connection, protection from the rain, real exposure, willingness of the family to troubleshoot the monitors in case of connection loss or other problems.

Figure 6. Foobot (left) and Air Quality Egg (right)

The monitors where installed as explained in the instructions and technical sheets. However, only the Foobot worked as supposed. The readings from the Air Quality Egg were not realistic. After contacting the company, they assured that the behaviour of the readings was wrong and that the monitor was defective. Nevertheless, measurements of VOC, and PM2.5 were taken every 5 minutes for a period of 36 days.

Cookstove efficiency

Two standardized methods to evaluate the performance of the cookstove were used, namely, the Water Boiling Test -WBT- version 4.2.3 and the Controlled Cooking Test -CCT- version 2.0. The first one is designed to determine the energy efficiency under controlled conditions (*Volunteers in Technical Assistance (VITA)*, 1985). The CCT allows to calculate the energy consumption to cook a specific food. It is designed primarily to compare the performance of an improved stove with a traditional stove in a standardized cooking task, usually a traditional meal of the community.

Water Boiling Test. Thermal efficiency is the relationship between the useful energy when heating and evaporating water, with the energy consumed by burning wood or fuel. The first one is designed to evaluate the thermal efficiency, the specific fuel consumption in the stove, and the power.

$$H = \frac{4186 \times W_w(T_f - T_i) + 2260 \times W_v}{f_d \times LHV} \quad (1)$$

where W_w is the mass of the water in the pot, the specific heat of the water (4,186 J/g-°C) and the temperature change (T_f - T_i), the product of the amount of evaporated water from the pot (W_v), and the latent heat of water vapor (2260 J/g). The equivalent of dry wood consumed during each phase of the test (f_d) and the LHV, lower calorific value.

The flame power P [W] is a ratio of the energy of the wood consumed by the stove per unit of time during each phase of the test.

$$P = \frac{f_d \times LHV}{60(t_f - t_i)} \tag{2}$$

where the (t_f - t_i) is the duration of the specific test phase.

Specific fuel consumption (SFC) is the ratio between the the amount of fuel and heated material e.g., grams of fuel to heat 1kg of water. In this case, the specific fuel consumption refers to a measure of the amount of fuel required to bring a liter of water from room temperature up to its local boiling point.

$$SFC = \frac{W_{wf}}{fd} \tag{3}$$

where W_{wf} is the mass of evaporated water.

The WBT consists of three phases, which must be carried out three times per stove:

1. Cold start: the test begins with the stove at room temperature and uses fuel previously weighted, with known humidity percentage. The amount of fuel and time required to boil 5 liters of water in standard 7 liters pots with their respective lid are measured.
2. Hot start: Once the stove has reached a thermal steady state, the fuel is quickly replace by newly weighted fuel and once again, the time and fuel required to bring 5l of water from room temperature up to its boiling point are measured. The purpose is to calculate the impact of the stove's mass and physical properties.
3. Simmering or low-power phase: The remaining fuel from the second hot start plus (if needed) a third package of weighed fuel are used to keep the remaining water as close as possible to the boiling point. If the temperature drops below 6 degrees from the local boiling point. The test must be discarded and repeated. [1]

Controlled Cooking Test. The most important result from CCT is the Specific Fuel Consumption (SFC) of a stove. Mathematically, SFC is expressed (on dry basis) as follows.

$$SFC = \frac{f_d[C_h(H_{Ofw}/H_{Och})]}{Xkg_{beans/maize}} \tag{4}$$

where C_h is the amount of residue in the tray due to the result from combustion of firewood, H_{Ofw} is the enthalpy of red pine wood (20 MJ/kg) and H_{Och} is the enthalpy of ash (28 MJ/kg).

To determine the water content of the firewood a Fluke 117 was used to measure the resistivity of the wood using an array of nails and the humidity tables (James, 1963). This technique is based in the principle that commercial wood hygrometers use. The set up can be seen in Figure 7

Figure 7. Wood moisture measurement

Results

Biomass potential for the department of Chiquimula was approximated around 23 m^3 per hectare for broad-leaf trees and 84.5 m^3 per hectare of conifers (IARNA-URL (Instituto de Agricultura, Recursos Naturales y Ambiente de la Universidad Rafael Landívar), 2012). However, the department has heterogeneous biodiversity, therefore it is recommended to study the forest cover and available area in detail for each community to increase accuracy.

85 families participated in this study, from 10 communities for a total of 492 people surveyed. Based on that, it was found that all the families used firewood for cooking application, 24% did it in combination with propane gas. Only 2 cooked on open fires, while 42 families used iron stoves and the remaining used poyeton type cookstove. It was also found that 81% used at least two type of the aforementioned technologies.

From the surveys of the wood consumption perception, the answer to the question *how long does a wood task last for you?* are depicted as percentages in Figure 8 [2].

[1] For detailed explanation of the phases, the adjustment on local altitude, humidity and room temperature, see *Water Boiling Test version 4.2.3 (for Clean Cookstoves, n.d.)*

[2] This question was modified after validating the survey, the original question was *How much fire wood do you consume per day*

Fuel collection is a physically demanding activity. It is reported that long exposure to carrying biomass loads can cause serious health issues including spinal and head injuries (Advisors, 2013).

From the survey it was found that nearly 70% households collects wood while the remaining purchases it. The acquisition period of firewood varied considerably among families with nearly 20% families collecting it daily.

Firewood consumption and cost

In order to quantify the fuel consumption, firstly, a common measuring unit was needed. Based on experience while visiting rural communities not only on Chiquimula, it was known that the unit used throughout the country is the *tarea*, or "task". It is defined as $1.1m^3$ by the (INAB, IARNA-URL & FAO/GFP, 2012) which is also approximately the volume of the back of a pick up commonly used pick up truck, means of transportation in firewood businesses. This unis was used as the basic one.

From the surveys, the value of a task is approximately €35, although it depends of the species of the tree. The Oak wood was the most expensive with a cost of around €40 per task while the cheapest options were "cuje", *Inga spuria*, pine and coffee with approximate cost of €30-35 per task.

Three methods were employed to study the wood consumption within the communities. Based on the literature review it was found that on average, the yearly consumption per capita for the Chiquimula department was estimated at $0.7m^3$ for the urban areas and $2.6m^3$ for the rural areas.

The results from the second method, where the perceived consumption was estimated based on surveys, are presented in Figure 8.

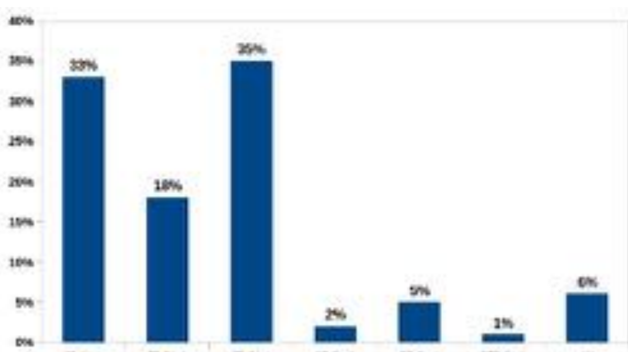

Figure 8. Perception of firewood consumption

The results from the the third method, where the consumption was directly measured every day at every time of cooking, are presented in Table 1. It is important to note that the data was filtered out by those numbers that were physically unrealistic and or entirely repetitive since for different thermal loads (different cooking tasks), different fuel amounts are required.

Cookstove energy efficiency

Aside of the technical aspects of a cookstove, such as the geometrical characteristics that influence the efficiency of the combustion, the culture also has imperative effects on the wood consumption. For example, in rural areas where people depend on their work on agriculture, the day starts very early, and although the morning meal is not as energy demanding as the lunch or dinner, the cookstove must be turned on entirely, and due to its difficult control, it remains burning for the rest of the day. So even though firewood is a limited and expensive resource (either time or money wise), they use it with poor efficiency an limited control. But this is the reality of it use.

Based on discussion in the methodology section and also accessibility of firewood as a resource, the stoves which uses carbon and other liquid fuels were not considered for testing. The technologies which were evaluated are shown in Figure 9 and has been listed below (Table 2).

The WBT Laboratory protocol was executed in a controlled environment, located in Guatemala City. The fuel used was red pinewood obtained from a community where CCT was carried out. The relative humidity range was determined to be 17% - 20%. Results from WBT are shown in the Table 3

The CCT protocol was slightly modified and was carried out in houses with controlled environment, pinewood with the same humidity used in the WBT, from the community of Zapotalito, municipality of Esquipulas, Chiquimula. The types of standardized meals for this test were two: nixtamalization i.e., the process of of corn with calcium hydroxide and cooking of beans, these foods are the base of a Guatemalan diet.
The women from the Zapotalito community cooked 6 pounds of corn and 5 pounds of beans respectively, 4 times per technology. Namely, Berkeley (rocket), Envirofit M5000 (rocket), Poyeton type stove and electromagnetic induction stove. Due to the physical capacity of the solar oven, it was not possible to cook the same amount, but instead 0.45 kg of corn were cooked four times.

The results from CCT test are shown in Table 4. This test was only conducted for three types of stoves, the gasifiers were not added because people were not willing to use the stoves at the time of cooking, both for their size and their operation. These gasifiers are batch type and therefore the

Table 1
Firewood consumption per capita per day, reported 3 times per day

Cookstove type	Firewood consumption[kg] at 20% moisture
Iron top stove combined with propane stove, n=10	2.43 ±0.77
Iron top stove, n=16	3.56 ±0.46
Poyeton with chimney, n=23	4.63 ±0.94
Poyeton without Chimeney, n=3	5.19 ±0.36

Figure 9. Picture of different cookstoves evaluated

Table 2
Different cookstoves evaluated

S.no	Cookstove	Type	Reference no. from Figure 9	Country of import
1	Berkeley Darfur	Rocket	4	Uganda
2	Envirofit	Rocket	3	United States
3	Mimi Moto	Gasifier	1	Netherlands
4	Biolite	Gasifier	5	United States
5	Gosun Solar Oven	Solar	2	China
6	Induction Duxtop	Electromagnetic induction stove		United States
7	Envirofit Saverpro 50	Iron		

gasifier container must be filled every time with biomass after completion of a single combustion process. This batch system did not seem practical since the food they cook takes approximately 1-2 hours to cook.

Household air quality. Due to technical problems with the egg monitor, the measurements for carbon monoxide and nitrogen dioxide were not recorded properly and were not considered for further analysis. Due to the large amount of data and the limited space, the concentration charts only for a period of 15 days have been shown. The internet connection was not stable during the entire period of the study, nor the electrical connection. Therefore there are some periods of missing data, regardless of that, it was possible to measure the concentration of Particulate Matter (PM2.5) and Volatile Organic Compounds (VOCs).

According to Environmental Protection Agency (EPA) a concentration of 12 $\mu g/m^3$ (shown in blue in Figure 10) marks the safety limit level for the vulnerable population including children and elderly people (for others the safety limit is 15 $\mu g/m^3$). The PM2.5 concentrations observed during the cooking periods reached peak values of up to two orders of magnitude higher than the safe limit during the ignition as combustion is very poorly efficient (see Figure 10). During the remaining cooking process, values were commonly observed in the ranges of 200 - 400 $\mu g/m^3$ (Figure 10).

Another relevant result was found by plotting the VOC (in ppb-parts per billion) and the PM2.5 $\mu g/m^3$ together. An offset in the peak for both the concentrations can be seen and it is attributed to the combustion process (Figure 11). While

Table 3
Firewood consumption fron WBT and CCT

Cookstove	Thermal Efficiency	Power [kW]	Specific fuel consumption [kg/l]
Cold start			
Poyeton	15.3 ±3.3	6.17 ±0.84	0.14 ±0,045
Iron plate	9.3 ±1.20	7.43 ±0.37	0.23 ±0.004
Mimimoto gasifier	34.0 ±0.8	2.05 ±0.03	0.06 ±0.002
Rocket Envirofit	32.3 ±0.5	2.63 ±0.03	0.06 ±0.001
Rocket Berkeley	37.3 ±0.5	2.28 ±0.19	0.05 ±0.004
Hot start			
Poyeton	15.7 ±4.5	6.92 ±1.40	0.21 ±0,053
Iron plate	10.0 ±1.4	7.77 ±0.24	0.23 ±0.007
Mimitoto Gasifier	34.3 ±0.5	1.93 ±0.10	0.05 ±0.002
Biolite CampStove	37.0 ±0.5	1.81 ±0.01	0.05 ±0.001
Rocket Envirofit	34.7 ±0.5	2.95 ±0.15	0.06 ±0.002
Rocket Berkeley	39.7 ±0.5	2.34 ±0.08	0.04 ±0.003
Simmering			
Poyeton	15.0 ±0.8	1.21 ±0.05	0.04 ±0,002
Iron plate	21.3 ±1.9	1.40 ±0.35	0.04 ±0.001
Gasifier Mimitoto	13.3 ±0.5	1.97 ±0.08	0.07 ±0.003
Biolite CampStove	13.7 ±0.5	1.15 ±0.15	0.04 ±0.005
Rocket Envirofit	26.3 ±0.9	0.20 ±0.05	0.01 ±0.002
Rocket Berkeley	20.3 ±0.5	0.38 ±0.11	0.01 ±0.003

Table 4
Controlled Cooking Test Results

Food and cookstove	Specific fuel consumption [g/kg]	Cooking time	Fuel and time savings [% Kg / % min]
Black beens:			
Iron top	202.00 ±10.50	125.00 ±4.08	- / -
Berkeley Darfur	71.00 ±6.10	83.00 ±8.96	65.00 / 34.00
Envirofit M5000	71.00 ±8.40	82.00 ±10.5	65.00 / 35.00
Nixtamal:			
Iron top	225.00 ±25.00	119.00 ±4.32	- / -
Berkeley Darfur	74.00 ±12.20	81.00 ±2.83	66.00 / 32.00
Envirofit M500	70.00 ±12.70	88.00 ±5.00	78.00 / 26.00

the peak concentration for PM2.5 is at the ignition point, the peak concentration for VOC's appears with a "delay". This is attributed to the fact that with the development of combustion, the temperature of firewood increases along with the gasification process. This results in devolatization of gases which increases the concentration of VOC in the air.

The results clearly indicates that during the entire cooking time PM2.5 concentration is always above the safety limit set by EPA. Confirming that cooking in the current conditions is harmful for the health of the people, specially women and children whom are in the kitchen the most.

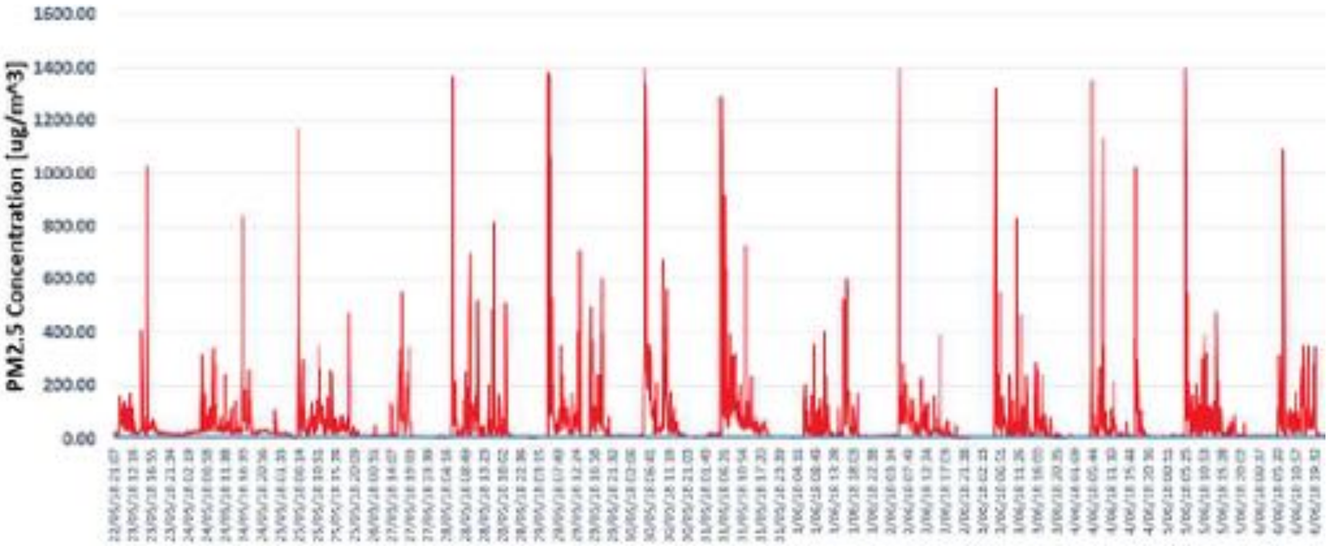

Figure 10. Concentration of PM2.5 (red) measured in a house of the community El Zapotalito for a period of 15 days

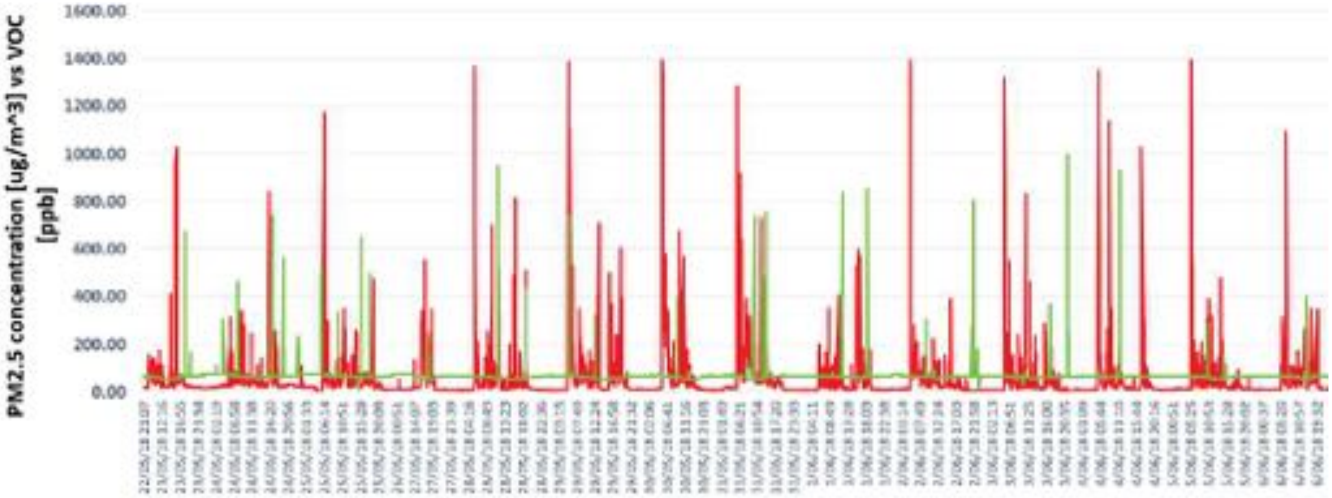

Figure 11. Concentration of PM2.5 (red) vs VOC (green) measured in a house of the community El Zapotalito for a period of 15 days

Conclusion

1. 100% families surveyed in the department of Chiquimula uses biomass cookstoves while 24% also used propane for cooking along with biomass
2. Average wood consumption (at 20% relative humidity and stacking factor of 0.78) from different families using the following technologies was: For iron stove along with propane stove (2.01 ± 0.63) m^3, iron stove only (2.94 ± 0.38) m^3, poyeton stove with fireplace (3.83 ± 0.78) m^3, poyeton stove without Fireplace (4.29 ± 0.3) m^3
3. In the WBT tests of the improved stoves, the technologies with the best performance were: Rocket-type stoves (Berkeley and Envirofit) with an efficiency close to 35% during the phases of cold ignition on hot ignition. In the slow cooking phase, the efficiency of the Berkeley dropped to 20.3% while the Envirofit dropped to 26%. The gasifiers (Biolite and Mimimoto) had an efficiency of 34% for the first two phases, while in the third phase, the efficiency fell to 13%.
4. In the WBT tests of the traditional stoves, the poyeton type had an efficiency close to 15% for the three stages, while the iron type had an efficiency of 9.3%, 10% and 21.3%, respectively.
5. In CCT tests (for beans), the technologies that showed the best results were the Rocket, with savings of 65% in terms of firewood and 35% savings in terms of cooking time, both for the Berkeley and for Envirofit.
6. In CCT tests (for nixtamal), the technologies that showed the best results were again the Rocket, with savings of 66% in terms of firewood and 32% savings in terms of cooking time for the Berkeley and 78% wood savings and 26% time savings for Envirofit.
7. The quality of air inside the households evaluated shows alarming levels of contamination particularly PM2.5, which exceed the safe limit defined by Environmental Protection Agency. During the evaluation, it was found that several times in a day the concentration exceeded 200 $\mu g/m^3$ and atleast once per day it exceeded 1000 $\mu g/m^3$. This happened even when the household in which the tests were conducted had ample ventilation.
8. It was found that the mere technical improvement of the performance of the cookstove, namely efficiency, time for cooking, indoor air pollution and fuel reduction are not conditions enough to replace the traditional cookstoves. The food they prepare, the meaning the stove has for the family, the implications of their daily life, among other cultural variables are also necessary conditions for switching technologies. Therefore, in future plans of improving the technologies, these variables and the families input is determinant in the success of the projects.

Recommendations

It is imperative to improve life quality of people living in poverty throughout the world. One concrete option that could have positive impacts in terms of health, environment, and overall life quality is the introduction energy efficient cookstoves. However, this process is not trivial, it must incorporate the cultural variables of the people. It is therefore recommended to not only perform testing under control conditions, but to validate the cultural assumptions, and also involve the community in the development of the project, since the earliest stage.

The low quality air monitors, although capable of measuring key parameters did not perform as expected. However, it is not statistically significant to make a categorical claim about their quality or reliability. In the future, it is suggested to use a larger quantity of them to get statistical reliable information.

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