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# Uncontrolled Cooking Efficiency Test (UCET) Protocol

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# 1. Introduction

The purpose of the Uncontrolled Cooking Efficiency Test (UCET) is to measure the thermal efficiency, fuel consumption, and cooking time of unimproved and improved cooking stoves under real-world use. Other cookstove tests collect efficiency values exclusively in the lab (ISO and WBT) where water is boiled in a pot. This provides a replicable test result but does not simulate local cooking practices or other cooking methods. Cookstove tests performed in the field (KPT, CCT, UCT) measure fuel consumption per day or task but do not quantify efficiency. The UCET was designed to measure the thermal efficiency of the stove while allowing the user to cook what they like how they want, aiming for minimal influence on user behavior. The UCET can also be used as a design development tool to observe how a stove is used and identify potential usability issues.

## 1.1. Benefits and Limitations

The main benefit of the UCET is that it provides efficiency data in real-world conditions without limiting the cook to specific meals or cooking methods. While this does not provide the replicable results that are found in lab tests, it does provide more realistic results of the stove's performance using a variety of cooking methods, tending styles, and power levels. The UCET does allow the cook to select the meal, ingredients, and how the stove is operated in an attempt to minimize the influence of the testing process on results. However, the presence of testing personnel throughout the duration of the test can impact results with users potentially cooking less typical meals, cooking larger quantities of food to feed testing personnel, or behaving differently while being observed (Hawthorne Effect) .

The UCET requires temperature and weight sensors which can be obtained at a relatively low cost. It also requires trained personnel to be present throughout each test. Due to the variability between meals and methods, a greater number of tests is required for statistically significant results relative to a CCT or laboratory-based test.

## 1.2. Definitions

**Cooking Power Levels:** The firepower (W) used during cooking; categorized as high, medium, and low. Multiple power levels may be used in a single meal.

**Efficiency:** The percentage of energy absorbed by the food divided by the energy released by the fuel.

**Household:** A single house with a group of people living in it.

**Kindling and tinder:** Smaller pieces of dry wood used start a fire.

**May:** Use of may in the following protocol indicates *permitted* actions.

**Meal:** A single duration of cooking that is measured from the time a fire in the stove is lit to the time the fire is extinguished by the user or goes out by itself. A meal may include heating non-food items if the heat comes from the same fire/stove that cooked the food.

**Shall:** Use of shall in the following protocol indicates *required* actions.

**Should:** Use of should in the following protocol indicates *recommended but not required* actions.

**Shutdown:** The procedure used to extinguish the fire when cooking is complete. This could be an active intervention or leaving the fire until it extinguishes on its own.

**Stove:** A device used for cooking.

**Testers:** Skilled labor with formal training equivalent to laboratory technician or higher.

### 1.2.1. Cooking Methods

A single stove may vary in efficiency depending on what cooking method (e.g. boiling, frying, etc) is used. Some stoves may be more efficient for certain methods than others. It is important to identify what cooking methods are commonly used in a project region so the stove can be optimized for those methods. The three main cooking methods are described below:

**Direct fire:** This method cooks the food with little to no obstructions between the fire and the food itself. This means that no pot, pan, or other surface is blocking the food from the fire therefore the food is mainly being heated by convection and radiation. A grill or mesh may be used to support the food above the fire.

**Pan frying:** This method uses a pot, pan, or other surface as a barrier between the fire and the food. The surface is heated which then heats the food. The important distinction for pan frying is that the surface is not fully covered and gaps between food allow the heat to escape.

**Boiling/simmering:** This method uses a pot or pan but unlike pan frying, the entire surface of the pot/pan is covered by food or liquid.

There are two cooking styles that can impact the above cooking methods that shall also be tracked when performing a UCET:

**Continuous Stirring:** Continuous stirring can be used while pan frying or boiling/simmering. This cooking style involves frequent to constant stirring of the food which can release more heat and lead to more evaporation.

**Steaming:** Steaming can be used while boiling/simmering. Steaming involves raising the temperature of a liquid to a point where it produces steam and placing food on top of the liquid in a device that captures the steam. The food is cooked through steam rather than conduction from the pan/pot, like boiling/simmering.

Some recipes may use multiple cooking methods and styles. All methods and styles shall be recorded with a note on which was predominantly used.

## 2. Methodology

### 2.1. Overview

The UCET measures the change in temperature and weight of each ingredient from right before it is cooked to when it is finished cooking. It also records various fuel metrics and collects additional data on the stove, household, and meal to form a larger picture of all potential impacts on thermal efficiency. The UCET may be paired with emission testing equipment if desired.

To obtain accurate data, it is imperative that each measurement is taken correctly and precisely. For this reason, skilled labor shall be used throughout each test. Skilled labor is defined as a minimum qualification of a lab technician or equivalent. This personnel shall actively watch what the user is doing as mistakes often occur when the user does not understand what needs to be measured.

### 2.2. Equipment Needed

- Infrared temperature with a 300 C temperature range and 1 C resolution
- Metal food-safe temperature probe with a 300 C temperature range and 1 C resolution
- Environmental sensor or sensor suite capable of measuring temperature (50 C range and 2 C resolution), humidity (100 % range and 5 % resolution), and pressure (32 inHg range and 0.01 inHg resolution)
- Battery-powered platform scale with a 30 kg capacity and 0.001 kg resolution
- Resistive type wood moisture meter with 0.5 % resolution (if measuring stoves using wood as fuel)
- Lab oven or food dehydrator capable of achieving 100 C to determine the moisture content of the fuel (if measuring stoves using charcoal or other biomass fuels)
- Metal tray for collecting and weighing hot charcoal
- Metal tongs
- Heat resistant gloves

- Clean containers for weighing ingredients
- Clean containers/buckets for storing cleaning and cooking water
- Alcohol or sanitizing wipes
- Ruler
- Air-tight bags for fuel samples (if measuring stoves using charcoal or other biomass fuels)
- Data entry sheet (Appendix A)
- Bomb calorimeter (optional)

### 2.3. Calibration

Regular calibration of the equipment used for the study shall be carried out to ensure results are standardized. Refer to manufacturer calibration recommendations for frequency and calibration instructions.

### 2.4. Household Selection

Sample size may vary depending on the scope of the project with a minimum sample size of 10 households per community. A survey shall be conducted within each community sampled to find the demographics within the community and ensure the selected households are representative. The number of households surveyed shall be at least double the intended sample size with a minimum survey size of 30.

The survey should consist of factors that may impact the thermal efficiency of the stove such as:

- Fuel(s) used
- Fuel(s) moisture content
- Fuel(s) dimensions
- Stove material
- Stove diameter
- Pot diameter
- How often each cooking method is used
- Shutdown procedure

An example survey can be found in Appendix D.

Household selection shall reflect within 10% of ratios found in the survey for factors that were found to be heterogeneous within the community (a factor may be considered homogeneous when more than 90% of answers are the same). In some cases there is no selection of households

that will be within 10% of ratios found. In this case, a selection that is as close as possible to 10% of all ratios should be chosen.

Each household selected shall have a minimum of 3 UCETs performed.

## 2.5. Procedure

The UCET procedure is split into three parts.

- Pre-test involves all measurements and steps that must be taken before cooking begins.
- During cooking involves all measurements and steps that must be taken while the user is cooking a meal. This step includes procedures for various scenarios that may happen while cooking.
- Post-test involves all measurements taken once the meal is finished including the shutdown procedure and measurements that need to be taken at the lab.

### 2.5.1. Pre-test

It is important that testers come prepared and organized to reduce the time taken out of the user's day to perform the test.

Before the test starts it is important to make sure that the user understands what is expected of them during the test to avoid errors. It may be useful to develop a script that can be read to the user. An example script can be found in Appendix C.

In some cultures, it is customary to cook for any guests in the house. Testers are often considered guests. Cooking additional food for testers should be avoided where possible as this influences how much food is cooked. Testers should find a way to explain declining food in a way that will not offend users. Testers may explain how additional food cooked will impact the test, say that they have eaten beforehand, or bring their own food. Explanations may vary for different cultures and regions.

The user shall be made aware that a temperature probe may be used in their food to measure temperature. The temperature probe shall be properly sanitized with wipes between every use. The user shall be allowed to opt out of the temperature probe being used in which case only the infrared thermometer will be used. Use of the temperature probe is preferred when dealing with liquid due to the impact of reflectance on the infrared thermometer.

It is important to establish with the user that water used for washing shall be kept separate from water used for cooking. Two containers or buckets should be provided to the user, one bucket

should be strictly used for the addition of water to the meal being cooked. The second container may be used for any water that will not be heated.

The washing, cutting, and peeling of ingredients shall be done prior to temperature and mass measurements except in the case where the ingredients will retain water after washing (such as rice). In this case, the mass of the ingredient should be weighed before and after washing. The additional mass after washing will be added to the weight of water.

All fuel that may be used for the meal shall be put into a distinct pile. The mass, moisture content (if the fuel is wood), and average dimensions of the fuel shall be measured (Table 4, Appendix A). Measure the moisture content of the fuel according to instructions in the [Water Boiling Test](#) – in three places on at least three different sticks, averaging the values. For charcoal and other fuel that is not wood, a sample of the fuel shall be put into an airtight container and brought back to the lab to have moisture content measured using the oven dry method (Section 2.5.4.1). Tester may also take fuel samples at this time for calorific value analysis if desired. If the user requires more fuel while cooking, the mass of the fuel may be added to the previously measured mass. The mass of kindling shall also be measured.

The UCET allows for multiple fuel types or species to be burned in the same stove. To record multiple fuel types, perform measurements separately for each type and track accordingly. If a user is using a wood stove and there is charcoal that will not be removed prior to cooking then the charcoal counts as a secondary fuel.

The ambient temperature, pressure, and humidity shall be taken prior to the start of the meal (Table 2, Appendix A).

The user shall be asked to put each ingredient used into a container. If an ingredient is to be used in two separate dishes or cooked separately, the ingredient shall be split into two containers and treated as two separate ingredients. All ingredients shall be weighed in their containers (Table 5, Appendix A). Dried spices, seasonings, and herbs may be excluded from measurements if the combined mass of exclusion is less than 162 g (Appendix I). Ingredients where only a small amount may also be excluded if the combined mass of exclusion is less than 60 g (Appendix J).

The mass of each pot/pan used must also be weighed (Table 3, Appendix A). Weigh all pots/pans without a lid.

Right before the start of the meal, the temperature of the stove shall be measured to determine if this is a hot or cold start (Table 1, Appendix A).

## 2.5.2. During Cooking

Once all pre-test measurements have been completed, the user may be allowed to start the fire and begin cooking. The time of the start of the fire shall be recorded (Table 5, Appendix A).

Throughout the cooking process, household, operational, and stove characteristic data shall be taken to fill out (Table 1, Appendix A). This data will be helpful for analyzing factors that impact thermal efficiency as well as ensuring that replicate tests of the same house are tracked accordingly.

The temperature of each ingredient shall be measured immediately before they are added to the meal (Table 5, Appendix A). If ingredients are mixed together prior to being added, the temperature of the mixture shall be used as the temperature for each individual ingredient. If using a temperature probe, use alcohol wipes or sanitizing wipes between each measurement to avoid contamination.

As ingredients are added to the meal, weigh the container the ingredient was in along with any of the ingredient that was not added (Table 6, Appendix A). The purpose of this measurement is to capture the mass of the ingredient added to the food. The weight of the container will be subtracted during calculations.

The user should be allowed to cook and tend the fire as they normally would and the tester should avoid influencing them. This includes avoiding helping with tending the fire, prepping ingredients, cooking the food, or helping with other tasks.

Once an ingredient or mix of ingredients is removed from the fire, the final temperature shall be recorded (Table 5, Appendix A). If the ingredients reached a temperature greater than the final temperature, use the maximum temperature reading. This may occur when ingredients are boiled and then simmered or kept warm. The final temperature of ingredients that are mixed together shall be the final temperature of each individual ingredient.

As pots/pans of food are removed from the fire, record the final temperature if not already done. Weigh all ingredients in the pot/pan along with the pot/pan and record the final weight (Table 5, Appendix A). Multiple pots/pans may be used in a meal that consists of multiple dishes. Each pot/pan with their respective ingredients shall be weighed and have the temperature taken individually. It may be useful to track what ingredients went into in each pot/pan to avoid errors.

### 2.5.2.1. Potential Scenarios

During the UCET, the tester may experience different cooking procedures that vary from what is outlined in the section above. The user shall not be prevented from cooking how they want, the

tester must adapt measurements to work with the scenario. Several scenarios and their adaptations are listed in this section.

If an ingredient (or mix of ingredients) is removed from the pot/pan prior to the end of cooking, the temperature at the time of removal shall be recorded and the weight of the ingredient (or mix of ingredients) shall be added to the final weight of the pot/pan.

If an ingredient (or mix of ingredients) is removed in batches, the temperature and weight of each batch shall be measured. The average temperature shall be recorded as the final temperature unless a maximum temperature was recorded before batch removal. The total weight of all batches shall be added to the final weight of the pot/pan.

If an ingredient (or mix of ingredients) is removed and will be added back to the fire later, the temperature upon removal shall be taken along with the temperature right before it is added back into the fire. The change in temperature (recorded as a positive temperature if the second temperature is lower than the first) shall be added to the final temperature when the ingredient or mix of ingredients is done cooking.

If the cook wants to taste their food, weigh what is going to be eaten and add it to “weighed additional mass loss” (Table 5, Appendix A). If the total mass of all food sampled is less than approximately 60g, then the sample does not need to be weighed or accounted for as it will not meaningfully impact thermal efficiency (Appendix J)

If food is spilled, if the food can be collected and weighed, record the weight in “weighed additional mass loss” (Table 5, Appendix A). If the food cannot be collected, note the spill and size of the spill in “observed additional mass loss” (Table 5, Appendix A). Note that unweighted mass loss will result in a falsely inflated thermal efficiency.

During some meals, food that was previously cooked is reheated. If this meal was observed being cooked at the household during a previous test, the specific heat can be determined using a weighted average of all ingredients added based on the weight of each ingredient. If it was not previously measured, the test cannot be used to due to not being able to determine the specific heat and therefore the energy absorbed by the food.

### 2.5.3. Post-Test

When all food is finished cooking, record the end of the cooking time (Table 5, Appendix A). The end of cooking time does not mean the end of the fire. Some users may heat bathwater or other things not used during the meal using the residual heat from the fire. This shall be treated as an additional pot/pan with an additional ingredient and the temperature and weight shall be taken before and after heating.

Users may shutdown their stove according to normal practice.

- Some users may leave sticks and charcoal in wood stoves or the remaining charcoal in charcoal stoves. The tester shall wait until the fuel left in the stove has ceased active combustion and cooled before measuring any remaining fuel and charcoal (Table 5, Appendix A).
- Some users may extinguish hot fuel using dirt or water. The tester shall measure the weight of the remaining fuel and charcoal prior to it being extinguished as to avoid additional weight from the dirt or water (Table 5, Appendix A).

Some users may use the residual heat from the stove to heat other items such as bath water prior to stove shutdown. In this case, anything that is heated with the same fire that was used for cooking the measured meal shall be included as additional ingredients. The mass and temperature change shall be recorded along with all other metrics outlined in Section 2.

The time of shutdown when the remaining fuel and charcoal are measured shall be recorded (Table 5, Appendix A). For charcoal stoves, the charcoal remaining in the stove will be measured and recorded in the ‘weight of charcoal in stove + tray’ section of Table 5, Appendix A while any charcoal that was not added to the stove may be recorded as remaining fuel.

If any charcoal is removed from the stove at any point during the test prior to shutdown, the mass shall be recorded and added to the final mass of charcoal.

Any fuel that was initially weighed and was not used during the cooking period shall be weighed and recorded for the final fuel mass (Table 5, Appendix A).

After ensuring all measurements were recorded, the tester may exit the household. If compensation is being provided to the household, it should be provided at the end of the testing series to avoid influencing what ingredients users buy and what dishes users cook.

#### 2.5.4. Lab Measurements

The specific heat of each ingredient shall be recorded. Specific heat for many ingredients can be found in Appendix E. Trusted online sources or publications may also be used to find specific heats. Some ingredients do not have measured specific heats. In this case, an ingredient that is similar and has a known specific heat may be substituted. Similar ingredients should be determined by ingredients that have a similar composition and moisture content. The substitution shall be noted as to ensure that the same substitution is made across all tests.

If fuel samples were taken for moisture content analysis, the steps outlined in Section 2.5.4.1 for the oven dry method shall be taken to determine the moisture content.

If fuel samples were taken for calorific value analysis, follow the instructions provided in the bomb calorimeter for measurements. If fuel samples were not taken for calorific value analysis, default values based on fuel type and species may be entered (Appendix G, Appendix H).

#### 2.5.4.1. Oven Dry Method

- A. Weigh samples and record their initial weight.
- B. Place samples in an oven that's temperature is maintained at 102 - 103 °C.
- C. Weigh the samples again after 24 hours and calculate the moisture content:

$$MC_{wet\ basis} = \frac{m_{wet} - m_{dry}}{m_{wet}} * 100 \quad \text{Eq. 1}$$

Where:

$MC_{wet\ basis}$  = Moisture content on a- wet basis (%)

$m_{wet}$  = Initial wet sample mass

$m_{dry}$  = Final dried sample mass

- D. Return samples to the oven for 2 more hours and calculate the moisture content. If the change in moisture content is more than 0.1%, repeat step D until a change of less than 0.1% is achieved (Boone, et al, 1998).

### 3. Notes and Assumptions

Due to measurement limitations, there are some assumptions that need to be made:

- Any loss of mass is assumed to be a loss due to evaporated water either from water contained in the ingredients or water added to the dish.
- The specific heat of each ingredient is assumed to remain constant as it is cooked.
- The final temperature of each ingredient is assumed to be the same as the final temperature of the food mixture at the end unless the ingredient is taken out prior to the end of the cooking time.
- Heat removed by stirring utensils is less than 1% of total energy transfer and is therefore neglected.
- Charcoal produced during UCET is assumed to have 0% moisture content.
- Values of specific heat for some ingredients may be substituted for specific heat values of similar ingredients when there is no accessible specific heat for the primary ingredient.
- The use of a lid is recorded but the impact a lid may have on thermal efficiency (retaining evaporated water, retaining heat) is not factored into calculations.

## 4. Interpreting Results

The data from the UCET may be used in several ways. The primary goal of the test is to obtain the thermal efficiency of the stove. Data can also show common power levels used in the region, charcoal productivity, fuel use per meal, and average cooking times. The additional household, operational, and stove data collected can show what stoves are used in a region and what majorly impacts thermal efficiency. These data may be used as a tool for designing more efficient stoves that meet regional needs.

### 4.1. Calculations

#### 4.1.1. Thermal Efficiency

Thermal efficiency can be calculated by subtracting the energy value of the remaining charcoal from the chemical potential energy of the fuel used or based solely on the mass of fuel burned. Thermal efficiency with credit to charcoal is calculated as:

$$TE_{with\ charcoal} = \frac{\sum \text{sensible energy} + \text{latent energy}}{\text{chemical potential energy with char}} \quad \text{Eq. 2}$$

The sum of sensible energy is the sum of the mass of each ingredient multiplied by the specific heat of each ingredient and the temperature change:

$$\sum \text{sensible energy} = \sum_{c=1}^n m_{i,c} * C_{p,c} * (T_{f,c} - T_{i,c}) \quad \text{Eq. 3}$$

Where:

*sensible energy* = Energy used to heat up food (kW)

$m_{i,c}$  = The initial mass of the ingredient (kg)

$C_{p,c}$  = The specific heat of the ingredient (kJ/ kg°C)

$T_{i,c}$  = The initial temperature of the ingredient (°C)

$T_{f,c}$  = The final temperature of the ingredient (°C)

Latent energy is calculated by the mass of water that evaporated during cooking and the latent heat of vaporization:

$$\text{latent energy} = h_{vap,w} * \left( \sum_{c=1}^n m_{f,c} - \sum_{c=1}^n m_{i,c} \right) \quad \text{Eq. 4}$$

Where:

*latent energy* = Energy used to evaporate water (kW)

$m_{i,c}$  = The initial mass of the ingredient (kg)

$m_{f,c}$  = The final mass of the ingredient (kg)

$h_{vap,w}$  = The latent heat of vaporization of water (kJ/ kg)

The latent heat of vaporization is determined by interpolating values based on the local boiling point which is calculated using the ambient pressure.

Chemical potential energy with the energy value from the remaining charcoal subtracted is calculated as:

$$\text{chemical potential energy with char} = NCV_{fuel} * \frac{m_{f,fuel} - m_{i,fuel}}{M} - LHV_{char} * (m_{f,char} - m_{i,char})$$

Eq. 5

Where:

*chemical potential energy with char* = Chemical energy from fuel used including energy held in remaining charcoal (kW)

$NCV_{fuel}$  = The net calorific value of fuel (kJ/ kg)

$m_{i,fuel}$  = The initial mass of fuel (kg)

$m_{f,fuel}$  = The final mass of fuel (kg)

$M$  = Moisture content of fuel (wet-basis) (%)

$LHV_{char}$  = Lower heating value of charcoal (kJ/kg)

$m_{i,char}$  = The initial mass of charcoal (kg)

$m_{f,char}$  = The final mass of charcoal (kg)

For charcoal stoves, the mass of charcoal that is subtracted from the chemical potential energy is the mass of charcoal remaining in the stove after shutdown, while the final mass of fuel is the mass of charcoal that was not added to the stove.

If multiple fuels are used in the same stove, the overall net calorific value of fuel can be calculated as:

$$NCV_{fuel} = \sum_{f=1}^n \frac{NCV_f * m_f}{m_{fuel}}$$

Eq. 6

Where:

$NCV_f$  = The net calorific value of each fuel (kJ/ kg)

$m_f$  = The initial mass of each fuel

$m_{fuel}$  = The sum of the initial masses of all fuels

For multiple fuels, the moisture content is the average of all fuel moisture contents weighted by mass of each fuel.

Thermal efficiency may also be calculated based on the mass of the fuel burned without accounting for any remaining charcoal. This can be calculated as:

$$TE = \frac{\sum \text{sensible energy} + \text{latent energy}}{\text{chemical potential energy}} \quad \text{Eq. 7}$$

Where chemical potential energy is calculated as:

$$\text{chemical potential energy} = NCV_{fuel} * \frac{m_{f,fuel} - m_{i,fuel}}{M} \quad \text{Eq. 8}$$

#### 4.1.2. Other Metrics

The data from the UCET can be used to calculate additional metrics that evaluate stove performance and inform stove design.

##### 4.1.2.1. Fire and Cooking Power

An important metric for both design and evaluation is the firepower (energy release rate) and cooking power (rate of energy delivery to the food) that is used. This may be evaluated by finding the range of common firepower and cooking powers used in order to design a stove that meets current needs. Firepower is the rate of energy use over time and it is calculated as:

$$\text{firepower} = \frac{\left( \frac{m_{f,fuel} - m_{i,fuel}}{M} \right) * NCV_{fuel} - (m_{f,char} - m_{i,char}) * LHV_{char}}{t} \quad \text{Eq. 9}$$

Where:

firepower = Energy used over time (kW)

$m_{i,fuel}$  = The initial mass of fuel (kg)

$m_{f,fuel}$  = The final mass of fuel (kg)

$M$  = Moisture content of fuel (wet-basis) (%)

$NCV_{fuel}$  = The net calorific value of fuel (kJ/kg)

$m_{i,char}$  = The initial mass of charcoal (kg)

$m_{f,char}$  = The final mass of charcoal (kg)

$LHV_{char}$  = Lower heating value of charcoal (kJ/kg)

$t$  = time (s)

Cooking power is related to firepower through efficiency but focuses specifically on the rate of energy delivered to the food over time:

$$\text{cooking power} = \frac{\Sigma \text{sensible energy} + \text{latent energy}}{t} \quad \text{Eq. 10}$$

Where:

cooking power = Energy delivered to food over time (kW)

*sensible energy* = Energy used to heat up food from ambient to end temperature (kW)

*latent energy* = Energy used to evaporate water in food (kW)

*t* = time (s)

#### 4.1.2.2. Charcoal Productivity

Charcoal productivity measures the percentage of charcoal created from the fuel input. Charcoal productivity can measure how effective a stove is at making charcoal that could be used for fuel or biochar or how effective a stove is at burning all the fuel that is given to it. This metric may be measured in terms of mass or energy productivity. For charcoal mass productivity the equation is:

$$\text{charcoal mass productivity} = \frac{m_{f, \text{char}} - m_{i, \text{char}}}{m_{f, \text{fuel}} - m_{i, \text{fuel}}} * 100 \quad \text{Eq. 11}$$

Where:

charcoal mass productivity = Percentage of charcoal created from fuel (%)

$m_{i, \text{char}}$  = The initial mass of charcoal (kg)

$m_{f, \text{char}}$  = The final mass of charcoal (kg)

$m_{i, \text{fuel}}$  = The initial mass of fuel (kg)

$m_{f, \text{fuel}}$  = The final mass of fuel (kg)

To measure charcoal energy productivity the equation is:

$$\text{charcoal energy productivity} = \frac{(m_{f, \text{char}} - m_{i, \text{char}}) * LHV_{\text{char}}}{\left(\frac{m_{f, \text{fuel}} - m_{i, \text{fuel}}}{M}\right) * NCV_{\text{fuel}}} * 100 \quad \text{Eq. 12}$$

Where:

charcoal mass productivity = Percentage of energy from charcoal created from energy from fuel (%)

$m_{i, \text{char}}$  = The initial mass of charcoal (kg)

$m_{f, \text{char}}$  = The final mass of charcoal (kg)

$m_{i, \text{fuel}}$  = The initial mass of fuel (kg)

$m_{f, \text{fuel}}$  = The final mass of fuel (kg)

$NCV_{\text{fuel}}$  = The net calorific value of fuel (kJ/ kg)

$LHV_{char}$  = Lower heating value of charcoal (kJ/kg)

# Appendix A - Data Entry Sheet

Appendix A shows the full data entry sheet that will be used during lab and field testing. The version shown below is designed to be printed for easy data entry in the field. The sheet found [digitally](#) may be used with the data processing app (Appendix B) for metric calculations.

Table 1: Household, Stove, General Data		
	units	data
Name of Tester		
Date	mm-dd-yyyy	
Test Number		
Country		
Region		
Community		
Household		
# of people cooked for		
Age and Gender of each person	ex: M45, F10	
Stove type/model		
Combustion chamber dimensions (height x length x width or height x diameter)	cm x cm	
Stove material(s)		
Cold or hot start		
Dimensions pot/pan 1	cm x cm	
Dimensions pot/pan 2	cm x cm	
Dimensions pot/pan 3	cm x cm	
Dimensions pot/pan 4	cm x cm	
Material pot/pan 1		
Material pot/pan 2		
Material pot/pan 3		
Material pot/pan 4		
Single or double pot used at once		
Lid used? Pot/pan 1		
Lid used? Pot/pan 2		
Lid used? Pot/pan 3		
Lid used? Pot/pan 4		
Skirt used? Pot/pan 1		
Skirt used? Pot/pan 2		
Skirt used? Pot/pan 3		
Skirt used? Pot/pan 4		
Charcoal door		
Dish name/type		
Meal time		
Time since stove was last used	hh:mm	
Cooking method		
Cooking method		
Cooking method		
Will remaining charcoal be used for another fire later?		
Stove description:		

Table 3: Ingredient and Pot/Pan Data		
	units	data
Dry weight of pot/pan 1	kg	
Dry weight of pot/pan 2	kg	
Dry weight of pot/pan 3	kg	
Dry weight of pot/pan 4	kg	
Ingredients in pot/pan 1		
Ingredients in pot/pan 2		
Ingredients in pot/pan 3		
Ingredients in pot/pan 4		
Weight of charcoal tray	kg	
Name Ingredient 1		
Name Ingredient 2		
Name Ingredient 3		
Name Ingredient 4		
Name Ingredient 5		
Name Ingredient 6		
Name Ingredient 7		
Name Ingredient 8		
Name Ingredient 9		
Name Ingredient 10		
Specific Heat Ingredient 1	kJ/kgC	
Specific Heat Ingredient 2	kJ/kgC	
Specific Heat Ingredient 3	kJ/kgC	
Specific Heat Ingredient 4	kJ/kgC	
Specific Heat Ingredient 5	kJ/kgC	
Specific Heat Ingredient 6	kJ/kgC	
Specific Heat Ingredient 7	kJ/kgC	
Specific Heat Ingredient 8	kJ/kgC	
Specific Heat Ingredient 9	kJ/kgC	
Specific Heat Ingredient 10	kJ/kgC	

Table 2: Environmental Data		
	units	data
Wind velocity (if cooking outside)		
Air temperature	C	
Relative humidity	%	
Ambient air pressure	In Hg	

Table 4: Fuel Data		
	units	data
Fuel species 1		
Fuel source 1		
Gross calorific value fuel 1	kJ/kg	
Fuel 1 moisture content (1)	%	
Fuel 1 moisture content (2)	%	
Fuel 1 moisture content (3)	%	
Fuel 1 moisture content (4)	%	
Fuel 1 moisture content (5)	%	
Fuel 1 moisture content (6)	%	
Fuel 1 moisture content (7)	%	
Fuel 1 moisture content (8)	%	
Fuel 1 moisture content (9)	%	
Average fuel 1 moisture content	%	---
Fuel 1 type		
Fuel species 2		
Fuel source 2		
Gross calorific value fuel 2	kJ/kg	
Fuel 2 moisture content (1)	%	
Fuel 2 moisture content (2)	%	
Fuel 2 moisture content (3)	%	
Fuel 2 moisture content (4)	%	
Fuel 2 moisture content (5)	%	
Fuel 2 moisture content (6)	%	
Fuel 2 moisture content (7)	%	
Fuel 2 moisture content (8)	%	
Fuel 2 moisture content (9)	%	
Average fuel 2 moisture content	%	---
Fuel 2 type		
Fuel species 3		
Fuel source 3		
Gross calorific value fuel 3	kJ/kg	
Fuel 3 moisture content (1)	%	
Fuel 3 moisture content (2)	%	
Fuel 3 moisture content (3)	%	
Fuel 3 moisture content (4)	%	
Fuel 3 moisture content (5)	%	
Fuel 3 moisture content (6)	%	
Fuel 3 moisture content (7)	%	
Fuel 3 moisture content (8)	%	
Fuel 3 moisture content (9)	%	
Average fuel 3 moisture content	%	---
Fuel 3 type		
Fuel diemnsions (diameter or height x width) (1)	cm	
Fuel diemnsions (diameter or height x width) (2)	cm	
Fuel diemnsions (diameter or height x width) (3)	cm	
Average fuel dimensions	cm	---
Higher heating value charcoal	kJ/kg	

Table 5: Test Data					
START			END		
	units	data		units	data
Time	h:mm:ss		Time	h:mm:ss	
Temperature of stove	C		Shutdown time	h:mm	
Weight of fuel 1	kg		Weight of fuel 1	kg	
Weight of fuel 2	kg		Weight of fuel 2	kg	
Weight of fuel 3	kg		Weight of fuel 3	kg	
Weight of kindling	kg		Final/max temperature of ingredient 1	C	
Initial Temperature of ingredient 1	C		Final/max temperature of ingredient 2	C	
Initial Temperature of ingredient 2	C		Final/max temperature of ingredient 3	C	
Initial Temperature of ingredient 3	C		Final/max temperature of ingredient 4	C	
Initial Temperature of ingredient 4	C		Final/max temperature of ingredient 5	C	
Initial Temperature of ingredient 5	C		Final/max temperature of ingredient 6	C	
Initial Temperature of ingredient 6	C		Final/max temperature of ingredient 7	C	
Initial Temperature of ingredient 7	C		Final/max temperature of ingredient 8	C	
Initial Temperature of ingredient 8	C		Final/max temperature of ingredient 9	C	
Initial Temperature of ingredient 9	C		Final/max temperature of ingredient 10	C	
Initial Temperature of ingredient 10	C		Final mass of dish and pot/pan 1	kg	
Initial mass of ingredient (and container) 1	kg		Final mass of dish and pot/pan 2	kg	
Initial mass of ingredient (and container) 2	kg		Final mass of dish and pot/pan 3	kg	
Initial mass of ingredient (and container) 3	kg		Final mass of dish and pot/pan 4	kg	
Initial mass of ingredient (and container) 4	kg		Weight of charcoal in stove + tray	kg	
Initial mass of ingredient (and container) 5	kg		Weighed additional mass loss	kg	
Initial mass of ingredient (and container) 6	kg		Boil time	h:mm:ss	
Initial mass of ingredient (and container) 7	kg		Time spent tending fire	mm	
Initial mass of ingredient (and container) 8	kg		Observed additional mass loss:		
Initial mass of ingredient (and container) 9	kg				
Initial mass of ingredient (and container) 10	kg				
Fire starting material					
Table 6: Excluded Mass (mass from table 5 that was not cooked)			Additional comments and observations:		
	units	data			
Mass ingredient 1 container + any unused ingredient	kg				
Mass ingredient 2 container + any unused ingredient	kg				
Mass ingredient 3 container + any unused ingredient	kg				
Mass ingredient 4 container + any unused ingredient	kg				
Mass ingredient 5 container + any unused ingredient	kg				
Mass ingredient 6 container + any unused ingredient	kg				
Mass ingredient 7 container + any unused ingredient	kg				
Mass ingredient 8 container + any unused ingredient	kg				
Mass ingredient 9 container + any unused ingredient	kg				
Mass ingredient 10 container + any unused ingredient	kg				

## Appendix B - Data Processing App

Appendix B is a digital link to data processing software written in Python. This software will calculate all metrics in Section 4.1 and average multiple test metrics together if multiple are entered. All metrics may be calculated by hand or another software if preferred.

The software may be found at: <https://github.com/aprovechodotorg/Data-Processing-Software>  
Instructions for use and download will be in the README file at the bottom of the page.

# Appendix C - Recommended Household Instructions

These instructions should be given to the household when contacting them about the UCET.

We are testing the thermal efficiency of stoves. We will be measuring the mass and temperature of each ingredient that is cooked and the fuel used to cook it. The goal of this study is to reflect how people are using their stoves so we want you to use your stove as you normally would.

Here is what is needed when preparing for the test:

- We will take temperature of each ingredient
  - Water temperature will be taken with a probe, the probe will be cleaned with alcohol before the test
- Water for washing ingredients must be kept separate from water for cooking - we can provide clean containers for each
- Let us know what times you normally cook your meals and we will arrive at that time
- Ideally the fire should not be started before we arrive
  - Tell us when to come so that we can see the start of the fire
  - If you can't want to start the fire we can manage
- Ingredients can be cut up and prepared but they have to be separate from all other ingredients - we will need the weight of every ingredient being used including water but not spices
- Ideally each ingredient will be in it's own plate or bowl - we can provide plates
- Cook whatever you were planning to cook for your meal
- Please do not cook for the testers, only for those you were already going to cook for

These instructions should be given before the start of the test

- The cook should inform us when ingredients are added to the pot
- The cook should inform us when ingredients are taken out of the pot
- In general, the cook should inform us before doing anything with the ingredients
- The cook should cook should try to cook their meal as they normally would despite us being there
- The cook does not have to stay by the food at all points during the cooking period, if other activities are normally done during this period, please continue doing them
- All washing of ingredients and pots/containers should be done before cooking begins/measurements are taken
- The cook should inform us if they need more fuel than what was measured in the pile
- The cook may taste their food, but we must weigh what is tasted first

We will be taking the temperature of each ingredient before and after cooking. For the best measurement, we need to use a temperature probe for water and other liquids. We will clean the temperature probe before each use. Are you willing for us to use a temperature probe?

# Appendix D - Household Survey Example

Date: \_\_\_\_\_

Surveyor's name: \_\_\_\_\_

Household code: \_\_\_\_\_

Community name: \_\_\_\_\_

Name of primary cook: \_\_\_\_\_

Household contact: \_\_\_\_\_

Household address/location: \_\_\_\_\_

What is the Primary Stove Used in the Household?

- Three Stone Fire
- Jiko
- Chitetezo
- Other \_\_\_\_\_

What Type of Fuel is Used in all Stoves in the Household?

- Wood
- Crop residue
- Charcoal
- Other \_\_\_\_\_

Average moisture content of wood (if used): \_\_\_\_\_

Average fuel dimensions

- Under 2 cm
- 2-3 cm
- 3-4 cm
- 4-5 cm
- Larger than 5 cm

Number of Stoves in the Household: \_\_\_\_\_

Main Material of Primary Stove

- Steel
- Fired clay/ceramic

- Rock
- Bricks
- Mud/unfired clay
- Aluminium
- Other: \_\_\_\_\_

Height of Primary Stove: \_\_\_\_\_

Diameter of Primary Stove: \_\_\_\_\_

Diameter of Most Common Pot: \_\_\_\_\_

Rank how Common the Cooking Practices Below are

<b>Cooking Practice</b>	<b>Never Done</b>	<b>Rarely Done</b>	<b>Sometimes Done</b>	<b>Often Done</b>	<b>Done for Almost Every Meal</b>
<b>Boiling/Simmering</b>					
<b>Steaming</b>					
<b>Continuously Stirring</b>					
<b>Pan frying</b>					
<b>Direct Fire</b>					

Use of a Pot Cover (lid)

- Always used
- Sometimes used
- Rarely used
- Never used

Shutdown Practice for Primary Stove

- Fire left to burn out (fuel and coals not touched)
- Charcoal and wood removed soon after cooking event to stop fire
- Water dumped on fuel
- Sand/dirt dumped on fuel
- Coal bed spread out to allow fire to die out

- Fuel and charcoal removed after flame dies out but before stove is cold
- Fuel removed after flame dies out, charcoal never removed
- Fire is rarely ever shutdown between cooking events and is fed between events
- Other \_\_\_\_\_

Is the Remaining Charcoal Used for a Fire Later?

- Yes
- No

## Appendix E - Specific Heat of Ingredients

Appendix C is a table with the specific heat values of different food ingredients. This table may be referenced when completing the data entry sheet. The table includes sources for values and assumptions that were made when necessary. Additional resources may be used to find the specific heat of specific ingredients.

Food	Specific Heat (kJ/(kgC))	Source	Notes
Apples	3.64	1	
Apricots, fresh	3.68	1	
Artichokes	3.64	1	
Asparagus	3.94	1	
Asparagus beans	3.68	1	
Avocados	3.01	1	
Bacon	2.01	1	
Bananas	3.35	1	
Barracuda	3.35	1	
Bass	3.43	1	
Beef, carcass	2.85	1	
Beef, corned	2.64	1	
Beef, flank	2.34	1	
Beef, hamburger	3.52	1	
Beef, loin	2.76	1	
Beef, rib	2.81	1	
Beef, round	3.1	1	
Beef, rump	2.6	1	
Beef, shanks	3.18	1	
Beets	3.77	1	
Blackberry	3.64	1	
Blueberries	3.64	1	
Brains	3.52	1	
Broccoli	3.85	1	
Brussels sprouts	3.68	1	
Butter	2.72	1	
Butter-fish	3.22	1	
Cabbage	3.94	1	
Candy	3.89	1	
Carp	3.43	1	
Carrots	3.81	1	
Cassava dough	2.76	4	SH from wheat-cassava dough blend middle value
Cauliflower	3.89	1	
Celery	3.94	1	
Chard	3.89	1	
Cheese, cottage	3.27	1	
Cherries, sour	3.68	1	
Cherries, sweet	3.52	1	
Chicken, broilers	3.22	1	
Chicken, capons	3.68	1	
Chicken, fryers	3.1	1	
Chicken, hens	2.72	1	
Chicken, squab	3.35	1	
Chocolate (aprox.)	1.6	1	

Food	Specific Heat (kJ/(kgC))	Source	Notes
Coconut, meat and milk	2.85	1	
Coconut, milk only	3.98	1	
Cod Roe	3.18	1	
Codfish	3.6	1	
Corn dough	1.39	4	SH from wheat-maize
Cow-peas, dry	1.17	1	
Cow-peas, fresh	3.06	1	
Crab apples	3.56	1	
Crabs	3.52	1	
Cranberries	3.77	1	
Cream	3.77	1	
Cucumber	4.1	1	
Currants	4.06	1	
Dandelion greens	3.68	1	
Dates	0.84	1	
Eels	3.22	1	
Eggplant	3.94	1	
Eggs	3.18	1	
Endive	3.98	1	
Figs, candied	1.55	1	
Figs, dried	1.63	1	
Figs, fresh	3.43	1	
Fish, canned	3.35	1	
Fish, dry	3.6	1	SH from fish, fresh
Fish, fresh	3.6	1	
Fish, powdered	1.52	1	SH from milk, dry
Flounders	3.6	1	
Flour	1.59	1	
Frogs, legs	3.68	1	
Garlic	3.31	1	
Gizzards	3.27	1	
Goat	3.06	1	SH from lamb carcass
Goose	2.55	1	
Gooseberry	3.6	1	
Granadilla	3.52	1	
Grape juice	3.43	1	
Grapefruit	3.81	1	
Grapes	3.6	1	
Guavas	3.6	1	
Guinea hen	3.14	1	
Haddock	3.56	1	
Halibut	3.35	1	
Herring, smoked	2.97	1	
Horseradish, fresh	3.31	1	
Horseradish, prepared	3.68	1	
Ice cream	3.1	1	
Kale	3.73	1	
Kidney beans, dried	1.17	1	
Kidneys	3.39	1	
Kohlrabi	3.85	1	
Kumquats	3.56	1	
Lamb, carcass	3.06	1	
Lamb, leg	2.97	1	
Lamb, rib cut	2.55	1	

Food	Specific Heat (kJ/(kgC))	Source	Notes
Lamb, shoulder	2.81	1	
Lard	2.26	1	
Leeks	3.81	1	
Lemon juice	3.85	1	
Lemons	3.81	1	
Lettuce	4.02	1	
Lima beans	3.06	1	
Lime juice	3.89	1	
Limes	3.73	1	
Litchi fruits, dried	1.63	1	
Liver, raw beef	3.5	1	
Lobsters	3.43	1	
Loganberries	3.6	1	
Loganberry juice	3.81	1	
Maize Flour	1.59	1	SH from flour
Milk, cow - whole pasteurized	3.77	1	
Milk, dry no fat	1.52	1	
Milk, skim	3.98 - 4.02	1	
Mushrooms, dried	1.26	1	
Mushrooms, fresh	3.89	1	
Muskmelons	3.94	1	
Nectarines	3.6	1	
Nuts, Almonds	2.2	1	
Nuts, Peanuts raw	2.23	1	
Nuts, Peanuts roasted salted	2.08	1	
Nuts, Pecans	2.17	1	
Nuts, Walnuts	2.08	1	
Olives, green	3.35	1	
Onion, Welsh	3.81	1	
Onions	3.77	1	
Orange juice	3.73	1	
Oranges, fresh	3.77	1	
Oysters	3.52	1	
Peach juice fresh	3.73	1	
Peaches, Georgina	3.64	1	
Peaches, Maryland	3.77	1	
Peaches, New Jersey	3.81	1	
Peaches, North Carolina	3.73	1	
Pears, Bartlet	3.73	1	
Pears, Beurre Bosc	3.56	1	
Pears, dried	1.63	1	
Peas, medium	3.39	1	
Peas, old	3.68	1	
Peas, split	1.17	1	
Peas, young	3.56	1	
Pepper, powdered	1.54	3	Assumed middle value
Peppers, ripe	3.81	1	
Perch	3.43	1	
Persimmons	3.01	1	
Pheasant	3.14	1	
Pickerel	3.52	1	
Pickles, sour and dill	4.02	1	
Pickles, sour mixed	3.98	1	
Pickles, sweet	3.43	1	
Pickles, sweet mixed	3.27	1	

Food	Specific Heat (kJ/(kgC))	Source	Notes
Pig's feet, pickled	2.09	1	
Pike	3.52	1	
Pineapple, fresh	3.68	1	
Pineapple, juice	3.77	1	
Pineapple, sliced or crushed	3.43	1	
Plums	3.73	1	
Pomegranate	3.56	1	
Pompano	3.22	1	
Porgy	3.39	1	
Pork, bacon	1.51	1	
Pork, ham	2.6	1	
Pork, loin	2.76	1	
Pork, salted	1.3	1	
Pork, shoulder	2.47	1	
Pork, smoked ham	2.72	1	
Pork, spareribs	2.6	1	
Potato	3.43	1	
Prickly pears	3.81	1	
Prunes	3.39	1	
Pumpkin	3.85	1	
Quinces	3.68	1	
Rabbit	3.18	1	
Radishes	3.98	1	
Raisins	1.63	1	
Raspberries, black	3.56	1	
Raspberries, red	3.73	1	
Raspberry juice, black	3.81	1	
Raspberry juice, red	3.89	1	
Reindeer	3.06	1	
Rhubarb	4.03	1	
Rice, 10% moisture	1.55	1	
Rose Apple	3.73	1	
Rutabagas	3.81	1	
Salmon	2.97	1	
Salt	0.88	2	
Sand dab	3.6	1	
Sapodilla	3.81	1	
Sapote	3.06	1	
Sardines	3.22	1	
Sauerkraut	3.89	1	
Sausage, beef and pork	2.34	1	
Sausage, Bologna	2.97	1	
Sausage, Bratwurst	2.97	1	
Sausage, Frankfurter	2.89	1	
Sausage, salami	1.88	1	
Shad	3.18	1	
Shrimp	3.48	1	
Skim milk	4	1	
Spanish mackerel	3.06	1	
Starch	1.75	1	
Strawberries	3.98	1	
Strawberry juice	3.31	1	
String beans	3.81	1	
Sturgeon, raw	3.48	1	
Sturgeon, smoked	2.97	1	

Food	Specific Heat (kJ/(kgC))	Source	Notes
Sugar apple, fresh	3.31	1	
Sweet potatoes	3.14	1	
Swordfish	3.35	1	
Terrapin	3.35	1	
Tomato paste	3.67	1	SH from tomato soup concentrate
Tomato soup, concentrate	3.67	1	
Tomato, juice	3.98	1	
Tomatoes, green	4.02	1	
Tomatoes, red	3.98	1	
Tongue, beef	3.1	1	
Tongue, calf	3.31	1	
Tongue, lamb	3.18	1	
Tongue, pork	3.1	1	
Tongue, sheep	2.89	1	
Tripe, beef	3.48	1	
Tripe, pickled	3.73	1	
Trout	3.43	1	
Tuna	3.18	1	
Turkey	2.81	1	
Turnips	3.89	1	
Turtle	3.52	1	
Veal, carcass	3.1	1	
Veal, flank	2.72	1	
Veal, loin	3.14	1	
Veal, quarter	3.1	1	
Veal, rib	3.06	1	
Veal, shank	3.22	1	
Venison	3.27	1	
Watercress	3.98	1	
Watermelon	3.94	1	
Whitefish	3.18	1	
Yams	3.27	1	

Sources	
1	Food and Foodstuff - Specific Heat, Engineeringtoolbox.com
2	Specific Heat of Common Substances, Engineeringtoolbox.com
3	Ghodki, Bhuendra M. et al. (2016). Thermal and Mechanical Properties of Black Pepper at Different Temperatures. Journal of Food Process Engineering.
4	Oladunmoye, Olufunmilola O. et al. (2012). Thermo-physical Properties of Composite Bread Dough with Maize and Cassava Flours. Institute of Food Science and Technology.

## Appendix F - Specific Heat of Liquid

Appendix D is a table with the specific heat values of different liquids. This table may be referenced when completing the data entry sheet. These values were obtained from Engineering Toolbox. Additional sources may be used to find the specific heat of other liquids if necessary.

<b>Food</b>	<b>Specific Heat (kJ/(kgC))</b>
Alcohol, ethyl 32°F (ethanol)	2.3
Alcohol, ethyl 104°F (ethanol)	2.72
Castor Oil	1.8
Citron Oil	1.84
Linseed Oil	1.84
Light Oil, 60°F	1.8
Light Oil, 300°F	2.3
Milk	3.93
Oil, Castor	1.97
Oil, Olive	1.97
Oil, mineral	1.67
Oil, vegetable	1.67
Olive oil	1.97
Sesame oil	1.63
Soya bean oil	1.97
Water, fresh	4.19
Water, sea 36°F	3.93

## Appendix G - Gross Calorific Values of Wood Species

Appendix E is a table of gross calorific values of wood from various types of trees. This table may be referenced when completing the data entry sheet. The table includes sources for where each value was obtained.

Tree species	Gross Calorific Value (kJ/kg)	Source
Abies Balsamea (Balsam Fir)	18916.15	2
Abies Religiosa (Oyamel)	20070	5
Acacia Auriculiformis (Ear-Leaf Acacia, Ear-Pod Wattle)	20370	1
Acacia Caffra (SenegaliaCaffra, Hook-thorn)	19810	5
Acacia Davyi (Cork-bark Thorn, Corky Thorn, Paper-bark Thorn, Paper Thorn, Paper-bark Tree)	19290	5
Acacia Dealbata (Silver Wattle, Blue Wattle, Mimosa)	19260	5
Acacia Decurrens (King Wattle, Green Wattle, Sydney Black Wattle)	18700	4
Acacia Farnesiana (Sweet Acacia, Sweet Wattle)	19200	4
Acacia Karroo (Vachellia Karroo, Sweet Thorn, Common Acacia, Karoo Thorn, Cape Gum, Cockspur Thorn)	18770	5
Acacia Leucophloea (Kikar, Kuteera Gum)	21800	4
Acacia Mearnsii (Black Wattle)	19530	1
Acacia Melanoxylon (Australian Blackwood)	19320	5
Acacia Nilotica (Egyptian Thorn, Babul (India), Babar (Pakistan))	20475	1
Acacia Sieberiana (Vachellia Sieberiana, Paperback Thorn, Paperback Acacia)	19370	5
Acacia Tortilis (Umbrella Thorn)	18480	1
Acer Rubrum (Red Maple)	18544.79	2
Agathis Robusta (Queensland Kauri (Pine), Smooth-barked Kauri)	20290	5

Albizia Adianthifolia (Fabaceae, Flat-crown)	19900	5
Albizia Falcataria (Batai, Malucca Albizia, Placata)	18100	4
Albizia Lebbeck (Lebbek, East Indian Walnut Tree)	21840	1
Albizia Procera (Albicia, Silver Bark Rain Tree)	19700	4
Alnus Nepalensis (Nepal Alder)	17150	4
Alnus Rubra (Red Alder)	19320	1
Alstonia Macrophylla (Devil Tree)	19200	4
Anogeissus Latifolia (Axle-Wood Tree, Dhausa (Hindi))	20580	1
Anthocephalus Cadamba (Labula (Indonesia))	19350	4
Antidesma Ghaessimbilla	19100	4
Apodytes Dimidiata (White Pear, umDakane)	19700	5
Araucaria Angustifolia (Parana Pine, Brazilian Pine, Candelabra Tree)	20220	5
Anthocleista Grandiflora (Forest Fever Tree)	19810	5
Average Hardwood	19734	3
Average Softwood (Conifer)	20817	3
Avicennia Officinalis (Mangrove, Api-Api Sudu (Philippines))	18500	4
Balanites Aegyptiaca (Desert Date, Thorn Tree, Soapberry Tree)	19320	1
Berchemia Zeyheri (Pink ivory, Purple Ivory, Red Ivory, Umnini, Umgoloty)	19570	5
Bridelia Micrantha (Mitzeeri, Costal Golden-leaf)	18990	5
Bruguiera Gymnorrhiza (Black Mangrove, Large-Leafed Mangrove)	20400	4
Bruguiera Parviflora (Thua Shale, Slender-Fruited Orange Mangrove)	18700	4
Bruguiera Sexangula (Orange Mangrove)	19400	4
Burkea Africana (Wild Syringa, Bambara)	20720	5
Calliandra Calothyrsus (Calliandra)	19425	1

Carya Spp (Hickory)	18684.05	2
Cassia Fistula (Cassia Stick Tree, Guayaba Cimarrona, Canafistula, Golden Shower, Indian Laburnum, Baton Casse, Chacara, Nanban-Saikati, Kachang Kayu (Woody Bean), Kallober, Keyok, Klober)	18400	4
Cassia Siamea (Siamese Cassia)	18800	4
Cassine Peragua (Cape Saffron, Bastard Saffron, Forest Spoonwood)	19210	5
Casuarina Cunninghamiana (River oak, River Sheoak, Creek Oak)	19840	5
Casuarina Equisetifolia (Casuarina, She-Oak, Whistling Pine)	20790	1
Canthium Obovatum	18870	5
Cedrus Libani (Cedar of Lebanon, Lebanese Cedar)	20370	5
Celtis Africana (White Stinkwood)	19450	5
Ceratonia Siliqua (Carob)	19420	5
Cedrela Toona (Toona Ciliata, Red Cedar, Australian Red Cedar, Burma Cedar, Indian Cedar, Moulmein Cedar, Queensland Red Cedar)	19930	5
Ceriops Tagal (Tagal Mangrove, Kandal)	19600	4
Cinnamomum Camphora (Camphora Officinarum)	20280	5
Cocus Nucifera (Coconut Palm)	19000	4
Colophospermum Mopane (Mopane, Mopani, Balsam tree, Butterfly Tree, Turpentine Tree)	20390	5
Cordia Dichotoma (Anunang (Philippines), Bird Lime Tree)	18400	4
Croton Sylvaticus (Forest Fever-berry)	19170	5
Cryptomeria Japonica (Sugi, Japanese Cedar, Japanese Redwood)	20250	5
Cupressus Lusitanica (Mexican Cedar, Cedar-of-Goa)	20410	5
Cupressus Torulosa (Himalayan Cypress, Bhutan Cypress)	21250	5
Curtisia Dentata (Assegai Tree, Cape Lancewood)	18840	5

Dalbergia Latifolia (East Indian Rosewood, Malabar Rosewood, Sitsal, Beete, Shisham)	19800	4
Dalbergia Sissoo (Sissoo, Shisham, Karra, Shewa)	21210	1
Derris Indica (India: Pongam, Ponga, Kona, Kanji, Karanja, Karanda; English: Indian Beech)	19320	1
Dichrostachys Cinerea (Sicklebush, Bell Mimosa, Chinese Lantern Tree, Kalahari Christmas Tree)	19860	5
Diospyros Philippinensis (Kamagong (Philippines))	18600	4
Diospyros Pilosanthera (Bolong-Eta (Philippines))	18100	4
Diospyros Whyteana (Bladdernut, Swartbas, Wild Coffee, umTenatane)	19160	5
Dombeya Rotundifolia (Dikbas, South African Wild Pear)	19330	5
Emblca Oficinalis (Madre De Cacao, Kakauati (Philippines), Mexican Lilac, Madera Negra)	21840	1
Erythrina Lysistemon (Coral-tree, Lucky Bean Tree)	19000	5
Eucalyptus Camaldulensis (Red River Gum, Red Gum)	20160	1
Eucalyptus Deglupta (Rainbow Gum Tree)	18700	4
Eucalyptus Globulus (Southern Blue Gum, Fever Tree)	20160	1
Eucalyptus Grandis (Rose Gum, Grand Eucalyptus)	19750	4
Fagus Spp (Beech)	18916.15	2
Faurea Saligna	20440	5
Ficus Sycomorus (Sycamore Fig, Fig-mulberry)	19500	5
Gigantochloa Apus (Pring Tali, Tabasheer Bamboo)	18400	4
Gliricidia Sepium	20580	1
Gmelina Arborea (Gmelina, Gumhar (India))	20160	1
Gonioma Kamassi (Kamassi, Igala-gala)	20160	5
Grevillea Robusta (Southern Silky Oak, Silk Oak, Silky Oak, Silver Oak, Australian silver Oak)	20320	5
Halleria Lucida (Tree Fuchsia, umBinza, Notsung)	19570	5

Heteropyxis Natalensis (Lavender Tree)	19890	5
Ilex Mitis (Cape Holly, African Holly, Waterboom, umDuma)	19370	5
Jacaranda Mimosifolia (Blue Jacaranda, Black Poui, Napur, Fern Tree)	20030	5
Kirkia Acuminata (White Seringa)	19500	5
Lagerstroemia Speciosa (Queen's Crape Myrtle, Giant Crape Myrtle)	19300	4
Leucaena Leucocephala (Leucaena, Ipil-Ipil (Philippines), Uaxin (Latin America), Lamtora (Indonesia), Lead Tree)	18480	1
Liquidambar Styraciflua (American Sweetgum, American Storax, Hazel Pine, Bilsted, Redgum, Satin-walnut, Star-leaved Gum, Alligator wood, Sweetgum)	19280	5
Lophostemon Confertus (Brush Box, Queensladn Box, Brisbane Box, Pink Box, Box Scrub, Vinegartree)	20080	5
Mangifera Indica (Mango tree)	15652.34	6
Maytenus Acuminata (Silky Bark, umNama, Sybas)	19250	5
Maytenus Heterophylla (Gymnosporia Heterophylla, Common Spike-thorn)	19440	5
Maytenus Peduncularis (Cape Blackwood)	19800	5
Melia Azedarach (China Berry, Persian Lilac, Bead Tree, Cape Lilac)	21459.9	1
Ocotea Kenyensis	19630	5
Parinari Curatellifolia (Bambara)	19830	5
Peltophorum Africanum (Weeping Wattle)	19970	5
Pinus Elliottii (Southern Pine)	19960.6	2
Pinus Patula (Patula Pine, Spreading-leaved Pine, Mexican Weeping Pine)	20420	5
Pinus Ponderosa (Ponderosa Pine)	18684.05	2
Pinus Roxburghii (Char Pine, Longleaf Indian Pine)	20470	5
Pithecellobium Dulce (Quamachil, Guamuchil (Mexico), Manila Tamarind)	22680	1

Platanus Occidentalis (Sycamore)	18544.79	2
Platylophus Trifoliatu	19410	5
Podocarpus Falcatus (Common Yellowwood, Bastard Yellowwood, Outeniqua Yellowwood, African Pine Tree, Weeping Yew)	20400	5
Podocarpus Latifolius (Broad-leaved Yellowwood, Real Yellowwood)	20770	5
Populus Euphratica (Euphrates Poplar, Saf-Saf, Indian Poplar)	21056.7	1
Populus Trichocarpa (Black Cottonwood)	20424.8	2
Populus X Canescens (Grey Poplar)	19440	5
Prosopis Cineraria (Jand, Khejri (India))	21000	1
Prosopis Pallida (Kiawe)	19750	4
Pseudotsuga Menziesii (Douglas Fir)	20633.69	2
Psidium Guajava (Guava, Guayaba)	20126.4	1
Ptaeroxylon Obliquum (Sneezewood Tree)	21060	5
Pterocarpus Angolensis (African Teak, Wild Teak, Mlombwa)	20880	5
Quercus Bicolor (White Oak)	18916.15	2
Quercus Palustris (Pin Oak, Swamp Spanish Oak)	19350	5
Quercus Rubra (Red Oak)	18684.05	2
Rapanea Melanophloeos (Cape Beech, Kaaose, Boekenhout, isisCalabi)	19240	5
Rhizophora Spp (Mangrove Spp (Also Avicennia Spp))	17430	1
Rhus Lancea (African Sumac)	20170	5
Rhus Leptodictya (Searsia Leptodictya, Mountain Karee, Bergkaree)	20670	5
Sapium Sebiferum (Chinese Tallow Tree, Soap Tree, Tarchabi (Pahari) Shishum (India))	17663.1	1
Schema Noronha	20000	4
Schleichera Oleosa (Kosambi (Indonesia), Lac Tree)	18700	4

Schotia Brachypetala (Weeping Boer-bean)	20340	5
Sequoia Sempervirens (Coast Redwood, Costal Redwood, California Redwood)	20490	5
Sesbania Grandiflora (Scarlet Wisteria Tree, Agati, Corkwood Tree, West Indian Pea)	19300	4
Spirostachys Africana (Tamboti, Tambotie, Tambootie, Tambuti)	20740	5
Strychnos Decussata (Cape Teak)	20000	5
Swietenia Macrophylla (Brazilian Mahogany, Caoba, Honduras Mahogany, Big Leaf Mahogany)	20700	4
Syzygium Cordatum (Waterbessie, Water Berry)	19550	5
Syzygium Cumini (Jambolan, Java Plum)	20160	1
Terminalia Sericea (Clusterleaf, Silver Cluster-leaf, Silver Terminalia)	19970	5
Thuja Plicata (Western Red Cedar)	22513.7	2
Trema Orientalis (Charcoal-tree, Indian Charcoal-tree, Pigeon Wood, Oriental Trema, Gunpowder Tree, Nalita)	19370	5
Trema Spp	18900	1
Tsuga Canadensis (Eastern Hemlock)	19519.61	2
Tsuga Heterophylla (Western Hemlock)	19519.61	2
Ulmus Spp (Elm)	18962.57	2
Xylocarpus Granatum (Cannonball Mangrove, Cedar Mangrove)	16300	4
Xylocarpus Moluccensis (Cedar Mangrove)	15400	4
Ziziphus Mucronata (Buffalo Thorn)	18920	5
Ziziphus Mauritiana (Indian Jujube, Indian Plum)	20580	1
Ziziphus Talanai	18300	4

<b>Sources</b>	
1	NAS (1980). Firewood Crops. Washington DC, National Academy of Sciences.

2	Cheremisinoff, N. (1980). Properties of Wood. Wood for Energy Production. Ann Arbor, MI, Ann Arbor Science: 31-43.
3	Harker, A. P., A. Sandels, et al. (1982). Calorific values for wood and bark and a bibliography for fuelwood. London, Tropical Products Institute: 20.
4	FAO (1993). Energy and Environment Basics. Bangkok, Regional Wood Energy Development Program (RWEDP): 85.
5	A. A. Eberhard (1988). Calorific Values and Combustion Characteristics of South African Grown Fuelwoods. Energy Research Institute, University of Cape Town: 13-16.
6	N. S. Sonawane, et al. (2018). Fuel Properties of Charcoal from Mango ( <i>Mangifera Spp.</i> ) Tree Biomass. Green Farming: Vol. 9 No. 5

## Appendix H - Gross Calorific Values of Other Fuels

Appendix F is a table of gross calorific values of other fuel sources that may be used during the UCET procedure. Appendix E is subject to change and additions to accommodate other fuels found to be commonly used during cooking. The table includes sources for where each value was obtained.

Fuel Type	Moisture Content(%)	Gross Calorific Value (kJ/kg)	Source
Charcoal	1.7	25,700	1
Charcoal	5	29,200	2
Maize Stalks	5	15,400	3
Maize Stalks	9.1	16,100	4
Rice Stalks	5	14,200	3
Rice Stalks	8.8	13,000	1
Dung	5	15,400	3
Dung	7.3	11,800	1

Sources	
1	Smith et al, 2001
2	Pennise et al. 2002
3	RWEDP, 1993
4	Zhang et al., 2000

# Appendix I - Allowable Mass of Dried Spices that Can be Excluded

There are limited studies on the specific heat of common spices, making it difficult to enter various spices into the final calculations. Many dishes also require small amounts of multiple spices, which can become tedious to measure and enter. This section proves that spices weighing a combined mass of under 162g may be excluded from calculations.

Due to the low moisture content of dried spices, the specific heat of spices can be assumed to be low when compared to other ingredients. Two dried spices with known values are salt (0.88 kJ/kg\*K) and pepper (1.54 kJ/kg\*K), Appendix C. The calculations below use the higher specific heat (pepper) to avoid underestimating the impact of excluding spices from calculations.

The spices are assumed to be heated from room temperature to 100°C and compared to the average total sensible energy of ingredients (1000kJ) from 4 preliminary tests. The impact removing spices from the calculations was restricted to not exceed 2% of the total sensible energy (20kJ).

$$m_{spices} = \frac{\text{Sensible Energy}}{C_{p,spices} * (T_{f,spices} - T_{i,spices})}$$

Where:

$m_{spices}$  = Allowable total mass of spices that can be excluded

*Sensible Energy* = Allowable sensible energy to be excluded = 20 kJ

$C_{p,spices}$  = Specific heat of spices = 1.54 kJ/kg\*K

$T_{i,spices}$  = Initial temperature of spices = 20 C

$T_{f,spices}$  = Final temperature of spices = 100 C

Given the above, the allowable total mass of spices that can be removed is 162 g. Excluding this mass will not significantly impact the final calculated thermal efficiency.

## Appendix J - Allowable Mass of Other Ingredients that Can be Removed

Some recipes may include small amounts of ingredients. As with the spices discussion above, to make measurement easier, ingredients below a certain weight may be excluded from calculations as they will not significantly impact the final thermal efficiency.

The substance used in cooking with the highest specific heat is water (4.19 Kj/kg\*K (Engineeringtoolbox)). The calculations below will use this specific heat as to avoid underestimating the impact of excluding low mass substances from final calculations.

The ingredients are assumed to be heated from room temperature to 100C and compared to the average total sensible energy of ingredients (1000kJ) from 4 preliminary tests. The impact removing low mass ingredients from the calculations was restricted to not exceed 2% of the total sensible energy (20kJ).

$$m_{ingredients} = \frac{Sensible\ Energy}{C_{p,ingredients} * (T_{f,ingredients} - T_{i,ingredients})}$$

Where:

$m_{ingredients}$  = Allowable total mass of ingredients that can be excluded

*Sensible Energy* = Allowable sensible energy to be excluded = 20 kJ

$C_{p,ingredients}$  = Specific heat of ingredients = 4.19 kJ/kg\*K

$T_{i,ingredients}$  = Initial temperature of ingredients = 20 C

$T_{f,ingredients}$  = Final temperature of ingredients = 100 C

Given the above, the allowable total mass of ingredients that can be removed is 60g. Excluding this mass will not significantly impact the final calculated thermal efficiency. Excluding the maximum mass of spices and maximum mass of ingredients will only impact the total sensible energy by 4%.