Stove Design and Performance Training

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Our Task

To determine what will be the performance of every stove we have built for all of eternity without having to go and monitor the performance of every stove we have built for all of eternity…

Just that easy!!!!!

Rationale for the Stove Performance Testing

Demonstrate impact of ICS projects using methods that are…

- Standardized and repeatable

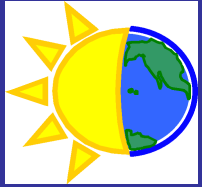- Comparable within and across projects

- Statistically sound

…*but still appropriate and flexible enough to adapt to local circumstances and constraints!*

- Caveat: Monitoring is important but question of allocation of resources

And because everything…

… 'works'

Stove Performance Testing (SPT)
Past and present

- In 1985 VITA developed a set of protocols for testing stove performance

- Functional, yet somewhat cumbersome and not generally used

- In 2003 Shell/EPA request UC Berkeley and Aprovecho to develop a new set of universally adopted SPT protocols
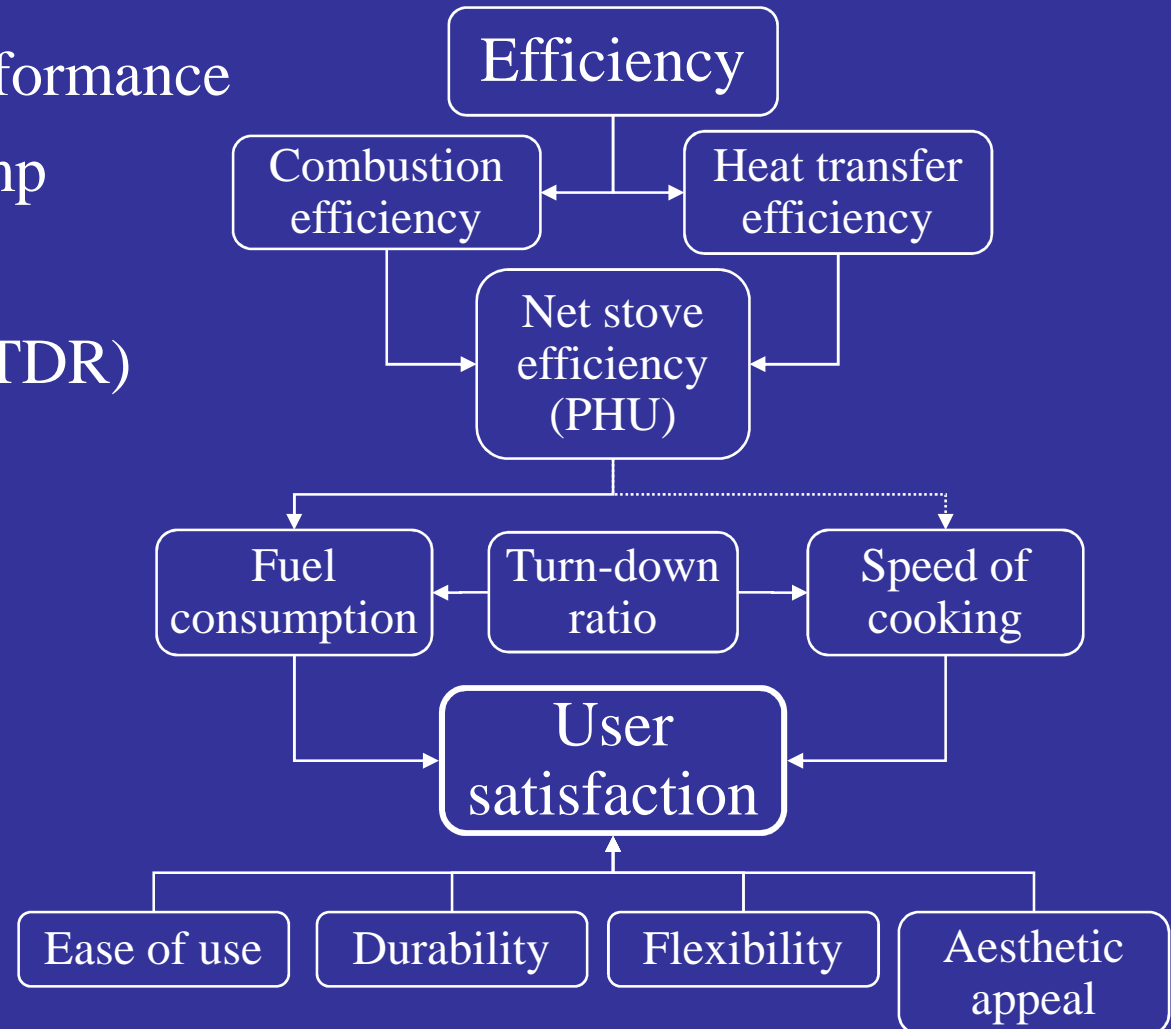
What is *Stove Performance*?

Measures of Stove Performance

1. Efficiency/exit temp
2. Fuel consumption
3. Turn-down ratio (TDR)
4. Speed of cooking
5. Emissions
6. *User satisfaction*

Efficiency

Combustion efficiency

Heat transfer efficiency

Net stove efficiency (PHU)

Fuel consumption

Turn-down ratio

Speed of cooking

User satisfaction

Ease of use | Durability | Flexibility | Aesthetic appeal

# Clarifying

Questions?

Measures of performance

1. Efficiency

Entirely lab-based

- Combustion efficiency
    - Difficult to measure directly
    - Can be approximated by measuring PICs (e.g. Smith, Uma et al. 2000)
- Heat transfer efficiency
    - Very difficult to measure directly
- PHU (Percentage Heat Utilized)

Overall Efficiency

Combustion efficiency CE ↔ Heat transfer efficiency (HTE)

Overall efficiency (PHU = CE x HTE)
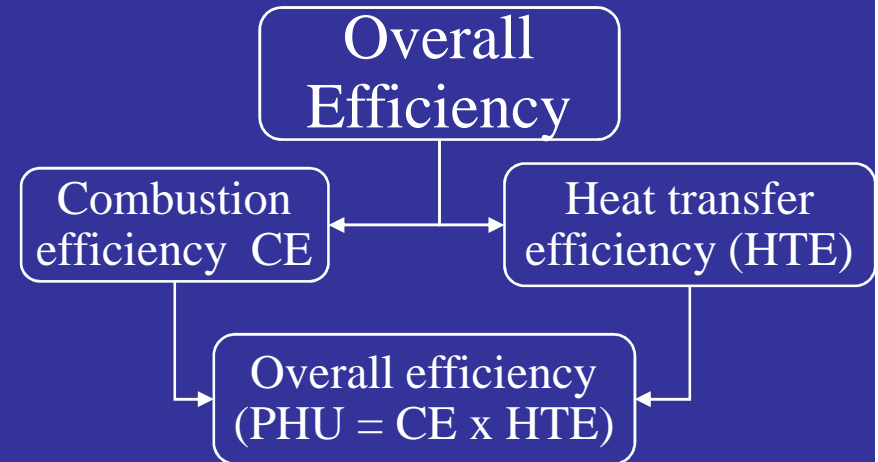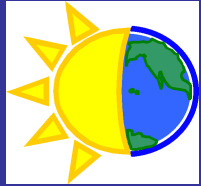
Measures of performance

1. PHU (Efficiency)
   - Fairly easy to measure directly (assuming fuel HV is known)

$$\cdots\cdots\blacktriangleright \quad \frac{\text{Energy into the food (or water)}}{\text{Fuel energy consumed}}$$

•Energy into food = energy it took to the rise in water temp (called sensible heat) + energy required to evaporate water (called latent heat)

Fuel energy consumed is found by taking the energy in the amount of wood consumed and subtracting the energy left in the charcoal*
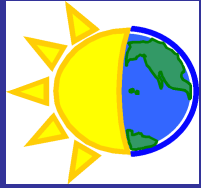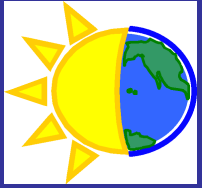
Measures of performance

1. PHU
   - Fairly easy to measure directly (assuming fuel HV is known)
   -

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$$\frac{\text{Energy into the food (or water)}}{\text{Fuel energy consumed}}$$

• So if we compare 2 stoves, the one with the higher PHU is the "better" stove right ?

• Not necessarily! Because PHU rewards the stove that makes a lot of steam
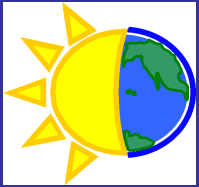
Measures of performance

2. Specific Consumption- The amount of fuel needed to complete a particular task (example: boil a kilo of water, cook a kilo of food, or bake a kilo of bread)

For us this is the most useful number to make a guess as to which stove will most likely save fuel in real use

$$\text{Specific consumption} = \frac{Mw - 1.5Mc}{Wf}$$
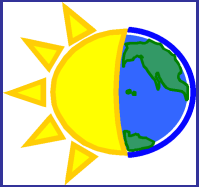
Specific Consumption vs. PHU

Stove 1

- Time to boil   10 minutes
- Wood burned   1000 grams
- Water vaporized   100 grams
- Water remaining   4.9 liters

Stove 2

- Time to boil   100 minutes
- Wood burned   1000 grams
- Water vaporized   1000 grams
- Water remaining   4.0 liters

Specific Consumption vs. PHU

Stove 1

- Time to boil   10 minutes
- Wood burned   1000 grams
- Water vaporized   100 grams
- Water remaining   4.9 liters

Stove 2

- Time to boil   100 minutes
- Wood burned   1000 grams
- Water vaporized   1000 grams
- Water remaining   4.0 liters

Eff= 9.9 %

SC = 204 grams/litre

Eff= 21.3%

SC = 250 grams/liter

Measures of performance

3. Turn-down ratio (TDR) or Control efficiency

- For the most part cooking has two parts

    a- high power (bringing to a boil)

    b- low power (simmering)

- TDR is ratio of high to low power

- Stoves with large TDRs can be operated more efficiently and may be more preferable to users

- When a stove has a high TDR (a large difference in fuel consumption between boiling and simmering phase) this is a good indicator that the stove will use less wood

Measures of performance

4. Speed of cooking

   This is a measure more of user friendliness then fuel consumption

   Can be either lab or field-based

   – Lab-based, easy to measure

       - Cooking is simulated (not directly predictive of real household use)

   – Field-based

       - Can be measured directly, but better to rely on survey

Measures of performance

5. Emissions

Testing of emissions/exposure/dose is a much less exact science without proper equipment

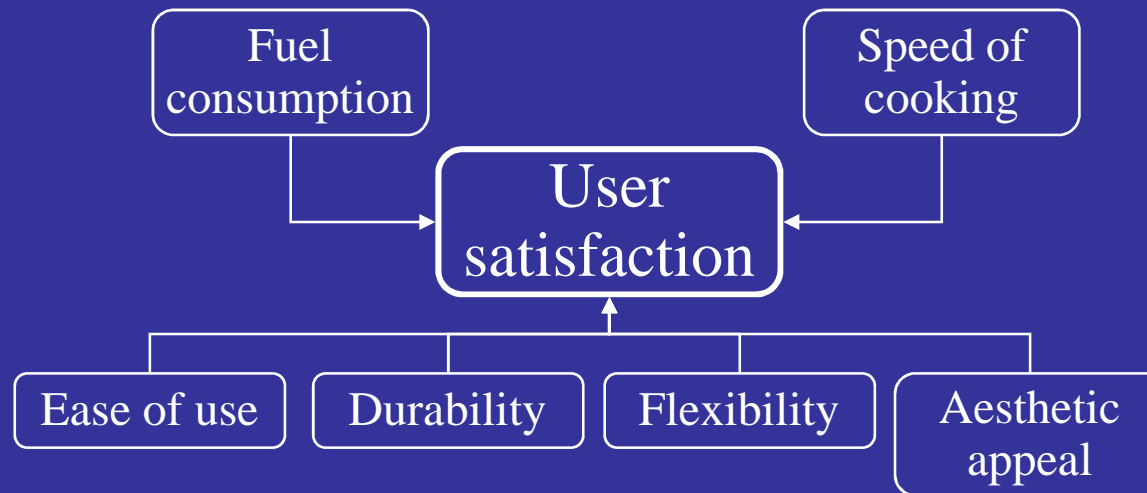With PEMS/IAP meter we hope to make this more accessible

Measures of performance

6. Overall User satisfaction
   – Hard to measure, subjective, and dependent on many factors

Measures of Performance

Clarifying Questions?

Water Boiling Test

1 - Based largely on VITA (1985) and Baldwin (1986) with small modifications

- **Limits Variables**
- **Transferable between various projects**

Lab-based test provides 4 of the 6 indicators of SP:

1. PHU
2. Specific Consumption
3. TDR
4. Time to boil

But its difficult to extrapolate these results to actual field performance without complimentary data from actual users (the CCT and KPT).

Overview of the WBT

Each WBT consists of 3 parts:

- High-power cold start
- High-power hot start
- Low-power (simmer)

And takes roughly 2 hours to complete

We recommend 3 tests of each type of stove

Sufficient to detect a 30% improvement with 95% confidence if the pooled CV of measurements is 15% and a 20% improvement in PHU if the pooled CV is 10% (more on this later).

Controlled Cooking Test (**CCT**)

- lab controlled test with added variables of an actual cook cooking real food

- Only can be used to compare two stoves from a particular project

- Compares fuel consumption (specific consumption), and speed of cooking

- Much better at predicting actual stove performance and fuel consumption in the field
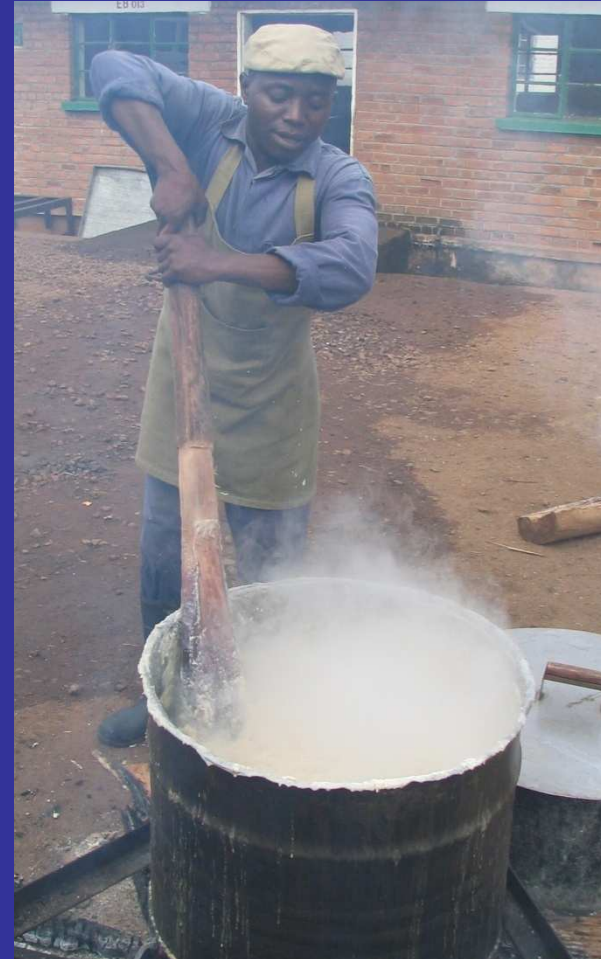
Kitchen Performance Test **KPT**

More complex than WBT:

–Both qualitative survey and quantitative measurements

–Takes stove testers into peoples households

–Sampling procedure and study design are critical

–Variability in "real-world" setting increases the number of samples needed to make results statistically valid (more later).

–Gives daily wood consumption and gauges user satisfaction

Where to find the detailed tests

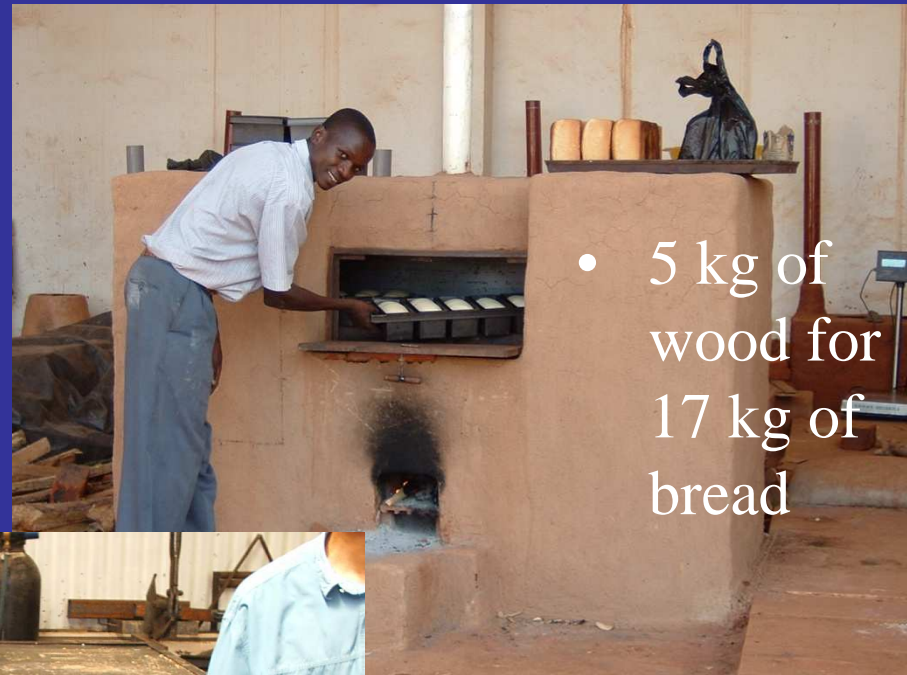http://www.aprovecho.org/lab/pubs/testing

Clarifying

Questions?

Rocket Bread Oven

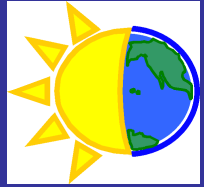200 kg of wood for 17 kg of bread

- 5 kg of wood for 17 kg of bread

08/30/2003

A visual comparison between the quantity of wood used (170kg) for the open fire vs. the amount of wood used (13kg) by the 100L Rocket stove. Independently tested by EP Lauderdale Tea Estates (Malawi)

Stove Design and Performance

Thank You