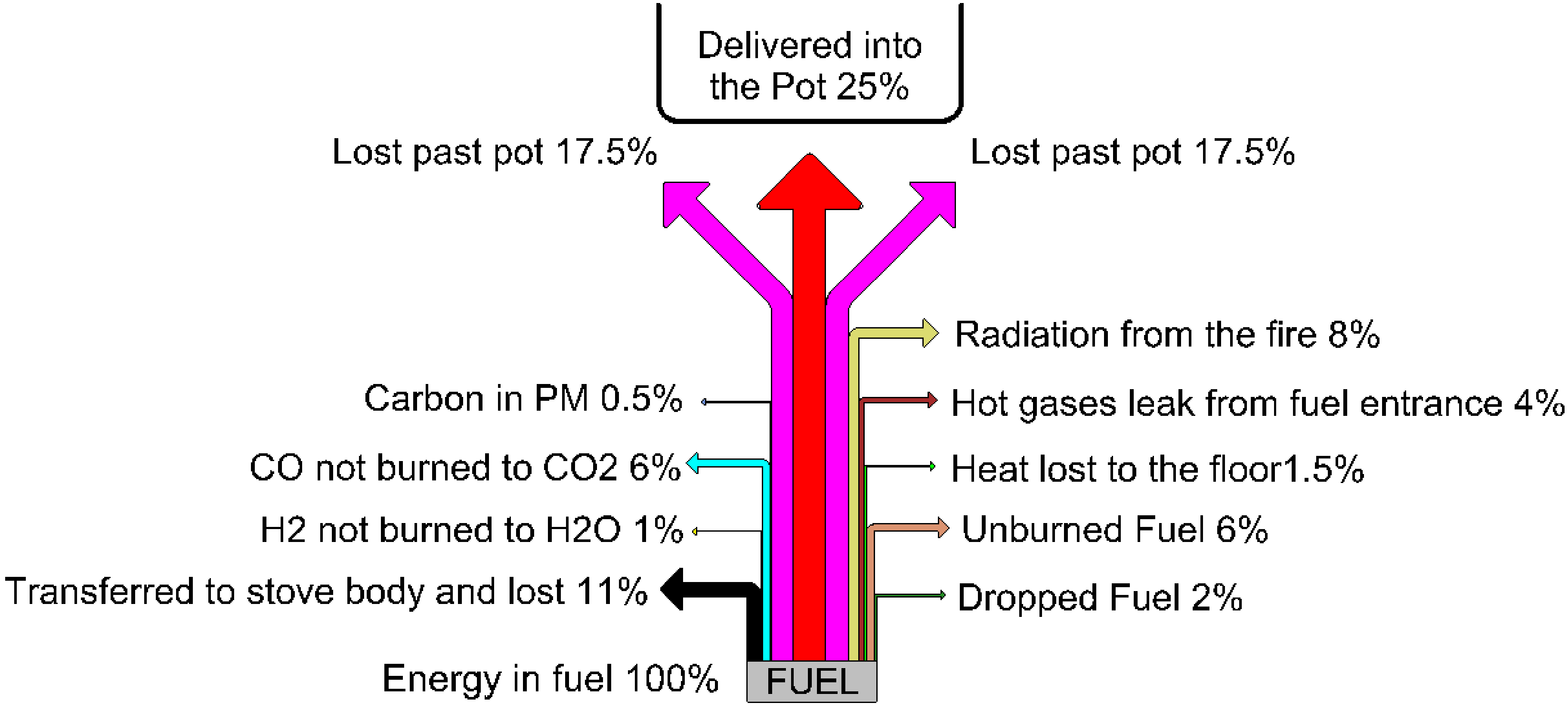
Test Theory – what is available to measure

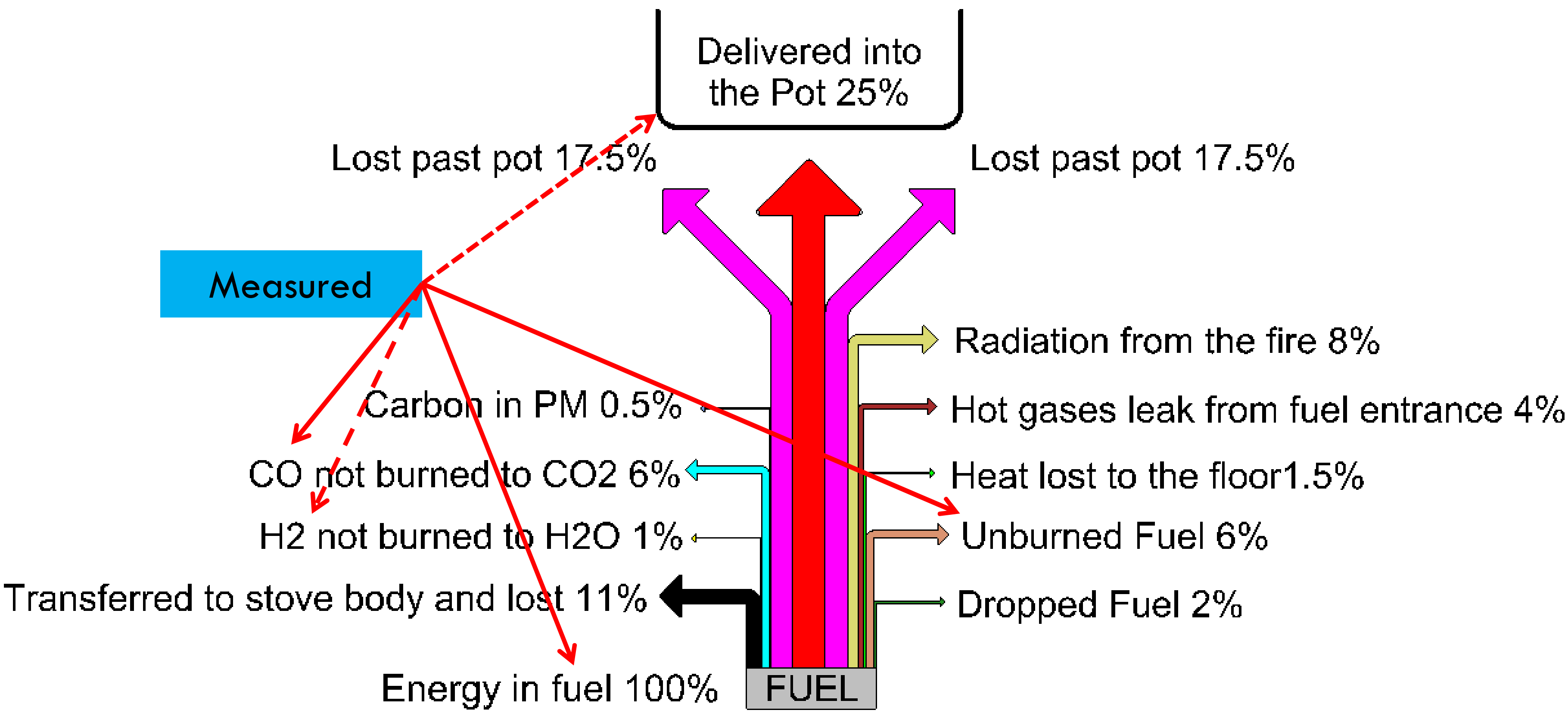
The following presentation explains where the heat goes during a cooking event, what is available to be measured, and why great care must be taken when selecting variables for analysis.

Heat Flow Diagram - Fire



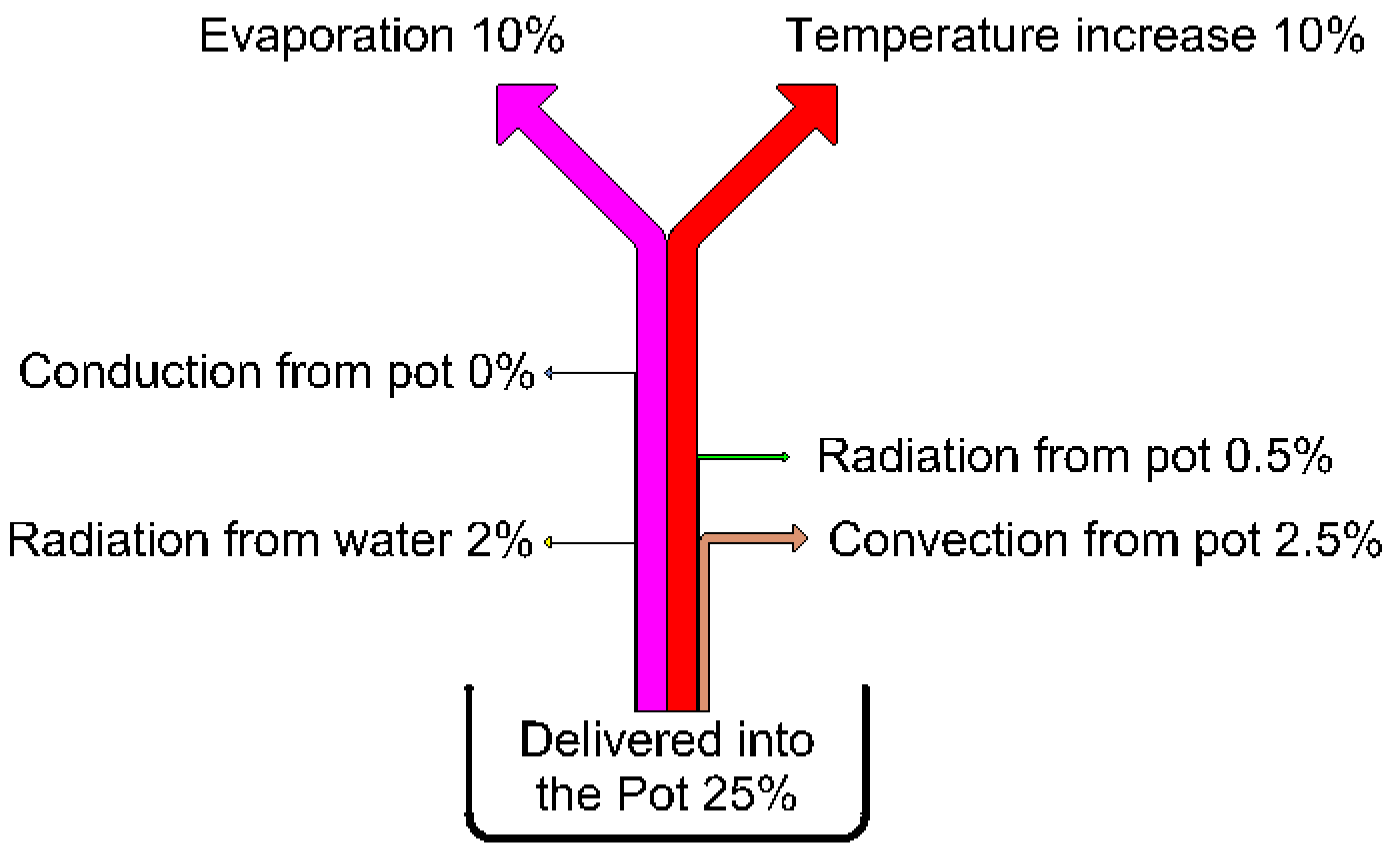
Some fuel energy paths can be measured easily. For example, heat is easier to trace than unburned fuel. Losses are chemical, mechanical or wasted heat in gases. “Efficiency” is 25%.

Heat Flow Diagram - Fire



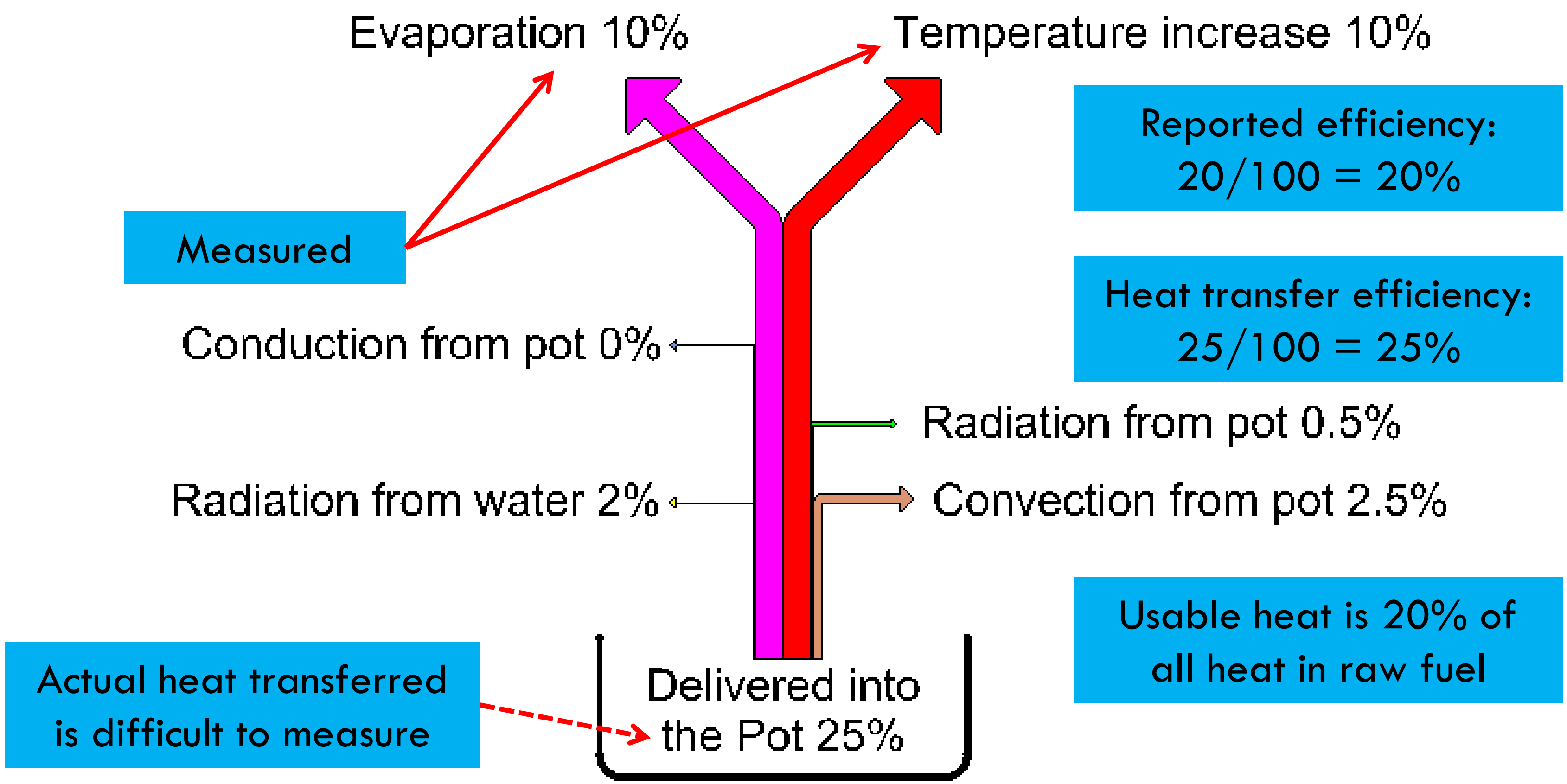
Some fuel energy flows can be measured easily. Heat flow is easier to evaluate than heat in unburned fuel. Losses are chemical, mechanical or wasted heat in gases. “Efficiency” is 25%.

Heat Flow Diagram: Cold Pot, High Power



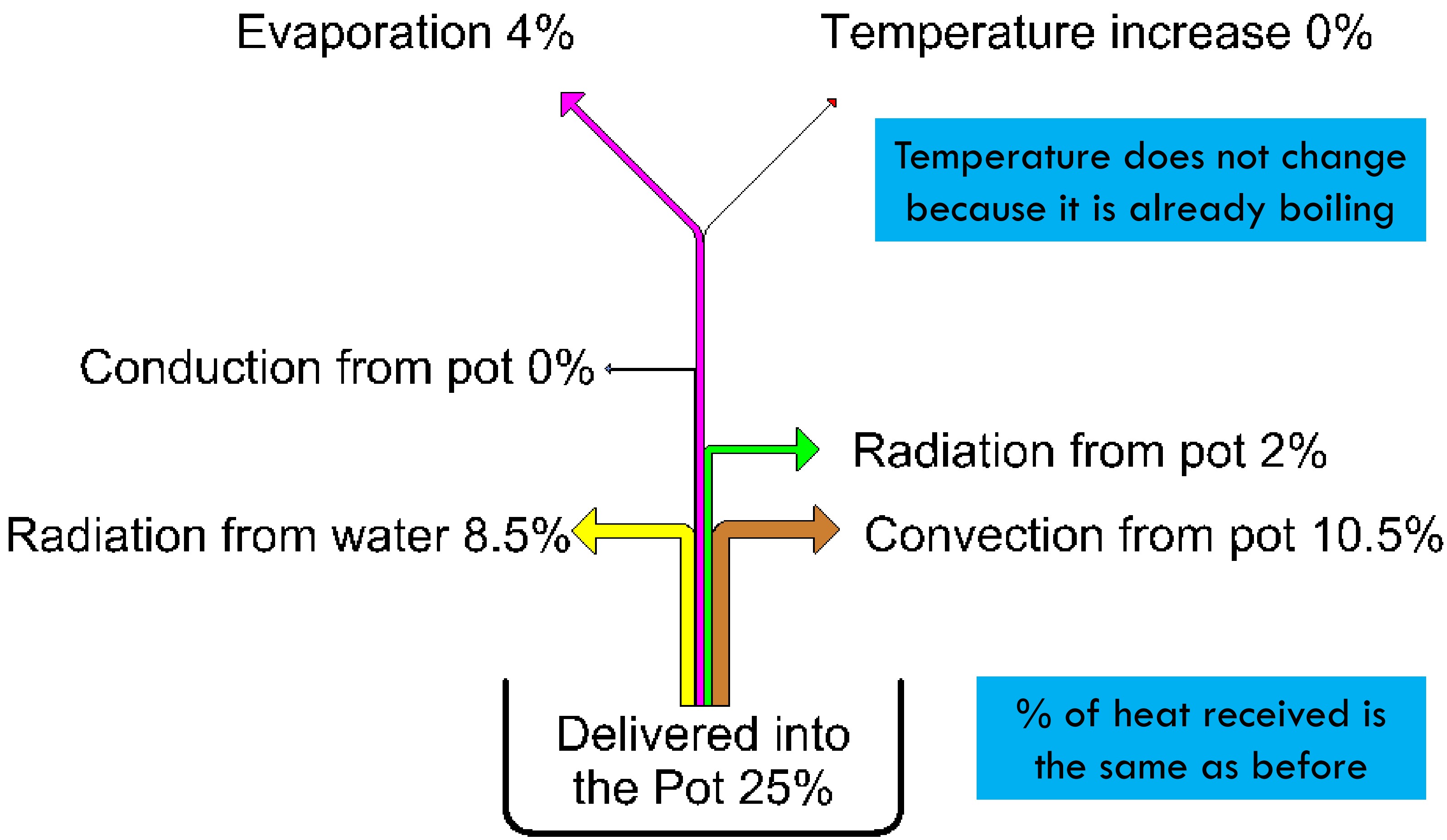
Only some fuel energy paths can be measured easily. For example, heat is easier to trace than unburned fuel. Losses can be chemical, mechanical or wasted heat in gases.

Heat Flow Diagram – Cold Pot, High Power



Only some fuel energy paths can be measured easily. For example, heat is easier to trace than unburned fuel. Losses can be chemical, mechanical or wasted heat in gases.

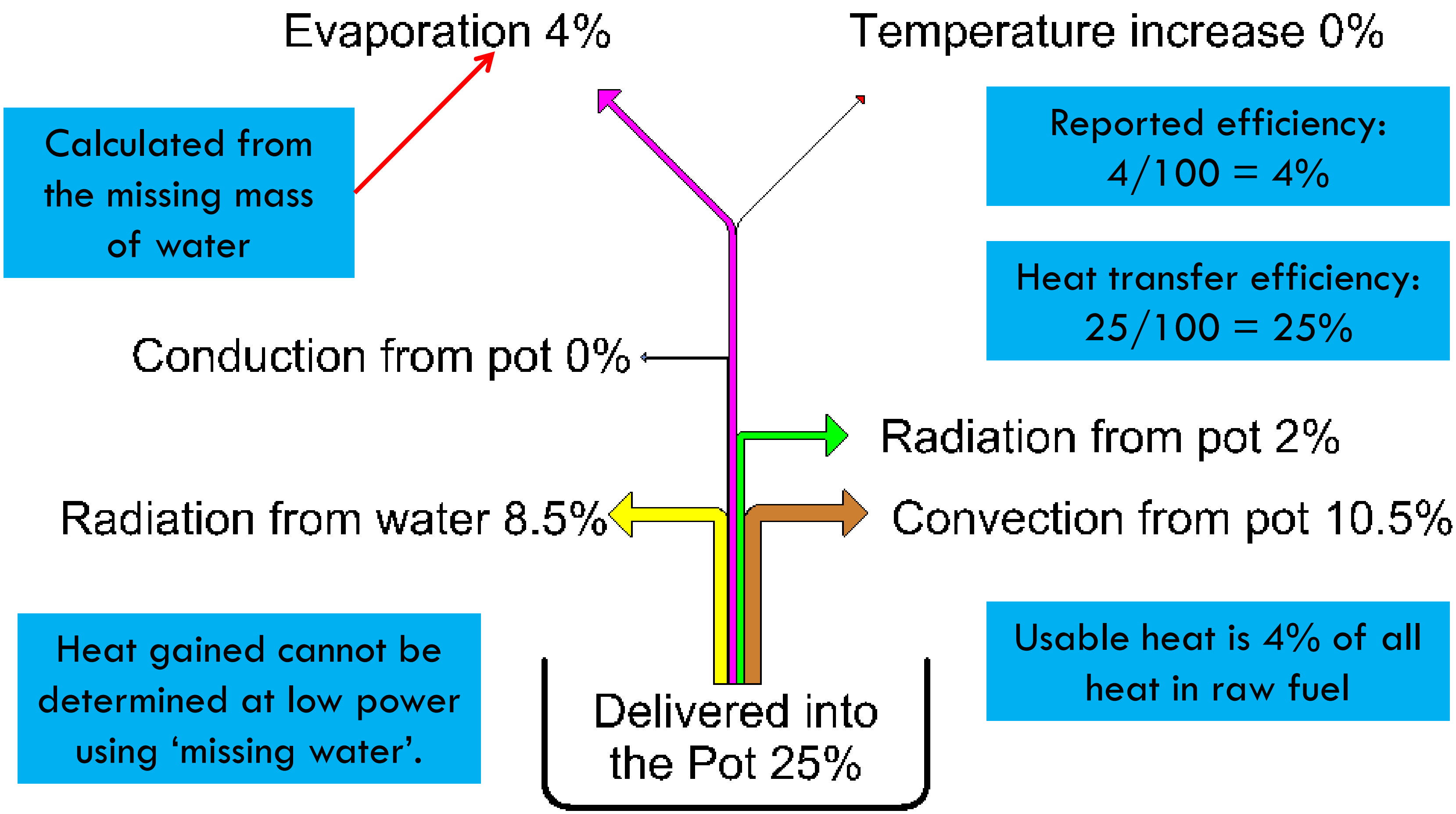
Heat Flow Diagram – Hot Pot, Low Power



Temperature does not change because it is already boiling

% of heat received is the same as before

Heat Flow Diagram – Hot Pot, Simmering



Thermal Efficiency – which one for cooking?

Efficiency is a ratio, but of what to what? Let us follow the heat and decide which 'efficiency' we want.

1. Heat available in the raw fuel if it was to be burned completely
2. Heat available in the dry portion of the raw fuel
3. Heat available from the fire considering incomplete combustion
4. Heat available to the pot, at the pot in the hot gas stream passing by

5. Heat transferred to the pot – all of it
6. Heat transferred to the pot and subsequently lost from the pot into the surrounding environment
7. Heat absorbed the pot material changing its temperature
8. Heat absorbed by the water – all of it
9. Heat absorbed by the water changing its temperature
10. Heat absorbed by the water and evaporating water (whether the water is hot or not)
11. Heat absorbed by the water and lost from the water (by radiation, not by evaporation)
12. Heat absorbed into the food and being absorbed chemically (transforming it into cooked food)

Which pair were you thinking of when asked to report the 'efficiency'?
Heat transfer efficiency is …. ?
System efficiency is …. ?
[Overall thermal efficiency] is (7+9+10+12)/1 [When 12 is boiling water only,12=0]

Thermal Efficiency – what else can we know?

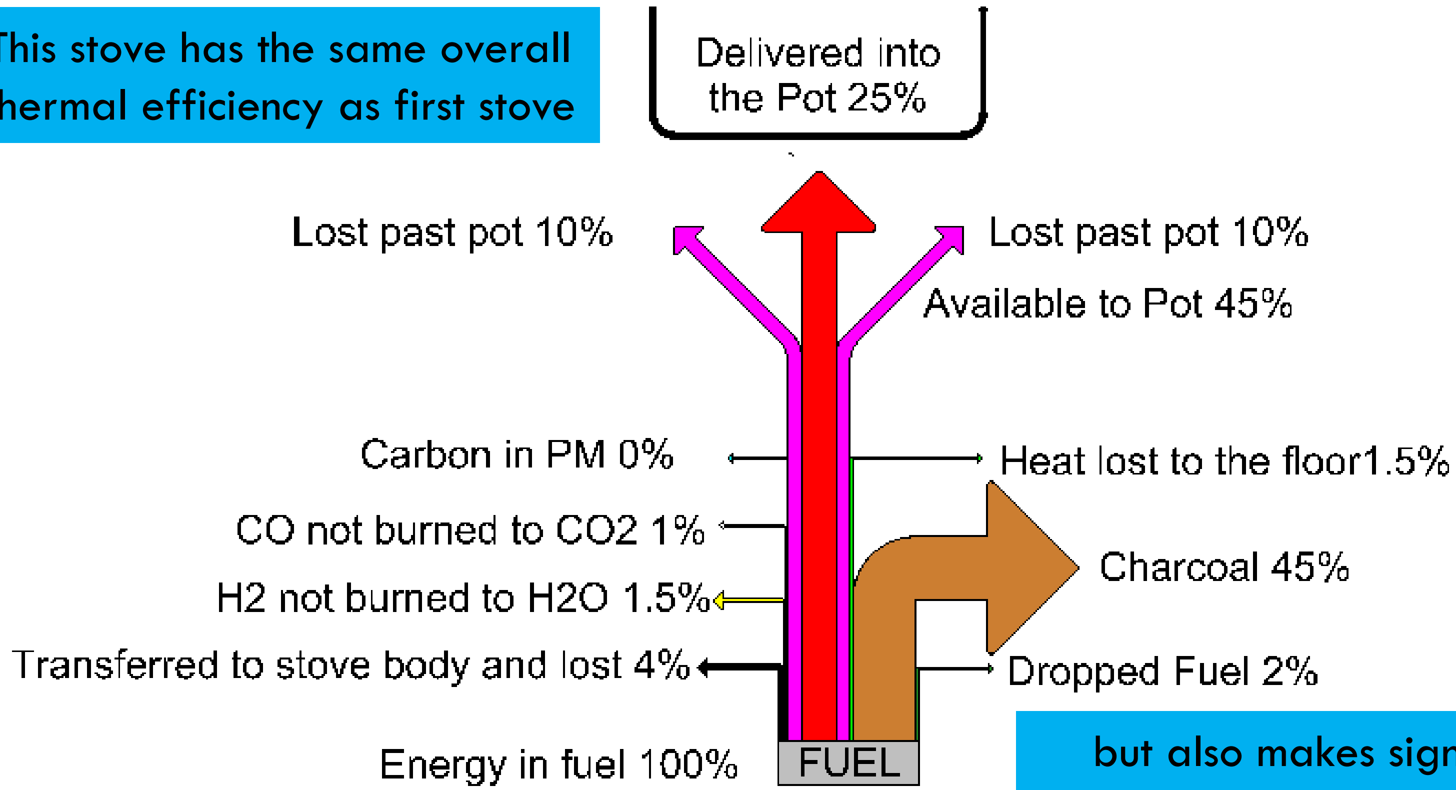
Energy reaching the pot (including the mass of the pot material)
Energy in the fuel remaining, divided in to two portions: usable fuel and unusable waste
Energy that escapes as heat that bypasses the pot and unburned H2, CO and H2S (etc) i.e. chemical losses.

The calculable outputs are:
Heat gained by the pot: quantity of heat Q [Joules], rate of heat gain Q' [Watts] and heat flow rate Q'' [Watts/cm^2]
Heat yielded by the fire considering chemical losses [J]
Energy consumption based on raw fuel consumed (potential total input energy)
Overall thermal efficiency (pot gain divided by Energy consumption)
Heat transfer efficiency (pot gain [J] divided by heat yielded [J])
Combustion efficiency (heat yielded [J] divided by heat theoretically yieldable [J])
Space heating efficiency (fire heat [J] minus chemical losses [J] and sensible heat losses [J], i.e. stack losses)
Average fuel consumption rate
Maximum power.

If the burn cycle is correctly chosen, a turn down ratio can be determined.

Heat Flow Diagram – Charcoal maker

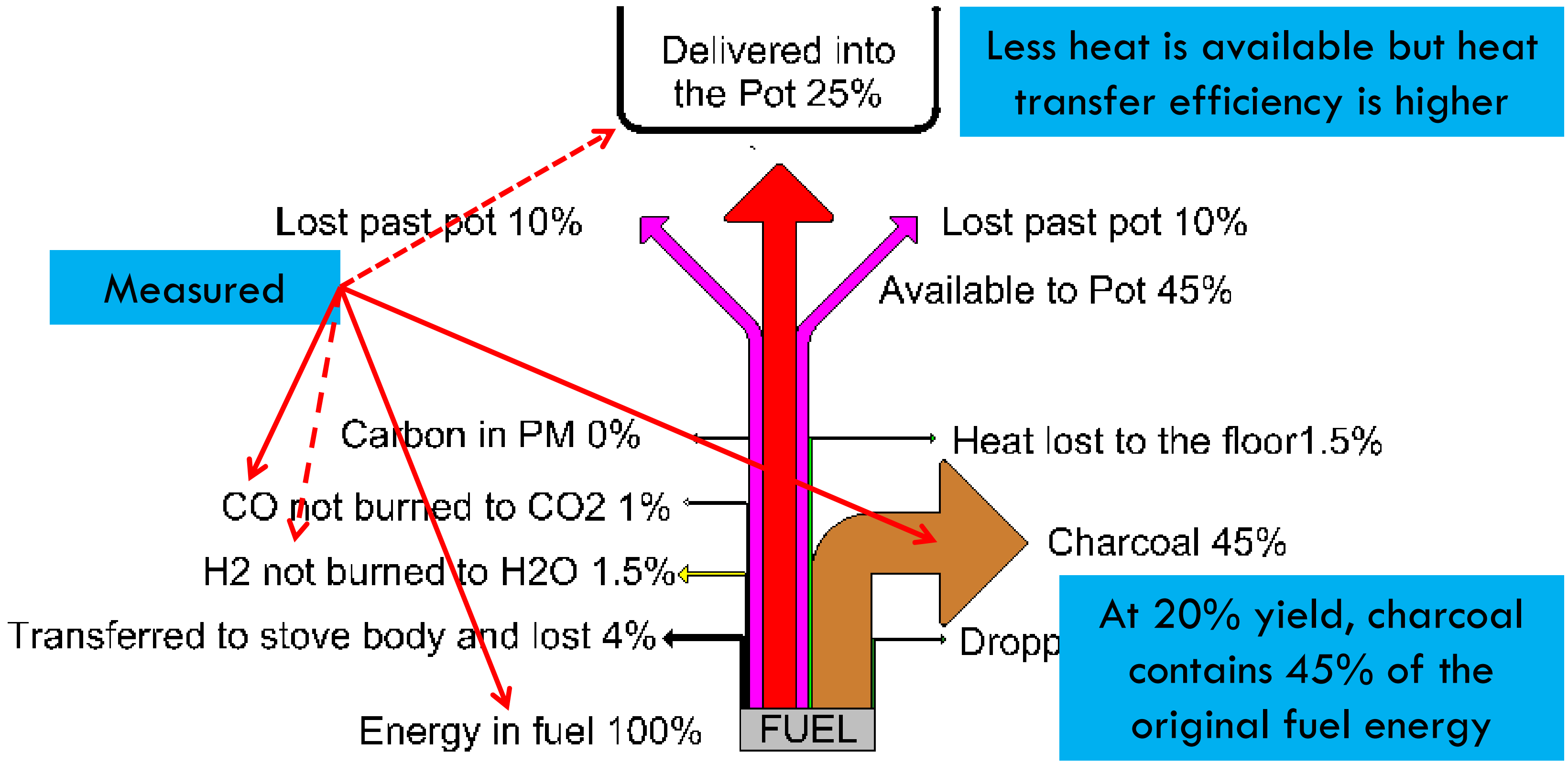
This stove has the same overall thermal efficiency as first stove



but also makes significant amounts of charcoal.

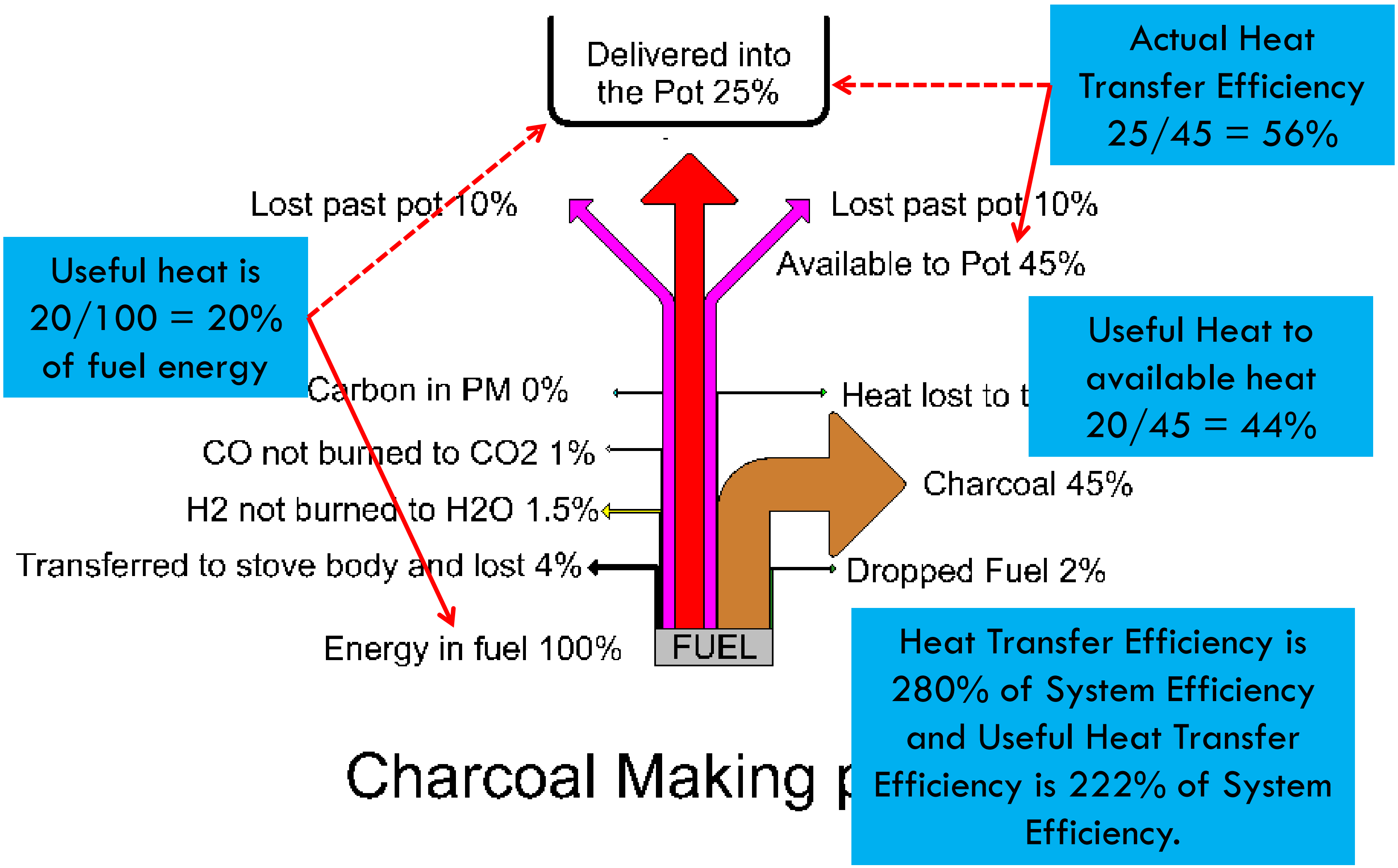
Charcoal Making pyrolyser

Heat Flow Diagram – 20% Charcoal maker



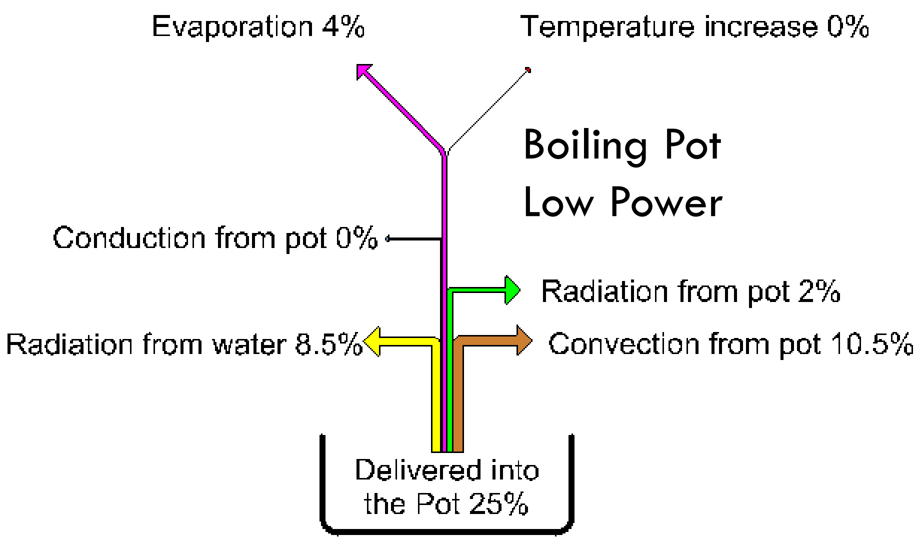
Charcoal Making pyrolyser

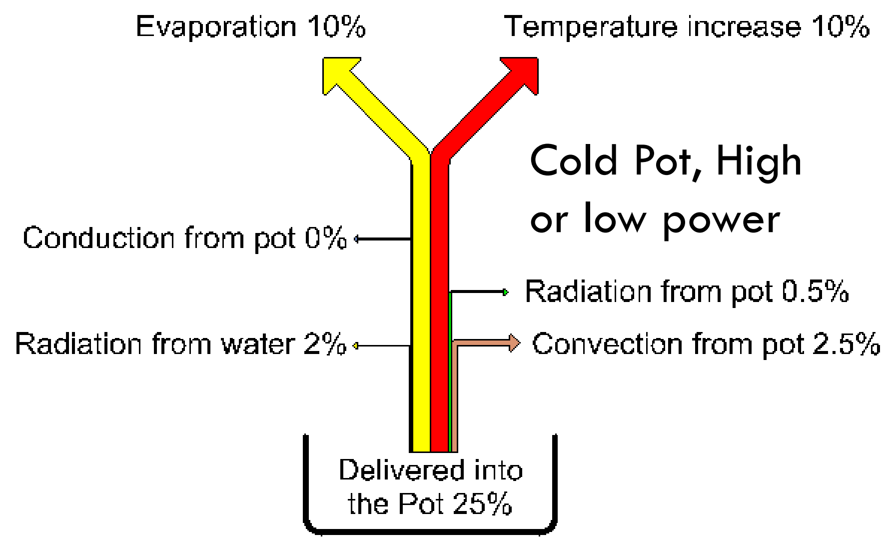
Heat Flow Diagram – Thermal efficiency



Heat Flow Diagram – Thermal efficiency determined using a boiling or cold pot with high or low power produces very different results

Efficiency of heat transfer is the same as before in both cases: 25%





Low power *reported* efficiency = 4%

High power *reported* efficiency = 20%

While heat transfer efficiency *appears to be* 4/45 = 9%

While heat transfer efficiency *appears to be* 20/45 = 44%

Heat Flow Diagram – Conclusions

- Fuel consumption (the CSI program metric) is determined by the overall thermal performance based on the energy available in the fuel and the useful heat that is retained in the pot or evaporates water (only).
- It is difficult to accurately measure the quantity of heat entering a pot if it is already hot, even at high power.
- The heat transfer efficiency does not represent the fuel consumption in most cases but is often applied as if it does.
- The overall thermal efficiency, or system efficiency, represents energy consumed, expressed as 'fuel' consumed.
- Measuring thermal performance with cold water is (by far) the most accurate method.

Performance Evaluation using cold water

- Measurements are made with cold pots of water
- Pots are changed when water is ≤70°C (India uses 95°)
- Power of the fire is varied according to the documented burn cycle
- 'Fuel remaining' **fr** is weighed and reused on two conditions:
  - the stove can burn at least *some* of the remaining fuel
  - the *local practice* is to reuse fuel remaining
- The pot-swapping procedure can be used during all burn cycles
- The measurement precision of heat gained by a pot using **ΔT** is much more accurate than measuring evaporated water mass
- The procedure for the ignition and extinction of the fire is taken from local practise which varies greatly. Improved methods of ignition and extinction are accepted as part of the standard operating procedure of an improved stove.