Development of a 465-Litre, Tier 5 Institutional Wood Stove Using Low-Resolution Real-time Flow Simulations And Novel Metrics

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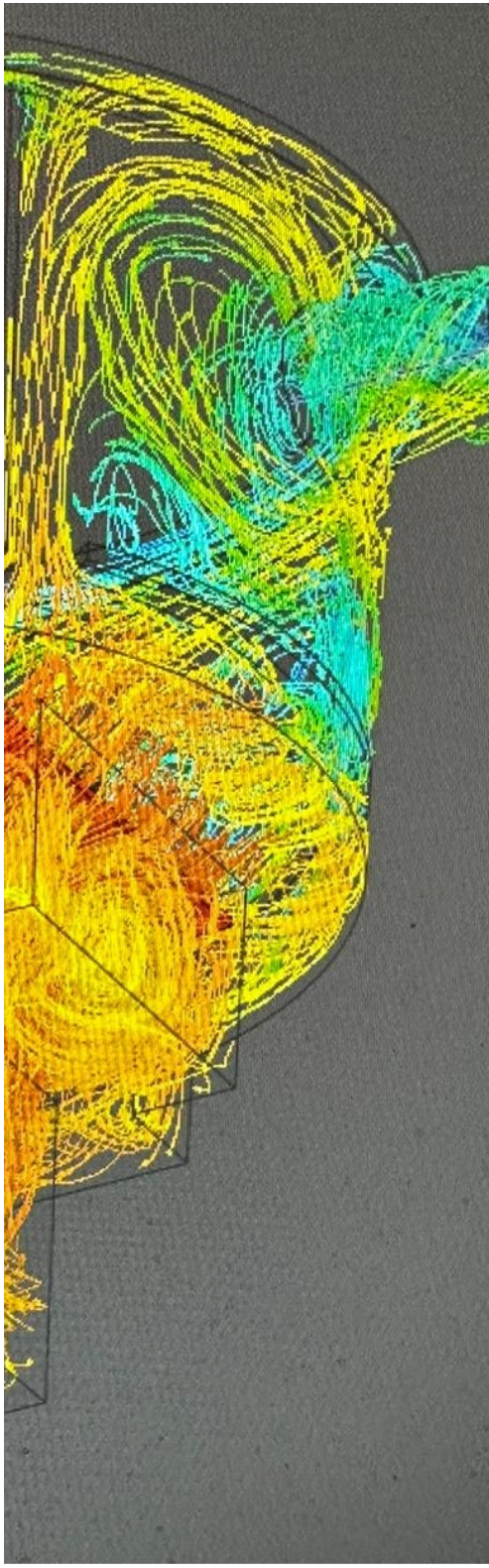


In Rwanda 77% of energy consumption is provided by wood

Schools purchase wood for cooking student meals

Traditional stove, 300 L

Typically the pot sits on a metal frame with an open fire underneath.

The cement wall provides some shelter from the wind.

Combustion zone under the pot

Many schools use more than one pot + fire

This shows two “chimney stoves” with a fuel entrance, a supported pot and a chimney at the back. Most are in this condition.

Schools serve as many as 2600 meals at once

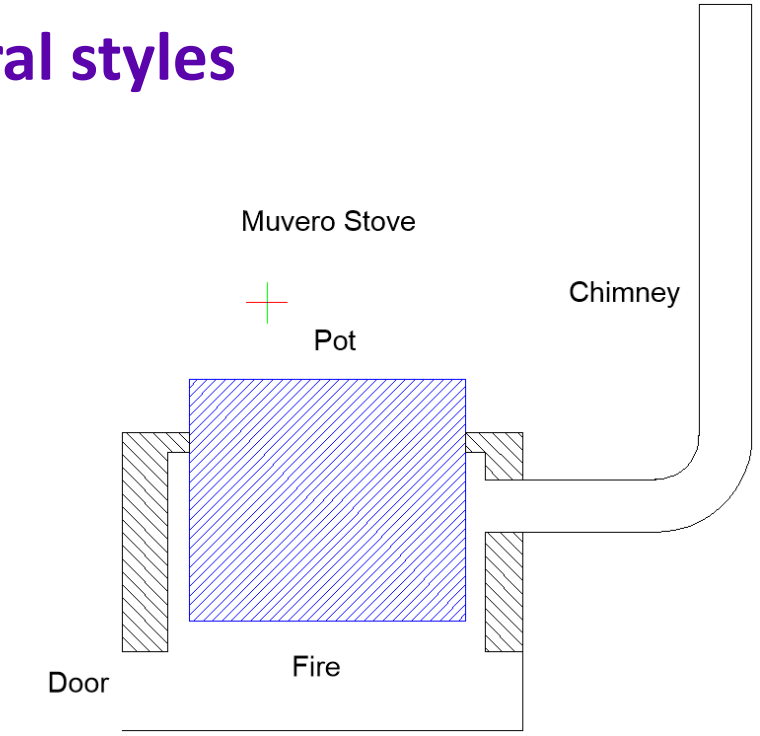
Muvero style stove

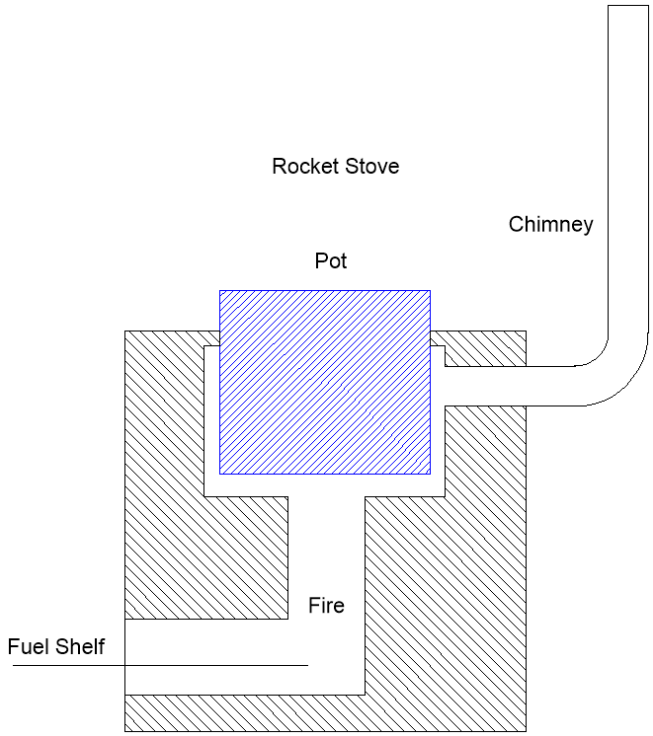
The original Muvero is from the Netherlands. These are widely copied, all with the same features:
Fuel and air entrance, drum-shaped fuel burning area under the pot, rear exit to a chimney.

This layout is common in two general styles

- One is the Muvero which has no defined combustion chamber, only a space in which the fuel is burned.

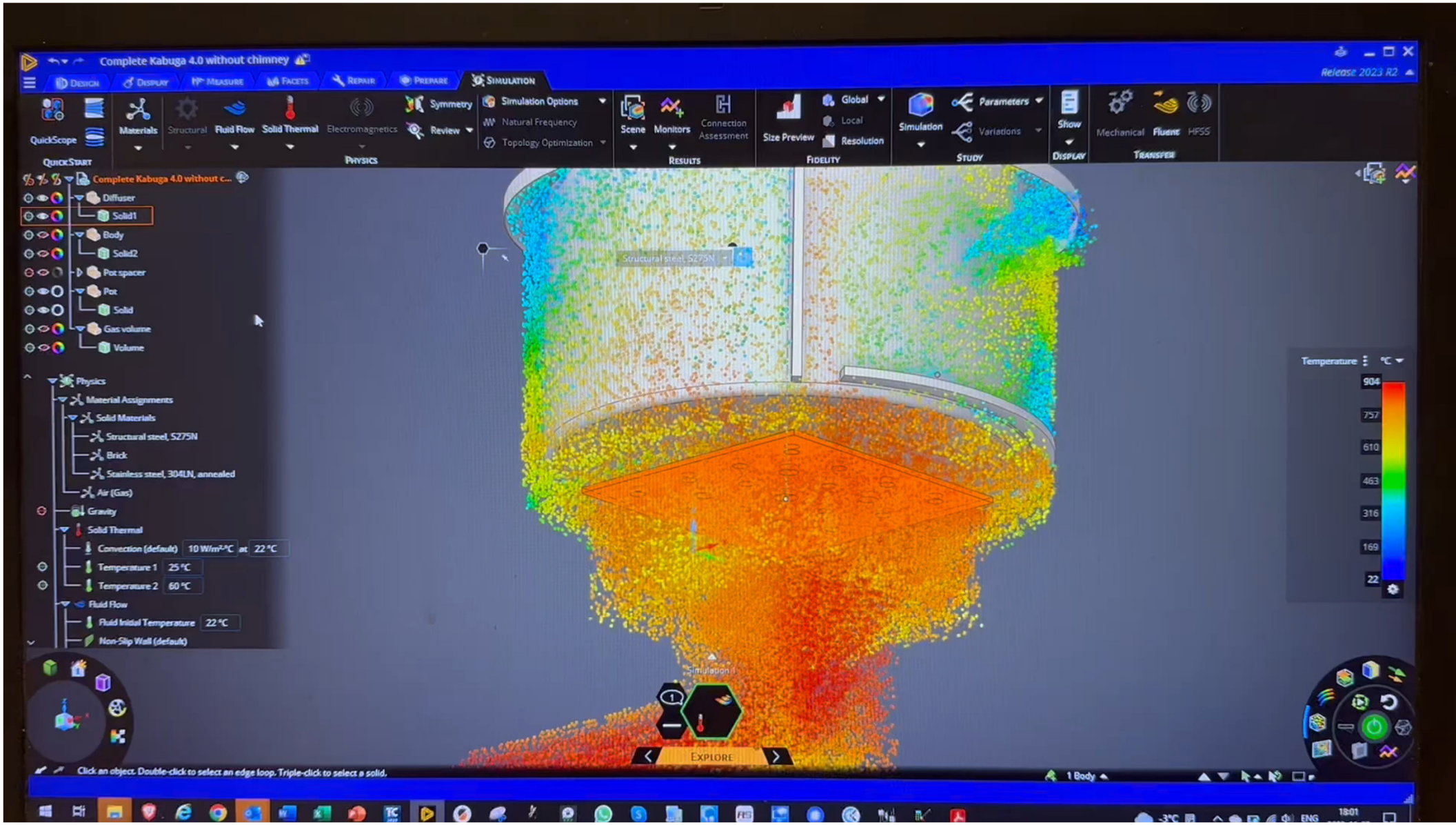
- The second has a constrained combustion chamber between the fire and the pot. This is often called a Rocket Stove or Rocket-style design.



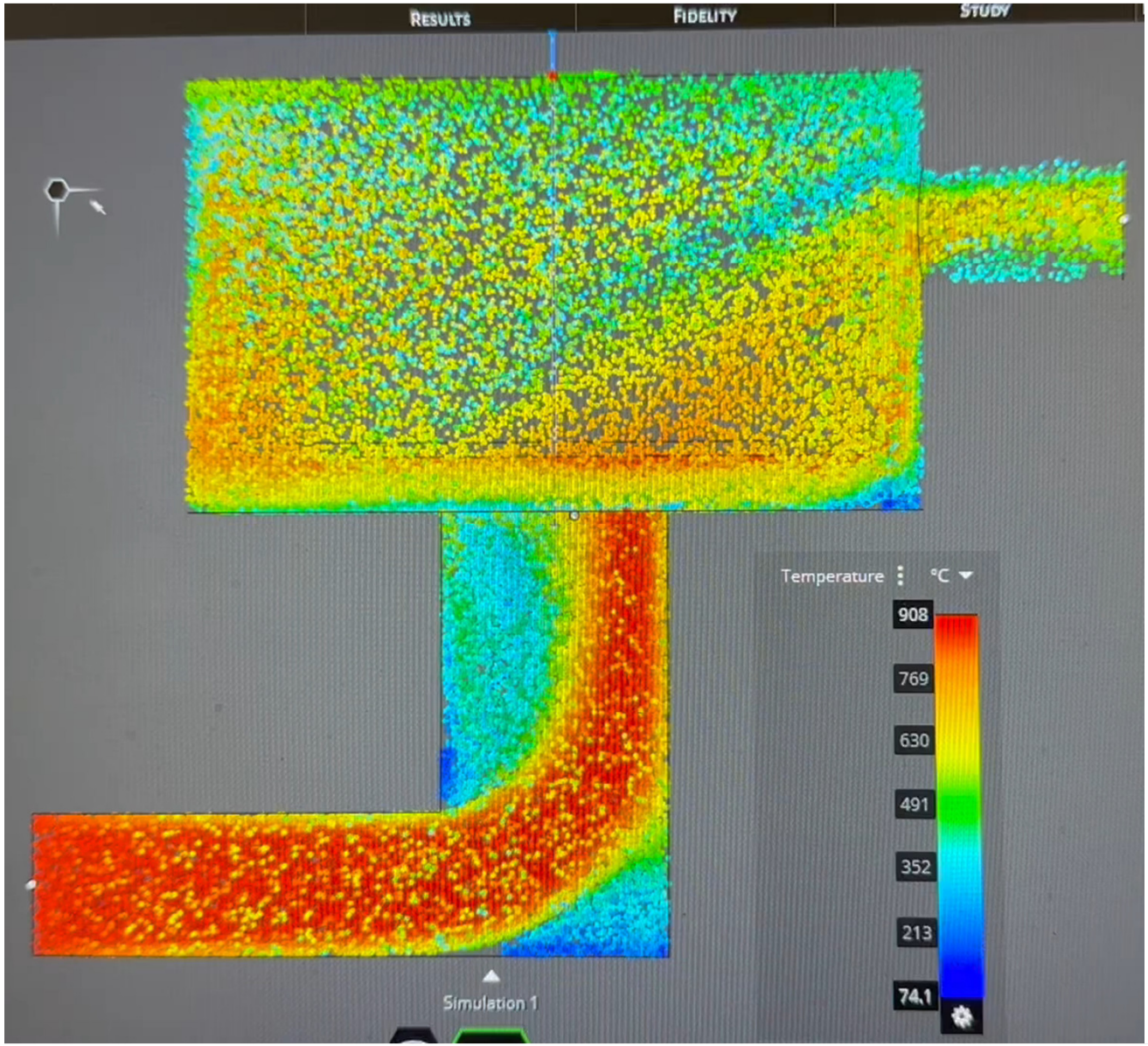


Low resolution CFD modelling package – ANSYS Discovery Live

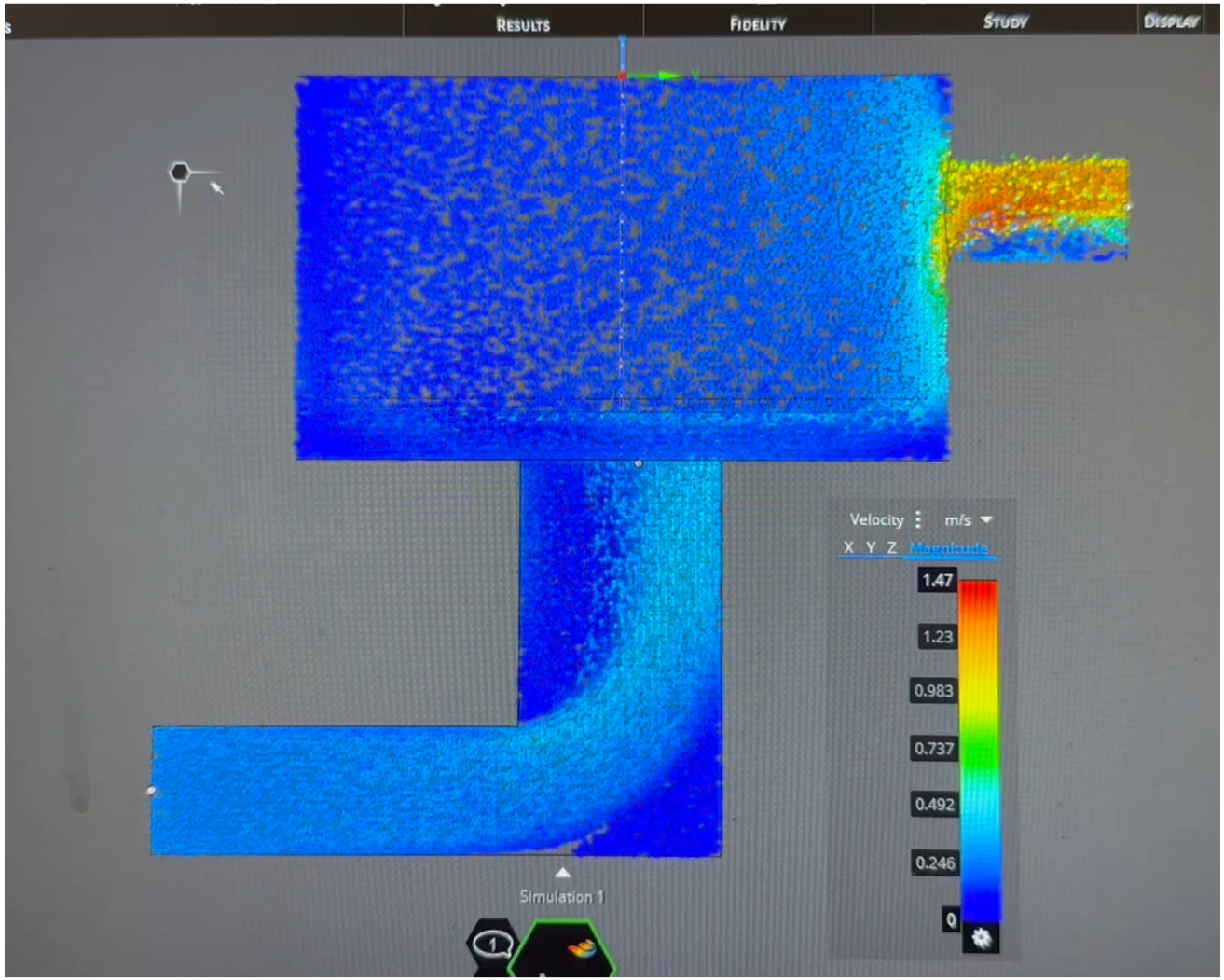
Simulations were created using a ~10mm^3 volume resolution = 4x10^6 data points.



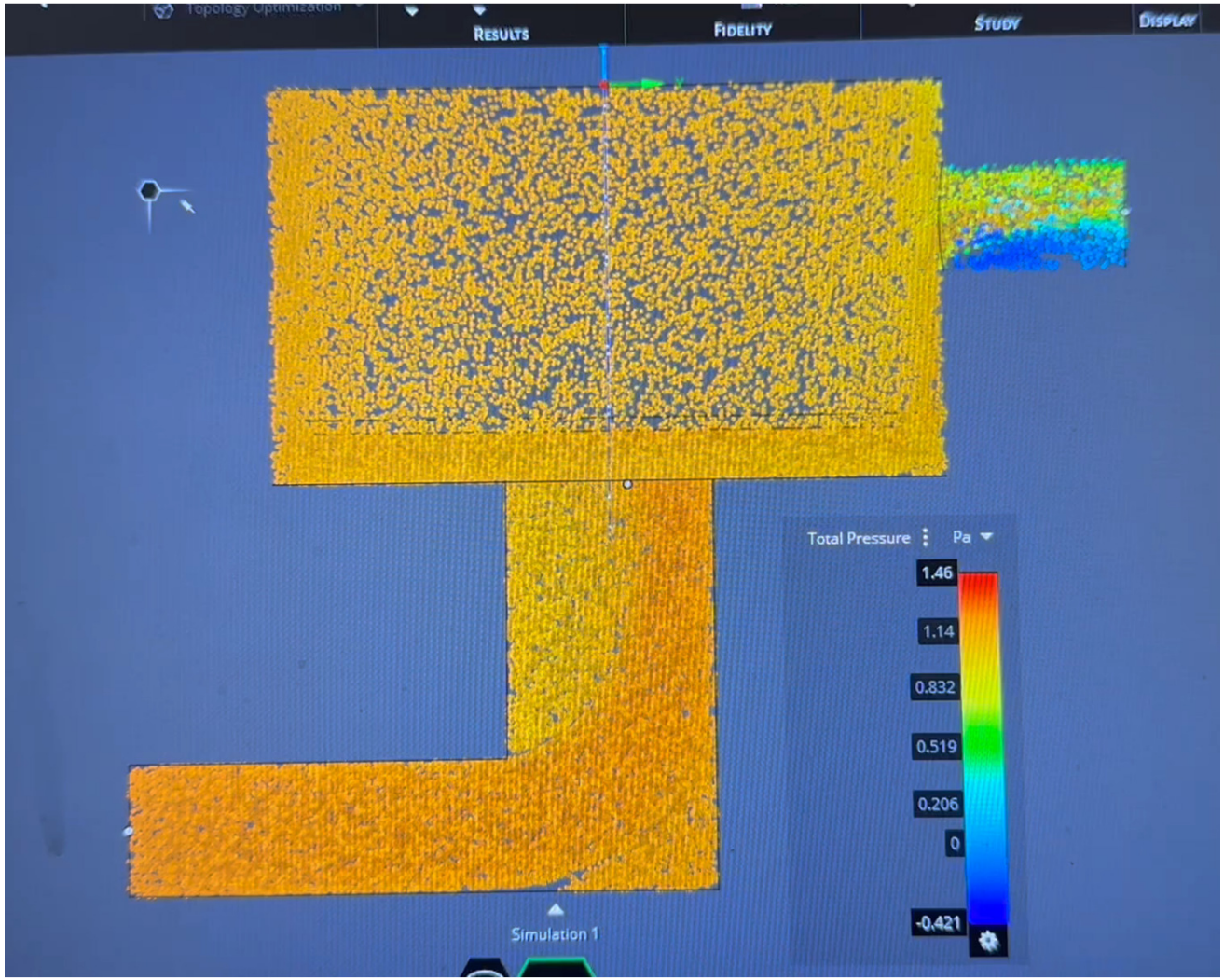
Heat flow in a Rocket Stove with a sunken pot



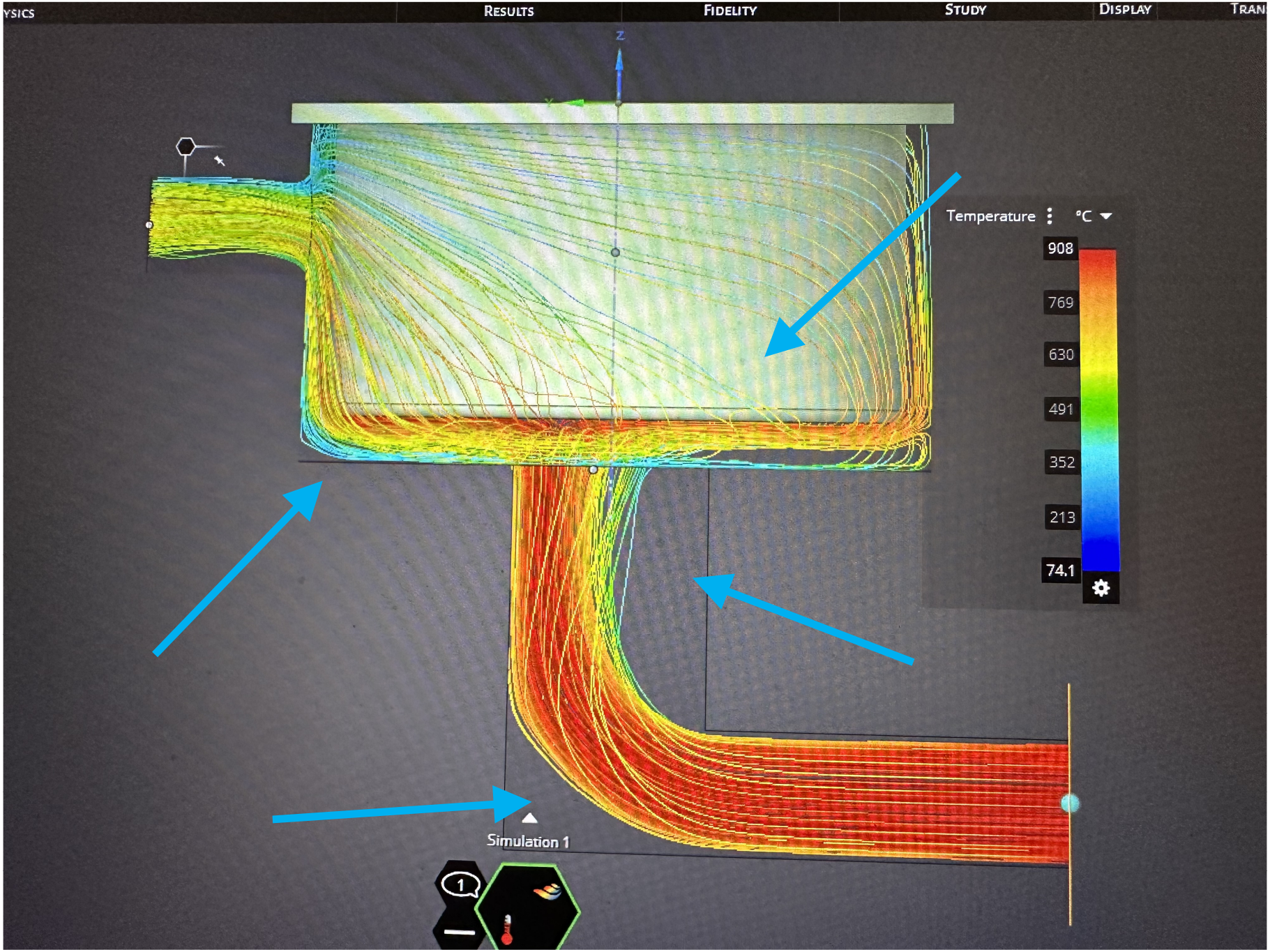
Hot gas velocity in a Rocket Stove with a sunken pot



Hot gas pressure in a Rocket Stove with a sunken pot

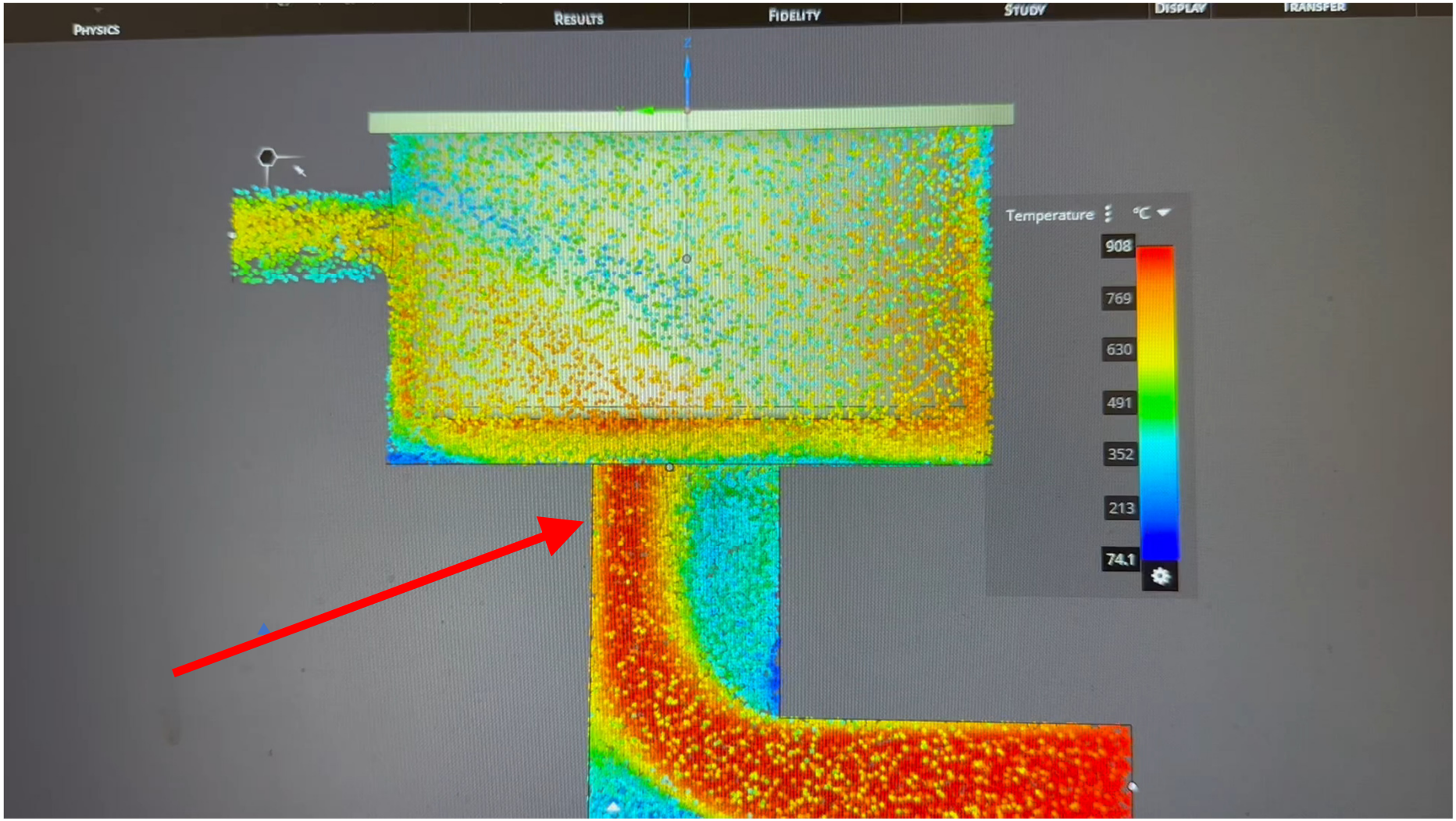


Flow distribution in a sunken pot Rocket Stove



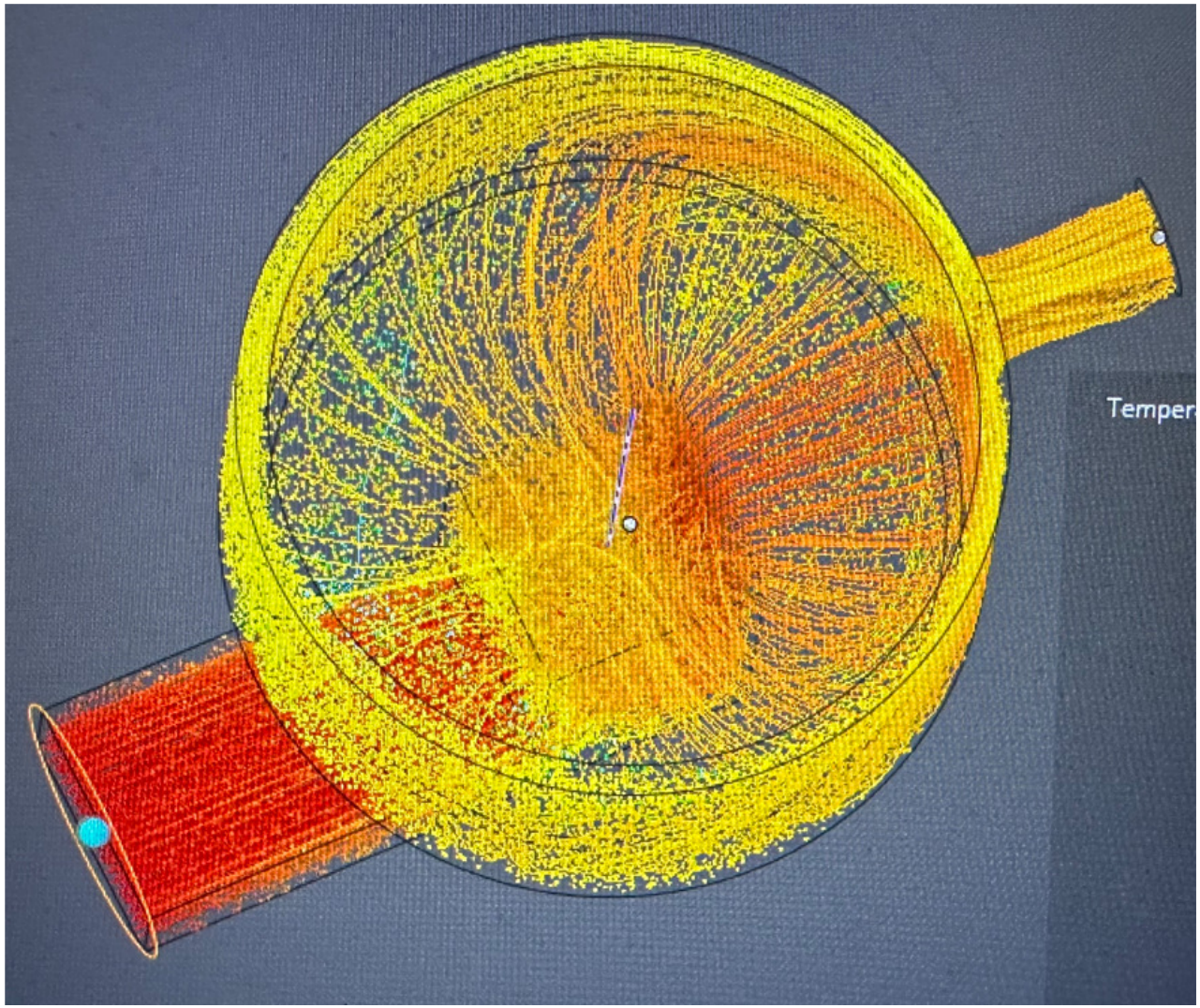
Temperature showing cold streams and cold zones

Significant heat damage is caused to the back wall of the combustion chamber whether it is made from brick, refractory ceramic or metal.



Top view of pressure distribution

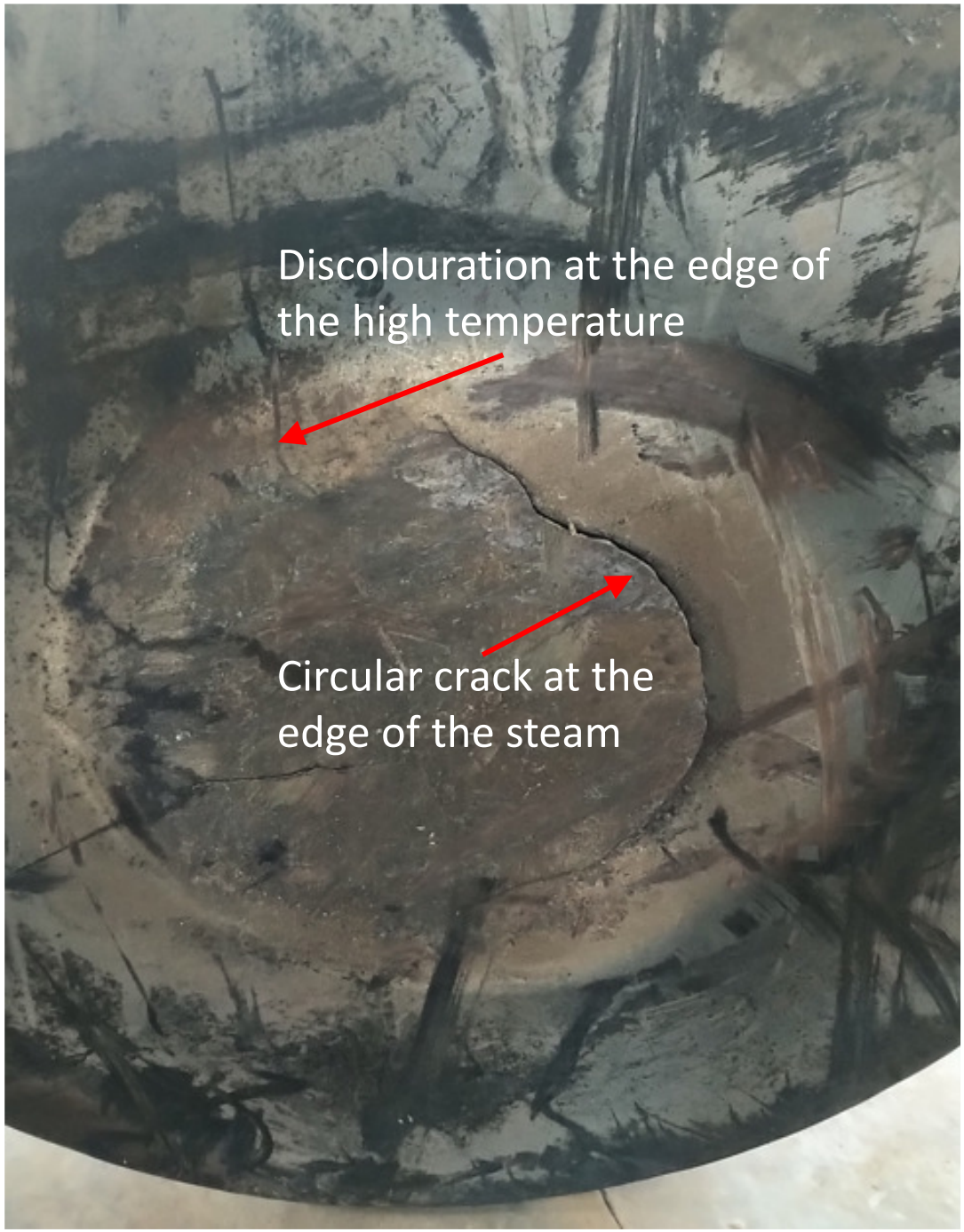
Pressure is highest at the back of the pot nearest the chimney, which is the worst place to find it as it leads directly to the chimney.



Overheating the pot centre

The colour indicates high temperature in the pot centre and lower in the surrounding area.

The centre is so hot it is not cooled by water because of an insulating layer of steam. Thermal expansion of the centre cracks the metal and the centre circle drops out.



Repairing a pot with a cracked centre

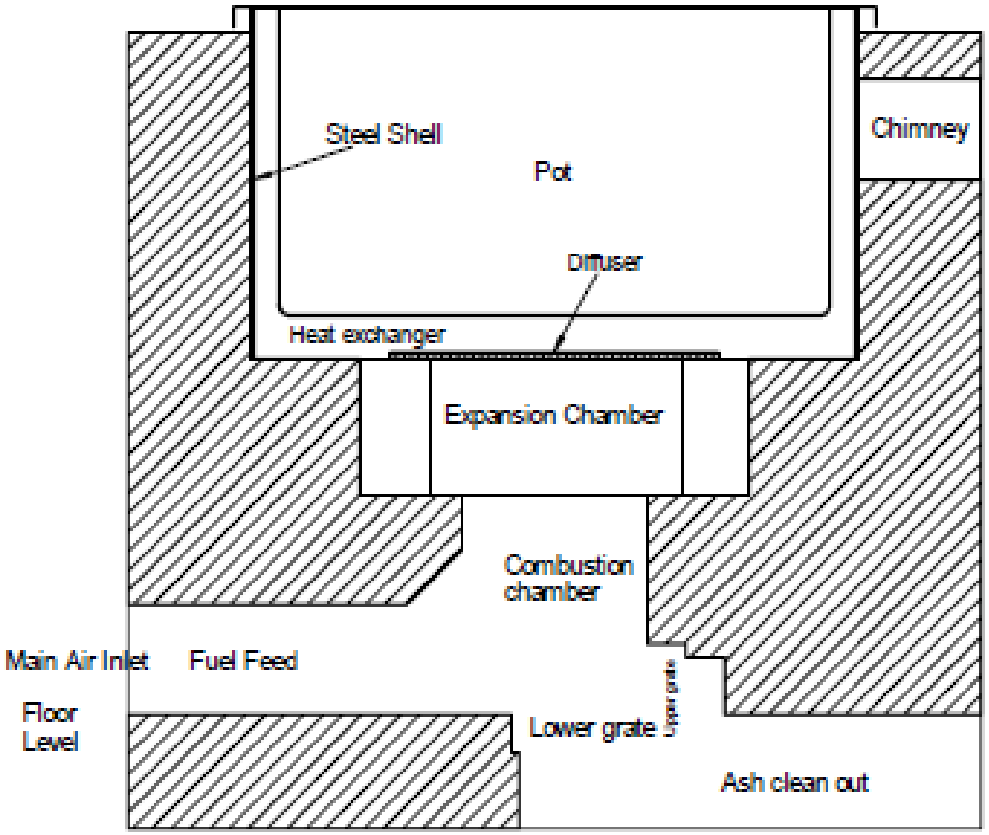
A patch is welded on the inside covering the cracked region. Notice that hole and patch are **off-centre**. This shows that the heating is towards the back (chimney) side of the stove.

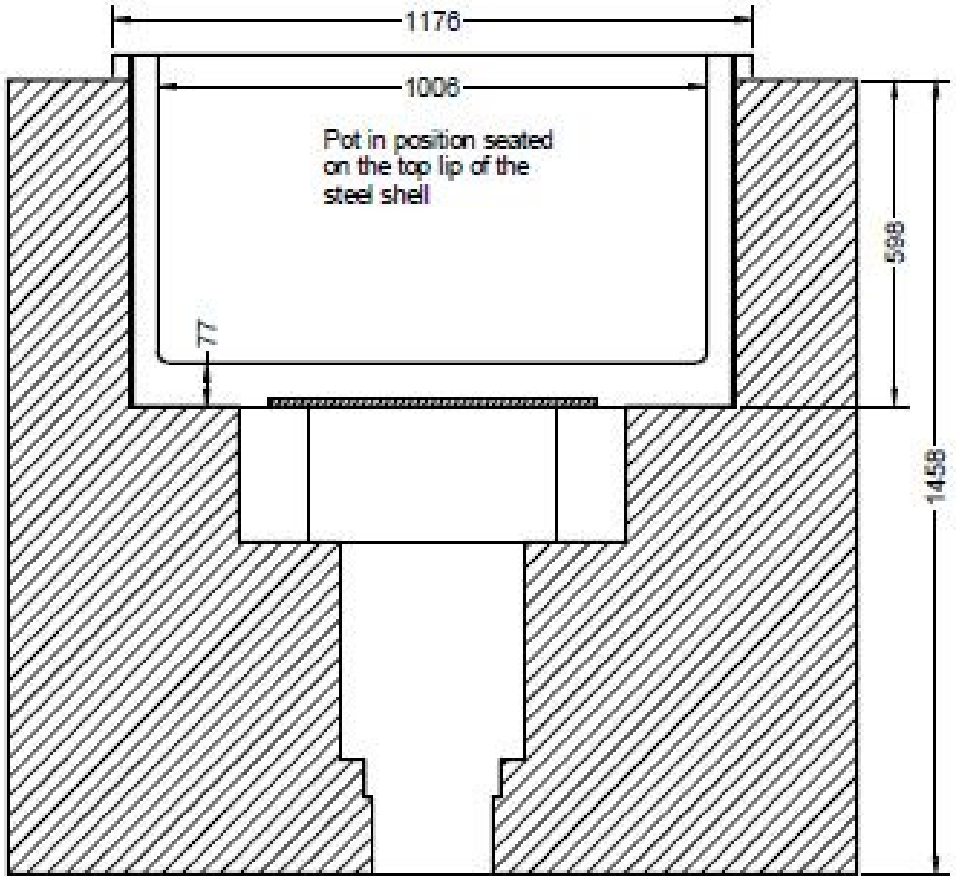
Direct measurements

Measurements in the stack of a 275 L Muvero stove show PM is high, O_2 is low (3%), exhaust temperature as high as 680°C. Stack heat loss is >50%.

Proposed Design KB4-465

Main features





KB4-465 (left) Mayenkho 1000 L (right) with no chimney

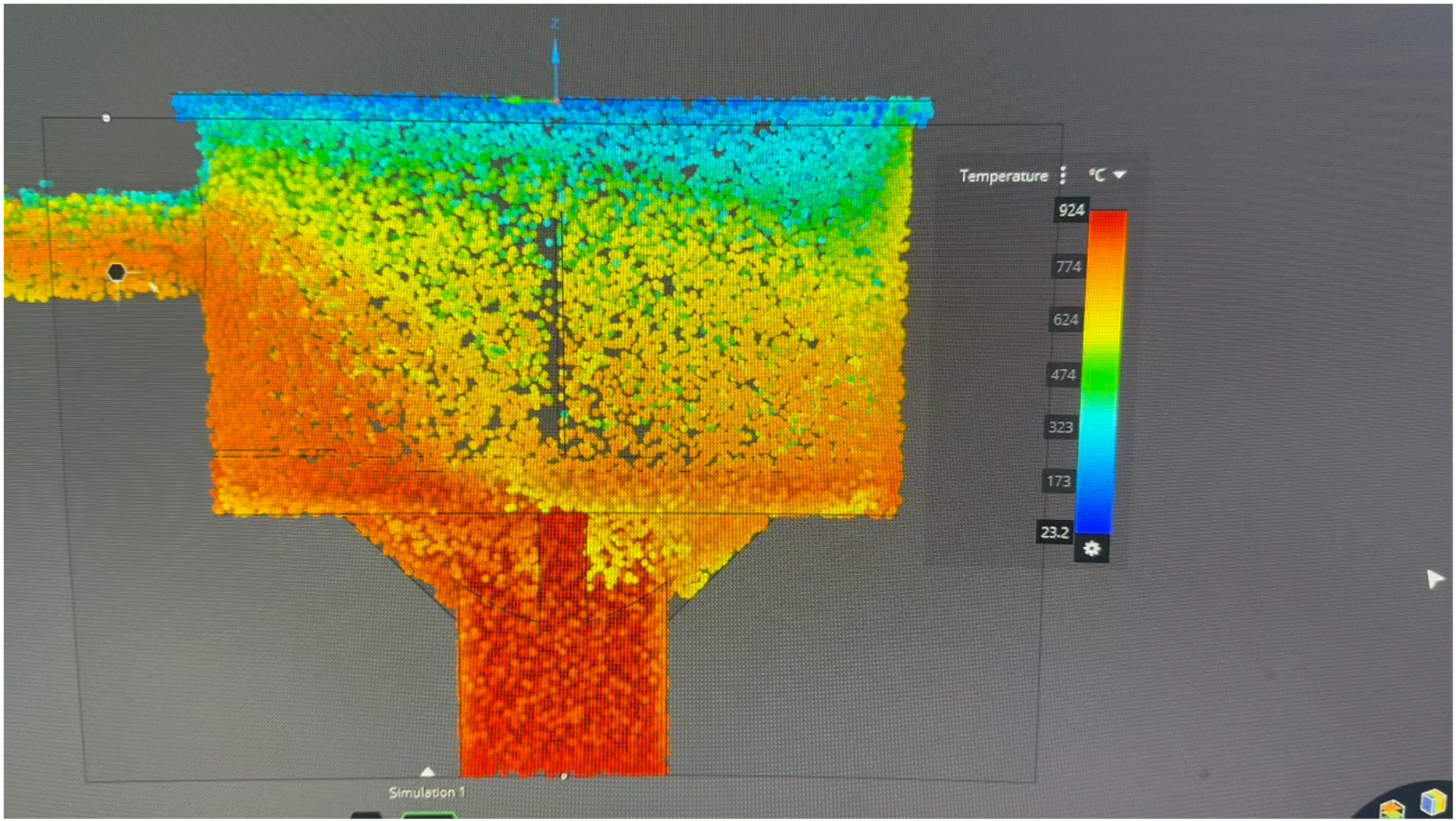
Zone heating problem with Pot 1

The left (back) of the pot is heated far more than the right (front). A clear diagonal line in the discolouration is visible.

At the top front of the pot, carbon particles were found clinging to the pot indicating low temperature and no flame in that area.

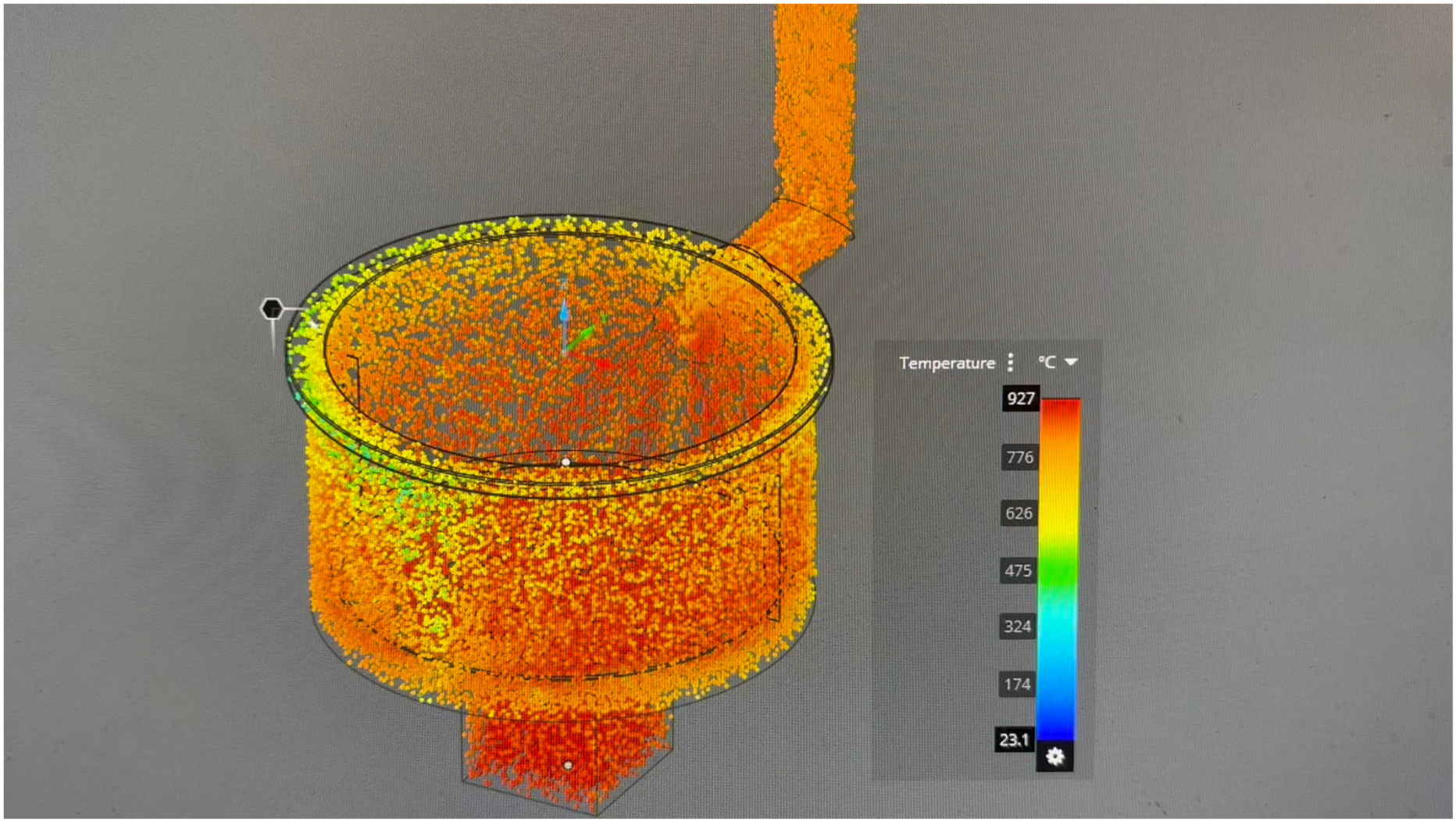
Adding 3 vertical vanes 90 degrees apart – no benefit

Vanes protruding 45mm from the pot did not significantly alter the direction of the hottest gas flow. The front top still remains cool.



3 vertical vanes, flow and temperature

Note the low flow rate at the front of the pot = poor heat flux.



Original grate under the fire

In order to increase the air flow under the fuel (2022) a grate was added made from 25mm reinforcing bar and angle iron. The grate lasts 10 to 14 days, then burns away.

To address overheating: a conical expansion chamber added

The 4 supports hold a diffuser plate.

At the bottom is a square space for the grate.

Primary air enters from behind and under the stove.

To address durability: a grate made from castable refractory

The view shows the grate in position. Light can be seen in the channel under the stove,

This channel serves as a primary air entrance and an ash cleaning portal.

The top of the grate is flush with the floor of the fuel entrance.

A perforated diffuser plate is placed on the 4 supports

The diffuser is perforated ~5% of its area above the hottest part of the fire. This passes ~15% of the heat to the middle of the pot.

Disk diameter is 600mm. The prototype is 12mm mild steel. Material should be 5mm SS430.

The 4 clean exit ports show evidence of high temperature and high velocity.

There are 4 pot supports however it is preferred to have the pot hang on the top lip of the steel shell liner.

Performance: 1st test, KB3-465, Pot 1, with no external vanes

Performance, July 2023

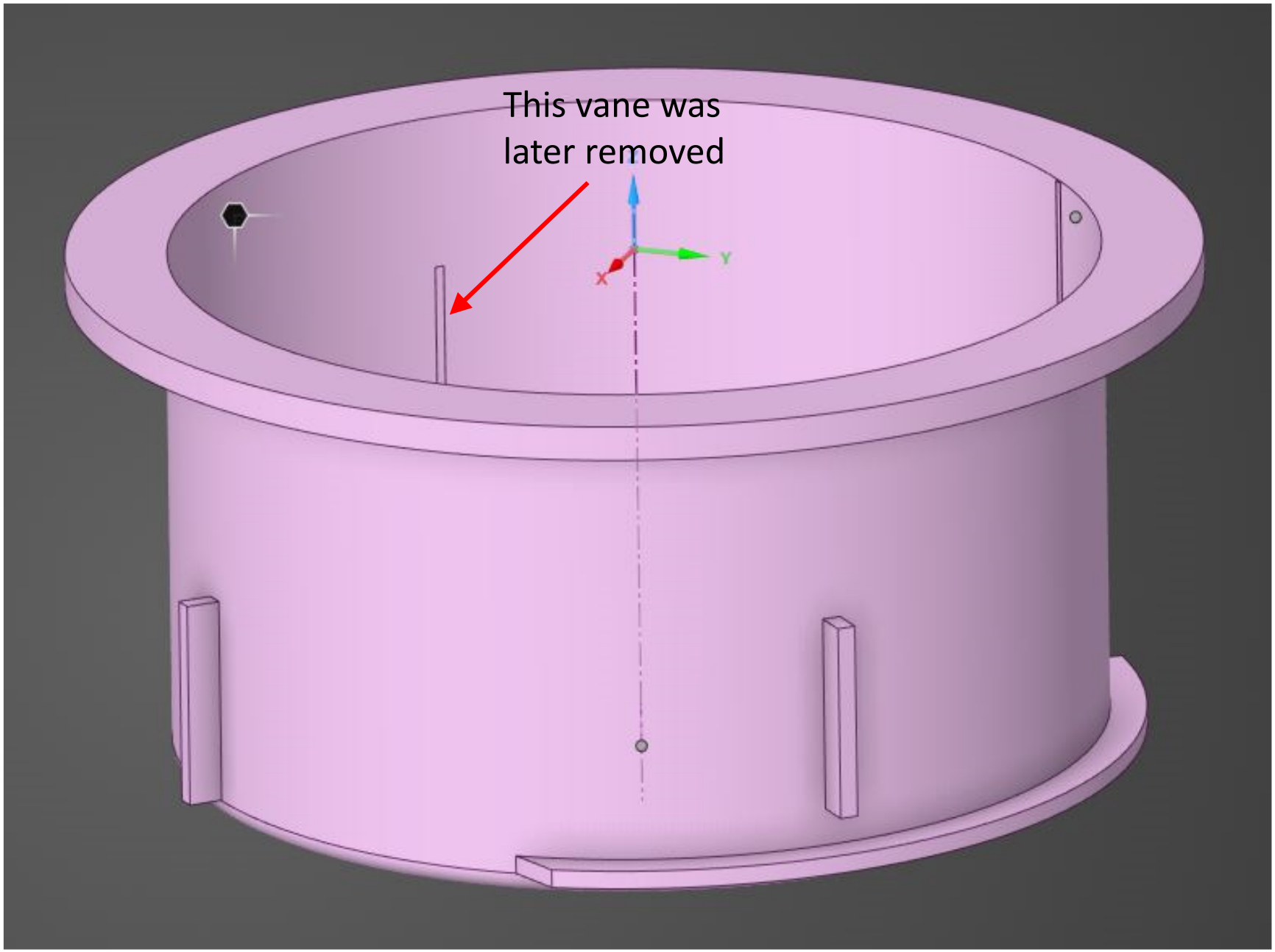
- Total load: 420 L
- Thermal efficiency (energy received by the pot/fire energy)%
  - Average until thermal equilibrium ~25% (high power)
  - After thermal equilibrium ~43% (high power)
  - Low power ~72%
  - Overall cooking ~50%, depends on low power duration
- Maximum heat gain rate 34 kW

Performance: 2nd test, KB4-465, Pot 5 with 4 vanes

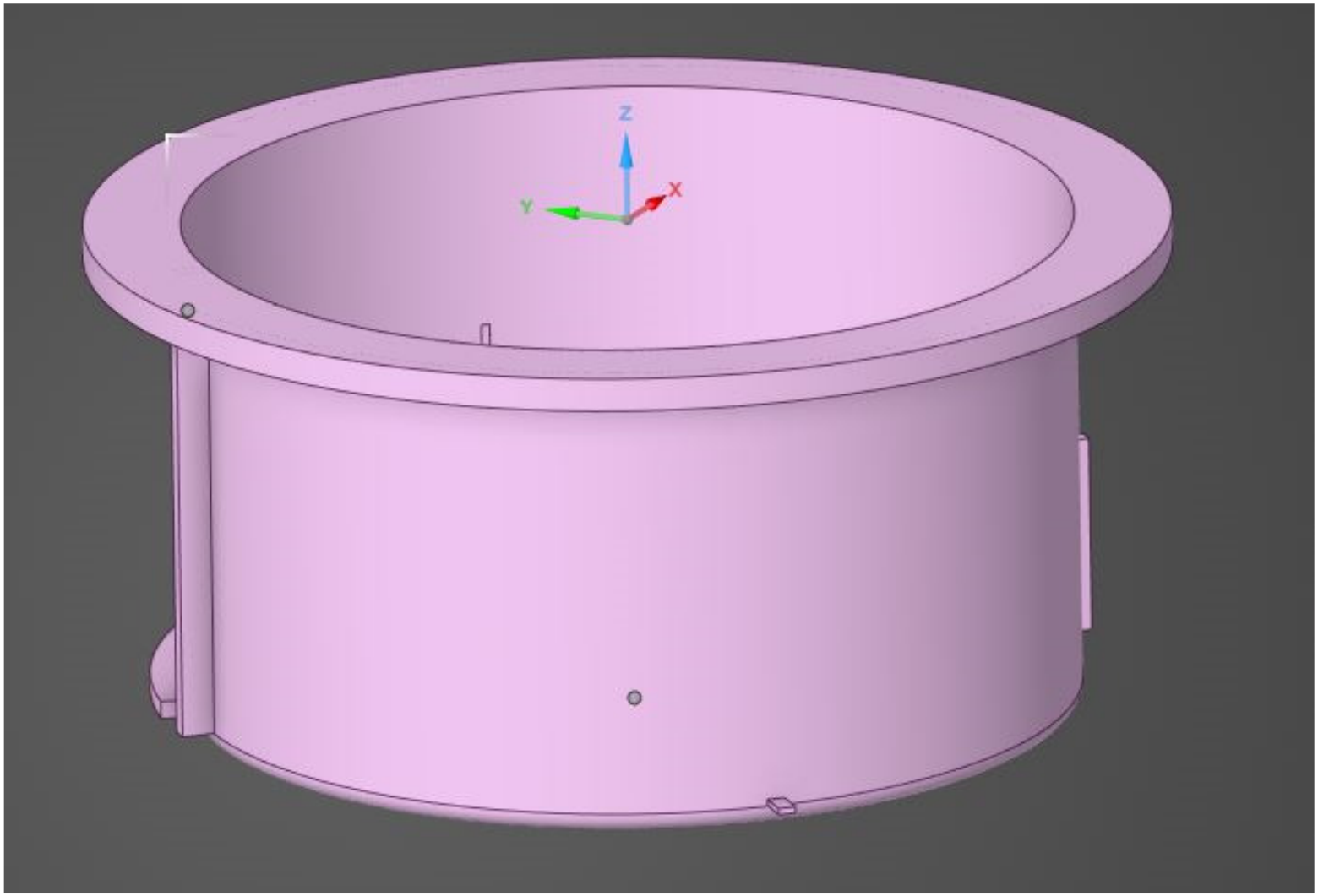
Performance, September 2023

- Total load 415 L
- Time, ignition to rolling boil 70 minutes from ignition
- Fuel consumption 23.5 kg *eucalyptus grandis* 11% moisture
- Thermal efficiency
  - Until thermal equilibrium ~25% (high power)
  - After thermal equilibrium ~50% (high power)
  - Low power ~72%
  - Overall cooking ~60%, depend on low power duration
- Maximum heat gain rate 38 kW

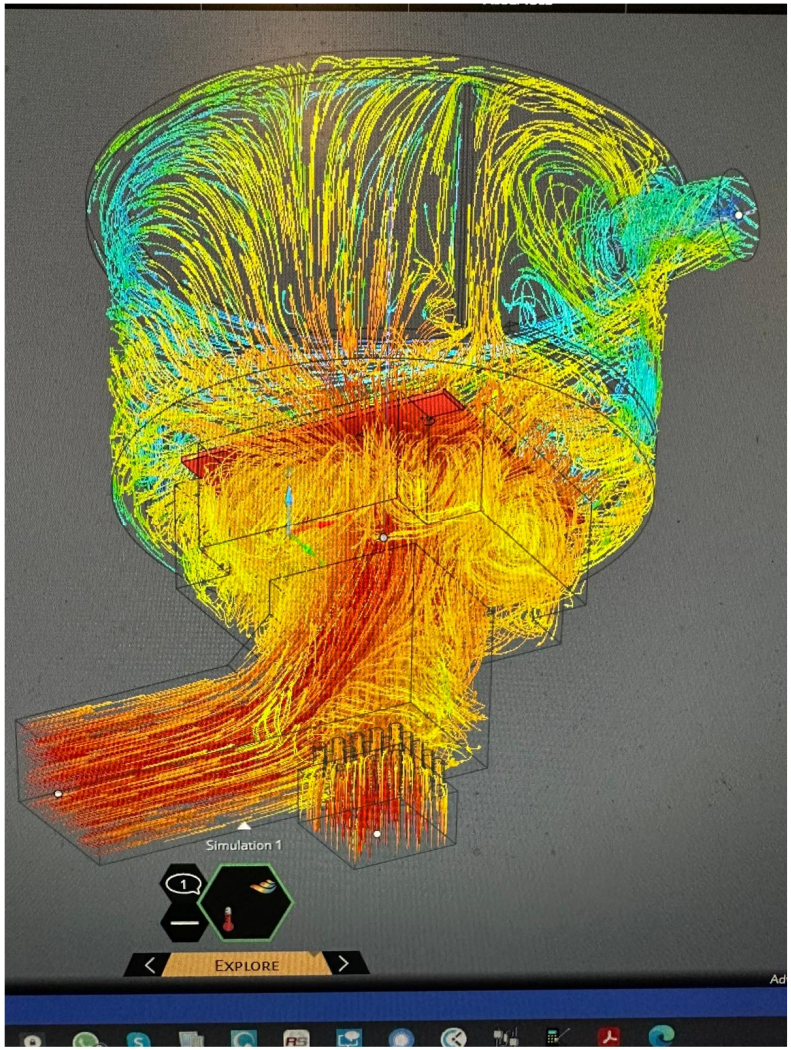
Right side of Pot 4



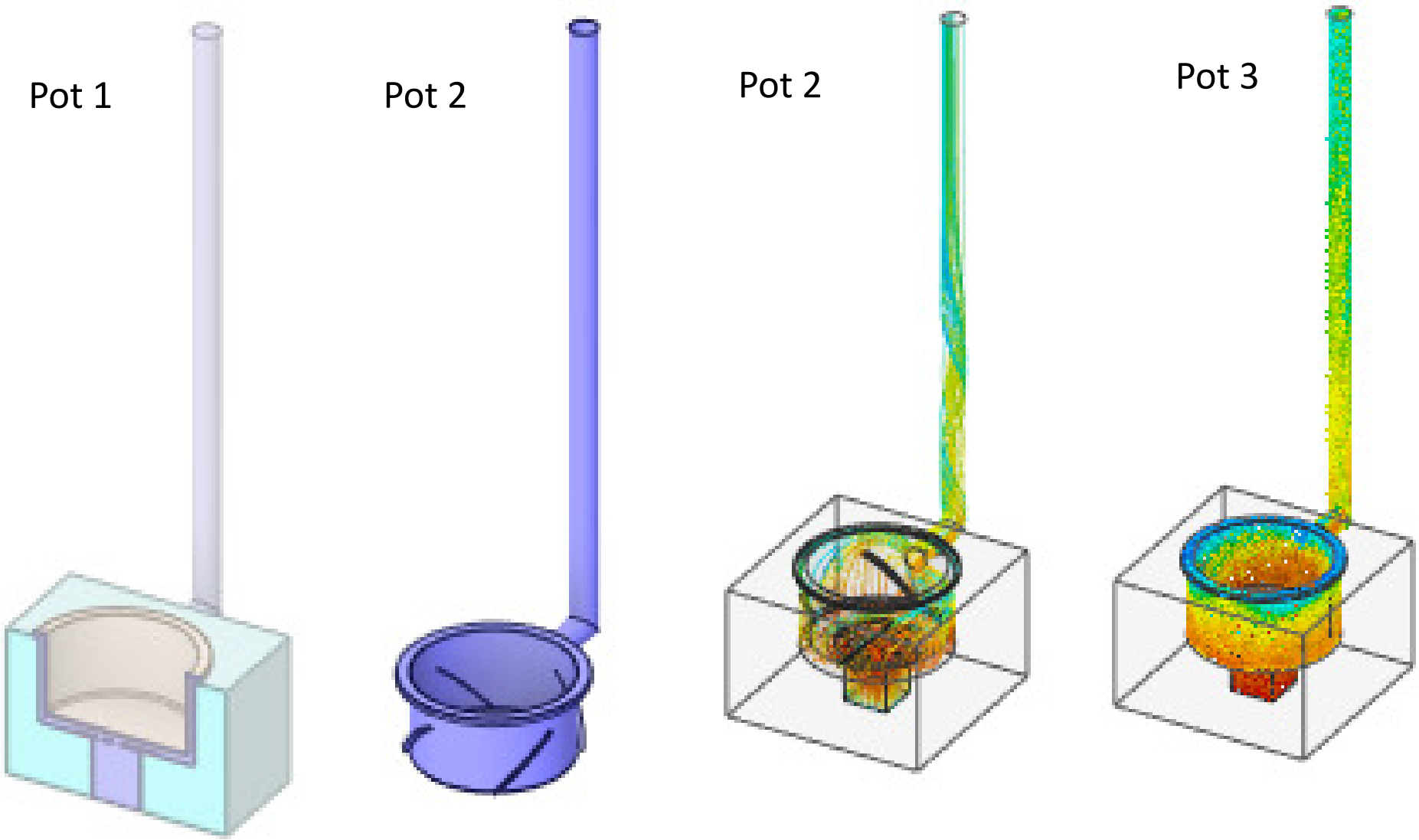
Left side of Pot 4



Square Diffuser simulation with Pot 5

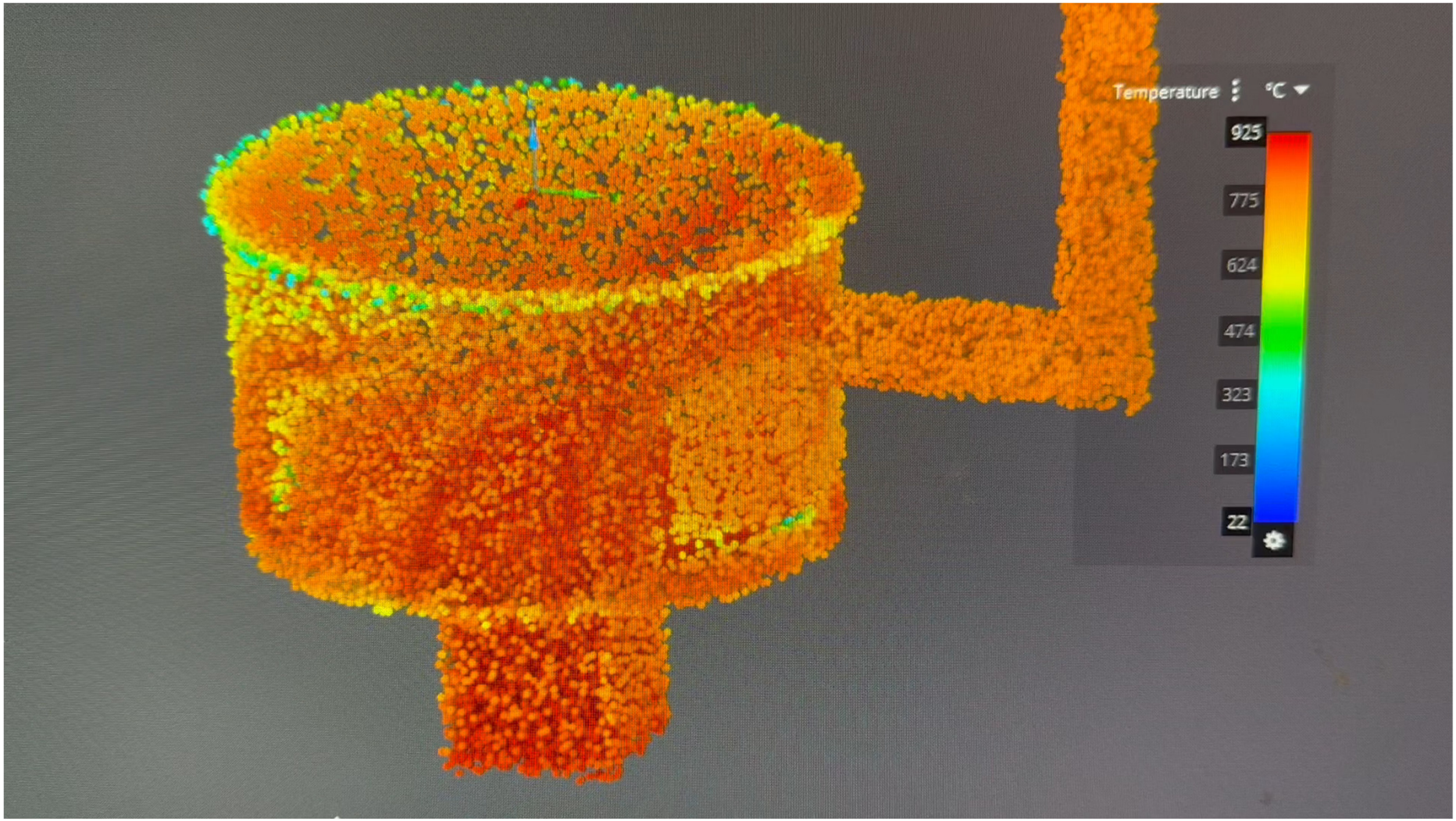


Pots 1, 2 and 3

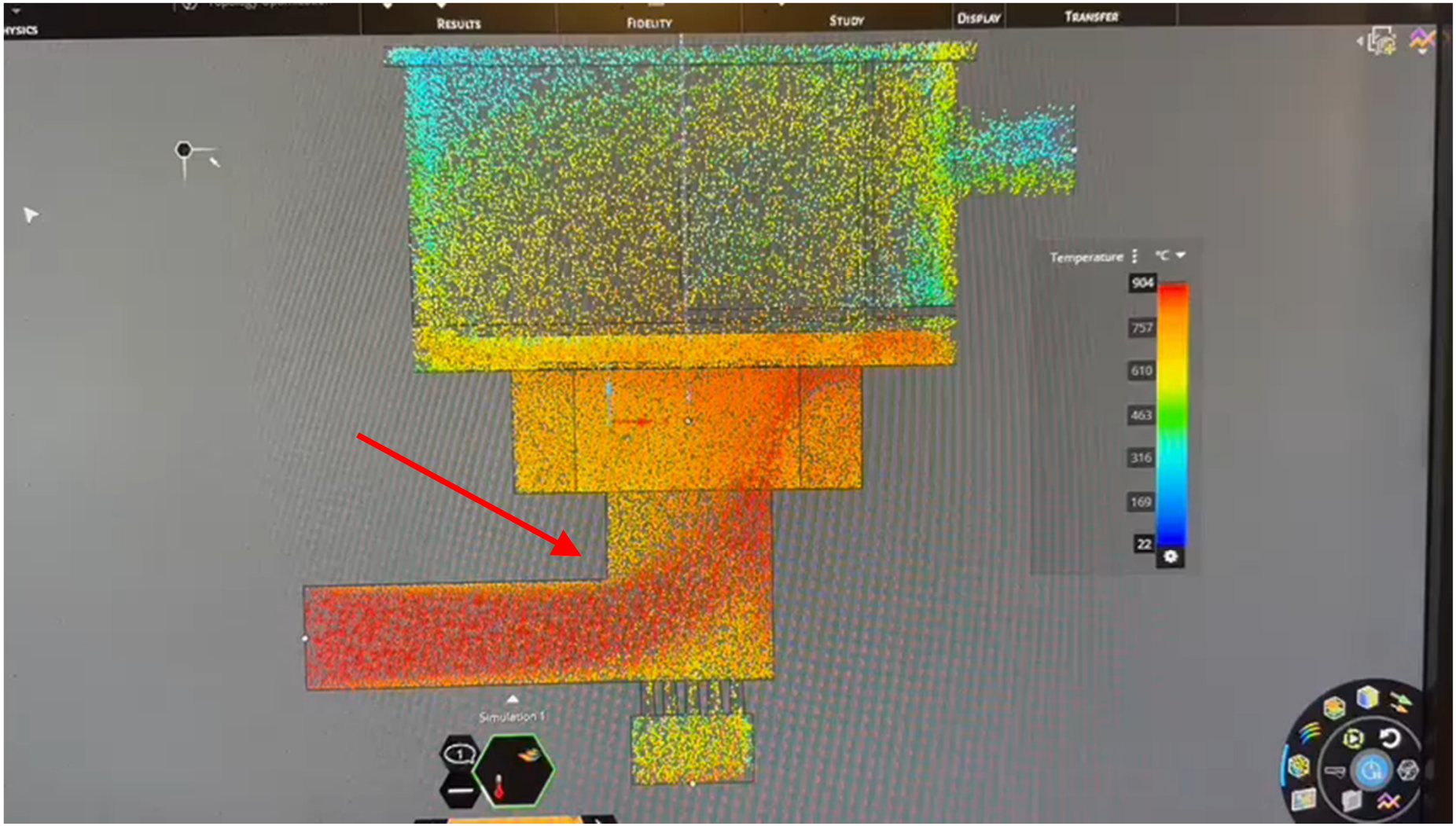


Original 4 vanes to rotate 4 vanes thermal 4 vertical

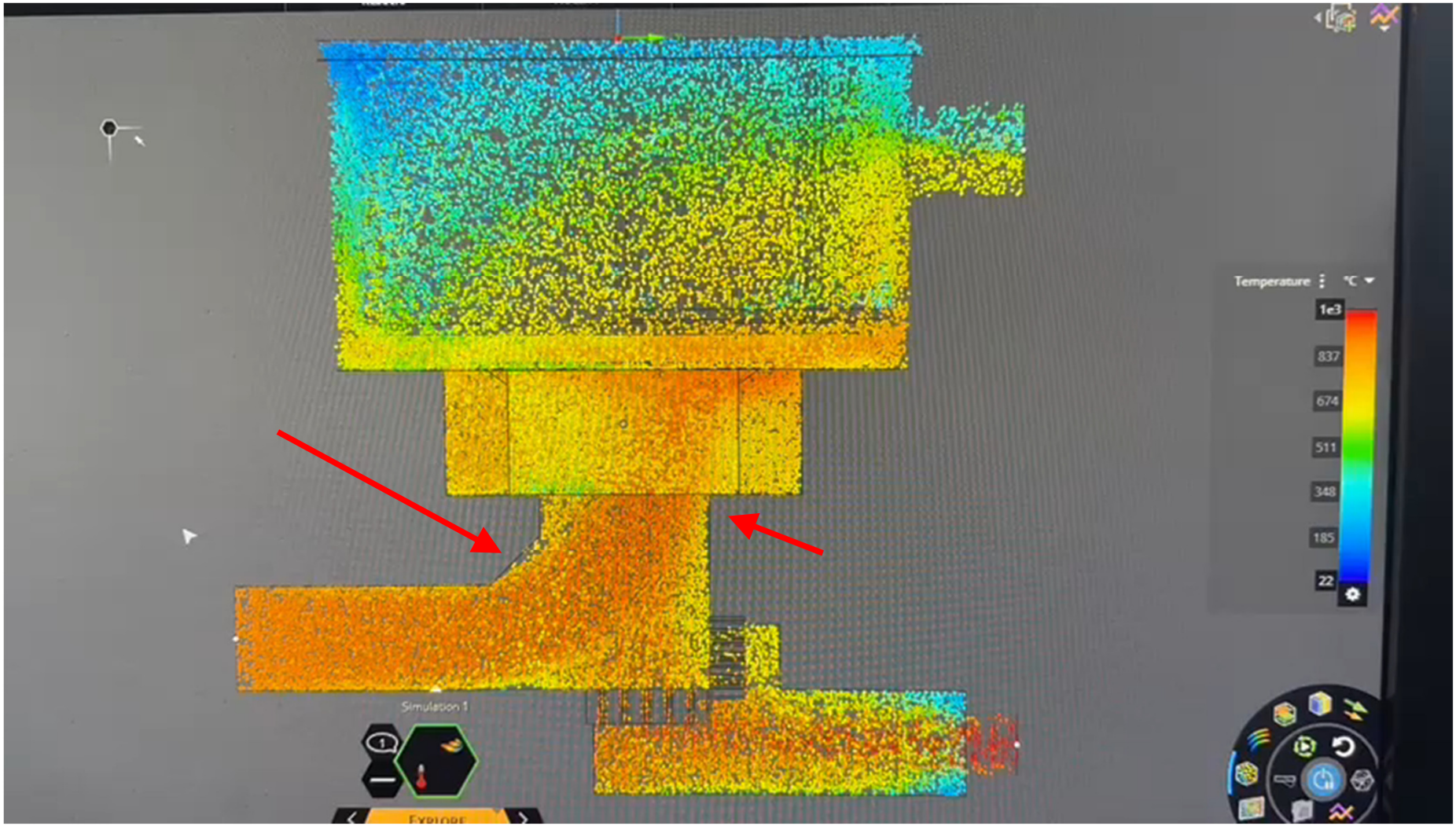
Round diffuser, 4 vanes Pot 5



Square Diffuser, Pot 5



Square Diffuser, second grate added



Current activities

- Build two more Model KB4-465 at Kabuga School
- Continue to collect performance data for meals cooked and meal size, fuel condition and species.
- Localise production of the grates from castable refractory
- Create 6 new sizes for 50 L, 100 L, 150 L, 200 L, 250 L and 300 L pots for 600 Ugandan schools
- Build at least one stove with replaceable “volcanic rock” inserts lining the combustion chamber.

Thank you!

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CAU for travel support and accommodation to be able to attend the conference.

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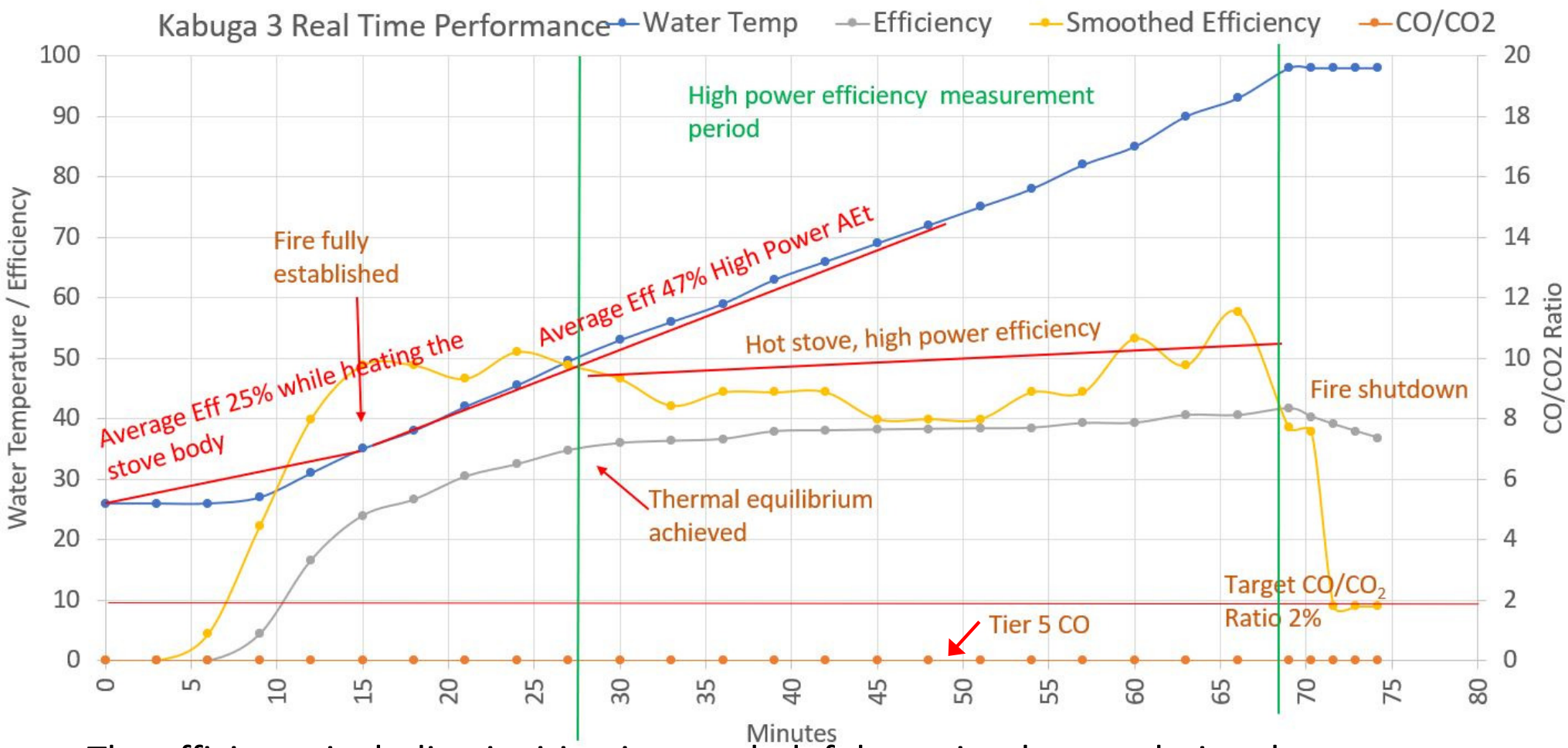
Performance – CO and Thermal Efficiency in Real Time



The efficiency including ignition is not a helpful metric when analysing the performance of a high mass institutional stove. We determined the thermal efficiency after the system reached thermal equilibrium (AE_T)which typically takes 25 to 45 minutes. After this point, the heat gain rate of the pot is constant. If the firepower is changed, wait until AE_T is achieved before making a determination. Above, the CO/CO_2 ratio is so low it does not show above the axis. PM is negligible.