Simulation of premixed flames with FDS

Application to the hot smoke testing system Izar

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Introduction

Don't worry, this section is not long…

- This work is based on the hot smoke testing system, Izar
- It was developed by the swiss company Basler & Hofmann AG
- A premixed combustion is the source of energy for the test
- The results presented in this work are part of its development process
  - The entire work was presented as master thesis within the IMFSE program in 2013

Before we begin, what is Izar?

I am very happy with your question…

Izar is a system with... a gas burner

… a gas supply system…

… and some fog generators

Our clients wanted to see the smoke,… and my boss too

It sounds interesting, but what makes Izar something special?

Well Izar is definitely a cool machine…

- It doesn't generate soot
  - Nobody likes to clean…
- Live control of the HRR
  - It is possible to follow fire curves like the t^2-curve
- A validated FDS model is available

How is that you decided to combine FDS with Izar?

- We do the test in rooms in use or just before commissioning
- The room limiting factor must be considered (sprinklers, lights, protected ceilings)

Calculate the plume temperatures originated by Izar

- The temperature is one of the main factors to design the smoke tests
- Realistic test = high temperatures
- Necessary temperature data from Izar for different powers and room heights

How to calculate temperatures from premixed flames?

- The combustion efficiency is the most important factor for premixed flames
- What happens afterward? –> Not enough studied

A new framework is developed with FDS to calculate the plume temperature

And how did you create the FDS model for Izar?

- The combustion itself is “not important”, we want to model the plume
  - The combustion will not be modeled
- We model the combustion products which conform the plume, the “smoke”
- Three initial factors

The initial species (1/2)

- The combustion takes place under stoichiometric conditions
- Well known which the combustion products are

$$C_3H_8 + 5\,O_2 + 5 \cdot 3.76\,N_2 = 3\,CO_2 + 4\,H_2O + 5 \cdot 3.76\,N_2$$

We define the mass ratio fuel/product

Specie	Molecular weight (g)	Amount of products (g)	Mass ratio
C_3H_4	40	-	-
CO_2	44	132	3.3
H_2O	18	72	1.8
N_2	28	526.40	13.16

The initial species (2/2)

- We calculate the necessary mass flow rate for a desired HRR with the fuel heat of combustion
- Example for 500 kW
  - Propane heat of combustion: 46 kJ/g
  - Mass flow to achieve 500 kW
    500 kW / 46 kJ/g = 10.85 g/s

Specie	Amount of fuel (g/s)	Mass ratio	Amount of products (g/s)
C_3H_4	10.85	-	-
CO_2	-	3.3	35.80
H_2O	-	1.8	19.53
N_2	-	13.16	142.78

Proper initial values for the subsequent system mass balance

The initial temperature

- The initial temperature of the gas is related with the flame temperature
- The combustion takes places under stoichiometric conditions
- The adiabatic combustion temperature characterizes the flame temperature
- For our case: Flame temperature = 1.995 °C (Propane adiabatic temperature)

Grid mesh and geometry

- The mesh definition is a critical value in a FDS model
- The combustion product must be introduced in $kg/m^2 \cdot s$
- The combustion surface defines the initial moment in the system
- Our system has a geometry of 122 cm (length) x 17 cm (width)
- A 6.5 cm cell size was chosen after a sensitivity analysis

Radiation

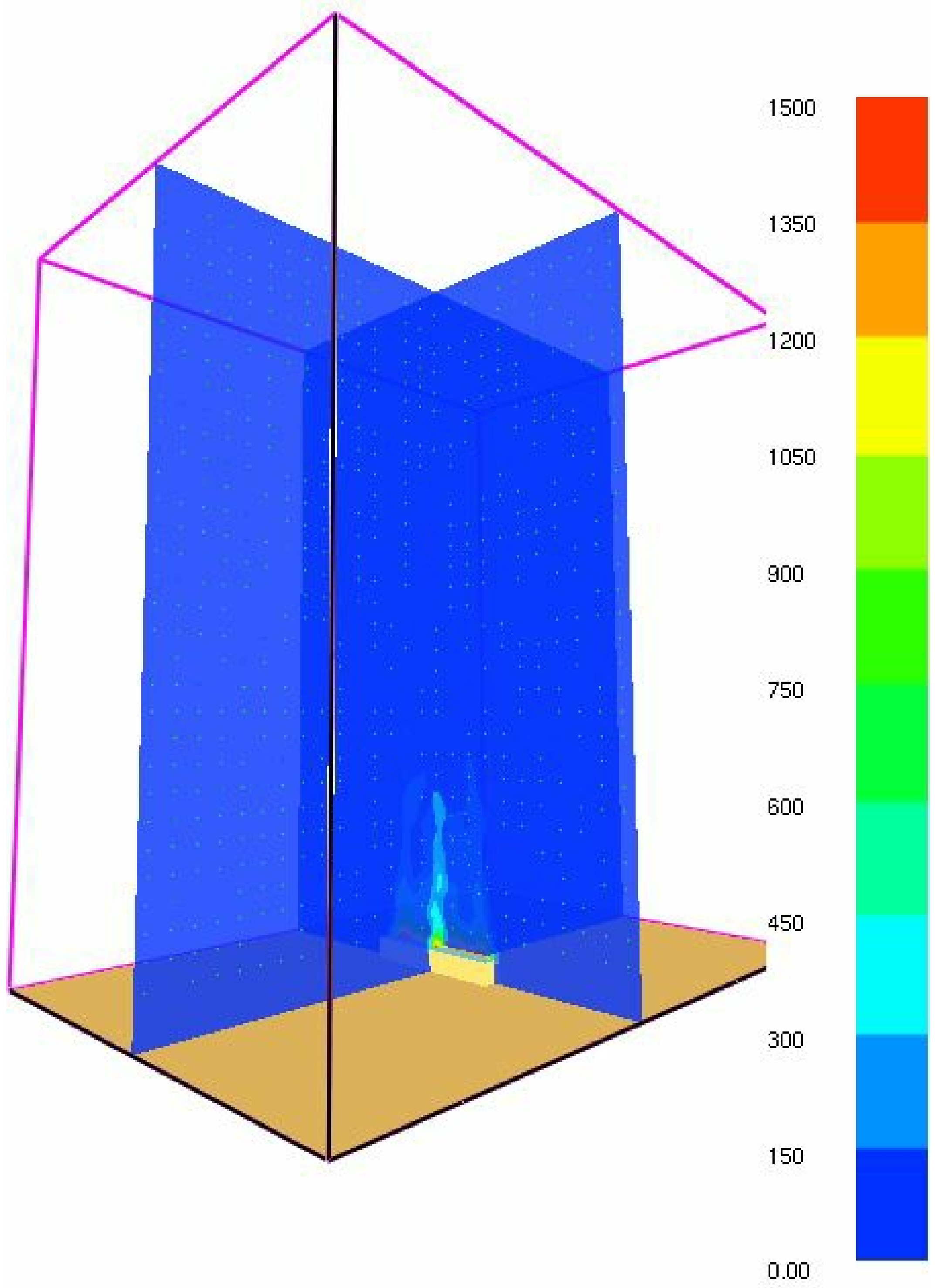
- High combustion efficiency –> low radiation loses
- The radiation fraction can be calculated considering the partial pressures
- The radiation loses of the system are around 3 %

Well you can find the equation in my paper…

Validation of the FDS model

- You are probably thinking
  - Nice method
  - The theory is interesting, but I want to known if it works
  - Does he have more cool pictures?
- Well, let's show the result
  - And yes there are some cool photos

Slice Data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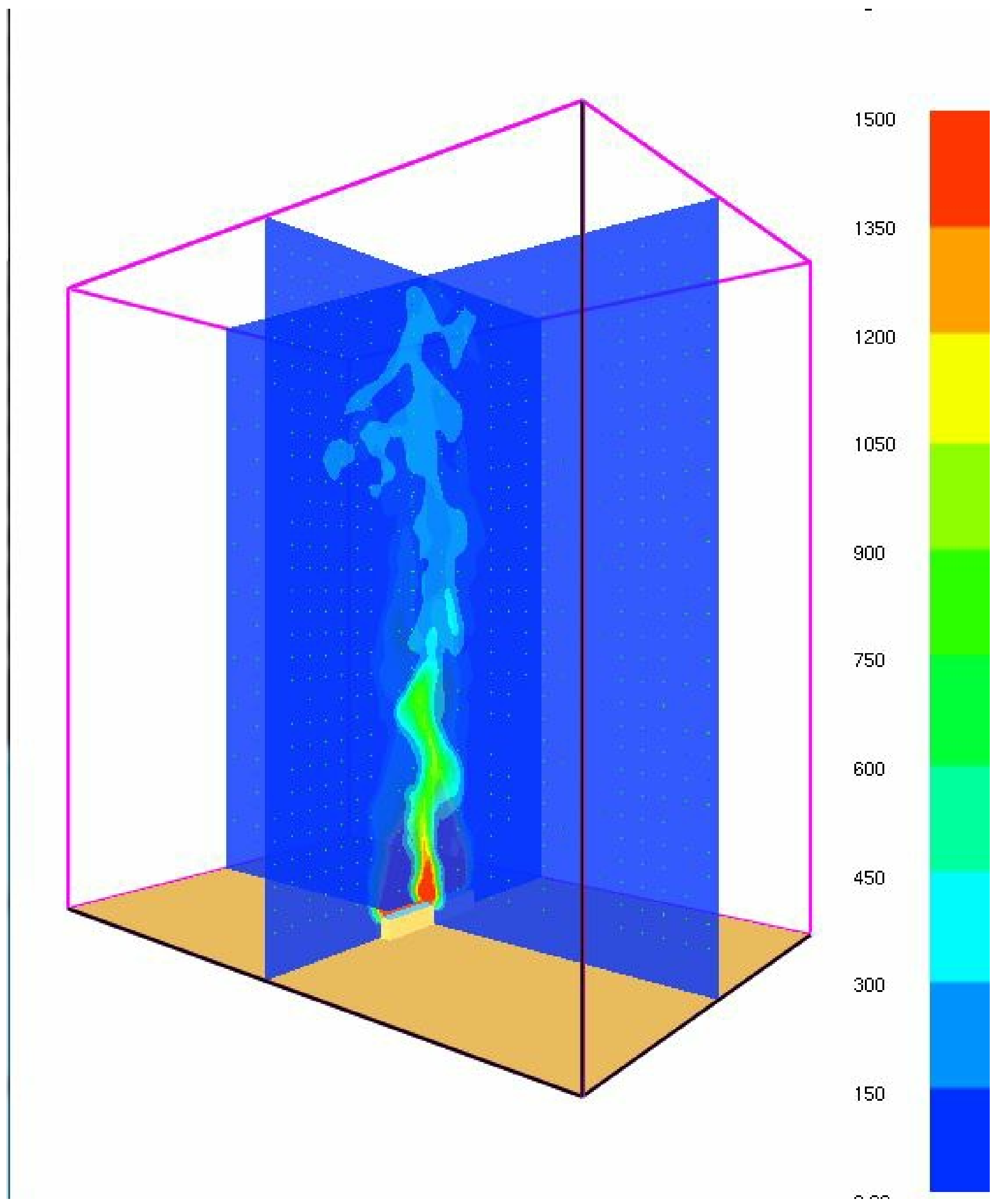
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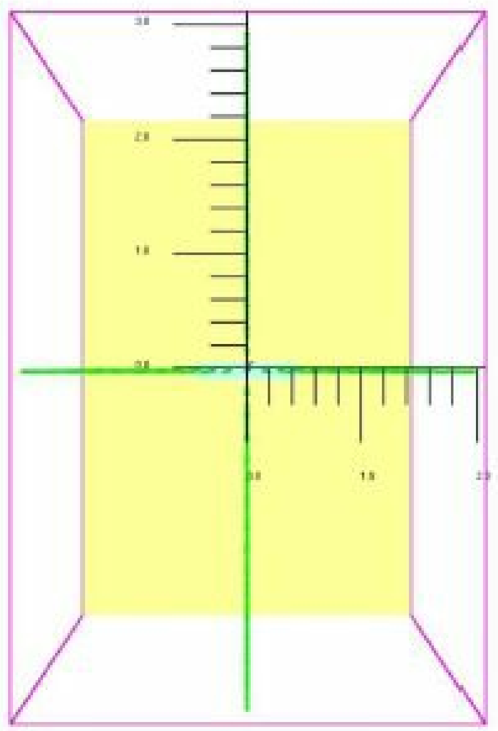
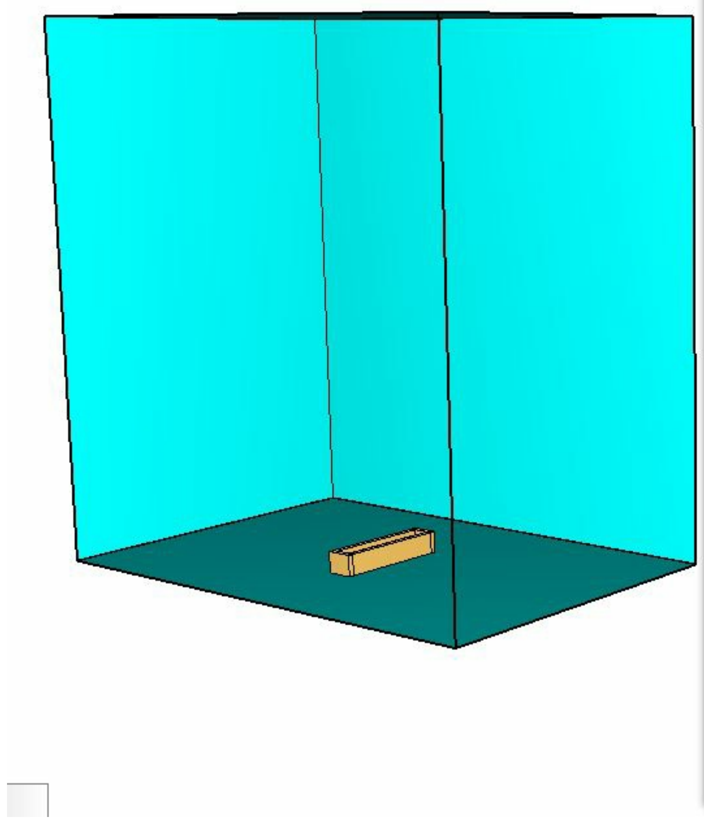
Let's begin with the plume in FDS

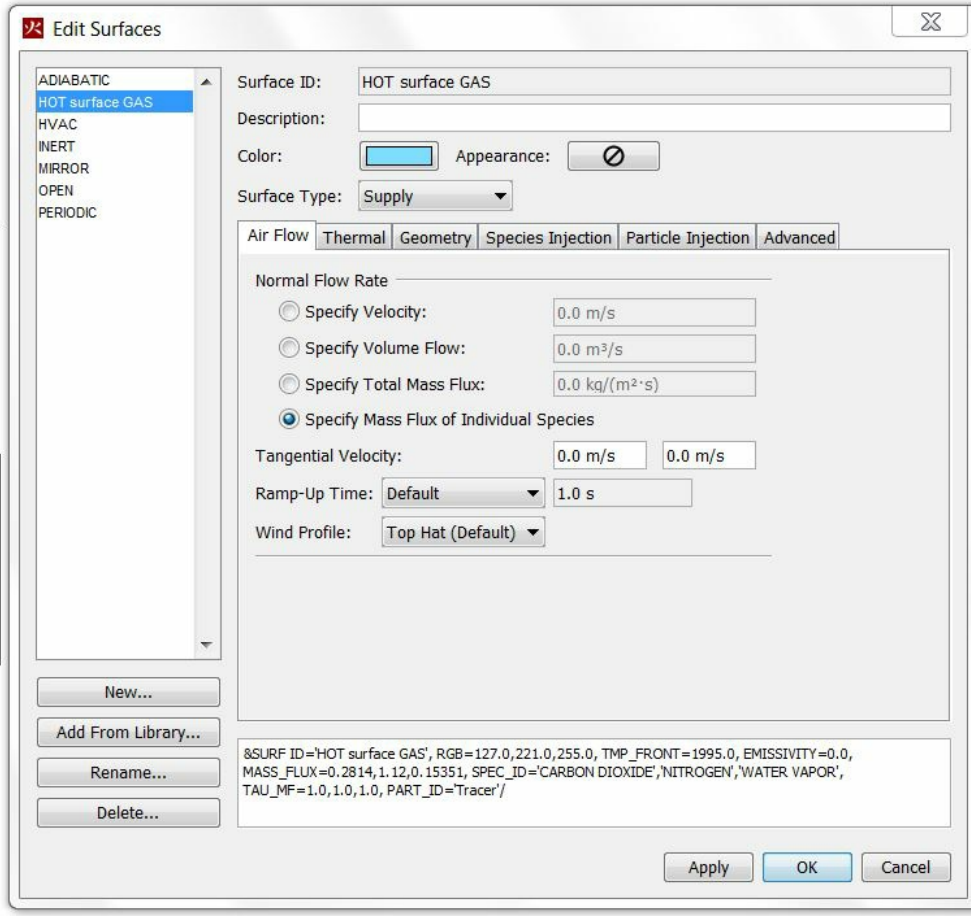
- Using the described initial inputs, Izar was modeled in FDS
- A grid was programmed to measure the temperature
  - Temperature sensor every 20 cm in the X and Y axis
  - Repeated each 19.5 cm in the Z-Axis
- This way of simulating the system avoid possible uncertainties related with the combustion



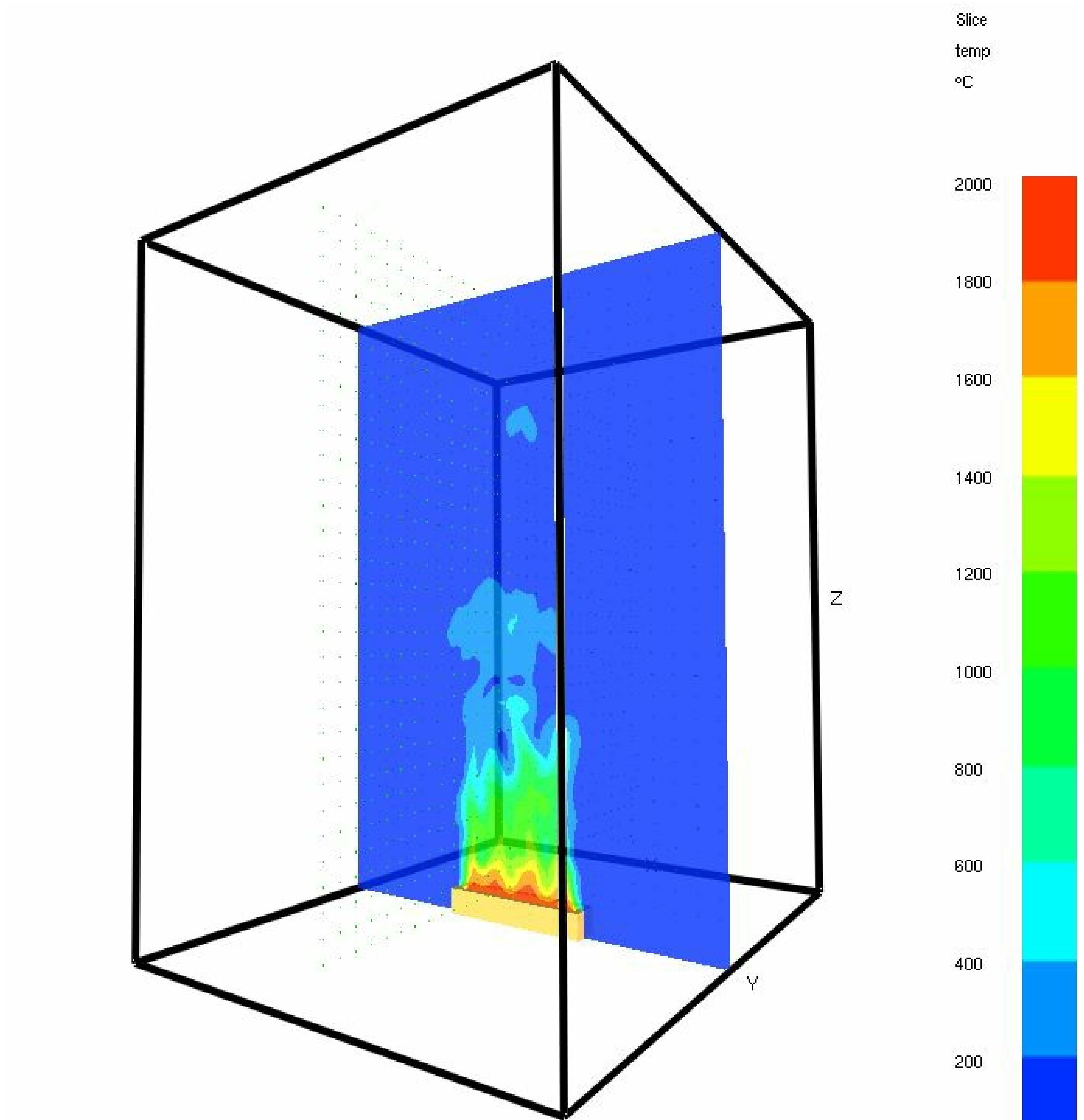
Input values in FDS…

- The gas burner is rectangle 130 cm (200 cells) x 19.5 cm (3 cells)
- The amount of combustion products is in kg/m$^2 \cdot$ s
- The boundaries are open –> “free plume”





… and it looks like that

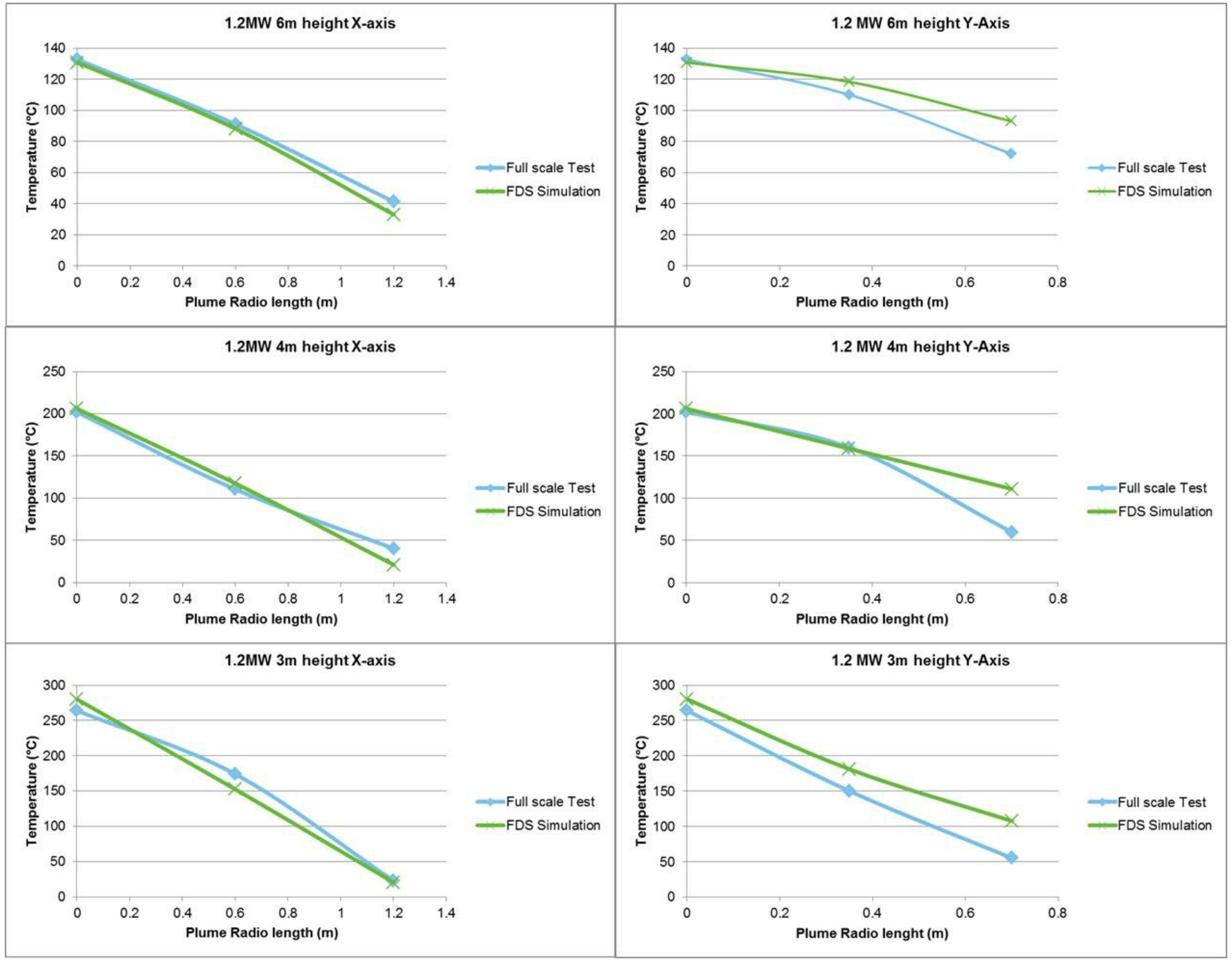


The next step is to validate the results

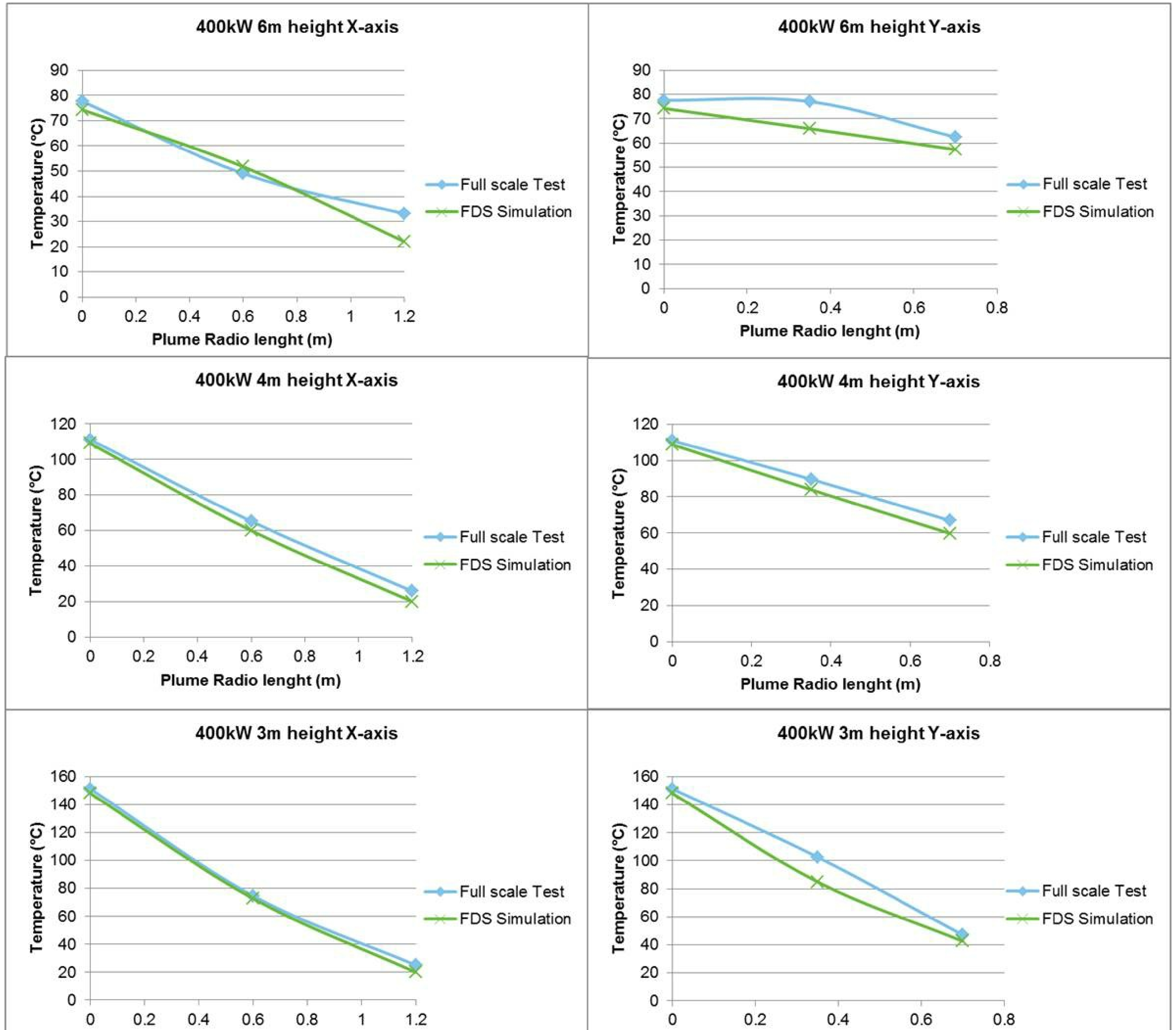
And that means?

- Switch on Izar
- Do some real fire
- Measure the temperatures in the plume

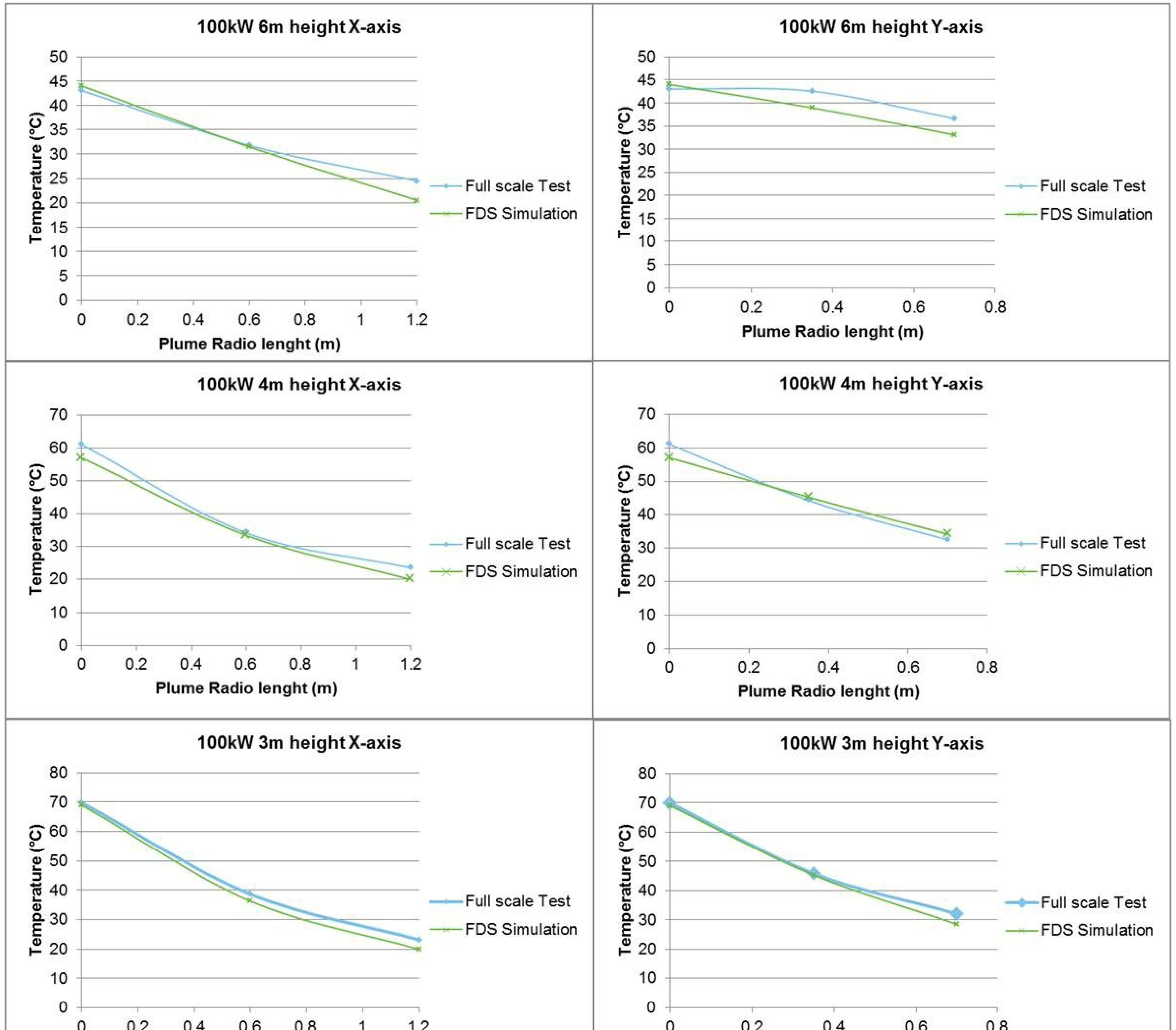
And it turns out that the results match at 1.200 kW…



… but also with Izar working at 400 kW…



… or just working at 100 kW



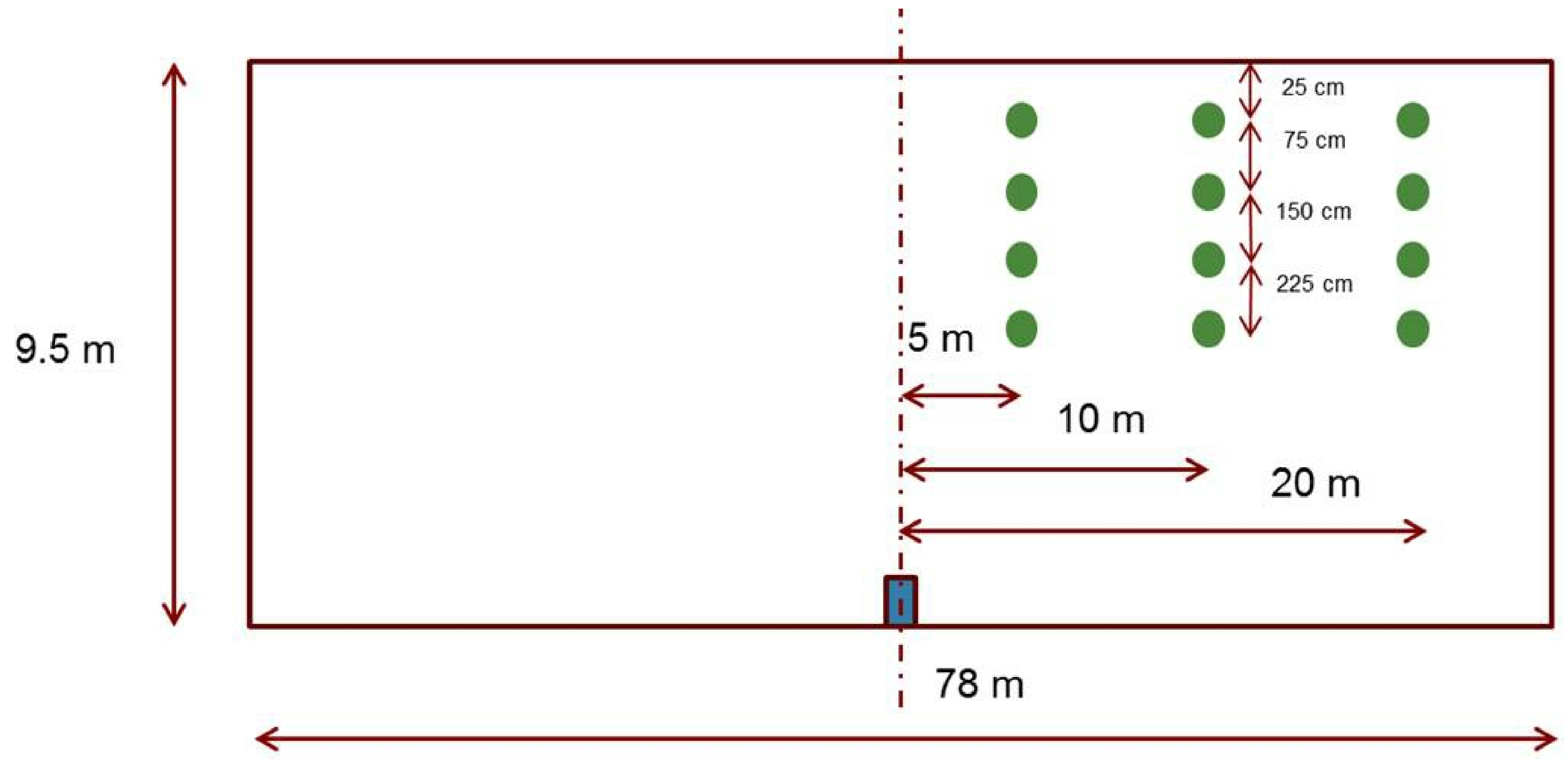
Next step, a full scale test

- The plume model works
- Therefore, it should be possible to model a real scale
- Is it really possible to simulate that ?

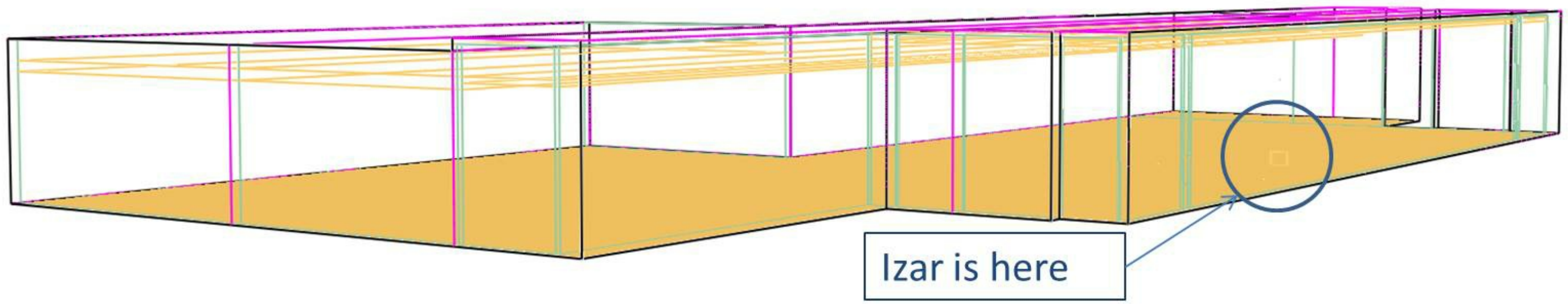
Full scale test

The full scale test

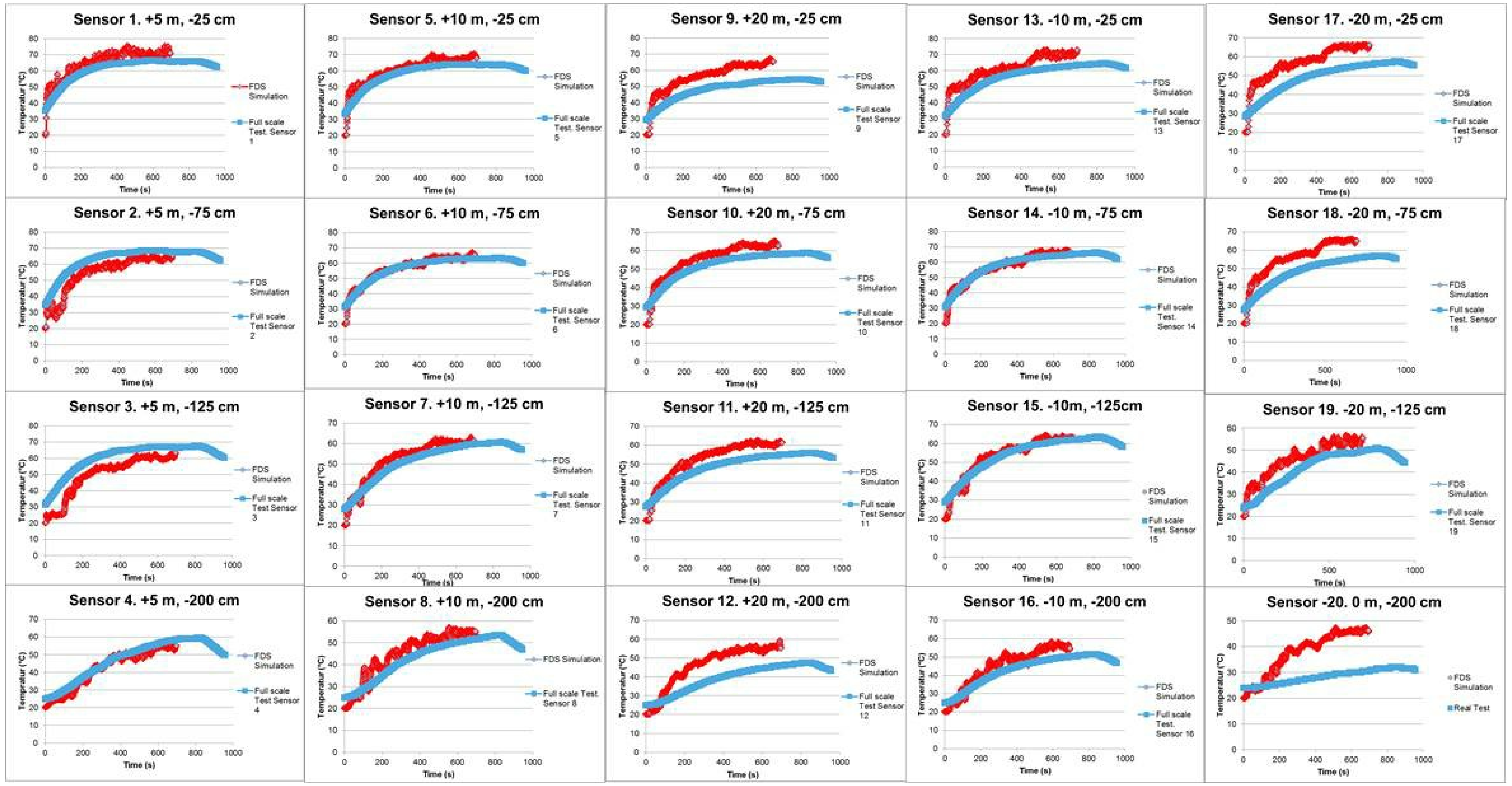
- We measured the temperatures within the smoke layer
- We carried out tests at different powers



We modeled the full scale test with our FDS model…

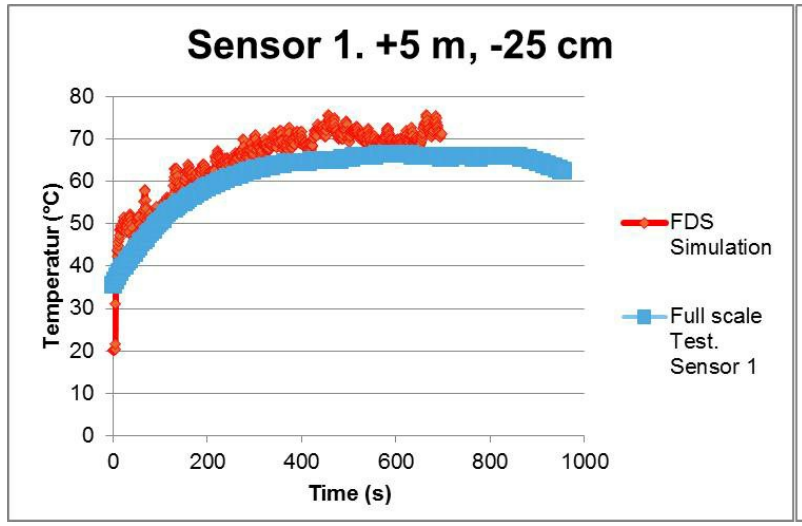


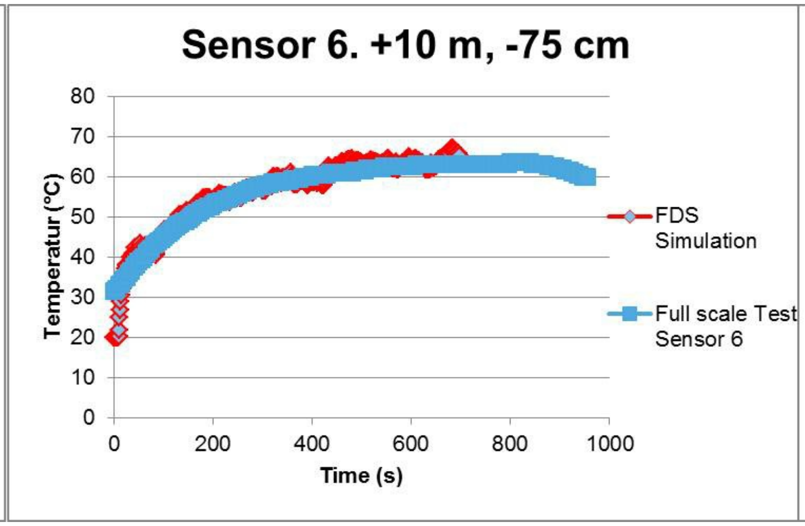
… and these are the results

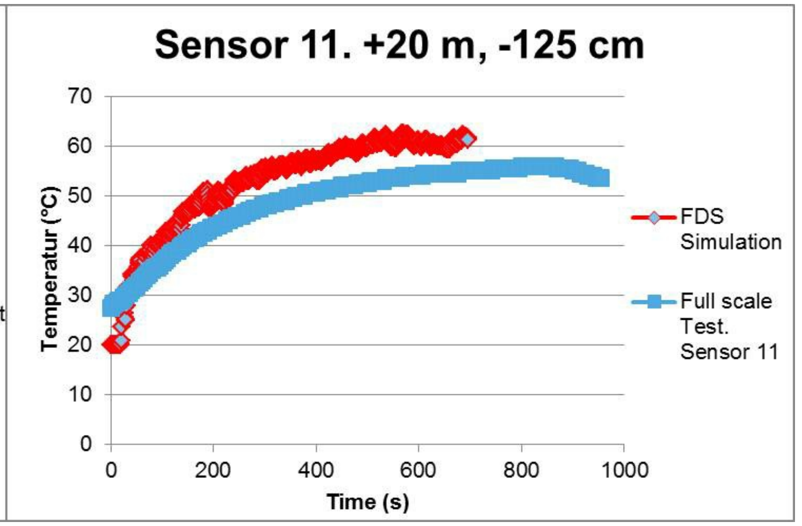


I know that you cannot see too much here…

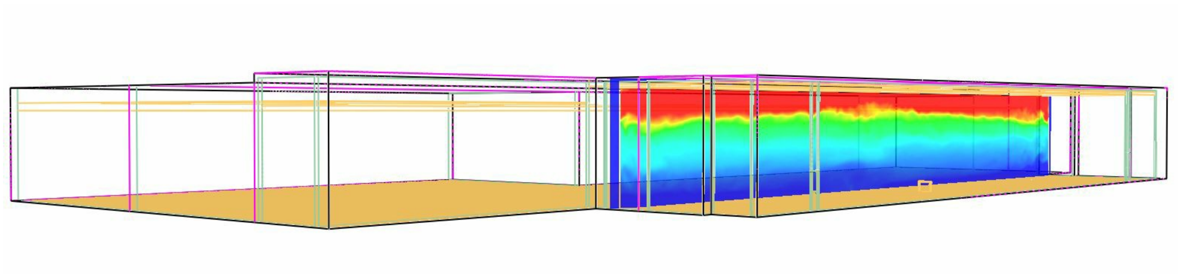
here three examples







they look definitely similar



(a)

(b)

Conclusions

- The methodology efficient tool to model the system Izar
- The main inputs are:
  - Combustion products
  - Flame temperature
  - Combustion region geometry
- FDS resolves properly the turbulence and entrainment around the plume
  - The centerline plume temperatures confirm this point

Future work

- Different configurations
  - Different fuels
  - Different geometries
- Validate the model in tunnels
- Development of plume equations
- Test and validate new premixed burning submodel

The future of the FDS Simulations?

- The model can be used to validate FDS geometries “a priori”
  - We can carry out a test with Izar
  - We take the necessary measures
  - We use the validated FDS model from Izar to calibrate the simulation
  - We program the design fire
- This way we reduce the uncertainties related with the geometry
- Reduce the safety factors
- Optimize the smoke extraction system

Thanks for your attention